Draft Columbia River System Operations Environmental Impact Statement

Appendix A
Alternatives Development

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CHAPTER 1 - INTRODUCTION

The intent of this appendix is to provide a more detailed description of how the co-lead agencies proceeded through the iterative steps to develop the alternatives of the CRSO EIS. During the alternatives development process, the co-lead agencies reached out in various ways, such as workshops and technical team working meetings, to receive input from regional stakeholders to include the public, states, tribes and other federal agencies on the scope, objectives, and measures that informed the alternatives development process.

1.1 PURPOSE AND NEED

The co-lead agencies undertook this environmental impact study for the purpose of evaluating alternative means of continuing to operate and maintain the 14 hydropower projects of the Columbia River System. The interrelated system of projects are operated for the Congressionally-authorized purposes of flood risk management, navigation, hydropower production, irrigation, fish and wildlife conservation, recreation, municipal and industrial water supply, and water quality. Multiple biological opinions have influenced the way the co-lead agencies coordinate operation of these 14 projects. This study is needed for review of the current operations and maintenance practices in light of changed conditions in the Columbia River basin, as well as to evaluate potential new measures to avoid, offset, or minimize impacts to affected resources. The timing of initiation of this study was influenced by the Opinion and Order issued by the U.S. District Court for the District of Oregon. The language within the Opinion and Order guided the co-lead agencies to emphasize development of alternatives that would include measures aimed at improving conditions for endangered or threatened species as they encounter the Columbia River System projects.

1.2 OVERVIEW OF ALTERNATIVES DEVELOPMENT

The first step of alternatives development was to brainstorm potential objectives for the EIS using input from public scoping comments as well as Tribal, cooperating agency, and co-lead agency subject matter experts. These objectives were then screened to ensure they met the purpose and need for the CRSO EIS. Potential measures were also brainstormed and screened to ensure they met the purpose and need as well as one or more objective. The alternatives were then built around unifying strategies or themes over the course of multiple iterations.

The initial alternatives development iteration was a reconnaissance-level assessment of multiple concepts, including improving conditions for specific life stages of anadromous salmonids, water management flexibility, future water supply, and hydropower production options. The initial iteration resulted in 11 preliminary draft alternatives that were single-objective focused.

The next iteration was a first attempt at combining these single-objective focused concepts into integrated alternatives. The purpose of this combining was to begin to crosswalk potential conflicts between measures and maximize a range of reasonable alternatives. This next iteration resulted in 5 preliminary draft alternatives that were integration focused.

The final iteration prior to development of the Preferred Alternative was to refine the preliminary draft alternatives into a suite of multiple-objective focused alternatives that combined the information learned from development of the single-objective focused and integration-focused preliminary draft alternatives. This final iteration resulted in 4 multiple-objective focused alternatives that were taken through full analysis.

1.3 OBJECTIVES

The co-lead agencies solicited ideas for objectives of the EIS through multiple venues and with diverse audiences. The views of the public provided in scoping comments, along with the expertise of the cooperating agencies, were used in an objectives-development workshop to focus efforts on finding solutions to operational problems identified for the co-lead agencies to consider changing.

Compilation of public scoping input as well as brainstorming during cooperating agency and co- lead agency workshops resulted in over 100 proposed objectives. Those objectives that met the CRSO EIS Purpose and Need were retained and refined. Those objectives that did not meet the Purpose and Need were determined to be outside the scope of the EIS and were removed from further consideration. In addition, the team removed objectives for the authorized purposes of recreation and flood risk management, as the team did not formulate the alternatives to specifically meet those purposes. Instead, project purposes such as these were considered part of the criteria for alternative evaluation.

Objectives were developed, then refined, to focus on resources with an institutional requirement (such as congressional direction or ESA protection) or on resources identified as important to the region during the scoping phase (such as lamprey). Measures to meet the final CRSO EIS objectives were combined form the basis of a "reasonable range of alternatives."

The 8 objectives presented below, along with the EIS purpose and need, guided the development of a reasonable range of alternatives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical and reliable power supply that supports the integrated CR Power System.

- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integration of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and the environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.
- Improve conditions for lamprey within the CRSO project area through actions potentially including, but not limited to, project configurations, flow management, spill operations, and water quality management.

1.4 MEASURES

Numerous measures were submitted during the scoping process and cooperating agency and co-lead agency workshops. Some measures were determine to actually be an objective, existing condition, mitigation action, or related to impacts analysis. These measures were removed from consideration, but retained for possible use in later phases of the EIS process. If a suggested measure was already being implemented or was planned for implementation (funding and NEPA in progress or in place) within the next 5 years by one of the co-lead agencies, it was also removed from consideration for an action alternative of this EIS. In addition, measures related to navigation and recreation were removed from consideration for use in action alternatives development, as the co-lead agencies already meet these missions. Instead, navigation, recreation, and flood risk management were evaluated in the impacts analysis phase of the EIS (Chapter 3).

An initial range of over 500 measures were compiled from those submitted during the public scoping period and multiple co-lead agency workshops. Of the measures submitted from public scoping comments, 129 were related to economic considerations. The largest number of measures offered (374) were related to fish and wildlife considerations. The remaining measures were related to other items, such as water quality and infrastructure maintenance. In some cases, the high number of submittals (e.g., fish and wildlife) reflected only minor variations on a theme. After multiple rounds of screening, measures that remained were combined to create the preliminary and subsequently refined alternatives. Table 1-1 lists categories of measures submitted during the scoping phase.

Table 1-1. Summary of Measures from Early Project Scoping

Resource Category		Number of Measures Submitted
Economics	Hydropower	40
	Water Supply	33
	FRM	38
	Navigation	5
	Recreation	13
	Sustainable Local Economies	5
Fish and Wildlife Conservation	General	213
	Adult Salmon and Steelhead	37
	Juvenile Salmon and Steelhead	46
	Resident Fish (sturgeon, bull trout, and others)	24
	Piscivore Control	35
	Lamprey	18
Infrastructure Maintenance		7
Contaminant Transport		12
Miscellaneous Water Quality		3

1.5 MEASURES SCREENING CRITERIA

The first round of measures screening resulted in the elimination of 244 measures that did not meet the purpose and need for the CRSO EIS. The co-lead agency team next reviewed each measure to ensure it met one or more objectives. It was determined that 176 measures met objectives and these were retained for further consideration. Those measures that did not meet objectives were removed from further consideration, but a record of the rationale for removal was maintained such that the measure could be revisited in the future if analysis warranted.

The technical teams then developed technical screening criteria to help identify measures with high potential to contribute to a solution. Technical criteria included, for example, engineering feasibility or whether the action might result in known detrimental effects to other ESA-listed species. The technical team for each resource (e.g. fish, hydropower, water management, water supply) developed and applied their own technical criteria, then reviewed it with the larger multidisciplinary team, which included cooperating agency members, for discussion and feedback. The screened measures were grouped with their corresponding CRSO objective and utilized to build the range of action alternatives.

1.6 SINGLE OBJECTIVE FOCUSED ALTERNATIVES

Formulation of a broad range of alternatives for analyses began with single objective-focused alternatives developed to maximize certain project purposes and emphasize specific resources. These early drafts provided the framework for collaboration of staff from across the Columbia River Basin and the exchange of expertise across technical disciplines. As information was exchanged, redundancies between alternatives and conflicts between proposed measures became more clearly understood, leading to refinement of the draft alternatives in subsequent iterations.

The first iteration of the alternative formulation process focused on combining measures associated with a primary objective and determining the compatibility of those measures at each of the 14 projects in the CRS. The technical teams collaborated to determine where those measures would be most effective ("measures siting"). These same participants then used best professional judgment to determine whether there were any operational or structural measures that could not be performed together (conflicting measures). If measures were determined to be conflicting, the team decided which measure to retain and/or modify to meet the intended primary objective. The resulting Single Objective Focused Alternatives are described in the following paragraphs with additional detail provided in the corresponding "Detailed Description Sheet" found at the conclusion of this appendix.

1.6.1 Juvenile Anadromous Fish Survival Alternative

The Juvenile Anadromous Fish Survival Alternative was designed to maximize juvenile salmonid survival through the CRS by prioritizing juvenile-focused actions above some of the other congressionally-authorized project purposes and above other life stages. Although juvenile anadromous fish do not experience the CRS separately from their adult counterparts, this alternative emphasizes how the survival of juvenile salmonids impacts both the adult life stage and other co-lead agency missions (e.g., FRM, hydropower production, and water quality).

This alternative includes operating the spillways of the lower Snake and Columbia River projects up to, but not exceeding, 120% total dissolved oxygen, as measured in the downstream tailrace. This is an increase in use of the spillway for downstream juvenile fish passage over the No Action Alternative. In conjunction, the alternative would draw down the eight lower Columbia and Snake River projects to their respective minimum operating pool (MOP) elevations and, in lower water years, up to 2 million acre-feet (MAF) of water would be released from McNary Dam to augment downstream Columbia River flows. The intent of this alternative is to measure potential to increase survival for juvenile anadromous fish as they pass through these eight projects, as well as reduce negative impacts associated with the time spent migrating downstream from McNary Dam to the ocean. Besides reducing impacts from travel time, this alternative seeks to impact the reproductive success of juvenile fish predator species (e.g., smallmouth bass, Northern pikeminnow, etc.) during the spring months. This could include raising the John Day pool elevation to inundate downstream bird nesting colonies, and systematically exposing the shoreline of Lake Wallula (behind McNary Dam) to expose and desiccate predatory fish eggs along the lake margins as water is released from the reservoir.

This alternative also utilizes structural measures to maximize juvenile salmonid survival. Under this alternative, additional powerhouse surface passage routes would be constructed at the Ice Harbor and McNary Projects and existing spillway weirs at six of the eight lower Columbia and Snake River dams would be converted to adjustable spillway weirs (ASWs) so they could be operated under a wider range of flow conditions.

The Juvenile Anadromous Fish Survival Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

Table 1-2. Juvenile Anadromous Fish Survival Alternative – Structural and Operational Measures

Structural Measures
• Construct additional powerhouse surface passage routes at McNary and Ice Harbor (S1) • Upgrade spillway weirs to ASWs (S2)
Operational Measures
• Manage juvenile fish passage spill to not exceed120% TDG tailrace gas cap at all lower Snake River and lower Columbia River projects (O1) • Strive to maintain minimum 220 kcfs spring flow objective at McNary from May 1-June 15 and minimum 200 kcfs summer flow objective at McNary from June 16-July 31 through the use of four U.S. storage reservoirs, up to a maximum of 2.0 Million acre-feet (O2) • Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for outmigration (O3) • Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (piscine predators) (O4) • Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (avian predators) (O5)

1.6.2 Adult Anadromous Fish Survival Alternative

The Adult Anadromous Fish Survival Alternative contains a mix of structural and operational measures intended to improve the migration and survival of anadromous adult steelhead and salmon. Structural measures are focused on improving conditions for adult salmon migrating upstream through the fish ladders. Under this alternative, the adult fish trap and bypass loop at Lower Granite Dam would be modified to shorten the time it takes an adult salmon to travel through the bypass. Pumps would be installed at Lower Monumental and Ice Harbor Dams to provide cooling water for the fish ladders. The Washington Shore and Bradford Island fish ladders at Bonneville Dam would be modified to a vertical slot fishway to reduce upstream travel times for adult salmon and steelhead.

Operational measures would provide more spill through fish ladders to create improved attraction for adult fish. The Adult Anadromous Fish Survival Alternative would replace juvenile fish passage spill at Bonneville and John Day Dams with only ladder attraction spill. At McNary Dam and the four lower Snake River dams, no spill would occur from April to August each year unless necessary for FRM. Another measure would spill through spillway weirs, treating them as surface passage structures, to provide safer downstream passage for steelhead and kelts that overwinter in the reservoirs. A shift in timing of water releases from Dworshak to provide cooler water in the lower Snake River during adult migration seasons would also occur. In addition, the alternative includes a measure to transport juvenile salmonids from the collector projects at Lower Granite, Little Goose, Lower Monumental, and McNary Dams, and release them below Bonneville Dam.

The Adult Anadromous Fish Survival Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

Table 1-3. Adult Anadromous Fish Survival Alternative – Structural and Operational Measures

Structural Measures
• Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam (S1) • Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway (S2) • Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor Dams (S3)
Operational Measures
• Provide spill for attraction flow to adult ladders (additional spill outlined in O2) (O1) • Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead and kelt downstream passage (O2) • Implement modified timing of Lower Snake Basin reservoir draft to provide cooler water in the Lower Snake River during peak adult migration periods (O3) • Juvenile fish transportation [transport all juvenile salmonids entering the juvenile fish bypasses at collector projects to below Bonneville for release] (O4)

1.6.3 ESA-Listed Resident Fish Survival Alternative

The ESA-Listed Resident Fish Survival Alternative was intended to improve river and reservoir habitat conditions for ESA-listed resident fish in the Columbia River Basin through improving water temperature management, creating conditions for higher reservoir productivity during the summer months, and improving the likelihood of releasing instream flow targets for resident fish in the CRS. This alternative focused on the upper Columbia River dams, and did not include changes to the lower Columbia or Snake River operations. The ESA-Listed Resident Fish Survival Alternative emphasized the survival of resident fish juveniles and overall adult fecundity in CRS reservoirs through measures developed for spawning and egg-hatching success. The purpose of the alternative was to emphasize how the survival of ESA-listed resident fish impacts other ESA-listed fish of all life stages, as well as co-lead agency missions (e.g., FRM, hydropower production, and water quality).

The ESA-Listed Resident Fish Survival Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

Table 1-4. ESA-Listed Resident Fish Survival Alternative – Structural and Operational Measures

Structural Measures
• Construct upstream passage facility at Albeni Falls Dam for bull trout (S1)
Operational Measures
• Update VarQ procedure at Libby to improve local water management (O1) • Eliminate end-of-December variable draft at Libby and replace with a single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during the remainder of the water year. Single draft target elevation would be elevation 2420'. (O2) • Implement sliding scale summer draft at Libby and Hungry Horse (O3) • Juvenile fish transportation [transport all juvenile salmonids entering the juvenile fish bypasses at collector projects to below Bonneville for release] (O4)

1.6.4 Increased Spill to 125% Total Dissolved Gas with Extended Duration

The Single Focus Alternative for Increased Spill to 125% Total Dissolved Gas with Extended Duration was not an objective-focused alternative. Rather, it was developed based on scoping comments specifically requesting analysis of an increased juvenile fish passage spill target level. This alternative is comprised of two operational measures, but has no structural component. The first operational measure involves increasing the proportion of flow released over the spillway (referred to as "spill"), relative to the No Action Alternative, at the Lower Snake and lower Columbia River dams. Juvenile fish passage spill levels would be increased to a target not to exceed 125% TDG, as measured in the tailrace of each project, a level that is above state water quality standards in both Oregon and Washington. The second operational measure was prompted because flows associated with this level of spill necessitate the cessation of juvenile transportation operations at the Lower Granite, Little Goose, and Lower Monumental Projects. The Single Focus Alternative for Increased Spill to 125% Total Dissolved Gas with Extended Duration was intended to benefit juvenile fish migration during the March 1 to August 31 timeframe each year.

This alternative was refined, and became part of Multiple Objective Focus Alternative 4 (MO4) for analysis.

Table 1-5. Increased Spill to 125% Total Dissolved Gas with Extended Duration Alternative – Structural and Operational Measures

Structural Measures
• None
Operational Measures
• Set juvenile fish passage spill to not exceed 125 percent TDG, as measured in the tailrace, at all Lower Snake River and Lower Columbia River projects (O1) • Cease juvenile transport during implementation of Measure O1 (O2)

1.6.5 Water Management Alternative

The Water Management Alternative would provide water managers with the increased flexibility to react to unanticipated changes in river flow and forecast runoff volume, as well as prepare for the operational constraints of implementing ongoing maintenance at Grand Coulee Dam. This alternative does not include any structural measures or operational changes to the lower Columbia and Snake River dams. This, in turn, would provide downstream flow augmentation, faster turnover of the Libby reservoir to support downstream nutrient delivery, and better management of outflow temperature during Kootenai River white sturgeon spawning.

As storage reservoirs are drafted for FRM, situations can occur where rapid and large water releases are required in the March to April timeframe to achieve FRM draft goals (e.g., high runoff during late winter/early spring or years with rapidly increasing water supply forecasts). Drafting large volumes in a short timeframe can require increased spill (involuntary) to achieve the draft target or a deviation from FRM draft requirements, which could result in high TDG levels or slight increases in flood risk in a given year. In addition, heavy rain often results in near-term high runoff that cannot be forecasted in the same way as longer-term, snowmelt-induced runoff. Water management operating procedures that more explicitly account for the rain component of runoff would afford greater flexibility and adaptability in reservoir operations.

Table 1-6. Water Management Alternative – Structural and Operational Measures

Structural Measures
• None
Operational Measures
• When Libby’s water supply forecast is approximately 6.9 MAF or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft (O1). • Eliminate end-of-December variable draft at Libby and replace with a single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers’ ability to adapt to a wide range of runoff conditions during the remainder of the water year. Single draft target elevation would be elevation 2420’. (O2) • Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April (O3) • When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System’s Initial Controlled Flow (ICF) date and control flow approach (O4). • Update the Storage Corrections Method as applied to the Grand Coulee SRD (O5). • Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the SRD) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day (O6). • Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways (O7). • Develop draft requirements to protect against rain-induced flooding (O8).

The Water Management Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into all of the multiple objective alternatives.

1.6.6 Hydropower Generation Alternative

The Hydropower Generation Alternative describes action that would maximize hydropower generation at CRS projects. The proposed measures would create circumstances similar to conditions that existed prior to implementation of the Northwest Power Act and actions implemented for biological opinions and other agreements. These actions were enacted to benefit certain resources, but they have limited hydropower production. Restrictions on ramping rates, turbine operating ranges, reservoir operating ranges, and similar measures have reduced the flexibility needed for enough hydropower generation to serve hourly, daily, and seasonal power demands. The Hydropower Generation Alternative includes relaxing current restrictions on operating ranges and ramping rates found in the No Action Alternative in order to evaluate the potential to increase hydropower production efficiency and increase flexibility to respond to changing power demands.

The Hydropower Generation Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into all of the multiple objective alternatives.

Table 1-7. Hydropower Generation Alternative – Structural and Operational Measure

Structural Measures
• No installation of fish screens at Ice Harbor, McNary, John Day, and Bonneville projects (S1).
Operational Measures
• No fish passage spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects. Spill associated with high flow events and lack-of-market spill would continue as needed (O1). • No flow and pool elevation restrictions, except those that are safety-related, at all projects year-round to increase ability of hydropower to meet power-demand. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, specific elevation requirements for navigation safety, and maintaining ramp rates for minimizing dam erosion (O2). • At the four lower Snake River projects operate within the full reservoir operating range year-round (O2a) • At John Day, allow project to operate within the full reservoir operating range year-round except as needed for flood risk management (O2b). • The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak) may be drafted for hydropower, the maximum po9ol elevation is limited to the upper rule curves for FRM, and storage projects will not operate to meet flow targets for fish. Operate Canadian storage projects without flow augmentation (O2c). • Ramping rate limitations at all projects will be defined only for the purpose of safety or engineering (O2d). • Operate turbines across their full range of capacity year-round (O3). • Zero generation operations may occur lower Snake River projects September – March (O4).

1.6.7 Water Supply Alternative

The draft Water Supply Alternative was formulated to assess providing additional water to authorized, but not yet developed, lands within the Columbia Basin Project and the Chief Joseph Dam Project. The scope for this draft alternative was limited to the diversion of water from the Columbia and lower Snake River and did not include the fate of that water. This draft alternative maintained the No Action Alternative's configuration and operation of the Columbia and lower Snake River projects. Under the draft Water Supply Alternative, it was assumed irrigated lands would increase within the Columbia River Basin, since the authorized acreage of irrigated land is not fully used at present. Additional water at some projects would be utilized for municipal and industrial purposes, as previously authorized but not currently used. The draft Water Supply Alternative was focused on upstream dams and river segments, which included Lake Roosevelt and the Columbia River above Grand Coulee Dam, Hungry Horse Dam and reservoir on the Flathead River, and Chief Joseph Dam on the Columbia River. This draft alternative maintained the No Action Alternative's configuration and operation of the lower Columbia and Snake River projects.

The Water Supply Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into the MO1, MO3, and MO4 Alternatives.

Table 1-8. Water Supply Alternative – Structural and Operational Measures

Structural Measures
• None
Operational Measures
• Increase volume of water pumped from Lake Roosevelt into Banks Lake via the John W. Keys III Pumping Plant at the Grand Coulee project for increased deliveries to the Columbia Basin Project (CBP) mostly during the annual irrigation season. The new volume of irrigation water was calculated by multiplying the 336,300 undeveloped acres by the duty (4.1 acre-feet per acre) that is currently used by the CBP. The duty was calculated by dividing the water diverted in 2016 by the developed acres (O1). • Deliver current water volume using a revised monthly shape so as to not drawdown Banks Lake for delivery of water, pumped from Lake Roosevelt into Banks Lake via the existing configuration of the John W. Keys III Pumping Plant at the Grand Coulee project. This water delivery will include Odessa Subarea (164,000 acre-feet) and Banks M&I (15,000 acre-feet) water on-demand; current operations require draft of Banks Lake and refilling from Lake Roosevelt in September and October. This measure combined with the measure to increase delivery to Banks Lake from Lake Roosevelt would represent the total volume (and timing) of delivery to Banks Lake (O2). • Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the CSKT water rights settlement for irrigation or municipal purposes (O3). • Add pump units to increase water diversion from the Columbia River for the Chief Joseph Dam Project to supply an additional 9,600 acre-feet of irrigation water. Supply irrigation water throughout the irrigation season (O4).

1.6.8 Lower Snake River Dam Breaching Alternative

The Lower Snake River Dam Breaching Alternative was not an objective-focused alternative. It was developed based on formal scoping comments specifically requesting analysis of this action. The hypothesis for this alternative was that habitat conditions for four of the fourteen listed anadromous species in the Columbia River Basin could potentially be restored. The alternative proposed breaching the four lower Snake River dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) by removing the earthen embankments at each location. The reservoirs behind the dams would be drawn down slowly to avoid damage to adjacent infrastructure (e.g., roads, bridges, and railroads) and ensure life safety of downstream populations. The concrete portions of the dams would remain in place, but the powerhouses would be mothballed. The generators would be modified for use as outlets during a controlled reservoir drawdown. The breaching would occur over a 2-year period, with the two upstream dams (Lower Granite and Little Goose) breached first, and followed the next year by Lower Monumental and Ice Harbor. Spreading the breaching over 2 years allows the work to occur during the in-water work window, when very few ESA-listed fish are present in the reservoirs and inflows are relatively small.

The Lower Snake River Dam Breaching Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into the MO3 Alternative.

Table 1-9. Lower Snake River Dam Breaching Alternative – Structural and Operational Measures

Structural Measures
• Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown (S1). • Modify existing equipment and dam infrastructure to adjust to drawdown conditions. Existing equipment would not be used for hydropower generation, but instead would be used as low-level outlets for drawdown below spillway elevations. Depending on the outcome of additional analysis, turbines would be modified and/or operated in a manner to support controlled drawdown (S2).
Operational Measures
• Develop procedures to operate existing equipment during reservoir drawdown (O1). • Develop contingency plans to address unexpected issues with drawdown operations (O2).

1.6.9 Maximum Integration of Non-Hydropower Renewables Alternative

The draft Maximum Integration of Non-Hydropower Renewables Alternative was formulated to emphasize integration of other renewable sources of electricity (e.g., wind and solar) into the power grid. Given natural variation during wind and solar power production, hydropower generation would need to optimize flexibility in order to maintain a steady supply of power on the electric grid to meet demand. This alternative was intended to reduce overall hydropower generation for the purpose of maximizing integration of other renewable energy sources. All measures in this alternative were included for the purpose of providing hydropower generation flexibility to respond to changes in wind and solar generation.

This alternative contains a single structural measure, which was to cease the installation of fish screens at all lower Columbia and Snake River projects.

Under this alternative, juvenile fish passage spill would not be implemented at the lower Columbia and Snake River projects, although periods of spill associated with high flows or low market demand for hydropower would continue. Operational measures include allowing reservoir elevations to fluctuate across their full operating range at the lower Snake River projects with no restrictions for fish migration; operating all projects with no restrictions on ramping rates, except to maintain safe conditions; meeting project purposes for hydropower, navigation, and FRM; and minimize erosion. The John Day reservoir would not be required to maintain a minimum irrigation pool elevation, and could operate up to full pool except as needed for FRM.

Table 1-10. Maximum Integration of Non-Hydropower Renewables Alternative – Structural and Operational Measures

Structural Measures
• Cease annual installation of fish screens at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects to allow more flow to the units and increase turbine efficiency (S1).
Operational Measures
• Stop all voluntary spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects year-round. Involuntary spill associated with high flow events and lack-of-market spill would continue as needed (O1). • Lift all flow and pool elevation restrictions that are not safety-related from all projects to increase ability to meet power demand fluctuations from primarily hydropower generation year-round. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability (O2). • Reduce restrictions on ramping rates at all projects unless for the purpose of safety or engineering (O2a). • At the four, lower Snake River projects, seasonal pool elevations would no longer be restricted to within 1-foot of Minimum Operating Pool (MOP) during the juvenile fish passage season (April-August) (O2b). • At the John Day project, the seasonal pool elevation would no longer be restricted to within 1.5 feet of Minimum Irrigation Pool (MIP) during the juvenile fish passage season (April-August) (O2c). • At the storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak), the variable draft limits (VDLs) would not be enforced as a lower operating limit so that those reservoirs could be drafted deeper as needed for hydropower generation (O2d). • At Lake Roosevelt (Grand Coulee pool), lower pool elevation would not be limited for ferry operation (O2e). • At John Day, allow project to operate up to full pool (268 feet) except as needed for FRM (O2f). • Operate turbines across their full range of capacity by eliminating the restriction to only operate within their range of 1 percent of peak efficiency during the fish migration season (approximately April-October). Elimination of 1 percent peak efficiency restriction would increase ability to meet power demand fluctuations from primarily hydropower generation from Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects (O3).

The upper basin storage projects (Libby, Hungry Horse, Grand Coulee, and Dworshak) would be drafted for hydropower generation, but not for in-river flow augmentation. Hydropower turbines at the eight lower Columbia and Snake River projects would be operated across their full range of capacity throughout the year to maximize flexibility in hydropower generation and meet demand. The Grand Coulee Project would not limit the lower pool elevation on Lake

Roosevelt for ferry operation. All FRM-related measures would be retained, however, as these are required for human health and safety.

The Maximum Integration of Non-Hydropower Renewables Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

1.6.10 Anadromous Evolutionarily Significant Unit (ESU)/Adult and Juvenile Alternative

The Anadromous ESU/Adult and Juvenile Alternative was an early effort to combine measures from two single objective focused-alternatives: juvenile and adult salmonid survival. This preliminary draft alternative was developed as the team was transitioning from single-objective focused into multiple-objective focused draft alternatives. The intent was to seek a balance of measures that potentially benefit both the juvenile and adult salmonid life stages simultaneously. It highlighted opportunities to improve upstream passage for adults and downstream passage for juveniles.

Structural measures in this alternative include constructing additional surface passage routes at and reduce TDG in the tailrace, and reducing fish injury by increasing the size of entrance orifices and bypass pipes. Addition of a new turbine at Dworshak was proposed for release of cool water for downstream temperature management. Under this alternative, the adult fish trap and bypass loop at the Lower Granite Project would be modified to shorten the time it takes an adult salmon to travel through the bypass. In addition, a second fish passage ladder would be constructed at both the Lower Granite and Little Goose Projects.

Operational measures in the alternative include adjusting juvenile fish passage spill levels to optimize in-river survival for both juvenile and adult ESA-listed anadromous salmonids. Juvenile fish passage spill would target 120-percent TDG, as measured in the tailrace of the eight lower Columbia and Snake River dams. At Bonneville Dam, juvenile fish passage spill would be set to a flow target of 100 thousand cubic feet per second (kcfs) rather than a TDG target. The spill volume would be adaptable to fish presence. One or more existing surface passage structures, spillway weirs, or sluiceways would be used for the downstream passage of overwintering steelhead and kelts. Pumping systems would provide cooling water for the adult fish ladders at the Lower Granite and Little Goose Projects. The final operational measures of this alternative include reducing water temperatures through the lower Snake River projects by augmenting outmigration flow released from the Dworshak Project, and reducing water travel time for downstream migration in low water years by releasing a target of 220 kcfs flow at the McNary Project.

The Anadromous ESU/Adult and Juvenile Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

Table 1-11. Anadromous Evolutionarily Significant Unit (ESU)/Adult and Juvenile Alternative – Structural and Operational Measures

Structural Measures
• Construct additional surface passage (S1). • Modify stilling basins at Little Goose, Lower Monumental, McNary and John Day Dams to reduce system-wide TDG and/or the flexibility to spill higher volumes while remaining under the gas cap level (S2). • Add an additional turbine at Dworshak for flexibility to increase the volume of cool water released from Dworshak for in-season temperature management (S3). • Improve juvenile bypass facilities by enlarging orifices/pipes, which would reduce juvenile salmon and steelhead injuries caused by collision with debris (S4). • Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam (S5). • Add or improve fish passage (S6).
Operational Measures
• Adjust spill to optimize juvenile and adult in-river survival. The table below includes DRAFT spill operations for this alternative, which is still in refinement (O1). • Develop contingency plans to address unexpected issues with drawdown operations (O2).

1.6.11 Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative

The draft Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative was formulated to maximize the generation of carbon-free power through a combination of hydropower generation and integration of other renewable energy sources (e.g., wind and solar power). This alternative is essentially the same as the Maximum Integration of Non-Hydropower Renewables Alternative, but includes the addition of new hydropower turbines in existing skeleton bays at Dworshak and Libby Dams. The new turbines could provide additional generating capacity, when needed, to supplement electricity not provided by solar and wind power generation sources. In addition to new turbines, the structural measures of this alternative include no longer installing fish screens at all lower Columbia and Snake River projects. If fish screens were not installed, no fish collection could occur and barge and truck transport of juvenile salmon and steelhead in the CRS would be eliminated.

Under the draft Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative, spill would not be implemented at the lower Columbia and Snake River projects for juvenile fish passage, although periods of spill associated with high flows or low market demand for hydropower would continue. The operational measures of the draft alternative would include allowing reservoir elevations to fluctuate across their full operating range at the lower Snake River projects, with no restrictions for fish migration. All projects would operate without restrictions on elevations or ramping rates, except to maintain safe conditions, meet project purposes for hydropower, navigation, and FRM, and minimize erosion. The John Day reservoir would not be required to maintain a minimum irrigation pool elevation, and could operate up to full pool elevation except as needed for FRM. The upper basin storage projects (Libby, Hungry Horse, Grand Coulee, and Dworshak) would be drafted for hydropower generation, but not for in-river flow augmentation. Hydropower turbines at all eight lower Columbia and Snake River projects would be operated across their full range of capacity throughout the year to maximize flexibility in hydropower generation and meet demand. The FRM-related measures would be retained, however, as these are required for human health and safety.

The Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative was eliminated from further consideration as described in Chapter section 2.2. The measures from this alternative were carried into one or more of the multiple objective alternatives.

Table 1-12. Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative – Structural and Operational Measures

Structural Measures
• Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown (S1). • Modify existing equipment and dam infrastructure to adjust to drawdown conditions. Existing equipment would not be used for hydropower generation, but instead would be used as low-level outlets for drawdown below spillway elevations. Depending on the outcome of additional analysis, turbines would be modified and/or operated in a manner to support controlled drawdown (S2).
Operational Measures
• Develop procedures to operate existing equipment during reservoir drawdown (O1). • Develop contingency plans to address unexpected issues with drawdown operations (O2).

1.7 INTEGRATED ALTERNATIVES

The second iteration of the alternatives development process focused on creating strategies to meet more than one primary objective within individual alternatives. The multiple-objective integrated alternatives include a range of modifications to juvenile fish passage spill operations, a range of fish passage measures, and a range of measures to increase flexibility for water management and hydropower production operations. By bringing together measures from the single objective focused alternatives, draft integrated alternatives were formulated to explore the tradeoffs from blending measures while continuing to emphasize specific resources. Common to all the draft Integrated Alternatives are the measures of the draft Water Management Focus Alternative plus a suite of measures to benefit lamprey. As with formulation of single objective focused alternatives, the technical teams utilized their collective expertise to determine which measures conflicted across the 14 projects and with the overall resource of emphasis. The resulting 5 draft Integrated Alternatives are described in the following paragraphs.

1.7.1 Integrated Alternative 1 (Resource Emphasis on Hydropower Production Flexibility)

Integrated Alternative 1 was formulated to blend actions to emphasize hydropower production flexibility while avoiding negative impacts to other authorized project purposes and co-lead agency missions. Restrictions on ramping rates, turbine operating ranges, reservoir operating ranges, and similar measures have reduced the flexibility needed for hydropower generation to serve hourly, daily, and seasonal power demand. Integrated Alternative 1 includes relaxing the No Action Alternative’s restrictions on operating ranges and ramping rates to evaluate the potential to increase hydropower production efficiency and increase flexibility to respond to changing power demand. The measures of Integrated Alternative 1 would increase the ability to meet power demand with hydropower production by generating as much power as possible during the most valuable periods (e.g., winter, summer, and daytime peak demands).

Integrated Alternative 1 includes some measures developed for the single objective alternatives, such as those for water management flexibility. Details of the fish-focused single objective alternatives’ measures were also used, but were modified as needed to avoid operational conflicts with hydropower production. All FRM-related measures were retained, however, as they are required for human health and safety.

The structural and operational measures comprising Integrated Alternative 1 are provided in Table 1-13. The measures of this alternative were refined carried into one or more of the multiple objective alternatives for full analysis.

Table 1-13. Integrated Alternative 1 – Structural and Operational Measures

Structural Measures
• Construct additional powerhouse sluiceway surface passage routes at McNary, Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams (S1) • Upgrade spillway weirs to ASWs (S2) • Improve adult ladder passage through modification of the adult trap at Lower Granite Dam (S3) • Add and improve adult fish ladders (S4) • Reconfigure the adult trap at Ice Harbor dam (S5) • Modify tailrace configuration to reduce spill effects on adult passage (S6) • Install pumping systems to provide deeper (cooler) water in the Lower Monumental and Ice Harbor Dam fish ladders (S7)/(O4)
Operational Measures – Fish Passage Spill
• Reduce duration of summer juvenile fish passage spill, end July 31, No Action spill level (O1) • More spill over spillway weir than spillway during juvenile fish passage spill season (O2) • Measure juvenile fish passage spill TDG levels on a 12-hour rolling average (O3) • Allow contingency reserves to be carried within juvenile fish passage spill (O9)
Operational Measures – Water Management
• Modify Libby draft and refill operations: VarQ procedure (O11) • Eliminate end-of-December variable draft at Libby and replace with single draft target of 2420 feet by December 31 (O12) • Modify Libby draft and refill operations: SRD (O13) • Modify Libby draft and refill operations when water supply forecast is 6.9 MAF or less (O14) • Decrease Grand Coulee draft rate used in planning drawdown, 0.8 feet/day maximum draft (O15) • Operational constraints for ongoing Grand Coulee powerplant maintenance, limit maximum outflow (O16) • Develop draft requirements approach to protect against rain-induced flooding (O17)

Operational Measures – Other
• Implement modified timing of lower Snake River Basin reservoir draft for additional cooler water (O5) • Optimize adult fish trap operations (O6) • At the four lower Snake River projects, operate within the full reservoir operating range year-round (O7a) • At John Day, restrict seasonal pool elevation to within 2.5 feet of Minimum Irrigation Pool (MIP) (O7b) • Operate turbines at full capacity, and reduce turbine restrictions to operate at 1% peak efficiency (O8) • Zero generation operations may occur on lower Snake River projects from November through February (O10)

1.7.2 Integrated Alternative 2 (Resource Emphasis on ESA-Listed Salmon Survival)

Integrated Alternative 2 was formulated to combine actions to emphasize ESA-listed salmonid survival, while avoiding negative impacts to other authorized project purposes and co-lead agency missions. The measures included in Integrated Alternative 2 were intended to simultaneously consider both adult and juvenile life stages of ESA-listed salmonids in the CRS, whereas the adult and juvenile single objective focus alternatives allowed for tradeoff analysis between the two life stages. Measures of Integrated Alternative 2 include the cessation of juvenile fish passage spill during the summer months, except at John Day Dam, for the purpose of reducing the release of warmer surface water. At Bonneville Dam, juvenile fish passage spill would not occur in either spring or summer. The release of deeper, cooler water is intended to reduce impacts to adult salmonids associated with warmer temperatures (e.g., migration delay and health). In addition to modifying juvenile fish passage spill, Integrated Alternative 2 includes some measures developed for the single objective alternatives, such as those for water management flexibility. Details of the hydropower-focused single objective alternative were also used, but were modified to avoid operational conflicts with ESA-listed salmonid juvenile and adult life stages. All FRM-related measures were also retained, as these are required for human health and safety.

The structural and operational measures comprising Integrated Alternative 2 are provided in Table 1-14. The measures of this alternative were refined carried into one or more of the multiple objective alternatives for full analysis.

Table 1-14. Integrated Alternative 2 – Structural and Operational Measures

Structural Measures
• Construct powerhouse surface passage routes • Upgrade spillway weirs to ASWs • Improve adult ladder passage through modification of the adult trap (add and improve adult fish ladders) • Install pumping systems to provide deeper water in adult fish ladders • Modify tailrace configuration to reduce spill effects on adult passage
Operational Measures – Fish Passage Spill
• Modify juvenile fish passage spill TDG percentages to reduce spill effects on adult passage • During juvenile fish passage spill, put more spill over spillway weir than spillway • Measure juvenile fish passage spill TDG levels on a 12-hour rolling average • Allow contingency reserves to be carried within juvenile fish passage spill

Operational Measures – Water Management
• Modify Libby draft and refill operations: VarQ procedure • Modify Libby draft and refill operations: SRD • Modify Libby draft and refill operations: refill when 6.9 MAF or less • Eliminate end-of-December variable draft at Libby and replace with single draft target of 2420 feet December 31 • Decrease Grand Coulee draft rate used in planning drawdown, 0.8 feet/day maximum draft • Operational constraints for ongoing Grand Coulee powerplant maintenance, limits maximum outflow • Develop draft requirements approach to protect against rain-induced flooding
Operational Measures – Other
• Operate turbines at full capacity; reduce restriction to operate at or above 1% peak efficiency • Optimize adult fish trap operations • Implement modified timing of lower Snake River Basin reservoir draft for additional cooler water • Zero generation operations may occur on lower Snake River projects from November through February • Reservoir drawdown to MOP to reduce outmigration travel time • Support establishment of riparian vegetation at Libby Dam • Implement sliding scale summer draft at Libby and Hungry Horse Dams

1.7.3 Integrated Alternative 3 (Resource Emphasis on Minimized Greenhouse Gas Emissions for Power Production)

The Pacific Northwest is rapidly developing more non-hydropower renewable resources, especially wind and solar. During the formal scoping process, the co-lead agencies received a large number of public comments requesting an analysis of the impacts of using non-hydropower renewable power sources, either in conjunction with or in lieu of CRS hydropower. Integrated Alternative 3 emphasizes maximizing the total amount of carbon-free power production from renewable resources (e.g., wind and solar), and then adding hydropower production as a secondary power source. By making hydropower production a secondary priority, the CRS could increase flexibility to respond to the highest-demand periods for power generation. Like Integrated Alternatives 1 and 2, avoidance of negative impacts to other authorized project purposes and co-lead agency missions was added to the formulation process.

Integrated Alternative 3 includes maximum integration of wind- and solar-generated power sources into the grid during peak demand hours, as a priority over hydropower. The operating reserve would come from hydropower generation, which would serve as a backup power source to make up needed megawatts when wind and solar sources are unable to meet demand, particularly during peak hours. Measures contained in Integrated Alternative 3 include setting the juvenile fish passage spill to a cap of 110-percent TDG, as measured in the tailrace at the eight lower Columbia and Snake River projects to increase the flexibility of hydropower production in conjunction with non-hydropower, renewable power sources. Measures developed in the water management flexibility single objective alternatives were included in Integrated Alternative 3. Details of the measures from Single Objective Focus Maximum Integration of Non-Hydropower Renewables Alternative and Single Objective Focus Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production Alternative were used, but were modified as needed to avoid operational conflicts and achieve the intent of the alternative. All FRM-related measures were also retained, as they are required for human health and safety. The purpose of Integrated Alternative 3 is to show impacts to other resources in the CRS from increasing integration of wind- and solar-power sources into the grid.

The structural and operational measures comprising Integrated Alternative 3 are provided in Table 1-15. The measures of this alternative were refined carried into one or more of the multiple objective alternatives for full analysis.

Table 1-15. Integrated Alternative 3 – Structural and Operational Measure

Structural Measures
• Construct powerhouse surface passage routes • Upgrade spillway weirs to ASWs • Improve adult ladder passage through modification of the adult trap (add and improve adult fish ladders) • Install pumping systems to provide deeper water in adult fish ladders • Modify position of entrance weirs to reduce shad in adult fish ladders
Operational Measures – Fish Passage Spill
• Limit fish passage spill to 110-percent TDG • Measure juvenile fish passage spill TDG levels on a 12-hour rolling average • Allow contingency reserves to be carried within juvenile fish passage spill
Operational Measures – Water Management
• Modify Libby draft and refill operations: VarQ procedure • Modify Libby draft and refill operations: SRD • Modify Libby draft and refill operations: refill when 6.9 MAF or less • Eliminate end-of-December variable draft at Libby and replace with single draft target of 2420 feet December 31 • Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD • Decrease Grand Coulee draft rate used in planning drawdown; 0.8 feet day maximum draft • Operational constraints for ongoing Grand Coulee powerplant maintenance; 0.8 feet/day maximum draft • Develop draft requirements approach to protect against rain-induced flooding
Operational Measures – Other
• Implement modified timing of Dworshak for cold water releases • Ramping rate limitations at all projects will be defined only for safety or engineering • At the four lower Snake River projects, operate within the full reservoir operating range year-round • At John Day, restrict seasonal pool elevation is restricted to within 2.5 feet of MIP • The storage projects may be drafted slightly deeper for hydropower • Lake Roosevelt lower pool elevation not limited for ferry operation • At John Day, allow project to operate up to full pool except for FRM • Operate turbines at full capacity; reduce restriction to operate at or above 1% peak efficiency • Optimize adult fish trap operations • Zero generation operations may occur on lower Snake River projects from November through February

1.7.4 Integrated Alternative 4 (Resource Emphasis on ESA-Listed Anadromous Salmonids and Resident Fish)

Integrated Alternative 4 was formulated to integrate actions to emphasize improving conditions for upstream and downstream passage of ESA-listed anadromous salmonids of all life stages at CRS projects, while avoiding negative impacts to other authorized project purposes and co-lead agency missions. Improved conditions would include measures to reduce injury, increase detection of ladder entrances, reduce competition with non-native fish species for ladder use, and improve opportunities for native fish remaining in the reservoirs to move between projects. Measures to reduce injury include increasing the size of entrance orifices and bypass pipes and reducing water temperatures in the fish ladders. Measures to increase detection of ladder entrances include the reduction of confusing or repelling water conditions (eddies and water temperature) at fish ladder entrances.

Integrated Alternatives 2 and 4 are similar, as they both focus on benefits for ESA-listed anadromous salmonids of both juvenile and adult life stages. The two alternatives differ in that Integrated Alternative 4 has some opportunities for resident native fish benefits, while Integrated Alternative 2 has more opportunities for anadromous salmonids. For example, Integrated Alternative 2 includes drawdown of the lower Columbia and Snake River projects to their respective MOPs to reduce the cross-section of the downstream river reaches, which may reduce in-river travel time for downstream migrating juvenile fish. Integrated Alternative 4 does not include this drawdown measure.

Integrated Alternative 4 would set juvenile fish passage spill to a cap of 120-percent TDG, as measured in the tailrace at the lower Columbia and Snake River projects. However, at Bonneville Dam, juvenile fish passage spill would be limited to a flow target of 100 kcfs rather than a TDG target. It also includes some measures developed for the single objective alternatives, such as those for water management flexibility. Details of the Single Objective Focus Anadromous ESU/Adult and Juvenile Alternative measures were also used, but were modified as needed to avoid operational conflicts. All FRM-related measured were also retained, as these are required for human health and safety.

The structural and operational measures comprising Integrated Alternative 4 are provided in Table 1-16. The measures of this alternative were refined carried into one or more of the multiple objective alternatives for full analysis.

Table 1-16. Integrated Alternative 4 – Structural and Operational Measures

Structural Measures
• Construct additional surface passage routes • Upgrade spillway weirs to ASWs • Improve adult ladder passage through modification of the adult trap (add and improve adult fish ladders) • Install pumping systems to provide deeper water in adult fish ladders • Modify position of entrance weirs to reduce shad in adult fish ladders • Improve juvenile bypass facilities by enlarging orifices/pipes

Operational Measures – Fish Passage Spill
• Limit fish passage spill to 120-percent/115-percent TDG to evaluate latent mortality hypothesis • Measure juvenile fish passage spill TDG levels on a 12-hour rolling average • Allow contingency reserves to be carried within juvenile fish passage spill • Use existing surface passage structures for overwintering steelhead overshoots/kelts
Operational Measures – Water Management
• Modify Libby draft and refill operations: VarQ procedure • Modify Libby draft and refill operations: SRD • Modify Libby draft and refill operations: refill when 6.9 MAF or less • Eliminate end-of-December variable draft at Libby and replace with single draft target, 2420 feet December 31 • Update the upstream Storage Corrections Method as applied to Grand Coulee SRD • Decrease Grand Coulee draft rate used in planning drawdown, 0.8 feet/day maximum draft • Operational constraints for ongoing Grand Coulee powerplant maintenance; limits maximum outflow • Develop draft requirements approach to protect against rain-induced flooding
Operational Measures – Other
• Strive to maintain minimum 220 kcfs spring flow objective at McNary; up to 2 MAF • Implement modified timing of reservoir draft of Dworshak for cold water releases • Zero generation operations may occur on lower Snake River projects from November through February

1.7.5 Integrated Alternative 5 (Resource Emphasis on Lower Snake River Dam Breach with Lower Columbia River Modifications)

Integrated Alternative 5 was formulated to emphasize the conversion of reservoir conditions to riverine conditions in the lower Snake River. The US District Court for the District of Oregon noted, in the *NWF v. NMFS* case, that breaching of the four lower Snake River dams may be reasonable for consideration in this EIS. In addition, the co-lead agencies received a large number of public comments requesting an analysis of breaching the lower Snake River dams during the formal scoping process. Integrated Alternative 5 was formulated based on the Single Objective Focus Lower Snake River Dam Breaching, Alternative, and includes measures developed from the Single Objective Focus Water Management Alternative, as well as hydropower production and fish passage measures from Integrated Alternative 3. Details of measures from other draft alternatives were modified as needed to remove inclusion of the four lower Snake River projects, avoid operational conflicts, and achieve the intent of the alternative. All FRM-related measures were retained, as they are required for human health and safety.

Integrated Alternative 5 was developed as a means to improve conditions for four of the fourteen ESA-listed anadromous fish species in the Columbia River Basin, while avoiding negative impacts to other authorized project purposes and co-lead agency missions. The alternative proposed breaching the four lower Snake River dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) by removing the earthen embankments at each location. The reservoirs behind the dams would be drawn down slowly to avoid damage to adjacent infrastructure (e.g., roads, bridges, and railroads), and ensure the life safety of populations downstream. The concrete portions of the dams would remain in place, but the powerhouses would be rendered in operable. The generators would be modified for use as outlets during a controlled drawdown of the reservoir. The breaching would occur over a period of 2 years. The two upstream dams (Lower Granite and Little Goose) would be breached first, followed the next year by Lower Monumental and Ice Harbor. Spreading the breaching across 2 years allows the work to occur during the in-water work window, when very few ESA-listed fish would be present in the reservoirs, and inflows would be relatively small.

The structural and operational measures comprising Integrated Alternative 5 are provided in Table 1-17. The measures of this alternative were refined carried into one or more of the multiple objective alternatives for full analysis.

Table 1-17. Integrated Alternative 5 – Structural and Operational Measures

Structural Measures
• Construct additional surface passage routes • Upgrade spillway weirs to ASWs • Improve adult ladder passage modification of adult trap (add and improve adult fish ladders) • Modify position of entrance weirs to reduce shad in adult fish ladders • Improve juvenile bypass facilities by enlarging orifices/pipes
Structural and Operational Measures – Dam Breach
• *Structural* – Remove earthen embankments and adjacent structures, as required, at each lower Snake River dam • *Structural* – Modify equipment and infrastructure to adjust to drawdown conditions at each lower Snake River dam • *Operational* – Develop procedures to operate existing equipment during reservoir drawdown • *Operational* – Develop contingency plans to address unexpected issues with drawdown operations
Operational Measures – Fish Passage Spill
• Limit fish passage spill to 110-percent TDG • Allow contingency reserves to be carried within juvenile fish passage spill
Operational Measures – Water Management
• Modify Libby draft and refill operations: VarQ procedure • Modify Libby draft and refill operations: SRD • Eliminate end-of-December variable draft at Libby and replace with single draft target, 2420 feet December 31 • Modify Libby draft and refill operations when water supply forecast is 6.9 MAF or less • Update the upstream Storage Corrections Method as applied to Grand Coulee SRD • Decrease Grand Coulee draft rate used in planning drawdown • Operational constraints for ongoing Grand Coulee powerplant maintenance • Develop draft requirements approach to protect against rain-induced flooding
Operational Measures – Other
• Additional summer flow augmentation from Dworshak for cold water releases • Implement modified timing of reservoir draft of Dworshak for cold water releases • Ramping rate limitations at all projects will be defined only for safety or engineering • At John Day, restrict seasonal pool elevation to within 2.5 feet of MOP • Storage projects may be drafted slightly deeper for hydropower • Lake Roosevelt lower pool elevation not limited for ferry operation • At John Day, allow project to operate up to full pool except for FRM

- Operate turbines at full capacity; reduce restriction to operate at or above 1% efficiency
- Optimize adult fish trap operation

1.7.6 Transition from Integrated Alternatives to Multiple Objective Alternatives

During review of the draft Integrated Alternatives, the decision was made to revise and consolidate the five draft Integrated Alternates into three Multiple Objective Alternatives. This decision was based on the desire of the co-lead agencies to analyze key concepts of fish survival, hydropower generation, and lower Snake River dam breach in conjunction with a range of spill operations. The technical teams and cooperating agencies were provided first drafts of these Multiple Objective Alternatives for review and comment. A fourth draft Multiple Objective Alternative was submitted from a Cooperating Agency for consideration along with feedback on the other three.

The Cooperating Agency’s original version of the fourth, draft Multiple Objective (MO) Alternative was developed using both measures from the other three MO Alternatives with modifications and new concepts. The original fourth MO was developed with a central operational measure “low powerhouse encounter rate (high spill) during spring emigration period.” The goal of this measure was to utilize surface passage and juvenile fish passage spill operations in tandem to decrease the powerhouse encounter rate as statically measured as PITPH. The structural and operational measures of the original fourth MO are briefly listed in Table 1-18, below. For complete details, see the Detailed Descriptions section below.

Table 1-18. Original Draft Multiple Objective Alternative 4 – Structural and Operational Measures

Structural Measures

- Construct additional powerhouse surface passage routes to meet system-wide PITPH target (S1)
- Improve adult ladder passage modification of adult trap and adult trap bypass loop at Lower Granite Dam (S2)
- Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor dams (S3)
- Install new “fish-friendly” and high-efficiency/capacity turbines (S4)
- Expand network of lamprey passage structures (LPS) to bypass impediments in existing fish ladders (S5)
- Develop and implement an adult lamprey trap and haul program as an interim strategy for conveyance to upstream tributaries (S6)
- Modify turbine intake bypass screens that cause juvenile lamprey impingement and entanglement (S7)
- Modify existing fish ladders, incorporating lamprey passage features and criteria into ladder modifications (S8)
- Add fourth generation unit to Dworshak Dam (S9)

Operational Measures – Fish Passage Spill

- Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead and kelt downstream passage (O1)
- Low powerhouse encounter rate (high spill) during spring emigration period (O2)
    - Request to manage TDG up to 125% in tailrace and eliminate forebay target
- Transitional summer juvenile fish passage spill operations (O3)
- Allow contingency reserves to be carried within juvenile fish passage spill (O4)

Operational Measures – Other
- Maintain juvenile fish transportation during spring and fall periods (O5) - Cease juvenile transport during portions of summer spill period (O6) - Strive to maintain minimum 220 kcfs spring flow objective at McNary from May 1 – June 15 and minimum 200 kcfs summer flow objective at McNary from June 16 – July 31 through the use of four U.S. storage reservoirs, up to maximum of 2.0 Maf - Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for outmigration (O8) - Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (avian colonies, as well as small mouth bass and walleye spawning success) (O9) - Operate turbines within and above 1% of peak efficiency year round (O10)

1.8 ALTERNATIVES SCREENING

In order to make a more workable range of alternatives for full evaluation, the team screened the alternatives, with the intention of focusing effort on the most viable alternatives. A workshop was held with technical team leads to evaluate the formulated range of alternatives against criteria to determine those to be carried forward for full analysis in the CRSO EIS.

At this stage in the process, the co-lead agencies lacked complete information related to costs, environmental or social effects, or outcomes of modeling and analysis. Thus, a qualitative evaluation was conducted, using the following criteria commonly applied by water resources agencies to evaluate water resources alternatives:

- *Completeness:* The extent to which an alternative provides and accounts for all features, investments, and/or other actions necessary to realize the planned effects, including any necessary actions by others.
- *Effectiveness:* The extent to which an alternative alleviates the specified problems and realizes the specified opportunities.
- *Efficiency:* The extent to which an alternative alleviates the specified problems and achieves the specified opportunities.
- *Acceptability:* The viability and appropriateness of an alternative from the perspective of the Nation's general public and consistency with existing Federal laws, authorities, and public policies. It does not include local or regional preferences for particular solutions or political expediency.

Of these four criteria, the technical managers applied *completeness* and *efficiency*, to the range of alternatives. These two criteria were selected because they did not require cost information or modeling outputs for evaluation. Likewise, all alternatives were formulated to meet acceptability criteria, but it was determined best to apply this criteria later in the process. Using best professional judgment and existing information, the technical managers applied the criteria to the range of twelve alternatives.

Table 1-19. Columbia River System Operations Screening

Alternative	Meets Completeness Criteria – Comprehensive	Effectiveness – Not Evaluated	Meets Efficiency Criteria	Acceptability – Not Evaluated	Eliminated from Further Consideration
Water Management	No		No		Yes
Water Supply	No		No		Yes
125% Spill	No		No		Yes
Hydropower	No		No		Yes
Resident	No		No		Yes
Juvenile	No		No		Yes
Adult	No		No		Yes
Dam Breach	No		No		Yes
MO1	**Yes**		**Yes**		**No**
MO2	**Yes**		**Yes**		**No**
MO3	**Yes**		**Yes**		**No**
MO4	**Yes**		**Yes**		**No**

1.9 ALTERNATIVES CARRIED FORWARD

The third iteration of the alternatives formulation process focused on refinement. This iteration was informed by technical expert review of the results of the preliminary hydraulic and hydrological analysis. Measures from the preliminary draft Single Objective and Integrated Alternatives were refined and recombined into four Multiple Objective Alternatives. The refinement and recombination effort sought to eliminate apparent conflicts between measures, allow for tradeoff analysis of grouped measures, and better meet the identified objectives.

The result of this refinement effort was to produce five draft alternatives: 1) No Action; 2) Multiple Objective Alternative 1 (MO1); 3) Multiple Objective Alternative 2 (MO2); 4) Multiple Objective Alternative 3 (MO3); and 5) Multiple Objective Alternative 4 (MO4). These alternatives were developed to provide a range of possible actions for the continued operation and maintenance of the CRS. The following sections offer summary descriptions of the five alternatives carried forward for full consideration and analysis. For additional measure details, refer to the Detailed Descriptions section below.

1.9.1 Multiple Objective Alternative 1

The Multiple Objective Alternative 1 (MO1) was formulated to integrate actions that would especially benefit ESA-listed fish species without producing an appreciably negative impact to the other project purposes and co-lead agency missions. The MO1 Alternative is intended to meet most, if not all, of the CRSO EIS objectives rather than focus on individual objectives. For example, the MO1 Alternative aims to include measures to benefit both the juvenile and adult life stages of ESA-listed anadromous fish as well as measures to benefit ESA-listed resident fish all while incorporating measures for water management flexibility, hydropower production, and water supply.

Table 1-20. Multiple Objective Alternative 1 – Structural and Operational Measures

Structural Measures
• Construct additional powerhouse surface passage routes at McNary and Ice Harbor (S1) • Upgrade spillway weirs to ASWs (S2) • Improve adult ladder passage through modification of adult trap at Lower Granite (S3) • Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam (S4) • Install pumping systems to provide deeper water in adult fish ladders at Lower Monumental and Ice Harbor (S5) • Expand network of lamprey passage structures (LPS) to bypass impediments (S6) • Modify turbine cooling water strainer systems to safety exclude Pacific lamprey (S7) • Modify turbine intake bypass screens that cause juvenile lamprey impingement (S8) • Modify existing fish ladders, incorporating lamprey passage features and criteria (S9) • Install new “fish-friendly” and high-efficiency/capacity turbines at John Day (S10)
Operational Measures – Fish Passage Spill
• Limit fish passage spill to 120-percent/115-percent TDG to evaluate latently mortality hypothesis (O1) • Modify summer juvenile fish spill operations based on fish collection numbers (O2) • Change start of juvenile fish transportation during spring juvenile fish passage spill operations (O3) • Increase forebay operating range flexibility at the lower Snake and Columbia River and John Day projects (O4) • Allow contingency reserves to be carried within juvenile fish passage spill (O5)
Operational Measures – Water Management
• Modify Libby draft/refill operations when water supply forecast is 6.9 MAF or less (O6) • Eliminate end-of-December variable draft at Libby; replace with single draft target (O7) • Update upstream Storage Corrections Method as applied to the Grand Coulee SRD (O8) • Decrease the Grand Coulee Dam draft rate used in planning drawdown (O9) • Operational constraints for ongoing Grand Coulee maintenance of power plants (O10) • Develop draft requirements/assessment approach to protect against rain-induced flooding (O11)
Operational Measures – Water Supply
• Increase water pumped from Lake Roosevelt during annual irrigation season (O12) • Increase water managers’ flexibility to store and release water from Hungry Horse Reservoir (O13) • Increase water diversion from the Columbia River for Chief Joseph Dam Project (O14)
Operational Measures – Other
• Implement modified timing of lower Snake River Basin reservoir draft for additional cooler water (O15) • Implement sliding scale summer draft at Libby and Hungry Horse (O16) • Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction (O17)

To meet the multiple objectives, the MO1 Alternative utilized many of the same measures developed for the Single Objective alternatives and modified details of those previous measures as-needed to avoid operational conflicts. New measures were also included with the MO1 Alternative. The MO1 Alternative’s juvenile fish passage spill operation is intentionally different from those to be analyzed in the other alternatives in an attempt to evaluate latent mortality and continue the array of spill scenarios. In addition, the MO1 Alternative includes measures aimed at improving conditions for Pacific lamprey within the CRSO project area.

1.9.2 Multiple Objective Alternative 2

The Multiple Objective Alternative 2 (MO2) is intended to increase hydropower production while avoiding negative impacts to the other authorized project purposes and co-lead agency missions. The MO2 Alternative includes relaxing of the No Action Alternative’s restrictions on operating ranges and ramping rates to evaluate the potential to increase power production efficiency and increase flexibility to respond to changing power demand. The measures of the MO2 Alternative would increase the ability to meet power demand with hydropower production by generating as much power as possible during the most valuable periods (e.g., winter, summer, and daytime peak demands).

Table 1-21. Multiple Objective Alternative 2 – Structural and Operational Measures

Structural Measures
• Install new “fish-friendly” and high-efficiency/capacity turbines at John Day (S1) • Construct powerhouse and/or spill surface passage routes at John Day, McNary, and Ice Harbor Dams (S2) • No installation of fish screens at Ice Harbor, McNary, and John Day Projects (S3) • Upgrade spillway weirs to ASWs (S4) • Install pumping systems to provide deeper water in adult fish ladders at Lower Monumental and Ice Harbor (S5) • Expand network of LPS to bypass impediments (S6) • Modify turbine cooling water strainer systems to safety exclude Pacific lamprey (S7) • Modify turbine intake bypass screens that cause juvenile lamprey impingement (S8) • Modify existing fish ladders, incorporating lamprey passage features and criteria (S9)
Operational Measures – Fish Passage Spill
• Limit fish passage spill to 110-percent TDG (O1) • Allow contingency reserves to be carried within juvenile fish passage spill (O6) • Juvenile fish transportation at Lower Granite, Little Goose, Lower Monumental, McNary, down to Bonneville Dam from April 25 – August 31 (O4)
Operational Measures – Water Management
• Modify Libby draft/refill operations when water supply forecast is 6.9 MAF or less (O7) • Eliminate end-of-December variable draft at Libby; replace with single draft target (O8) • Update upstream Storage Corrections Method as applied to the Grand Coulee SRD (O9) • Decrease the Grand Coulee Dam draft rate used in planning drawdown (O10) • Operational constraints for ongoing Grand Coulee maintenance of power plants (O11) • Develop draft requirements/assessment approach to protect against rain-induced flooding (O12)
Operational Measures – Other
• Ramping rate limitations at all projects defined only for safety or engineering (O2a) • At the four lower Snake River projects operate within the full reservoir operating range year-round (O2b) • Allow project to operate up to full pool except as needed for FRM (O2c) • The storage projects may be drafted slightly deeper for hydropower (O2d) • Operate turbines across their full range of capacity year-round (O3) • Implement sliding scale summer draft at Libby and Hungry Horse (O5) • Zero generation operations may occur on lower Snake River projects November – February (O13)

The MO2 Alternative utilized many of the same measures developed for the Single Objective alternatives and modified details of those previous measures as-needed to avoid operational conflicts. Juvenile fish passage spill operations are limited to a cap of 110% total dissolved gas in MO2 Alternative to allow analysis of a reduced level of fish passage spill relative to other multiple objective alternatives and the impacts on hydropower production. The MO2 Alternative will evaluate an expanded juvenile fish transportation season and includes measures aimed at improving conditions for Pacific lamprey within the CRSO project area.

1.9.3 Multiple Objective Alternative 3

The Multiple Objective Alternative 3 (MO3) was developed as a strategy to meet, in part or in full, all objectives supporting the Federally-authorized purposes of the CRS. In addition, the alternative contains measures to improve conditions for Pacific lamprey within the CRS project area. Structural measures in this alternative include breaching the four lower Snake River dams by removing the earthen embankment at each dam location, resulting in a controlled drawdown. Operational measures in the MO3 Alternative are intended to improve juvenile fish travel times, improve conditions for resident fish in the upper basin, increase hydropower generation flexibility, provide more flexibility to water managers, and provide additional water supply. Measures intended to benefit ESA-listed fish include modifying the spring spill regime to improve juvenile salmon migration travel times, and implementing a sliding scale summer draft at Libby and Hungry Horse Dams to improve conditions for ESA-listed resident bull trout and Kootenai white sturgeon in the upper basin.

Table 1-22. Multiple Objective Focus Alternative 3 – Structural and Operational Measures

Structural Measures
• Construct additional powerhouse or spill surface passage routes at McNary Dam (S1) • No installation of fish screens at McNary Dam (S2) • Upgrade spillway weirs to ASWs (S3) • Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam (S4) • Expand network of LPS to bypass impediments (S5) • Modify turbine cooling water strainer systems to safety exclude Pacific lamprey (S6) • Modify turbine intake bypass screens that cause juvenile lamprey impingement (S7) • Modify existing fish ladders, incorporating lamprey passage features and criteria (S8) • Install new “fish-friendly” and high-efficiency/capacity turbines at John Day Dam (S9)
Structural and Operational Measures – Lower Snake River Dam Breach
• *Structural* – Remove earthen embankments and adjacent structures, as required, at each lower Snake River dam (S10) • *Structural* – Modify equipment and infrastructure to adjust to drawdown conditions at each lower Snake River dam (S11) • *Operational* – Develop procedures to operate existing equipment during reservoir drawdown (O1) • *Operational* – Develop contingency plans to address unexpected issues with drawdown operations (O2)
Operational Measures – Fish Passage
• Limit fish passage spill to 120-percent TDG at McNary, John Day, The Dalles, and Bonneville Dams (O3) • Reduce the duration of summer juvenile fish passage spill (O4) • Allow contingency reserves to be carried with juvenile fish passage spill (O5)

Operational Measures – Water Management
• Modify Libby draft/refill operations when water supply forecast is 6.9 MAF or less (O6) • Eliminate end-of-December variable draft at Libby; replace with single draft target (O7) • Update upstream Storage Corrections Method as applied to the Grand Coulee SRD (O8) • Decrease the Grand Coulee Dam draft rate used in planning drawdown (O9) • Operational constraints for ongoing Grand Coulee maintenance of power plants (O10)
Operational Measures – Water Supply
• Increase water volume pumped from Lake Roosevelt during annual irrigation season (O11) • Increase water managers' flexibility to store and release water from Hungry Horse Reservoir (O12) • Increase water diversion from the Columbia River for Chief Joseph Dam Project (O13)
Operational Measures – Other
• Ramping rate limitations at all projects defined only for safety or engineering (O14) • At John Day, allow project to operate up to full pool except as needed for FRM (O15) • Operate turbines within 1% peak efficiency during juvenile fish passage season (O16) • Implement sliding scale summer draft at Libby and Hungry Horse (O16)

1.9.4 Multiple Objective Alternative 4

The Multiple Objective Alternative 4 (MO4) was refined to incorporate measures from the earlier draft alternatives that were intended to provide flexibility to water managers for balancing flood storage and other project purposes such as actions for ESA-listed fish, water supply, and hydropower generation. In addition, this alternative contains measures to improve conditions for Pacific lamprey within the CRS project area. The alternative includes modifications for both structural and operational modifications.

Operational include actions for ESA-listed fish such as juvenile fish passage spill up to 125 percent TDG and extended spill for overwintering steelhead and kelts. Additional fish measures include modification of the current juvenile transport program schedule to only operate in the spring and fall, minimum flows for flow augmentation during summer months, and operation of the lower Columbia and Snake River projects at MOP from March to August. The alternative also contains a measure intended to improve conditions for ESA-listed resident fish, bull trout, and Kootenai sturgeon in the upper Columbia River Basin.

Table 1-23. Multiple Objective Alternative 4 – Structural and Operational Measures

Structural Measures
• Construct additional powerhouse and/or spill surface passage routes at McNary Dam • Improve adult ladder passage through modification of adult traps at Lower Granite (S1) • Install pumping systems to provide deeper water in adult fish ladders at Lower Monumental and Ice Harbor Dams (S2) • Install new "fish-friendly" and high-efficiency/capacity turbines at John Day Dam (S3) • Expand network of LPS to bypass impediments (S4) • Modify turbine intake bypass screens that cause juvenile lamprey impingement (S5) • Modify existing fish ladders, incorporating lamprey passage features and criteria (S6) • Addition of spillway weir notch gate inserts (S7)

Operational Measures – Fish Passage
• Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead, and kelts (O1) • Set juvenile fish passage spill to not exceed 125-percent TDG (O2) • Allow contingency reserves to be carried within juvenile fish passage spill (O3) • Implement juvenile fish transportation during spring and fall periods at Lower Granite, Little Goose, and Lower Monumental Dams (O4) • Cease juvenile transport during portions of summer spill period at Lower Granite, Little Goose, and Lower Monumental Dams (O5)
Operational Measures – Water Management
• Modify Libby draft/refill operations when water supply forecast is 6.9 MAF or less (O6) • Eliminate end-of-December variable draft at Libby; replace with single draft target (O7) • Update upstream Storage Corrections Method as applied to the Grand Coulee SRD (O8) • Decrease the Grand Coulee Dam draft rate used in planning drawdown (O9) • Operational constraints for ongoing Grand Coulee maintenance of power plants (O10) • Develop draft requirements/assessment approach to protect against rain-induced flooding (O11)
Operational Measures – Water Supply
• Increase volume of water pumped from Lake Roosevelt during irrigation season (O12) • Increase water managers' flexibility to store and release water from Hungry Horse Reservoir (O13) • Increase water diversion from the Columbia River for Chief Joseph Dam Project (O14)
Operational Measures – Other
• Strive to hold minimum 220 kcfs spring flow/200 kcfs summer flow objectives at McNary using upstream storage (O15) • Reservoir drawdown to MOP to reduce outmigration travel time (O16) • Operate turbines within 1% peak efficiency during juvenile fish passage season (O17) • Implement sliding scale summer draft at Libby and Hungry Horse Dams (O18) • Support establishment of riparian vegetation at Libby Dam by limiting Bonners Ferry stage height November – March (O19)

1.9.5 No Action Alternative

For this EIS, the No Action Alternative represents a snapshot in time of CRSO, from September 30, 2016, the date the Notice of Intent (NOI) to complete the CRSO EIS was published in the Federal Register. To the extent possible, all ongoing, scheduled, and routine maintenance activities for the Federal infrastructure and all structural features, including those recently constructed or reasonably foreseeable, are assumed to be included in the No Action Alternative. It also assumes existing and ongoing predator control programs and other project operations would continue.

As described in Chapter 1, the CRS is operated to meet multiple authorized purposes, and consider other concerns (e.g., Tribal interests, lamprey, etc.). The volume of water in the CRS in any given year is variable and finite, and not all operations to benefit various resources may be achieved in a given year. In coordinating system water management, the co-lead agencies generally prioritize FRM and environmental responsibilities, such as conservation actions for ESA-listed fish species and other species of concern, before Bonneville Power Administration shapes any remaining flexibility to manage water flow for hydropower generation to meet daily and seasonal power demands.

The following table of No Action Alternative measures provides a brief description of the way the CRS is operated, and would be expected to operate, if no other changes are implemented. A more comprehensive description of current system operations is contained in Chapter 2, section 2.3.2.1. Table 1-24 contains structural and operational measures included in the No Action Alternative.

Table 1-24. No Action Alternative – Structural and Operational Measures

Structural Measures
• Hungry Horse Powerplant Modernization • Lower Granite Juvenile Facility Bypass Improvements • Lower Granite Spillway Passive Inducer Transponder (PIT) Monitoring System • Little Goose ASW Closure • Little Goose Adult Ladder Temperature Improvements • Little Goose Boat Barrier
Operational Measures – Hydropower Production
• Coordinated water management of the CRS to schedule water used for hydropower generation • Balance between generation and load within the Bonneville Balancing Authority Area
Operational Measures – Flood Risk Management
• Minimal Fall Operations: September through December • Storage Evacuation Operations: January through April • Refill Operations: May through August • Drum Gate Maintenance at Grand Coulee Dam • Allowable Rate of Change of Release at the John Day Project
Operational Measures – Water Supply
• Operations for irrigation water supply at Grand Coulee (Lake Roosevelt) and John Day Projects
Operational Measures – Anadromous Fish
• Flow Augmentation from Libby, Hungry Horse, Dworshak, and Grand Coulee Projects • Spring and Summer Operations at Dworshak • Priest Rapids Spring Flow Augmentation • Flood Risk Management Shift • Spill Operations • Minimum Flows and Draft Limitations at Grand Coulee • Lake Roosevelt Incremental Storage Release • Chum Flows and Operations • Hanford Reach Fall Chinook Protection Program • Spring and Summer Flow Objectives • Turbine Operations Within ±1 Percent of Peak Efficiency • Minimum Operating Pool at lower Snake River projects • Minimum Irrigation Pool range at John Day Project • Juvenile Fish Transportation Program on lower Snake River projects

Operational Measures – Residential Fish
• Flow Augmentation from Libby Project Kootenai River white sturgeon and bull trout • Sturgeon Recovery Operations from Libby Project • Temperature Control Operations • Lake Pend Oreille Elevations for Kokanee and Bull Trout from Albeni Falls Project • Variable Draft Limits from Hungry Horse Project • Operations to Limit TDG at the Hungry Horse and Chief Joseph Projects
Operational Measures – Tribal Interests
• Development of Annual Fish Passage Plan for Fish Operations • Operations to Support Tribal Fishing at John Day, The Dalles, and Bonneville Projects
Operational Measures – Maintenance Measures
• Routine Maintenance: Planned, Scheduled, Preventative and Corrective Maintenance • Unscheduled Maintenance: Unplanned, Unforeseen Maintenance • Non-Routine Maintenance: Planned, Irregular-interval Maintenance
Operational Measures – Navigation Measures
• Operations for Navigation Safety • Annual Dredging to Maintain Deep Draft Federal Navigation Channel • Navigation Lock Maintenance

1.10 EVALUATION OF ALTERNATIVES

Evaluation factors considered in the comparison of the Multiple Objective Alternatives included environmental, economic, sociological, and stakeholder and cooperating agency input. Examples of reasons for elimination are: (1) failure of the alternative to meet the requirements of the purpose of and need for the action, (2) the alternative cannot be technically implemented, (3) the alternative is prohibitively greater in cost or in environmental impacts than the other alternatives, or (4) the alternative cannot be reasonably implemented.

1.11 PREFERRED ALTERNATIVE

The technical evaluation of the range of alternatives led to a final iteration in the alternatives development process. This iteration resulted in a mixing of measures from MO 1, MO 2, and MO 3, and the inclusion of a new measure that had not yet been evaluated, to develop a preferred alternative that meets Congressionally-authorized purposes and provides a balance of benefits to ESA-listed fish, supports the continuation of clean hydropower generation, and allows for adaptive management to meet changing river and climate conditions. This alternative, identified as the Draft Preferred Alternative, features most of the measures in Multi-Objective Alternative 1, including measures for flexible water management, continued delivery of water for irrigation and municipal and industrial water supply, with several measures from Multi-Objective 2 which will provide flexibility for hydropower generation under fluctuating reservoir conditions. The Draft Preferred Alternative also includes a spill regime, to be implemented at the lower Snake River and lower Columbia River projects, described as "Flexible Spill with Adaptive Management". This operation was tested in years 2018 and 2019, to understand the effects of higher spill for juvenile salmon migration, combined with opportunities to generate hydropower during periods of high demand. This measure would provide spill for juvenile fish passage (up to 125% TDG), balanced with opportunistic hydropower generation during the high-demand summer months. This alternative is described in more detail in Chapter 7.

1.12 DETAILED DESCRIPTIONS

To capture the detail of each alternative, a template was developed to help the technical teams fully describe the alternatives, the measures that make up each alternative, and the location, implementation details, and purpose of each measure. The intent of these templates was threefold: 1) to help the technical teams think critically about the issue addressed by each measure and the efficacy of the measure, 2) to fully describe each measure and its application, and 3) to inform the development of the strategy for modeling and analysis.

1.12.1 Preliminary Alternative: Juvenile Anadromous Fish Survival Focus Detailed Description

CRSO Objective: Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to configuration, flow management, spill operations, and water quality management.

The measures in all alternatives are changes relative to the No Action Alternative. If there are no changes listed for an existing structural or operational measure (e.g. juvenile fish transportation) in the alternatives, then the assumption is that the structure or operation would continue per the No Action Alternative.

The following measures address the objective(s):

Structural Measures:

S1. Construct additional powerhouse surface passage routes

- **Purpose:** May divert fish away from turbines and into a higher survival route, reduce exposure to screens, and reduce forebay delay.
- **Measure Location:** Ice Harbor and McNary Dams
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from March 1 to August 31.
  - Ice Harbor: Install surface passage through the Ice Harbor powerhouse
  - McNary: Install surface passage through the McNary powerhouse
- **Frequency and Duration:** March 1 – August 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and lower Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S2. Upgrade spillway weirs to Adjustable Spillway Weirs (ASWs)

- **Purpose:** Upgrade existing spillway weirs that are not adjustable spillway weirs (ASW's) to ASW's for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Lower Monumental, Ice Harbor, McNary, John Day Dams

- **Implementation:** Upgrade spillway weirs to ASW's. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (lower Snake River projects: June 20; lower Columbia River projects: June 15), 7 kcfs per weir discharge during summer spill operations (lower Snake River projects: June 21-August 31; lower Columbia River projects: June 16-August 31).
    - **Lower Granite.** Replace existing spillway weir with an ASW.
    - **Lower Monumental.** Replace existing spillway weir with an ASW.
    - **Ice Harbor.** Replace existing spillway weir with an ASW.
    - **McNary.** Replace the two existing spillway weirs with ASW's.
- **John Day.** Replace the two existing spillway weirs with ASW's.
- **Frequency and Duration:** March 1-August 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

Operational Measures:

O1. Manage juvenile fish passage spill to not exceed 120% tailrace gas cap at all lower Snake River and lower Columbia River projects

- **Specific Measure:** Increase juvenile fish passage spill.
- **Purpose:** Increase fish in river and long-term survival.
- **Measure Location:** The eight lower Columbia and lower Snake River Dams
- **Implementation:** Spill would be as shown in the table below. The dams would spill to the gas cap to maximize spill passage efficiency (SPE) since the spillway is typically one of the highest survival routes. Although there may be areas where increasing SPE may negatively affect passage survival, any potential negative effects will be documented in the effects analysis.

Location	Spill Regime
Lower Granite	120% tailrace Spill Cap*
Little Goose	120% tailrace Spill Cap*
Lower Monumental	120% tailrace Spill Cap*
Ice Harbor	120% tailrace Spill Cap*
McNary	120% tailrace Spill Cap*
John Day	120% tailrace Spill Cap*
The Dalles	120% tailrace Spill Cap*
Bonneville	120% tailrace Spill Cap*, not to exceed 150 kcfs spill

*The term “spill cap” refers to the maximum spill level at each project that is estimated to meet, but not exceed, the gas cap in the tailrace unless the spill cap is constrained (e.g. 150 kcfs maximum spill for Bonneville Dam). In this measure, spill caps will be set to meet, but not exceed, the gas cap of 120% TDG as measured at the tailrace fixed monitoring stations. This gas cap is consistent with the current Oregon TDG water quality standard modification and with the Washington TDG water quality standard criteria adjustment as measured at the tailrace. This measure is not consistent with the Washington TDG water quality criteria adjustment for measuring TDG at the forebay, which is 115% TDG. For the analysis of this measure, the spill caps will be set in a manner that accounts for the different methodologies the states of Washington and Oregon use to ascertain compliance with their respective standards.

- **Frequency and Duration:** March 1 to August 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

O2. Strive to maintain minimum 220 kcfs spring flow objective at McNary from May 1 – June 15 and minimum 200 kcfs summer flow objective at McNary from June 16 – July 31 through the use of four U.S. storage reservoirs, up to a maximum of 2.0 Million acre-feet (Maf).

- **Specific Measure:** Discharge up to 2.0 Maf additional water from U.S. storage reservoirs between May 1 – June 15 to meet spring flow objective at McNary dam. If the additional flow augmentation from U.S. reservoirs has not reached 2.0 Maf by June 15th, use the remaining volume to try to achieve the summer flow objective at McNary dam until July 31.
- **Purpose:** Lessen the impact of drier-than-normal juvenile salmon and steelhead outmigration periods by raising flows in the lower Columbia River during outmigration.
- Measure Locatio**n:** Libby, Hungry Horse, Albeni Falls, and Grand Coulee Dams
- **Implementation:** This measure would be implemented in years when the April issued April-August water supply forecast for The Dalles is below 87.5 Maf. This measure would be accomplished by operating Grand Coulee to target McNary Dam outflows described below. Grand Coulee will be allowed to draft to meet the target, but can only go as deep as minimum pool. Libby, Albeni Falls and Hungry Horse will backfill water to Grand Coulee by targeting a reduced fill elevation (i.e. this measure will result in a change in end-of-refill period reservoir elevations). To conserve the volume of water available, no more than 40 kcfs of flow augmentation shall be released on a given day. Current Canadian operations will be maintained (flow augmentation in Treaty and Non-Treaty agreements). Local resident fish ops will be maintained (e.g. minimum flows for resident fish, sturgeon pulse) unless they are maximum flows or minimum reservoir elevations, which could conflict with this measure and would be removed. Projects providing summer flow augmentation in the No Action alternative will attempt to provide at least the same volume as would have occurred without this augmentation, meaning they may

end the summer at a lower elevation. If the 2.0 Maf of flow augmentation specified in this measure is not fully used during the spring, the projects may provide summer flow augmentation in addition to flows specified in the No Action Alternative. Projects will provide a percentage of the flow augmentation based on their total storage capacity.

- **Frequency and Duration:** This measure would be implemented in years when the April issued April-August water supply forecast for The Dalles is below 87.5 Maf. Between May 1-July 31, strive to maintain minimum flows at McNary of 220 kcfs spring (May 1-June 15) and 200 kcfs summer (June 16-July 31) using up to 2.0 Maf additional volume discharged from four U.S. reservoirs.
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, and reduce in-river travel times.

O3. Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for Outmigration

- **Purpose:** Reduce water particle time through the reservoirs.
- **Measure Location:** McNary, John Day, The Dalles, and Bonneville Dams
- **Implementation:** Draw down the reservoir elevation, still allowing turbines to operate sustainably without cavitation issues:
    - Bonneville: MOP (forebay elevation 71.5’ + 1.5’ operating range above MOP)
    - The Dalles: MOP (forebay elevation 155’ + 1.5’ operating range above MOP)
    - John Day: MOP (forebay elevation 257’ + 1.5’ operating range above MOP)
    - McNary: MOP (forebay elevation 335’ + 1’ operating range above MOP)
- **Frequency and Duration:** April 3 (lower Snake River Dams)/April 10 (lower Columbia River Dams) through August 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

O4. Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (avian colonies, as well as small mouth bass and walleye spawning success)

- **Purpose:** Control avian colony success, smallmouth bass and walleye spawning (juvenile salmonid predators).
- **Measure Location:** McNary and John Day Dams

- **Implementation:** Raise and maintain reservoir elevations to full pool during the month of March, followed by drawdown to minimum operating pool elevations in April and May.
- **Frequency and Duration:** March 1 – May 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects by increasing juvenile salmonid predator management.

1.12.2 Errata Sheet - Juvenile Fish Single Objective Alternative, V4, October 12, 2018

Measure O4 has been replaced by 2 measures.

Revised Measure (O4): “Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (piscine predators)”

Proposed Language Change to Measure (if a bullet point is not being changed, leave blank):

- **Purpose:** Control smallmouth bass and walleye spawning (juvenile salmonid predators).
- **Measure Location:** McNary Dam
- **Implementation:** McNary forebay would operate between an elevation of 339 and 340 (NGVD29) from April 1 through May 31. Every two weeks, during this operation, drawdown the water to an elevation of 337 to 338 (NGVD-29) for 24 hours and then return to an elevation of 339 and 340 (NGVD29) between these drawdown periods.
- **Frequency and Duration:** April1 – May 31

New Measure (O5): Specific Measure Name: “Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (Avian predators)”

Proposed Language Change to Measure (if a bullet point is not being changed, leave blank):

- **Purpose:** Control avian colony success (juvenile salmonid predators).
- **Measure Location:** John Day Dam
- **Implementation:** Raise and maintain John Day Reservoir elevations between 263.5’-265’ (NGVD29) during the months of April and May. FRM operations determined by Vancouver stage are a constraint to this operation but may not be captured operationally in modeling for this measure.
- **Frequency and Duration:** April1 – May 31

Updates to measures were approved by CRSO NEPA Policy.

1.12.3 Preliminary Alternative: Adult Anadromous Fish Survival Focus Detailed Description

CRSO Objective: Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.

The measures in all alternatives are changes relative to the No Action Alternative. If there are no changes listed for an existing structural or operational measure (e.g. juvenile fish transportation) in the alternatives, then the assumption is that the structure or operation would continue per the No Action Alternative.

The following measures address the objective(s):

Structural Measures:

S1. Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam

- **Purpose:** Reduce passage time for adult salmonids as they move upstream through the fish ladder and allow volitional downstream passage through the ladder.
- **Measure Location:** Lower Granite Dam
- **Implementation:** Reconfigure adult trap bypass to reduce head, thus reducing the height diverted adults must ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move handled adults.
- **Frequency and Duration:** Year round
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates.

S2. Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway

- **Purpose:** Reduce passage time for adult salmonids as they move upstream through the fish ladder.
- **Measure Location:** Bonneville Dam
- **Implementation:** Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway. At Bonneville Dam's Bradford Island and Washington Shore ladder flow control sections (the portion of the ladder from the count stations to the ladder exit), remove the baffles from this section of the ladders and replace them with baffles that have in-line vertical slots and orifices. It would also likely involve modifying the auxiliary water supply controls and replacing the

ladders' PIT detection systems.

- **Frequency and Duration:** Year round
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates. A similar modification at John Day Dam, the only other CRS dam to use this type of ladder, resulted in significant passage time reductions for salmon and steelhead.

S3. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor Dams

- **Purpose**: Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor Dams
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by reducing the temperature differential between tailrace and ladder entrances (from surface water warming), which may minimize thermal barriers and adult passage delays.

Operational Measures:

O1. Provide spill for attraction flow to adult ladders (additional spill outlined in O2)

- **Purpose:** Improve upstream anadromous adult fish passage by reducing effects from juvenile spill.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams
- **Implementation:**
  - BON – Only ladder attraction spill (2.3 kcfs), no juvenile spill
  - TDA – Spill up to 30% in bays near north ladder only
  - JDA – Only ladder attraction spill (1.6 kcfs), no juvenile spill
  - MCN, IHR, LMN, LGS, LWG – No juvenile spill, if spill is needed use bays closest to ladder entrance(s)
- **Frequency and Duration:** Spill reduction applies from April 3-August 31 at Lower Snake River projects, and April 10- August 31 at Lower Columbia River projects.

- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by maintaining cooler water corridor through Lower Snake projects, lowering Total Dissolved Gas (TDG), and improving attraction flow to fishway entrances for less delay, and reducing fallback from spill designed for downstream juvenile fish passage.

O2. Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead and kelt downstream passage

- **Purpose:** Overwintering steelhead and kelts appear to experience higher survivability with surface passage routes rather than turbine passage. The purpose of this measure is to increase survival of adult salmonids (specifically overshoots and steelhead kelts) as they move downstream through the projects. This measure may provide a higher survival downstream passage route than turbines for adult steelhead moving downstream, thus reducing mortality, straying consequences, and spawning loss. It may increase steelhead kelt outmigration survival and repeat spawner fecundity (productivity to the populations), especially B-run steelhead repeat spawners to the Clearwater River and all higher age-class repeat spawners to the Yakima River.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day Dams
- **Implementation:** Lower Granite (existing removable spillway weir, RSW), Little Goose (existing adjustable spillway weir, ASW), Lower Monumental (existing RSW), Ice Harbor (existing RSW), McNary (existing top spillway weir, TSW), and John Day (existing TSW):
    - Lower Granite. One RSW.
    - Little Goose. One SW (high crest position).
    - Lower Monumental. One RSW.
    - Ice Harbor. One RSW.
    - McNary. One TSW.
    - John Day. One TSW.
- **Frequency and Duration:** March 1 – August 31 and October 1 – November 30
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by decreasing downstream passage mortality of adult steelhead.

O3. Implement modified timing of Lower Snake Basin reservoir draft to provide cooler water in the Lower Snake River during peak adult migration periods.

- **Purpose:** Provide earlier and later cold water releases for adult sockeye salmon, summer Chinook salmon, Fall Chinook salmon and steelhead that utilize the cool water corridor provided by Dworshak Reservoir through the Lower Snake River.
- **Measure Location**: Dworshak Dam
- **Implementation:** Shift Dworshak releases to draft earlier (June 21 – August 1) for

sockeye salmon and summer Chinook salmon and later (September 1 - September 30) for Fall Chinook and steelhead. Earlier releases will provide cooling water earlier in the summer. The end of August target will be set to 1540’ for higher water years (years when the April forecast for April-August Dworshak volume is at or above the 80th percentile) and 1545’ in years when the April forecast for April-August Dworshak volume is below the 80th percentile. August outflows are expected to average 3-8 kcfs depending on inflows and forecast with this operation. The end of September target will remain at 1520’. The Nez Perce Agreement release volume will not change, though releases may increase the total volume of Dworshak releases in September, and Dworshak will continue to operate within state TDG standards.

- **Frequency and Duration:** During sockeye salmon, summer Chinook salmon, fall Chinook salmon and steelhead upstream migration through June - September
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by improving water temperatures for adult migration and egg viability during the peak adult migration periods for summer Chinook salmon, sockeye salmon, steelhead, and fall Chinook salmon.

O4. Juvenile fish transportation

- **Purpose:** Transport all juvenile salmonids entering the juvenile fish bypasses at collector projects downstream to below Bonneville for release.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental and McNary Dams
- **Implementation:** Transport all fish entering fish bypasses at the collector projects past the downstream hydrosystem to the below Bonneville release site.
- **Frequency and Duration:** April 25-August 31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase juvenile salmon and steelhead survival under spill conditions designed for adult salmon and steelhead passage.

1.12.4 Errata Sheet - Adult Fish Single Objective Alternative, V4, October 12, 2018

Measure O2 has been revised with updated location, implementation, and frequency and duration sections as written below. No changes made to purpose or intended benefit sections.

Revised Measure (O2): Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead and kelt downstream passage

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams

- **Implementation:** Use existing spillway weirs and develop spillway weir inserts to provide effective downstream passage, assuming 2 kcfs spill at each dam through these inserts.
    - Lower Granite. One RSW + spillway weir insert
    - Little Goose. One SW (high crest position) + spillway weir insert
    - Lower Monumental. One RSW + spillway weir insert
    - Ice Harbor. One RSW + spillway weir insert
    - McNary. One TSW + spillway weir insert
    - John Day. One TSW + spillway weir insert
- **Frequency and Duration:** Feb 1 – spring spill start; summer spill end - November 31

Measure O3 has been revised with an updated implementation section as written below.

Revised Measure (O3): Implement modified timing of Lower Snake Basin reservoir draft to provide cooler water in the Lower Snake River during peak adult migration periods.

Proposed Language Change to Measure (if a bullet point is not being changed, leave blank):

Implementation: Shift Dworshak releases to draft earlier (June 21 – August 1) for sockeye 118 salmon and summer Chinook salmon and later (September 1 - September 30) for Fall 119 Chinook and steelhead. Earlier releases will provide cooling water earlier in the summer. The end of August minimum elevation target will be set to 1540’ for higher water years (years when the June forecast for April-July Dworshak volume is at or above the 80th percentile) and 1545’ in years when the June forecast for April-July Dworshak volume is below the 80th percentile. August outflows are expected to be 3 kcfs unless lower outflows are required to meet minimum elevation thresholds, or higher outflows are required to control overfilling.

The end of September target will remain at 1520’. The Nez 125 Perce Agreement release volume will not change, though releases may increase the total 126 volume of Dworshak releases in September, and Dworshak will continue to operate within 127 state TDG standards.

Updates to measures were approved by CRSO NEPA Policy.

1.12.5 Preliminary Alternative: ESA-Listed Resident Fish Survival Focus

<u>CRSO Objective</u>: Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.

The measures in all alternatives are changes relative to the No Action Alternative. If there are no changes listed for an existing structural or operational measure (e.g. juvenile fish transportation) in the alternatives, then the assumption is that the structure or operation would continue per the No Action Alternative.

The following measures address the objective(s):

Structural Measure:

S1. Construct upstream passage facility at Albeni Falls Dam for bull trout

- **Purpose:** Provide upstream passage for bull trout at Albeni Falls Dam.
- **Measure Location:** Albeni Falls Dam
- **Implementation:** Install permanent bull trout passage structure at Albeni Falls Dam.
- **Frequency and Duration:** Year round (except during summer maintenance period and winter ice events)
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival by providing reliable upstream passage for bull trout.

Operational Measures:

O1. Update VarQ procedure at Libby to improve local water management

- **Specific Measure:** Change the Flood Risk Management (FRM) operation at Libby Dam, known as VarQ (short for variable flow) to shift the Libby Storage Reservation Diagram (SRD) to evacuate space in the reservoir to an appropriate depth during the winter. Changes will include modifying the drawdown pattern of the reservoir based upon the local, Libby Water Supply Forecast (generally Jan-Apr).
- **Purpose:** Modify the SRD and refill procedure for the VarQ FRM to improve water quality, water temperature, and nutrient delivery for KRWS and Bull Trout.
- **Measure Location:** Libby Dam
- **Implementation:** Modify the SRD and VarQ refill flow calculation to incorporate the space needed at Libby Dam to reduce flooding in the basin during drawdown months (generally Jan-Apr). During the refill period (generally Apr/May-July), modify the VarQ refill flow calculation so that it (1) modifies past release calculations to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating “double-accounting”; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Libby Water Supply Forecast.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years that the forecast for Libby Dam’s April-August inflow volume was less than 6.9 million acre feet)
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival by improving water quality conditions (including reduced conditions for high TDG) for resident fish and allow for quicker turnover of the reservoir to support nutrient delivery and better management of outflow temperature for KRWS spawning.

O2. Eliminate end-of-December variable draft at Libby and replace with single draft target

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target of 2420 feet to reduce potential over-drafting of the reservoir in years that are drier than forecasted.
- **Purpose:** Reduce potential over-drafting of reservoir in years that are drier than forecasted. For most years, this would allow the timing of the draft to be shifted from November-December to January-February to reduce the accumulation of harmful invasive algae downstream from Libby Dam.
- **Measure Location:** Libby Dam
- **Implementation:** Target a single end of December draft elevation of 2420 feet instead of the current end of December variable target between 2411-2426.7 feet.
- **Frequency and Duration:** All years could affect flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure (when coupled with the proposed SRD for Libby in Operational Measure 1) has the potential to increase resident fish survival by positioning the reservoir to be adaptable to a wide range of runoff conditions to reduce the accumulation of harmful invasive algae downstream of Libby Dam during the winter and increase river productivity for resident fish the rest of the water year.

O3. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full based off the criteria in the table below

Percentile of Libby April-May Water Supply	**Minimum**	**15**	**25**	**75**	**85**	**Maximum**
Forecast (maf)	<4.8	4.8	5.1	7.2	7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of Sept target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meeting the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft. For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Use a graduated draft between 10th and 20th percentile, for example:

Table 1-25. Hungry Horse Summer Flow Augmentation Draft

Percentile (forecast)	HGH April-Aug FC	Draft (ft)	Draft elevation (ft)
10th	<=1203.3	20	3540
12th	1203.5-1239.1	18	3542
14th	1239.2-1273.93	16	3544
16th	1274-1324.2	14	3546
18th	1324.3-1349.8	12	3548
20th	>1349.8	10	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow

- **Frequency and Duration:** Applies to all years
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in

summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O4. Limit Libby outflow to 20 kcfs in December to aid in the survival of riparian vegetation below Libby

- **Purpose:** Increase survival of newly established riparian habitat to benefit Kootenai River White Sturgeon and bull trout. High flows in June and July downstream from Libby Dam deposit seeds for new riparian plants. This measure, when combined with measures O1 and O2 earlier in this alternative, improves the survival of these riparian plants by reducing the number of years when winter stages are higher than late June stages, thus allowing these plants to become more firmly established.
- **Measure Location:** Libby Dam
- **Implementation:** Limit flows in December to 20 kcfs or less. This should keep the river below Libby at a lower winter stage relative to the previous June 15th to July 15th period (peak stage) in more years.
- **Frequency and Duration:** December 1-31
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival by operating to support riparian habitat, which may shade and cool the adjacent water. The biological inputs from riparian vegetation also may contribute to food production, nutrient input, and habitat for forage, benthic species, and juvenile fish, including Kootenai River white sturgeon and bull trout.

1.12.6 Errata Sheet - Resident Fish Single Objective Alternative, V4, October 12, 2018

Measure O2 has been revised with an updated title/description, Purpose, Implementation, and Intended Benefit

Revised Measure O2: Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water mangers' ability to adapt to a wide range of runoff conditions during the remainder of the water year. Single draft target elevation would be elevation 2420.

- **Purpose**: Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.

  The phrase "to reduce the accumulation of harmful invasive algae downstream from Libby Dam" was removed from the last sentence.
- **Implementation**: Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft.
- **Intended Benefit**: Impact of implementation of this measure will be included in the impact analysis; however, end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

Measure O3 was revised with an updated Specific Measure description, and updated Implementation

Revised Measure O3 Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure** description, the third sentence was changed to read, "At Libby Dam base 5 to 20 foot drafts on appropriate **local** forecast for Libby Dam (inserted the word local).
- **Implementation**
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.

- The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	**Minimum**	**<=15**	**25**	**75**	**>=85**	**Maximum**
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking of flows and create flows of about 9 kcfs in September are below:
  - Target 2.5 ft above the end of September elevation on August 31st.
  - Calculate a release to target the end of Sept elevation that is below the end of August release, preferably around 9 kcfs.
  - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
- The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
  - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout.
  - Minimize fluctuation.
  - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
  - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
  - Maximum of one allowable increase within the above flow bands after the sturgeon pulse has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft. For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.

Table 1-26. Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	**Minimum**	**<=10**	**20**	**Maximum**
Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

- Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
- Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
- **The following NOTE is included in the MO measure description, but does not apply to the SO Resident Fish Alternative**, **as the measure it references (O14) is not included in the SO Alternative**. *NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure O14 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O14.*

Updates to measures were approved by the NEPA Policy Team.

1.12.7 Preliminary Alternative: Increased Spill to 125% TDG with Extended Duration Detailed Description

Summary: The Increased Spill to 125% TDG with Extended Duration Preliminary Alternative will analyze proposed juvenile fish passage spill above the current total dissolved gas (TDG) limits under applicable state water quality standards.

Context: During the formal scoping process, the co-lead agencies received multiple public comments requesting analysis of the impacts of changing operation to include increasing the proportion of flow released

through the spillways for juvenile fish passage to not exceed 125 percent TDG as measured in the tailrace, which is above current applicable state water quality standards for juvenile fish passage. The purpose of the Increased Spill to 125% TDG with Extended Duration Preliminary Alternative is to analyze potential impacts to juvenile anadromous fish and other resources in the System from increasing fish passage spill above the current adjustments to the applicable state water quality standards for juvenile fish passage spill (also referred to as the gas cap).

CRSO Objective(s):

This alternative is included to evaluate its ability to meet all or part of the following objective.

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.

Focus Issue(s) from Objective:

This alternative attempts to improve the issues below. Actual changes to these factors will be assessed during impact assessment.

- Juvenile fish travel time,
- Juvenile dam passage survival,
- Juvenile in river system survival, and
- Adult returns utilizing different models.

The following measures address the objective(s) and issue(s):

Structural Measures: There are no structural measures in this alternative.

Operational Measures:

O1. Set juvenile fish passage spill to not exceed 125 percent TDG, as measured in the tailrace, at all Lower Snake River and Lower Columbia River projects.

- **Specific Measure:** Alter the current fish passage spill regime.
- **Purpose:** Analyze the impacts to affected resources from increasing juvenile fish passage spill to not exceed 125 percent TDG.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Projects.
- **Implementation:** In order to meet minimum generation requirements, spill to not exceed 125 percent TDG would be dependent upon availability of sufficient flow and upstream storage reservoirs would not be drafted specifically to reach 125 percent TDG. For modeling purposes, there is not a forebay target for TDG and will calculate a 12 hour running average.
- **Frequency and Duration:** Start date of March 1 and end date of August 31 for all projects.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

O2. Cease juvenile transport during implementation of Measure O1.

- **Specific Measure:** Do not operate the juvenile transport facilities.
- **Purpose:** Because so few fish are anticipated to be available to transport during implementation of Measure O1 it is reasonable to assess ‘no juvenile fish transportation’ in conjunction with Measure O1.

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental
- **Implementation:** No juvenile fish transportation at Lower Granite, Little Goose, or Lower Monumental. All juvenile fish entering the fish bypasses are returned to the river to migrate and are not transported.
- **Frequency and Duration:** March 1 – August 31

Intended Benefit (why include this measure?): Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to decrease adult sockeye, Chinook, and steelhead fallback and adult straying. Given equal Columbia River System operations, fish that are not transported as juveniles have lower adult fish fallback and straying rates as they return upstream through the System.

1.12.8 Preliminary Alternative: Water Management Focus Detailed Description

Summary: The Water Management Focus Preliminary Alternative will analyze the impacts of allowing greater flexibility for water managers to react to unanticipated changes in river flow and forecast runoff volume as well as prepare for the operational constraints of implementing on-going maintenance at Grand Coulee Dam. Increased operating flexibility is intended to increase water managers' ability to address the multiple congressionally authorized purposes of the System's storage projects by reducing the likelihood of involuntary spill and associated increases in total dissolved gas (TDG), improving the likelihood of achieving refill of storage projects which provides for downstream flow augmentation and recreation benefits, faster turnover of Libby reservoir to support downstream nutrient delivery, and better management of outflow temperature during Kootenai River white sturgeon spawning.

Context: As storage reservoirs are drafted for flood risk management (FRM), situations can occur where rapid and large water releases can be required in the March-April timeframe to achieve FRM draft goals (e.g. high runoff during late winter/early spring or years with rapidly increasing water supply forecasts). Drafting large volumes in a short timeframe can require increased spill (involuntary) to achieve the draft target or a deviation from FRM draft requirements, which could result in high levels of TDG or slight increases in flood risk in a given year. In addition, heavy rain results in near-term high runoff that cannot be forecasted in the same way as longer-term snowmelt-induced runoff. Water management operating procedures that more explicitly account for the rain component of runoff would afford greater flexibility and adaptability in reservoir operations. The purpose of the Draft Water Management Focus Preliminary Alternative is to evaluate the impacts to resources in the System from implementing modified Storage Reservation Diagrams (SRDs) at Libby, Hungry Horse, Grand Coulee, and Dworshak dams and potentially modify VarQ FRM operations at Libby and Hungry Horse dams that would reduce the likelihood of involuntary spill during refill.

CRSO Objective(s): Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and the environment.

Focus Issue(s) from Objective:

- As storage reservoirs are drafted for FRM, situations can occur where rapid and large drafts can be required in the March-April timeframe to achieve draft goals (for example in high runoff years, years with rapidly increasing water supply forecasts, or years with high runoff during late winter/early spring months). Drafting large volumes in a short time frame can require increased spill to achieve the draft target or a deviation from FRM drafts which could result in slight increases in flood risk in a given year.
- As water years develop where system flood risk management becomes less of a concern, the operations of Libby project is currently constrained by system flood-risk management operations that prevent meeting local needs during refill.
- Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations.
- Grand Coulee's current flood risk draft and upstream storage adjustment were not updated when significant changes in system operations occurred and are not fully able to flexibly respond to the potential range of upstream storage. This is intended as a change in the process, but not an absolute change in resulting elevations in a no-action scenario. The current process will not properly reflect the value of upstream storage in regards to identifying the storage requirement at Grand Coulee if upstream operations change.
- Grand Coulee's Third, Left and Right powerplant are undergoing necessary overhauls over the next approximately 10 years to improve reliability and capacity. During overhaul the number of units available will be reduced.
    - Reduced powerplant hydraulic capacity will result in decreased generation and increased spill through regulating outlets and drumgates in high flow situations.
    - Grand Coulee drumgates will be undergoing necessary maintenance to recoat the gates. They have not been recoated in the history of the dam, recoating project will affect the availability of gates.

The following measures address the objective(s) and issue(s):

Structural Measures: There are no structural measures in this alternative.

Operational Measures:

O1. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May–June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-

accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management. Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May-June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby).
- **Intended Benefit (why include this measure?):** Local FRM operations are improved by having fewer instances of filling before the end of spring runoff ("fill and spill"). This would improve water quality conditions for resident fish. Also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O2. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam

- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** End-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O3. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and to reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby
- **Implementation:** Operational change: modify SRDs for Libby.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Reduced need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March-April timeframe.

O4. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.
- **Purpose:** Allow Libby project to better adapt local operations to dry water year needs when system FRM is less of a concern.

- **Measure Location:** Libby
- **Implementation:** At Libby Dam, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan-Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9 MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Water management operations (e.g., beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O5. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD and the computation of the Initial Controlled Flow (ICF) outlined in the current Flood Control Operating Plan (FCOP).

- **Specific Measure:** Update Grand Coulee storage reservation diagram (SRD) and upstream adjustment to better reflect benefit of upstream storage. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To ensure flood risk drafts are used as efficiently as possible, and that GCL operations are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Expected revisions to FCOP Chart 1, Chart 2, and Chart 3, and to each parameter applied to the Grand Coulee SRD to determine FRM draft. This could also include revised Grand Coulee FRM space calculation methodology.
- **Frequency and Duration:** December-August
- **Intended Benefit (why include this measure?):** Fully documented process that better reflects changes in upstream storage and hydrology, with built-in mechanism to adapt to possible future changes in how reservoir space upstream of Grand Coulee is managed. Ultimately, this will preserve the ability to operate Grand Coulee for FRM purposes, with the goal of maintaining a similar level of flood risk.

O6. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Reduce the probability of landslides. This is expected to have an ancillary benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O7. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of possible hydraulic capacity during maintenance activities. This more aggressive maintenance schedule, only limited by plant space restrictions to conduct maintenance on the Third Power Plant and the Left and Right Power plants (units 1-18) assumes three units out in the Third Power plant, three out in the Left Power plant, and three out in the Right Power plant (3/3/3). For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[1]) depending on head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.
- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.

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[1] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

- **Measure Location:** Grand Coulee; Third Power Plant, Left Power Plant, Right Power Plant **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Improved safety, reliability and capacity of powerplants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O8. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose of the measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs snow.
- **Measure Location:** Grand Coulee, Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at GCL, LIB, HGH, and DWR.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

1.12.9 Errata Sheet - Water Management Focus Single Objective Alternative, V4, November 2, 2018

Measure O1 has been revised as written below. The name of the measure and implementation section have been revised from the V4 language.

Revised Measure (O1): When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

- **Specific Measure:** Update the existing Libby local Storage Reservation Diagram (SRD) to evacuate FRM space to an appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). During refill (generally Apr/May–July), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; and (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill timing be tied to the Kootenai River Basin runoff. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin**;** (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 MAF for Libby).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operations by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery, while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements, and improve FRM operations for spring rain events in the Kootenay Basin.

Measure O5 has been revised as written below.

Revised Measure (O5): Update the upstream Storage Corrections Method as applied to the Grand Coulee (GCL) SRD.

- **Specific Measure:** The proposed methodology differs conceptually from the current methodology. Rather than adjusting The Dalles (TDA) forecast to determine GCL FRM requirements as with the current methodology, the proposed methodology utilizes the TDA forecast directly to determine the end of April draft requirement for GCL (figure 1) and requires a correction, in the form of a deeper draft target at GCL, when upstream storage reservoirs that fail to achieve their required drafts for whatever reason. It should be noted that the proposed methodology only affects the FRM draft requirements of GCL and does not change the operation or draft requirements of any other project. The proposed Grand Coulee FRM draft is based on four things: 1) The TDA forecast, 2) upstream storage reservoirs' required FRM draft or draft that is manageable and dependable for system flood risk management (called a Base Draft) 3) the in-season draft (actual) of upstream reservoirs in relation to the Base Draft and 4) the relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (Weighting Curves for certain projects). This is similar to the information used under the current methodology but the process of using it is different.

The basic concept of the proposed Grand Coulee upstream storage adjustment methodology is depicted in Figure 1 as a two-step process. First, a Grand Coulee unadjusted April 30 FRM requirement is determined using the curve in Figure 1 and TDA forecast. The relationship assumes that each upstream storage project is drafted or projected to be drafted to its Base Draft by April 30. Second, an adjustment is made to the Grand Coulee April 30 required draft only if storage projects upstream of The Dalles have not been drafted to their Base Draft. If upstream projects are drafted deeper than their base draft no adjustments are made to the GCL draft or if all projects are on their base draft no adjustments will be made. Because upstream projects contribute in differing proportions to overall system FRM, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment. The adjustment is then added to the unadjusted GCL required draft based on the April 30 curve to yield the adjusted required April 30th GCL draft target.

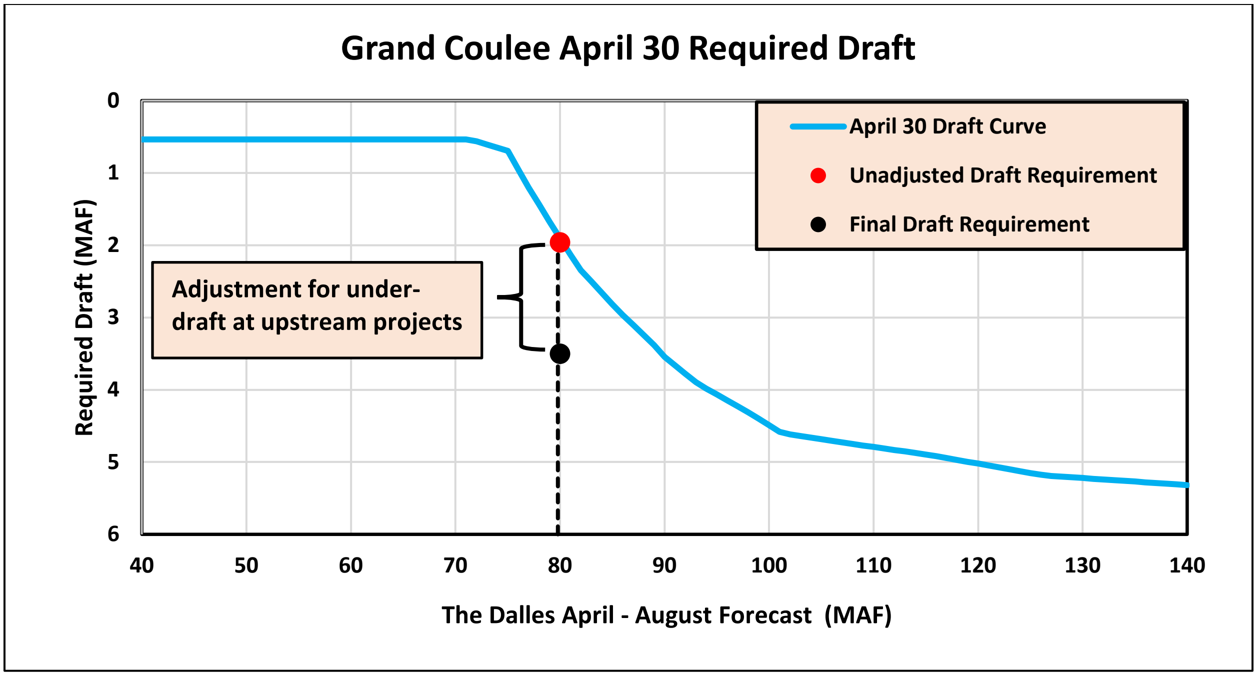

Figure 1-1. Grand Coulee Unadjusted April 30 FRM Requirement

There are a number of specific differences between the current and proposed methods.

1. The fixed FRM draft requirements for John Day, SKQ, Noxon, and Albeni Falls are embedded in the new end-of-April draft requirement for GCL and are therefore not necessary in the adjustment process.
2. The 3.6 Maf cap on the Arrow FRM space was removed in the proposed method.
3. Creditable refill checks on project space are not required because those checks are built into the Base Drafts, and the Weighting Factors.
4. The proposed method does not allow adjustments for over-draft conditions.

- **Purpose:** To update GCL operations and ensure they are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** There are four main components that will be used to determine GCL end of month FRM requirements during the drawdown period (Jan-Apr) under the proposed methodology; the GCL Unadjusted April 30 Draft Requirement Curve (GCL Curve), individual project Base Drafts, individual project Weighting Curves, and the GCL SRD. These will be developed, documented and incorporated into the model.
- **Frequency and Duration:** All years, *January-April*
- **Intended Benefit (why include this measure?):** The measure will provide a fully documented process that allows GCL to better respond to changes in upstream operations. The process will allow adaptation to possible future changes in management

of reservoir space upstream of The Dalles Dam. It is the intent that this proposed methodology will maintain a similar level of flood risk compared to the current practice and not significantly alter the magnitude and frequency of GCL water surface elevations given similar operations of upstream reservoirs.

Measure O8 has been revised as written below.

Revised Measure (O8): Develop draft requirements to protect against rain-induced flooding.

- **Specific measure:** Increase drafted space available at Grand Coulee for implementing winter operations. Grand Coulee, Albeni Falls and Dworshak Dams will operate to protect against rain-induced flooding at Vancouver and Portland.
- **Purpose of the measure:** Runoff from winter precipitation events associated with atmospheric rivers, that deliver significant amounts of rain over short durations, cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Not only are these events difficult to forecast with long lead times (>5 days), they also can lead to the highest amount of flood damage in the Portland/Vancouver area. Furthermore, there is strong evidence that winter flows and atmospheric river events will increase with climate change. Water management operating rules that more explicitly account for these rain-driven runoff events would offer greater flexibility and adaptability in reservoir operations. Albeni Falls and Dworshak have drafted space already in place for rain-induced flooding and will be adjusted to fill space under the same conditions as Grand Coulee.
- **Measure Location:** Grand Coulee, Albeni Falls, and Dworshak.
- **Implementation:** Grand Coulee will be drafted to provide up to 650 kaf of space for FRM from mid-December through March. All other existing winter operations will remain the same. The winter operations will first rely on the four lower Columbia projects when the stage at Vancouver is forecast to exceed a stage of 16 feet. If the forecast continues to project a stage exceeding 16 feet with the operation of the four lower Columbia projects then the winter operations will include Albeni Falls, Dworshak and Grand Coulee.
- **Frequency and Duration:** All years Mid-December - March.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

Updates to measures were approved by CRSO NEPA Policy.

1.12.10 Preliminary Alternative Description for Hydropower Generation Focus

Summary: The Hydropower Generation draft Preliminary Focus Alternative is intended to generate analysis to contrast with the analysis from other alternatives in order to show the tradeoffs between hydropower production and other operations that prioritize other System resources, including fish operations. It operates the system close to conditions prior to creation of the Northwest Power Act (Act) as far as removing restrictions placed on the system by the Act, but will be studied in the context of the modern environment, for example including wind power that has been developed since the Act was established. The information from this analysis will illustrate the impacts of different operations on various resources and will be used to help illuminate trade-offs. This analysis shows how much hydropower production has been reduced to balance the needs of other resources in the Columbia River System.

Context: Total hydropower production and flexibility have been reduced in the last two to three decades due to the implementation of juvenile anadromous fish passage spill and due to limitations on timing of water releases that have resulted in increased spill as well as requirements for increased operating reserves to integrate the growing fleet of wind-power generation in the Northwest. Restrictions on ramping rates, turbine operating ranges, reservoir operating ranges, and similar measures have reduced the flexibility for hydropower generation to respond to hourly, daily, and seasonal power demand and for responding to transmission reliability requirements. The Hydropower Generation draft Preliminary Focus Alternative will analyze the impacts of optimizing hydropower generation by examining operations without many of the restrictions that have been placed on the Columbia River System projects in the past two to three decades through the Northwest Power Act, several BiOps, and other changes. Flood Risk Management (FRM) operations would be retained to maintain the current level of risk tolerance with regard to human health and safety. The purpose of this study is to show the trade-offs between power production and impacts to other resources in the Columbia River System.

CRSO Objective(s): Provide an adequate, efficient, economical and reliable power supply that supports the integrated Columbia River Power System.

Focus Issue(s) from Objectives:

- Total hydropower production has declined in the last two to three decades due to the implementation of fish passage spill to benefit fish survival. Hydropower production has also declined due to flow shaping for fish which resulted in increased high flow events and associated involuntary spill.
- Restrictions on ramping rates, turbine operating ranges, reservoir operating ranges, and similar measures have reduced the flexibility of the hydropower system to match power production to meet demand hourly, daily, and seasonally.
- The demand for electricity is changing (e.g. declining winter demand and increasing summer demand), and the supply of power is changing (e.g. coal-fired generating units

are being retired while wind and solar power generation are increasing). Further, renewable portfolio standards for non-hydropower renewable generation are changing the dynamics of scheduling power generation.

The following measures address the objective(s) and issue(s):

<u>**Structural Measures:**</u>

S1. No installation of fish screens at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville projects.

- **Specific Measure:** Do not install fish screens at specific project on the lower Snake and lower Columbia Rivers.
- **Purpose:** Not installing fish-screens increases the efficiency of hydropower turbines.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor on the lower Snake River and McNary, John Day, and Bonneville second powerhouse on the lower Columbia River projects.[2]
- **Implementation:** The existing fish screens would be removed and no new fish screens would be installed. For hydroregulation modeling, this should not change flows. Generation would be increased slightly, maintenance costs decreased.
- **Frequency and Duration:** Currently fish screens are in place for monitoring and to divert fish away from turbine units into the fish bypasses during fish-passage season. Measure would leave screens out all year.
- **Intended Benefit:** Power efficiency is expected to be increased.

<u>**Operational Measures:**</u>

O1. No fish passage spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects. Spill associated with high flow events and lack-of-market spill would continue as needed.

- **Specific Measure:** No fish passage spill at the lower Snake and lower Columbia River projects.
- **Purpose:** Increase flows through turbines to increase hydropower production
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** This draft preliminary focus alternative will not model fish passage spill. Some spill may be necessary to provide INC and DEC reserves for reliability.

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[2] There are no fish screens at The Dalles.

(INC=increase and DEC=decrease reserves are buffers in generation that allow generation to increase or decrease in response to changes in load or changes in other generation such as wind.) Spill due to lack-of-turbine capacity during high flows will continue, as will lack-of-market spill. (Lack-of-market spill occurs when there is insufficient demand in the Northwest and adjacent electric power markets to use the hydropower that would be produced by the CRS projects, therefore the CRS projects are forced to spill instead of generate.)

- **Frequency and Duration:** Currently the projects are operated to provide juvenile anadromous fish passage spill during the fish-passage season (April-August). Measure would remove all anadromous fish passage spill throughout the year.
- **Intended Benefit:** Increased hydropower production; reduced O&M and capital program costs associated with fish-passage operations to support the objective of economical power supply.

O2. No flow and pool elevation restrictions, except those that are safety-related, at all projects year-round to increase ability of hydropower to meet power-demand. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, specific elevation requirements for navigation safety, and maintaining ramp rates for minimizing dam erosion.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations except for flood risk management, reduce restrictions on ramping rates unless there are safety or engineering restrictions, permit draft of reservoirs below Variable Draft Limits when it is beneficial for power.
- **Purpose:** More flexibility on seasonal, daily, and hourly flow. To increase flexibility in flows to alter the timing of water releases for hydropower production. This will allow projects to be drafted to provide more water and hence more power production during times of higher demand, primarily winter and summer. It will also allow projects to increase and decrease water flow and generation more in response to demand for power and to integrate intermittent renewable power generation into the electric grid.
- **Measure Location:** All CRS projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** Restrictions that are not for safety (e.g. flood risk management, navigation, or erosion) will be removed. Hydropower models will use the increased flexibility of the system to shape power to more closely match demand (both intrinsic load that the hydrosystem serves and market prices that signal a regional demand for power).

- **Frequency and Duration:** Current non-safety restrictions vary seasonally and would no longer apply at any time of year with this measure.
- **Intended Benefit:** Hydropower production can be increased and can more appropriately be shaped to meet demand. In addition, increase flexibility to integrate intermittent renewables to the grid.

The following sub-measures address specific operations that fit the category of flow and pool elevation restrictions:

O2.a. At the four lower Snake River projects operate within the full reservoir operating range year-round.

- **Specific Measure:** Allow the reservoirs behind the lower Snake River dams to use the full operating pool except as restricted for safety.
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** At the Lower Snake projects, the pools will no longer be restricted to within 1-foot above Minimum Operating Pool operating range during the fish passage season.
- **Frequency and Duration:** Current restrictions apply April to August at Little Goose to Ice Harbor, but continue longer at Lower Granite. With this measure, these restrictions would not apply at any time of the year. The larger operating ranges will not increase total generation and will not be apparent in monthly and perhaps not in daily models, but it will increase flexibility to shape flows and power generation within-day, which one or two hydropower impact assessment models will be able to analyze.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.b. At John Day allow project to operate within the full reservoir operating range year-round except as needed for flood risk management.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations at John Day
- **Purpose:** A larger operating range will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day
- **Implementation:** John Day pool will not be restricted to within 1 ½ feet above Minimum Irrigation Pool (MIP) operating range during the fish passage season.

- **Frequency and Duration:** Currently, John Day pool is restricted to operating within 1 ½ feet above MIP during the fish passage season (April – September). With this measure, this restriction will not be put into place at any time of the year, so the pool will operate between 257.0 and 266.5 ft all year, except as needed for flood risk management.
- **Intended Benefit:** The larger operating ranges will not substantially increase total generation but it will increase flexibility to shape flows and power generation within-day.

O2.c. The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak) may be drafted for hydropower, the maximum pool elevation is limited to the upper rule curves for FRM, and storage projects will not operate to meet flow targets for fish. Operate Canadian storage projects to the Treaty Storage Regulation without flow augmentation.

- **Specific Measure:** Reduce restrictions on pool elevations.
- **Purpose:** A larger operating range at the storage projects will allow more operating flexibility for seasonal shaping of flows to optimize hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak.
- **Implementation:** Hydroregulation modeling will operate the storage projects to shape generation to meet demand. This will likely require initial modeling by a hydropower model (HYDSIM) to develop rules that can be implemented by ResSim. Chief drivers will be demand for power (based on load forecasts) and market prices (for shaping surplus power into the high-demand periods).
- **Frequency and Duration:** Current restrictions vary seasonally by project. This measure would only impose flood risk management restrictions, most notably for the run-off (winter and spring).
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to match power production to meet demand.

O2.d. Ramping rate limitations at all projects will be defined only for the purpose of safety or engineering.

- **Specific Measure:** Ramping rate limitations at all projects will be defined only for the purpose of safety or geotechnical concerns such as erosion.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production.
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville).

- **Implementation:** Where restrictions are not for safety (e.g. flood risk management, navigation, or erosion), restrictions on flow will be lifted. More flexibility in ramping rates would not increase total generation and would not be apparent in monthly and daily models, but it would increase flexibility to shape flows and power generation within-day, which one or two hydropower impact assessment models will be able to analyze.
- **Frequency and Duration:** Current restrictions vary seasonally and vary by project.
- **Intended Benefit:** Increased flexibility to raise and lower flows increases the ability for hydropower to meet fluctuations in demand.

O3. Operate turbines across their full range of capacity year-round.

- **Specific Measure:** No longer restrict turbine operations to within 1% of peak efficiency.
- **Purpose:** Increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville.
- **Implementation:** Allow turbines to operate across the full range of capacity. Operating to a higher capacity would increase generation and would increase turbine flow capacities which reduce the amount of lack-of-turbine spill. These effects will be evident in monthly and daily hydroregulation models. Further, the increased turbine capacity would increase the amount of within-day shaping for hydropower, which will be analyzed in hydropower impact modeling.
- **Frequency and Duration:** Currently, restrictions apply during fish passage season. This measure would not impose restrictions at any time of the year.
- **Intended Benefit:** The primary benefit is to increase turbine range and increase turbine capacity. A secondary benefit is that during high flows, more water would be allowed to pass through the turbines, potentially reducing the incidence of high Total Dissolved Gas levels.

O4. Cease juvenile fish downstream transportation.

- **Specific Measure:** Do not collect juvenile fish for downstream transportation.
- **Purpose:** Transportation will no longer be possible since there will not be fish screens (see Structural Measure S1) to divert the juvenile fish into the bypass system where they would be collected for transportation.

- **Measure Location:** Collection currently occurs at Lower Granite, Little Goose, and Lower Monumental Dams.
- **Implementation:** This measure of not transporting fish will not affect hydroregulation modeling, but the impact of not transporting will be analyzed for impacts to fish. (Not installing fish screens, Measure S1, does impact hydropower production.).
- **Frequency and Duration:** Currently, transportation occurs during the juvenile migration season. With this measure, there would not be transportation.
- **Intended Benefit:** This measure is not included for a hydropower benefit, but rather as a clarification because fish transport is no longer possible when there are no fish screens (Structural Measure S1).

O5. Zero generation operations may occur on lower Snake River projects November – February.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.
- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

1.12.11 Errata Sheet - Hydropower Focus Single Objective Alternative, V4, October 12, 2018

Measure O1 has been updated.

Revised Measure (S1): No installation of fish screens at Ice Harbor, McNary, John Day, and Bonneville projects**.**

- **Specific Measure:** Do not install fish screens at specific project on the lower Snake and lower Columbia Rivers.
- **Purpose:** Not installing fish-screens increases the efficiency of hydropower turbines.
- **Measure Location:** Ice Harbor on the lower Snake River and McNary, John Day, and Bonneville second powerhouse on the lower Columbia River projects.[3]
- **Implementation:** The existing fish screens would be installed seasonally at these projects. For hydroregulation modeling, this should not change flows. (Screens will continue to be installed seasonally at Lower Granite, Little Goose, and Lower Monumental dams to collect fish for transportation.)
- **Frequency and Duration:** Currently fish screens are in place for monitoring and to divert fish away from turbine units into the fish bypasses during fish-passage season. Measure would not install screens at any time of the year except at the collector projects.
- **Intended Benefit:** Power efficiency and reliability (through reduced maintenance outages for screens) are expected to be increased. Maintenance and replacement costs of the fish screens would be reduced.

Revised Measure (O2a): At the four lower Snake River projects operate within the full reservoir operating range year-round.

- **Specific Measure:** Allow the reservoirs behind the lower Snake River dams to use the full operating pool except as restricted for safety.
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** At the Lower Snake projects, the pools will no longer be restricted to within 1-foot above Minimum Operating Pool operating range during the fish passage season.
- **Frequency and Duration:** Current restrictions apply April to August at Little Goose to Ice Harbor, but continue longer at Lower Granite. With this measure, these restrictions would not apply at any time of the year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

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[3] There are no fish screens at The Dalles. Ice Harbor, McNary, and John Day have fish screens currently, are not fish-collection locations, and are scheduled for new turbine runners specifically designed to achieve higher juvenile fish survival rates.

Revised Measure (O2c): The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak) may be drafted for hydropower, the maximum pool elevation is limited to the upper rule curves for FRM, and storage projects will not operate to meet flow targets for fish. Operate Canadian storage projects without flow augmentation.

- **Specific Measure:** Reduce restrictions on pool elevations.
- **Purpose:** A larger operating range at the storage projects will allow more operating flexibility for seasonal shaping of flows to optimize hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak, Mica, Arrow and Duncan.
- **Implementation:** Hydroregulation modeling will operate the storage projects to shape generation to meet demand. This will likely require initial modeling by a hydropower model (HYDSIM) to develop rules that can be implemented by ResSim. Chief drivers will be demand for power (based on load forecasts) and market prices (for shaping surplus power into the high-demand periods). Canadian Treaty projects (Mica, Arrow and Duncan) will not include operations agreed to under the Non-Power Uses Agreement (commonly called Flow-Augmentation) which can provide up to 1 Maf of discharge from Canadian projects between May and July to support the FCRPS 2007 Biological Assessment and NOAA Fisheries 2008 FCRPS Biological Opinion (BiOp) and 2010 FCRPS Supplemental BiOp.
- **Frequency and Duration:** Current restrictions vary seasonally by project. This measure would only impose flood risk management restrictions, most notably for the run-off (winter and spring).
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to match power production to meet demand.

Delete measure O4 “Cease juvenile fish downstream transportation”

Revised Measure (new number is O4): Zero generation operations may occur on lower Snake River projects September – March.

- **Specific Measure:** Allow the projects to shut off generation at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for generation on peak demand hours.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.

- **Implementation:** Allowing generation to go to zero would allow more water to be stored for generation during peak demand hours. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early September and extend through March.

Intended Benefit: Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow in low demand periods leaving more water for high demand periods.

1.12.12 Preliminary Alternative: Water Supply Focus

Summary: The Water Supply Focus Preliminary Alternative will analyze the impacts of delivering all current federally authorized water supply that met specific criteria listed below. Currently, a portion of the federally authorized water supply is being delivered for irrigation, municipal, and industrial purposes. This alternative focuses on the foreseeable possibility of delivering the additional authorized water, even though the future demand for this water is not known.

Context: In addition to addressing the objective, the measures in this alternative were selected using specific criteria including (1) the measure needed to be a federal action, (2) the measure needed to be reasonably foreseeable, which in this case meant that there was an existing authorization, and (3) the measure needed to be within the geographic scope of the EIS. The measures are designed to evaluate the extreme impacts of delivering the water, so they assume 100% of the water is delivered out of stream without any water returning to the river. “Current” is defined as September 30, 2016, plus any actions with completed NEPA that are not yet being implemented.

CRSO Objective(s) to be met: Objective #9 Provide for authorized, additional regional water supply.

Identify Issue(s) using bullets:

- Columbia Basin Project was originally authorized for 1,095,000 acres of irrigated land, but has developed 758,700 acres at present. To serve the additional 336,300 acres at the current duty of about 4.1 acre feet of water per acre, the additional volume of water required would be about 1,378,830 acre-feet. In addition the project has permits to deliver 32,478 acre-feet of water for municipal and industrial purposes (M&I).
- U.S. Bureau of Reclamation’s Hungry Horse Project was originally authorized for multiple uses including irrigation, but it has never been used for irrigation. The amount of water authorized for irrigation was not specified in the initial

authorization, but there has been a negotiated water rights settlement with the Confederated Salish and Kootenai Tribes (CSKT) for the Flathead Indian Irrigation Project. This settlement, if approved by Congress, would allocate 90,000 acre-feet of water for irrigation or municipal purposes.

- Chief Joseph Dam Project is a Reclamation Irrigation Project that was authorized with the construction of U.S. Army Corps of Engineers' Chief Joseph Dam, but is a separate project. The project was authorized over many years with individual authorizations totaling 33,050 acres (some of these acres have been transferred to non-federal ownership); to date, 2,821 acres were authorized for irrigation but have not been developed. The additional volume of water required to serve the additional 2,821 acres at the current duty of about 3.4 acre-feet per acre would be about 9,600 acre-feet.

The following measures address the objective(s) and issue(s):

O1. Specific Measure: Increase volume of water pumped from Lake Roosevelt into Banks Lake via the John W. Keys III Pumping Plant at the Grand Coulee project for increased deliveries to the Columbia Basin Project mostly during the annual irrigation season. The new volume of irrigation water was calculated by multiplying the 336,300 undeveloped acres by the duty (4.1 acre-feet per acre) that is currently used by the CBP. The duty was calculated by dividing the water diverted in 2016 by the developed acres.

Detail of measure:

- **Location of measure:** Grand Coulee Dam (Lake Roosevelt and Banks Lake). Measure does not extend beyond pumping water from Lake Roosevelt to Banks Lake because delivering additional water to the Columbia Basin Project would require NEPA, and that action is considered outside the scope of this EIS. This measure focuses only on the diversion of water from the Columbia River via Lake Roosevelt and does not account for increased return flows (i.e. non-consumptively used water that returns to the river) that may occur when delivering this water to CBP patrons.
- **How to implement measure:** Pump more water from Lake Roosevelt into Banks Lake using the existing John W. Keys Pumping Plant, which was designed and constructed to have the capacity to provide the full water delivery for the original authorization of 1,095,000 acres. The additional pumping would include 1,378,830 acre-feet for irrigation and an additional 32,478 acre-feet of M&I water.
- **When (frequency and duration):** Annual, mostly during irrigation season which is generally from April 1 through October 30. Table 1-25 shows the estimated monthly and total annual additional pumped water from Lake Roosevelt.

Table 1-27. Annual additional pumping from Lake Roosevelt to Banks Lake.

Month	Diversion Flow Rate (cfs[4])	Diversion Volume (acre-feet)
January	10	634
February	73	4,031
March	728	44,751
April	3,464	206,149
May	3,645	224,118
June	3,703	220,333
July	4,411	271,222
August	2,817	173,185
September	2,754	163,863
October	1,385	85,190
November	203	12,053
December	94	5,778
Total		*1,411,308*

- **Purpose of the measure:** To divert water from the Columbia River for irrigation and M&I.
- **Intended Benefit:** To provide water supply to an additional 336,300 authorized acres of irrigable land within the Columbia Basin Project for agricultural development.

O2. Specific Measure: Deliver current water volume using a revised monthly shape so as to not drawdown Banks Lake for delivery of water, pumped from Lake Roosevelt into Banks Lake via the existing configuration of the John W. Keys III Pumping Plant at the Grand Coulee project. This water delivery will include Odessa Subarea (164,000 acre-feet) and Banks M&I (15,000 acre-feet) water on demand; current operations require draft of Banks Lake and refilling from Lake Roosevelt in September and October. This measure combined with the measure to increase delivery to Banks Lake from Lake Roosevelt would represent the total volume (and timing) of delivery to Banks Lake.

Detail of measure:

- **Location of measure:** Grand Coulee Dam (Lake Roosevelt and Banks Lake). This measure focuses only on the depletion of water from the Columbia River via Lake Roosevelt.
- **How to implement measure:** Pump water from Lake Roosevelt into Banks Lake using the existing John W. Keys Pumping Plant, which was designed and constructed to have the capacity to provide the full water delivery for the original authorization

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[4] Cubic feet per second.

of 1,095,000 acres.

- **When (frequency and duration):** Annual, mostly during irrigation season which is generally from April 1 through October 30. Table 1-26 shows the estimated monthly and total annual pumped water from Lake Roosevelt for the current demand with the Odessa Subarea and Banks Lake M&I water reshaped into "on demand". Table 1-27 shows the reshaped demand combined with the additional demand from Table 1-25.

Table 1-28. Reshaped current demand from Lake Roosevelt to Banks Lake.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	21	1,291
February	148	8,219
March	1,508	92,723
April	7,245	431,107
May	7,944	488,457
June	8,338	496,145
July	10,021	616,167
August	6,537	401,944
September	6,036	359,167
October	2,929	180,097
November	413	24,575
December	191	11,744
Total		*3,111,636*

- **Purpose of the measure:** To divert water from the Columbia River for irrigation and M&I on demand.
- **Intended Benefit:** To simplify current water supply operations.

Table 1-29. Total pumping to Banks Lake including current operations, reshaping of Odessa Subarea and the additional water for Columbia Basin Project (Table 2 + Table 1).

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	31	1,925
February	221	12,250
March	2,236	137,474
April	10,709	637,256
May	11,589	712,575
June	14,041	716,478

July	14,432	887,389
August	9,354	575,129
September	8,790	523,030
October	4,314	265,287
November	616	36,628
December	285	17,522
Total		*4,522,944*

O3. Specific Measure: Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the CSKT water rights settlement for irrigation or municipal purposes.

Detail of measure:

- **Location of measure:** Hungry Horse Reservoir and diversion downstream within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water. Therefore, the diversion is placed within Flathead Lake to simplify the modeling.
- **How to implement measure:** Operationally, make sure that enough water is stored and released at certain times to accommodate new contracted diversion downstream of Hungry Horse. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. For years where the flow augmentation draft is 10 feet, the end of September elevation would be 3546 feet. In years where the flow augmentation draft is 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The modeled diversion is to occur within Flathead Lake since operations in Flathead Lake are not expected to be impacted by this measure. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.
- **When (frequency and duration):** Irrigation season which is generally from April 1 through October 30. Table 1-28 shows the estimated monthly and total annual additional delivered water from the Flathead River.

Table 1-30. Estimated monthly diversion above Flathead Lake.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April		
May		
June		
July	493	30,313
August	493	30,313
September	494	29,395

October		
November	0	0
December	0	0
Total		*90,021*

- **Purpose of the measure:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Intended Benefit:** To provide 90,000 acre-feet of water for a settlement with CSKT. This water could be used for irrigation or municipal purposes.

O4. Specific Measure: Add pump units to increase water diversion from the Columbia River for the Chief Joseph Dam Project to supply an additional 9,600 acre-feet of irrigation water. Supply irrigation water throughout the irrigation season.

Detail of measure:

- **Location of measure:** On the Columbia River just below Chief Joseph Dam.
- **How to implement measure:** Construct pump unit to deliver 9,600 acre-feet of water to authorized Chief Joseph Dam Project lands. Simulate diversion of water using the ResSim and Hydsim models.
- **When (frequency and duration):** Annually during the irrigation season. Table 1-29 shows the monthly estimated and total annual diversion from the Columbia River.

Table 1-31. Total water for additional Chief Joseph Dam Project lands.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April	3	179
May	19	1,168
June	42	2,499
July	50	3,074
August	34	2,091
September	7	417
October	2	123
November	0	0
December	0	0
Total		*9,550*

- **Purpose of the measure:** To divert water from the Columbia River for irrigation of authorized acres in the Chief Joseph Dam Project.
- **Intended Benefit:** To provide irrigation water to authorized acres in the Chief Joseph Dam Project for agricultural production.

1.12.13 Preliminary Focus Alternative Detailed Description: Lower Snake River Dam Breaching

Summary: For this preliminary alternative, the description for breaching the four Lower Snake River dams is similar to the breaching alternative described in the 2002 Lower Snake River Juvenile Salmon Migration Feasibility Study. As described in the 2002 report, breaching would be accomplished with removal of the earthen embankments. Most of the concrete portions of the dams would remain in place, and the powerhouses would be nonoperational but remain intact. Transmission lines from the dams to the adjacent high-voltage transmission substations would be removed, but the high-voltage transmission substations would remain in operation. The reservoirs would be drawn down in a controlled manner to minimize impacts to the stability of river banks, cultural resources, adjacent roads, and railroads. Hydropower generation and commercial barge navigation on the lower Snake River would cease.

Modifications to existing Corps mitigation areas such as hatcheries and Habitat Management Units are unknown at this time, and will be determined by additional analysis and through ESA consultation that will occur as part of this NEPA process. The analysis will also evaluate potential modifications or changes to the Bonneville Power Administration's (BPA) implementation of its Fish and Wildlife Program, as well as potential changes to the BPA transmission system to maintain reliability in the absence of hydropower generation at these facilities.

Additional studies and analyses will be necessary to seek congressional authorization for implementation of this alternative.

Context: Breaching of the four lower Snake River dams was studied by the Corps in the 2002 Lower Snake River Juvenile Salmon Migration Feasibility Study as a means to improve status of the four ESA-listed salmon evolutionarily significant units (ESUs) in the Snake River: Snake River Fall Run Chinook, Snake River Basin Steelhead, Snake River Sockeye, and Bull Trout. At that time, the alternative was not selected as the preferred alternative. In the 2009 Adaptive Management Implementation Plan developed jointly by the co-lead agencies and NOAA for the ESA consultation resulting in the 2010 supplemental Biological Opinion, dam breaching was identified as a “contingency of last resort,” an action that would be evaluated if ESA-listed salmon species dropped below agreed-upon thresholds. To date, ESA-listed salmon species have not declined below those identified thresholds, but there continues to be high public interest in breaching the four lower Snake River dams to address the needs of ESA-listed salmon and steelhead. In addition, the U.S. District Court for the District of Oregon noted in the *NWF v. NMFS* case that breaching of the four lower Snake River dams may be reasonable for consideration in this EIS.

Breaching the lower Snake River dams would be evaluated as a means to improve conditions for ESA-listed fish, including flow velocities, water depth and temperature, sediment movement and geomorphology, and the reestablishment of riparian and wetland habitats at the river margins. It is hypothesized that these conditions would contribute to more natural migration, spawning, and rearing conditions for some ESA-listed fish.

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed salmonid adult fish migration within the CRSO project area, through actions including, but not limited to project configuration, flow management, improving connectivity, project operations, and water quality management.
- Improve ESA resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.

Focus Issue(s) from Objective:

- Dam construction has converted riverine function to reservoir functions, changing flow, sediment, and nutrient conditions, and impacting habitat conditions for aquatic plants and animals, including ESA fish.
- Reservoir conditions result in delayed travel times for juvenile salmon migration.
- Construction of the lower Snake River dams inundated former spawning, migration, and rearing habitat and refugia, and impacted water quality.
- Reservoir habitat conditions make juvenile salmon more susceptible to predation

The following measures address the objective(s) and issue(s):

<u>Structural Measures:</u>

S1. Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown.

- **Specific Measure:** Remove earthen embankments and portions of existing structure to evacuate the reservoirs.
- **Purpose:** Return the river to a more natural hydraulic condition for Snake River ESA-listed fish passage.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** The earthen embankments, abutments, and structures at each dam would be removed as needed to provide a 140-mile stretch of river without impoundment. To control sediment inputs and maintain safe conditions at downstream

dams, breaching would be accomplished in phases, starting with Lower Granite and Little Goose dams, followed by Lower Monumental and Ice Harbor dams. Water control structures such as cofferdams and levees would be installed at breach locations to direct and control flows near the powerhouse, spillways, and navigation locks to facilitate safe drawdown of the reservoirs and provide fish passage. It has been calculated that a drawdown of 2 feet per day, beginning in August and continuing through the end of December, would safely evacuate the reservoirs and minimize damage to adjacent infrastructure.

- **Frequency and Duration:** Dam breaching activities would be conducted only once at each location. Work would be coordinated with the agencies and scheduled to minimize negative effects to Snake River ESA-listed fish.
- **Intended Benefit (why include this measure?):** Removal of earthen embankments would be a means to return this portion of the river to a more natural riverine condition in terms of water depth, local sediment movement, and habitats at river margins. However, because these dams are run-of-river projects, breaching would not appreciably affect the volume and timing of flows. These conditions could contribute to more natural migration, spawning, and rearing conditions for some ESA-listed fish in this stretch of the Snake River.

S2. Modify existing equipment and dam infrastructure to adjust to drawdown conditions. Existing equipment would not be used for hydropower generation, but instead would be used as low-level outlets for drawdown below spillway elevations. Depending on the outcome of additional analysis, turbines would be modified and/or operated in a manner to support controlled drawdown.

- **Specific Measure:** Modify existing equipment to support controlled reservoir drawdown.
- **Purpose:** To use all available outlets at the dam to provide controlled drawdown conditions.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** Existing equipment and infrastructure at the dams would be modified so that both spillways and powerhouse outlets may be used to evacuate the reservoir at various elevations.
- **Frequency and Duration:** Modifications and a required decommissioning would take place prior to initiation of drawdown at each location.
- **Intended Benefit (why include this measure?):** Modifications would be undertaken to allow use of existing facilities and outlets for a controlled reservoir evacuation. This would facilitate outflows with minimal creation of total dissolved gas.

Operational Measures:

O1. Develop procedures to operate existing equipment during reservoir drawdown.

- **Specific Measure:** Develop a plan for operation of equipment during reservoir drawdown
- **Purpose:** To provide information to dam and transmission operators and inspectors regarding how existing equipment would be modified and operated to draw down the four reservoirs on the lower Snake River.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** Equipment to be used in drawdown would be tested and calibrated to establish operational limits. Engineers and powerhouse and transmission operators would establish manual operations and procedures using modified equipment to facilitate controlled and safe reservoir evacuation.
- **Frequency and Duration:** The plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** This measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment.

O2. Develop contingency plans to address unexpected issues with drawdown operations.

- **Specific Measure:** Develop plans for operation or emergency shut down during reservoir drawdown
- **Purpose:** To provide information and training to dam and transmission operators and inspectors regarding how modified equipment would be operated or shut down in the event of an emergency or unanticipated circumstances during reservoir evacuation.
- **Measure Location:** Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, and Lower Granite Dam.
- **Implementation:** Engineers and operators would work together to develop plans for operating existing equipment under drawdown conditions. They would identify risks and required emergency responses should equipment not function as anticipated or expected conditions change.
- **Frequency and Duration:** The contingency plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** This measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment

1.12.14 Alternative Description Maximum Integration of Non-hydropower Renewables

Summary: Use the hydrosystem to maximize the integration of non-hydropower renewable power sources in the grid. The entails increasing the flexibility of the hydrosystem by removing restrictions that are not related to health and safety. The flexibility in the hydrosystem will then be operated to allow the hydrosystem to adjust generation both up and down (through the deployment of “INC” and “DEC” reserves) to offset changes in wind and solar generation so that there is a steady supply of power on the electric grid to meet demand. In this alternatives, hydropower generation may be reduced (deoptimized and even spilled) for the purpose of maximizing the integration of other renewable power sources.

CRSO Objective(s) to be met: Objective #5 Maximize integration of non-hydropower renewable power sources in the grid through maximum flexibility in hydropower generation. *[Note: This objective could reduce overall hydropower generation from the maximum possible.]*

Identify Issue(s) using bullets:

- The Northwest region is rapidly developing more non-hydropower renewable resources, especially wind and solar. These resources are variable and cannot generate power in the shape that meets demand (power is generated when the wind blows or the sun shines and does not change generation in direct response to changes in demand for electricity).
- Hydropower generation is well suited to respond to changes in wind generation and solar generation. Hydropower can increase rapidly when wind or solar decline and vice versa. Natural gas plants are able to do this as well, but the region has expressed an interest in adding more renewable generation and less natural-gas generation. However, the hydrosystem has lost flexibility in the past 2-3 decades due to the implementation of many new objectives, especially for fish.

Modeling Objective: The hydropower model will be run with priority on operating reserves. The secondary priority will be to use the remaining flexibility in the hydrosystem to shape generation to meet the demand for power generation, particularly shaping to the highest-demand periods.

The following measures address the objective(s) and issue(s):

Structural Measures:

S1. Cease annual installation of fish screens at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects to allow more flow to the units and increase turbine efficiency.

- **Specific Measure:** Remove Fish Screens
- **Purpose:** (Not identified)
- **Measure Location:** Lower Snake and lower Columbia dams
- **Implementation:** during the spill season, most of the fish-passage dams have fish screens installed during the fish-passage season.

- **Frequency and Duration:** currently the screens are in place during the fish-passage season. Measure would leave screens off all year.

  Intended Benefit: Power efficiency is increased. Maintenance and replacement cost of the screens is very high and would be avoided. Lamprey would benefit from screen removal.

Operational Measures:

O1. Stop all voluntary spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects year-round. Involuntary spill associated with high flow events and lack-of-market spill would continue as needed.

- **Specific Measure:** Decreasing/stopping spill (stop voluntary spill)
- **Purpose:** increase hydropower production
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** No longer model voluntary spill for fish passage. Some spill may be necessary to provide INC and DEC reserves for reliability. Involuntary spill during high flows will continue, as will lack-of-market spill.
- **Frequency and Duration:** no voluntary spill all year (i.e. no longer spilling April-August)
- **Intended Benefit:** increased hydropower production, benefit to adult upstream fish passage (less fall-back at dams), likely improved safety for navigation

O2. Lift all flow and pool elevation restrictions that are not safety-related from all projects to increase ability to meet power demand fluctuations from primarily hydropower generation year-round. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability

- **Specific Measure:** More flexibility on seasonal, daily, and hourly flow (Reduce restrictions on seasonal pool elevations except for flood risk management, reduce restrictions on ramping rates unless there are safety or engineering restrictions, permit draft of reservoirs below VDLs when it is beneficial for power)
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)

- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow will be lifted.
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Hydropower production can be increased and can more appropriately be shaped to meet demand when there is more flexibility in flows.

O2.a. Reduce restrictions on ramping rates at all projects unless for the purpose of safety or engineering.

- **Specific Measure:** *Incorporated into O2 per BPA comment 30 June 2017.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow will be lifted.
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Beneficial to generation if allowed to ramp down much faster than rates. Some restrictions for bank sloughing need to stay - earthen embankment projects (don't ramp @ rate to slough)

O2.b. At the four, lower Snake River projects, seasonal pool elevations would no longer be restricted to within 1-foot of Minimum Operating Pool (MOP) during the juvenile fish passage season (April-August).

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.c. At the John Day project, the seasonal pool elevation would no longer be restricted to within 1.5 feet of Minimum Irrigation Pool (MIP) during the juvenile fish passage season (April-August).

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day
- **Implementation:** At the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.d. At the storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak), the variable draft limits (VDLs) would not be enforced as a lower operating limit so that those reservoirs could be drafted deeper as needed for hydropower generation.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.e. At Lake Roosevelt (Grand Coulee pool), lower pool elevation would not be limited for ferry operation.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety

- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping of generation.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

O2.f. At John Day, allow project to operate up to full pool (268 feet) except as needed for FRM.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping of generation.
- **Measure Location:** John Day Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

  O3. Operate turbines across their full range of capacity by eliminating the restriction to only operate within their range of 1 percent of peak efficiency during the fish migration season (approximately April-October). Elimination of 1 percent peak efficiency restriction would increase ability to meet power demand fluctuations from primarily hydropower generation from Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.

- **Specific Measure:** Eliminate turbine operations (restrictions) to within 1% peak efficiency (not universal +/-1%) (No longer restrict turbine operations to within 1% of peak efficiency.)
- **Purpose:** increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** increase operating range of turbines in hydromodeling
- **Frequency and Duration:** restriction applied during fish passage season.
- **Intended Benefit:** The primary benefit is increase turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water can pass through the turbines, reducing involuntary spill and high TDG.

1.12.15 Alternative: Anadromous ESU/Adult and Juvenile Focus

CRSO Objective: Improve juvenile fish passage (travel time, survival), rearing, and long-term survival within the CRSO projects, including but not limited to configuration, flow management, spill, and water quality to benefit ESA-listed anadromous salmonids. Improve adult fish migration within the CRSO projects, including but not limited to configuration, flow management, spill, and water quality to benefit ESA-listed anadromous salmonids.

Identify issue(s):

- Anadromous Juvenile and adult fish dam passage
- Juvenile rearing
- Long-term survival (SARs)

The following measures address the objective(s) and issue(s):

Structural Measures:

S1. Construct additional surface passage

- **Specific Measure:** Additional surface passage (powerhouse passage)
- **Purpose:** Provide a surface passage route for outmigrating juvenile salmonids
- **Measure Location:** McNary and John Day
- **Implementation:** Install sluiceway surface passage over the McNary powerhouse. Install additional passage at John Day using one or two of the powerhouse skeleton bays.
- **Frequency and Duration:** NA - structural
- **Intended Benefit:** Juvenile salmonids

S2. Modify stilling basins at Little Goose, Lower Monumental, McNary, and John Day Dams to reduce system-wide TDG and/or the flexibility to spill higher volumes while remaining under the gas cap level.

- **Specific Measure:** Reconfigure stilling basins (project specific) to higher elevation/less depth for plunging flows to enable higher spill while staying within the gas cap. NOTE: Discussions indicate more spill is not always better. This action is located at projects where more spill above the existing gas cap could be beneficial.
- **Purpose:** Allow higher spill volumes within the gas cap limitations
- **Measure Location:** Little Goose, Lower Monumental, McNary, and John Day Dams
- **Implementation:** Reconfigure and/or fill the existing stilling basins to decrease depths and dissipate TDG. NOTE: This would likely increase fish mortalities from striking the shallower stilling basins, so may not provide any net benefit.
- **Frequency and Duration:** NA - structural
- **Intended Benefit:** Juvenile salmonids

S3. Drawdown John Day to minimum operating pool (MOP), and maintain forebay elevation within the range 257 feet to 259 feet. Add an additional turbine at Dworshak for flexibility to increase the volume of cool water released from Dworshak for in-season temperature management.

- **Specific Measure:** NOTE: The John Day drawdown measure was not evaluated on the original long form, Additional turbine at Dworshak for TDG abatement/management
- **Purpose:** Ability to retain capacity to move cool water and reduce the need to spill when unit 3 is out of service or when the reservoir must be drafted for flood risk management
- **Measure Location:** Dworshak
- **Implementation:** Add a fourth unit of the same type and capacity as Dworshak unit 3
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Juvenile Snake River fall Chinook salmon health and survival

S4. Improve juvenile bypass facilities by enlarging orifices/pipes, which would reduce juvenile salmon and steelhead injuries caused by collision with debris.

- **Specific Measure:** Improve JBS facilities by enlarging orifices/pipes for debris management, similar to existing condition at Lower Granite. NOTE: Workshop discussions identified this action as the main action with potential to improve JBS survival.
- **Purpose:** Reduce the collision of debris and juvenile salmonids at John Day. This may also improve the condition of fish exiting the bypass (reduce strike/abrasion, if it is an issue at John Day).
- **Measure Location:** John Day Dam
- **Implementation:** Enlarge JBS orifices/pipes at John Day to a 14-inch diameter

- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Juvenile salmonids at John Day

S5. Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam.

- **Specific Measure:** Improve adult ladder passage through modification of adult trap and/or adult trap bypass loo. NOTE: Fish handling for harvest monitoring at Bonneville is RM&E – mitigation.
- **Purpose:** Reduce adult salmonid upstream passage time through ladders
- **Measure Location:** Lower Granite Dam
- **Implementation:**
    - Reduce deployment of diversion gate in the main ladder
    - Reconfigure trap to reduce required head for operations, which would reduce height diverted adults must re-ascend
    - Use new technology to move handled adults over the dam (e.g., vacuum tube) NOTE: This is an emerging issue, and is currently under study
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Adult salmonid health and survival

S6. Add or improve fish passage

- **Specific Measure:** Fish ladders/passage (add or improve)
- **Purpose:** Reduce adult salmonid upstream passage time through ladders, and ensure reliability/redundancy
- **Measure Location:** Lower Granite, Little Goose, Grand Coulee/Chief Josephs or Dworshak. NOTE: Original long form includes actions for John Day South, and Bonneville (A Branch, B Branch, and Cascade Island)
- **Implementation:** NOTE: Differences exist between the original long form and the summary paper that need resolution.
    - Add a second ladder for redundancy during winter maintenance at Little Goose and Lower Granite.
    - Add fish ladders at Grand Coulee/Chief Joseph or Dworshak for trap-and-haul operations (Reintroduction Placeholder)
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Adult salmonid health and survival

<u>Operational Measures:</u>

O1. Adjust spill to optimize juvenile and adult in-river survival. The table below includes DRAFT spill operations for this alternative, which is still in refinement.

- **Specific Measure:** Alter spill (change timing, duration, frequency) – assumes flexibility to adapt over time to when fish are in the river
- **Purpose:** Increase in-river fish survival
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams
- **Implementation:**

Location	**Spill Regime** (**Juvenile-centric levels below**)	**Description of Constraint**
Lower Granite	Gas cap* or constraints?	
Little Goose	30%	Adult passage constraint
Lower Monumental	Gas cap* or constraints?	
Ice Harbor	Gas cap* or constraints?	
McNary	Gas cap* or constraints?	
John Day	45% spill	Juvenile constraint
The Dalles	Gas cap* or constraints?	
Bonneville	100 kcfs	

*Gas cap is defined here as the level set by the Oregon TDG waiver, which is not as restrictive as the Washington 115% forebay/120% tailrace TDG waiver levels.

- **Frequency and Duration:** March 1 through August 31 each year
- **Intended Benefit:** Juvenile salmon and steelhead

O2. Use one or more existing surface passage structures (spillway weirs or sluiceways) for overwintering steelhead and kelt downstream passage from September 1 through December 15 and March 1 through 31

- **Specific Measure:** Additional spillway weir operation for kelts and overwintering steelhead. Note: This is option 1 of 2 for more overwintering steelhead/kelt passage. Can implement using spill, or opening fish bypasses/sluiceways. Are kelts categorized as mitigation?
- **Purpose:** Overwintering steelhead and kelts appear to prefer surface passage routes rather than turbine passage. Measure could increase red counts and productivity or wild/endemic/natural listed DPS and ESU fish. It could also increase steelhead kelt outmigration survival and re-spawner/return productivity (fecundity to the populations), especially B-run steelhead re-spawners to the Clearwater River and all higher age-class re-spawners to the Yakima River.

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day. (The Dalles and Bonneville already have non-spill operations in place for overwintering steelhead and kelts. Detail/triggers can be provided, as needed.
- **Implementation:** Open fish bypasses and sluiceways for overwintering steelhead and kelts.
- **Frequency and Duration:** September 1 through December 15 for overwintering steelhead, and March 1 to March 31 for kelts
- **Intended Benefit:** Overwintering steelhead and kelts

O3. Use pumping systems to provide cooling water in the fish ladders from April through August.

- **Specific Measure:** Cooling water pumped through fish ladder as an attractant (existing condition at Lower Granite and Little Goose)
- **Purpose:** Attract adults to the adult ladders so they pass upstream. NOTE: Important to design so adults do not remain in ladders with cooler water. The purpose of this measure is passage through the structure.
- **Measure Location:** Lower Monumental, Ice Harbor, McNary, and John Day
- **Implementation:**
  - Lower Monumental – Replicate Little Goose design
  - Ice Harbor – Replicate Little Goose design
  - McNary – Would likely require system with four times the capacity of Lower Snake River projects (200 cfs) for a spray-only configuration
  - John Day - ????
- **Frequency and Duration:** April through August
- **Intended Benefit:** Adult salmonids

O4. In dry years, target maintaining minimum 220 kcfs flow at McNary (NOAA BiOp target flow) in May through the use of US storage and Canadian reservoirs. NOTE: No change to Canadian operations in this measure.

- **Specific Measure:** Maintain minimum 220 kcfs flow at McNary (NOAA BiOp target flow) from April 3 through June 15 through the use of US storage reservoirs, up to a maximum of 2.0 million acre-feet (MAF) flow augmentation from US and Canadian projects. In effect, this is flow augmentation for juvenile anadromous fish in dry years.
  - NOTE 1: This action is beyond the existing condition (1 MAF flow augmentation from Columbia River Treat + 0.5 MAF flow augmentation in Non-consecutive dry years from non-Treaty storage).

  - NOTE 2: The ability to store water in US reservoirs for flow augmentation diminishes in high water years due to drafting of the reservoirs for flood risk management. Providing flow augmentation water from US reservoirs may implicitly mean drafting reservoirs deeper than where flood risk management requirements may otherwise have them. This may introduce the risk of reservoirs being unable to meet refill targets for spring/summer fish operations.

- **Purpose:** Augment flows for quicker water travel time through system in low water years
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak
- **Implementation:** Remove resident fish constraints (minimum project flows for resident species).
- **Frequency and Duration:** April 3 through June 15 each year
- **Intended Benefit:** Juvenile salmonids

O5. Additional flow augmentation (seasonal, summer) from Dworshak for temperature operations in the Lower Snake River.

- **Specific Measure:** Additional flow augmentation (seasonal, summer) as a temperature operation at Dworshak, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Flows above 25 kcfs flood in Ahsahka, Dworshak current capacity with 3 units (2 small, 1 large) is 10.5 kcfs and would be around 15 kcfs with an additional large unit. The volume of cold water available varies by year. Drafting more and earlier during the warmest time of the year to beneficial, but we may risk refill if we draft deeper than 1520 feet. NOTE: Steve Hall should weigh in on this measure.
- **Purpose:** Provide more water from Dworshak to benefit adult sockeye and other adults using the cooler water corridor through the Lower Snake River projects.
- **Measure Location:** Dworshak
- **Implementation:** Draft deeper to provide more and longer cold water releases, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Need to evaluate what volume of cold water would be accessible with deeper draft and how existing condition temperature management operations would change.
- **Frequency and Duration:** During sockeye upstream migration, through July/August
- **Intended Benefit:** Adult salmonids

1.12.16 Alternative Description Minimize Greenhouse Gas Emissions through Maximum Carbon-free Power Production

Summary: Use the hydrosystem to maximize the generation of carbon-free power. This is a balance between generating as much hydropower as possible and using the hydrosystem flexibility to integrate of non-hydropower renewable power sources in the grid. The entails increasing the flexibility of the hydrosystem by removing restrictions that are not related to health and safety. For integrating other renewable power sources, the flexibility in the hydrosystem will be operated to allow the hydrosystem to adjust generation both up and down (through the deployment of “INC” and “DEC” reserves) to offset changes in wind and solar generation so that there is a steady supply of power on the electric grid to meet demand. In this alternatives, hydropower generation may not be shaped to maximize generation at peak hours, but rather to generate as many megawatts as possible while also retaining as much operating reserve as possible for integrating of other renewable power sources.

CRSO Objective(s) to be met: Objective #6 Minimize greenhouse gas emissions from power production in the Northwest by maximizing the generation of carbon-free power through a combination of hydropower and integration of other renewable energy sources. *[Note: This is a balance between maximum hydropower and maximum other renewable energy sources.]*

Identify Issue(s) using bullets:

- States in the Northwest are placing increasing emphasis on reducing their carbon footprint.
- The Northwest region is rapidly developing more non-hydropower renewable resources, especially wind and solar. These resources are variable and cannot generate power in the shape that meets demand (power is generated when the wind blows or the sun shines and does not change generation in direct response to changes in demand for electricity).
- Hydropower is a carbon-free resource. However, the hydrosystem has lost capacity and flexibility in the past 2-3 decades due to the implementation of many new objectives, especially for fish.
- Additionally, hydropower generation is well suited to respond to changes in wind generation and solar generation. Hydropower can increase rapidly when wind or solar decline and vice versa. Natural gas plants are able to do this as well, but the region has expressed an interest in adding more renewable generation and less natural-gas generation.

Modeling Objective: The hydropower model will be run with the dual objectives of maximizing the total amount of hydropower and maximizing the amount of operating reserves for integrating renewables. When hydropower generation might need to be spilled to free up operating reserves, the trade-off between the two may be made on the basis of how much carbon-free hydropower would be lost compared to how much carbon-free non-hydropower generation would be enabled for each unit of reserve.

After maximizing the total amount of carbon-free power is produced, the secondary priority will be to use the remaining flexibility in the hydrosystem to shape generation to meet the demand for power generation, particularly shaping to the highest-demand periods.

The following measures address the objective(s) and issue(s):

Structural Measures:

S1. Install a 4th turbine in an existing skeleton bay of the Dworshak power house.

- **Specific Measure:** Add a 4th unit at Dworshak Dam
- **Purpose:** To provide flexibility for power generation
- **Measure Location:** Dworshak Dam, Idaho
- **Implementation:** Add a 4th unit at Dworshak Dam. Best available information as of June 2017 estimates that a 130 MW unit is approximately the best size to match the amount of water typically available to run the unit efficiently. .
- **Frequency and Duration:** unit would be available year-round
- **Intended Benefit:** Provide more opportunities to generate more hydropower especially if other units are offline or during very high flows. Would also reduce involuntary spill and reduce TDG for the lower Snake, so would have benefits for fish below Dworshak Dam. Might also help reduce water temperature below DWR.

S2. Install a 6th power generating unit into one of the unused skeleton bays of the Libby power house.

- **Specific Measure:** Add a 6th unit at Libby Dam
- **Purpose:** To provide flexibility for power generation
- **Measure Location:** Libby Dam
- **Implementation:** Install a 6th power generating unit into one of the unused skeleton bays of the Libby power house.
- **Frequency and Duration:** unit would be available year-round
- **Intended Benefit:** reduce involuntary spill and reduce TDG

S3. Cease annual installation of fish screens at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects to allow more flow to the units and increase turbine efficiency.

- **Specific Measure:** Remove Fish Screens
- **Purpose:** (Not identified)
- **Measure Location:** Lower Snake and lower Columbia dams
- **Implementation:** during the spill season, most of the fish-passage dams have fish screens installed during the fish-passage season.
- **Frequency and Duration:** currently the screens are in place during the fish-passage season. Measure would leave screens off all year.
- **Intended Benefit:** Power efficiency is increased. Maintenance and replacement cost of the screens is very high and would be avoided. Lamprey would benefit from screen removal.

<u>**Operational Measures:**</u>

O1. Stop all voluntary spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects year-round. Involuntary spill associated with high flow events and lack-of-market spill would continue as needed.

- **Specific Measure:** Decreasing/stopping spill (stop voluntary spill)
- **Purpose:** increase hydropower production
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** No longer model voluntary spill for fish passage. Some spill may be necessary to provide INC and DEC reserves for reliability. Involuntary spill during high flows will continue, as will lack-of-market spill.
- **Frequency and Duration:** no voluntary spill all year (i.e. no longer spilling April-August)
- **Intended Benefit:** increased hydropower production, benefit to adult upstream fish passage (less fall-back at dams), likely improved safety for navigation

O2. Lift all flow and pool elevation restrictions that are not safety-related from all projects to increase ability to meet power demand fluctuations from primarily hydropower generation year-round. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability

- **Specific Measure:** More flexibility on seasonal, daily, and hourly flow (Reduce restrictions on seasonal pool elevations except for flood risk management, reduce restrictions on ramping rates unless there are safety or engineering restrictions, permit draft of reservoirs below VDLs when it is beneficial for power)
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow will be lifted.
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Hydropower production can be increased and can more appropriately be shaped to meet demand when there is more flexibility in flows.

O2.a. Reduce restrictions on ramping rates at all projects unless for the purpose of safety or engineering.

- **Specific Measure:** *Incorporated into O2 per BPA comment 30 June 2017.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow will be lifted.
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Beneficial to generation if allowed to ramp down much faster than rates. Some restrictions for bank sloughing need to stay - earthen embankment projects (don't ramp @ rate to slough)

O2.b. At the four, lower Snake River projects, seasonal pool elevations would no longer be restricted to within 1-foot of Minimum Operating Pool (MOP) during the juvenile fish passage season (April-August).

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)

- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.c. At the John Day project, the seasonal pool elevation would no longer be restricted to within 1.5 feet of Minimum Irrigation Pool (MIP) during the juvenile fish passage season (April-August).

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day
- **Implementation:** At the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.d. At the storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak), the variable draft limits (VDLs) would not be enforced as a lower operating limit so that those reservoirs could be drafted deeper as needed for hydropower generation.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP, JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season. Similarly, John Day pool will not be

restricted to within 1 ½ feet of MIP. At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.

- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.e. At Lake Roosevelt (Grand Coulee pool), lower pool elevation would not be limited for ferry operation.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping of generation.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

O2.f. At John Day, allow project to operate up to full pool (268 feet) except as needed for FRM.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping of generation.
- **Measure Location:** John Day Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

O3. Operate turbines across their full range of capacity by eliminating the restriction to only operate within their range of 1 percent of peak efficiency during the fish migration season

(approximately April-October). Elimination of 1 percent peak efficiency restriction would increase ability to meet power demand fluctuations from primarily hydropower generation from Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.

- **Specific Measure:** Eliminate turbine operations (restrictions) to within 1% peak efficiency (not universal +/-1%) (No longer restrict turbine operations to within 1% of peak efficiency.)
- **Purpose:** increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** increase operating range of turbines in hydromodeling
- **Frequency and Duration:** restriction applied during fish passage season.
- **Intended Benefit:** The primary benefit is increase turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water can pass through the turbines, reducing involuntary spill and high TDG.

1.12.17 Alternative: Multi-Objective Integration 1 Detailed Description

Summary: The Multi-Objective Integration Alternative 1 is intended to address multiple objectives. This alternative modifies spill, increases operational flexibility and hydropower production, and incorporates measures to improve fish passage at the projects.

Context: Multi-objective integrated alternatives attempt to incorporate measures that would address more than one objective. These alternatives do not necessarily attempt to balance all of the objectives but explore operational changes in order to determine impacts and trade-off of combining objectives under one alternative.

CRSO Objective(s):

This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.

  Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

The following measures address the objective(s):

Structural Measures:

S1. Construct additional powerhouse sluiceway passage.

- **Purpose:** Provide additional powerhouse passage route for outmigrating juvenile salmonids.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor and McNary projects.
- **Implementation:** Add deep powerhouse passage (orifices to spillway) at Lower Granite, Little Goose and Lower Monumental projects. Install sluiceway surface passage through Ice Harbor and McNary powerhouses.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S2. Upgrade and increase the number of spillway weirs to provide additional surface passage routes.

- **Purpose:** Provide more surface passage routes for smolt passage and upgrade existing top spillway weirs and removable spillway weirs to adjustable spillway weirs (ASW's) for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day projects.
- **Implementation:** Add additional and improve existing spillway weirs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (LSN projects: June 20; LCOL projects: June 15), 7 kcfs per weir discharge during summer spill operations (LSN projects: June 21-August 31; LCOL projects: June 16-August 31).
    - **Lower Granite.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7kcfs.
    - **Little Goose.** One additional ASW (2 total) at 7-11 kcfs.
    - **Lower Monumental.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **Ice Harbor.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **McNary.** Replace the two existing spillway weirs with ASW's and add an additional ASW (3 ASW's total) at 7-10 kcfs.
    - **John Day.** Replace the two existing spillway weirs with ASW's and add an additional ASW in a skeleton bay (3 ASW's total). 7-10 kcfs.
- **Frequency and Duration:** NA

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S3. Improve adult ladder passage through modification of adult trap and adult bypass loop at Lower Granite project.

- **Purpose:** Reduce passage time for migrating adults as they move upstream through the fish ladders.
- **Measure Location:** Lower Granite project.
- **Implementation:** Reconfigure to reduce head, thus reducing the height diverted adults must re-ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move adults from the handling facility over the dam.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may improve adult fish survival.

S4. Add and improve adult fish ladders.

- **Specific measure:** Add new or improve existing adult fish ladders.
- **Purpose:** To reduce adult salmonid upstream passage time through improved or additional ladders and ensure reliable upstream fish passage, including monitoring with PIT detection at ladder entrances for real-time adaptive management of passage delays. Ensure reliable year-round upstream passage capability for bull trout at dams on the lower Snake River.
- **Measure Location:** Lower Granite and Little Goose (additional ladders); all eight fish passage projects (PIT detection at ladder entrances.
- **Implementation:** Instrument all fish ladder entrances with PIT tag detection and add new secondary ladders with less slope than current ladders at Lower Granite and Little Goose projects.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?)** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmonid passage and survival, reduce travel, increase conversion rates, improve real-time adaptive management to reduce passage delays and provide reliable, year round, upstream passage for bull trout and other resident species.

S5. Reconfigure the adult trap at Ice Harbor dam.

- **Specific Measure:** Reconfigure the adult trap at Ice Harbor Dam to enable adult transport upstream past the lower Snake River dams and/or around thermal blockages between Lower Granite Reservoir and the confluence of the mainstem Snake River and the Salmon River.
- **Purpose:** Enable adult transport upstream past the lower Snake dams and/or around thermal blockages in the undammed portions of the middle Snake River and/or Salmon River.
- **Measure Location:** Ice Harbor project
- **Implementation:** Reconfigure the adult trap at Ice Harbor project and include a water chilling system to hold trapped adults to provide infrastructure for adult transport.
- **Frequency and Duration:** June 1 – August 31

  Intended Benefit (why include this measure?): Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult Snake River sockeye and adult summer Chinook salmon survival.

S6. Modify tailrace configuration to reduce spill effects on adult passage.

- **Purpose:** Address current issues where juvenile spill regime results in delays or inefficiencies in adult fish passage. Current configurations result in eddy development and complex flow patterns within trailraces during juvenile spill.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and Bonneville projects.
- **Implementation:** Alternative would include installation of divider walls to channelize spill and powerhouse flow. Specifically, install divider walls between the spillway and powerhouse at all but John Day and Bonneville projects. At Little Goose, tailrace fill would be required for wall installation.
    - **Lower Granite** – Install divider wall between spillway and powerhouse
    - **Little Goose** – Fill in bathymetry and install divider wall, both between spillway and powerhouse.
    - **Lower Monumental** – Install divider wall between spillway and powerhouse.
    - **Ice Harbor** – Install divider wall between spillway and powerhouse.
    - **McNary** – Install divider wall between spillway and powerhouse.
    - **John Day** – Install divider wall between spillway and powerhouse.
- **Frequency and Duration:** Once installed the modification would be permanent.

- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase passage efficiency and reduce delay of adults.

S7. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor projects.

- **Purpose:** Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce temperature differentials between the tailrace and ladder entrance (from surface water warming) to minimize thermal barriers and adult passage delays.

Operational Measures:

O1. Reduce the duration of summer juvenile fish passage spill.

- **Specific Measure:** Reduce the period for which summer juvenile fish passage spill is conducted.
- **Purpose:** To increase hydropower production.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.
- **Implementation:** Modify the duration of the summer spill period.
- **Frequency and Duration:** Summer spill will end August 1.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase power production flexibility in the month of August.

O2. During juvenile fish passage spill season put more spill over the spillway weir rather than over the spillway.

- **Specific Measure:** During juvenile fish passage spill season put more spill over the spillway weir rather than over the spillway.
- **Purpose:** More spill will be sent through the spillway weir

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor projects
- **Implementation:** When spilling during fish passage season, do not hold projects within 1 foot minimum operating pool (MOP). Bring projects out of MOP will shift more spill to spillway weirs, and this flexibility may assist with adult attraction
- **Frequency and Duration:** When spilling at a project using a spillway weir
- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may improve juvenile anadromous salmon passage.

O3. Measure juvenile fish passage spill total dissolved gas (TDG) levels on a 12-hour rolling average.

- **Specific Measure:** Measure TDG levels on a 12-hour rolling average.
- **Purpose:**
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.
- **Implementation:** Measure TDG levels on a 12-hour rolling average.
- **Frequency and Duration:** Continuously.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis.

O4. Use pumping systems to provide deeper (cooler) water in the fish ladder

- **Purpose:** Attract anadromous adult fish to the fish ladders and forebays so they can pass upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders and forebays by installing pumps that move cooler water into the ladders from depth. Replicate the existing Little Goose design for ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may reduce the temperature differential between the tailrace and ladder entrance (from surface water warming), minimized thermal barrier and adult passage delays.

O5. Implement modified timing of Lower Snake Basin reservoir draft to provide additional cooler water in the Lower Snake River during peak adult migration periods.

- **Purpose:** Provide earlier and later cold water releases for adult sockeye, summer Chinook salmon, Fall Chinook and steelhead that utilize the cool water corridor provided by Dworshak Reservoir through the lower Snake River.
- **Measure:** Dworshak project.
- **Implementation:** Draft earlier (June 21-August 1) for sockeye and summer Chinook salmon and later (September 1- September 30) for Fall chinook and steelhead. From July 16 – August 31, release 5 kcfs flow from Dworshak (surrogate for a higher temperature target like 22°C at lower Granite tailwater that will provide minimal cold water refuge but is not focused on migration).
- **Frequency and Duration:** During sockeye salmon, summer Chinook salmon, fall Chinook salmon and steelhead upstream migration June through September.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may create suitable water tempertures for adult migration and egg viability during the peak adult migration periods for summer Chinook salmon, sockeye salmon, steelhead, and fall Chinook salmon.

O6. Optimize adult fish trap operations.

- **Specific Measure:** Reduce fish trap operations for research purposes an increase trap utilization when temperatures reach or exceed °F.
- **Purpose:** Decrease upstream adult fish travel times and reduce exposure to high water temperatures.
- **Measure Location:** Lower Granite, Ice Harbor and Bonneville projects.
- **Implementation:**
  - Ice Harbor: when lower Snake River water temperatures reach or exceed 72°F, trap and haul adult salmonids upstream and release above Lower Granite project.
  - Bonneville and Lower Granite: Reduce trap operations for research purposes to a maximum of 5 days per week.
- **Frequency and Duration:** March - September.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may increase survival of adult salmonids and increased arrival at spawning grounds.

O7. Partially lift flow and pool elevation restrictions.

O7.a. At the lower Snake River projects seasonal pool elevations are operated within the full reservoir operating range year-round.

- **Specific Measure:** Remove restrictions on seasonal pool elevations.

- **Purpose:** To allow more operating flexibility for hourly and daily shaping of hydropower generation increasing ability to meet power demand fluctuations from year-round.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor projects.
- **Implementation:** The pools will no longer be restricted to within 2-feet of Minimum Operating Pool (MOP) during the juvenile fish passage season. Safety-related restrictions that would continue include maintaining ramp rates for minimizing project erosion, and maintaining grid reliability.
- **Frequency and Duration:** April through August.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to offer larger ranges of operating pools allow for more flexibility to shape power production to meet demand and may improve reservoir conditions for juvenile fish passage.

O7.b. At the John Day project, the seasonal pool elevation is restricted to within 2.5 feet of Minimum Irrigation Pool (MIP).

- **Specific Measure:** Relax restrictions on seasonal pool elevations.
- **Purpose:** To allow more operating flexibility for hourly and daily shaping of hydropower generation increasing ability to meet power demand fluctuations year-round.
- **Measure Location:** John Day project
- **Implementation:** John Day pool will be restricted to within 2 ½ feet of MIP. Safety-related restrictions that would continue include meeting flood risk management elevations and flows, maintaining ramp rates for minimizing project erosion, and maintaining grid reliability.
- **Frequency and Duration:** During the juvenile fish passage season from April 10 through August 1.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure has the potential to provide larger ranges of operating pools allow for more flexibility to shape power production to meet demand and may improve reservoir conditions for juvenile fish migration.

O8. Reduce the restriction on turbine operations during the juvenile fish passage season.

O8a. At the lower Snake River projects, relax turbine efficiency restrictions.

- **Specific Measure:** Eliminate/reduce restriction of turbine operation to within 1% peak efficiency resulting in less prescriptive turbine operation peak efficiency restrictions.
- **Purpose:** Provide additional flexibility to hydrogeneration.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice harbor projects.
- **Implementation:** The turbine operation peak efficiency restrictions would be lifted for operating above peak efficiency.
- **Frequency and Duration:** April through October.
- **Intended Benefit: (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure may provide more efficient power generation.

O8b. At some lower Columbia River projects, eliminate turbine efficiency restrictions.

- **Specific Measure:** Eliminate turbine operation to within 1 percent peak efficiency restriction.
- **Purpose:** Increase hydrogenation flexibility, especially during high flows.
- **Measure Location:** McNary, The Dalles, and Bonneville projects.
- **Implementation:** Increase operating range of turbines in hydromodeling.
- **Frequency and Duration:** Eliminate the restriction during fish passage season.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure increases turbine range and increases turbine capacity. During high flow periods, turbines will be able to operate at maximum turbine limits, increasing generation.

O9. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the measure:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.

- **Intended Benefit:** This measure increases the available capacity of hydrogenation. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O10. Zero generation operations may occur.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.
- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

O11. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May–June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management.
    - Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.

- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby project
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May-June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating “double-accounting”; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby).
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, local FRM operations may be improved by having fewer instances of filling before the end of spring runoff (“fill and spill”). This is anticipated to improve water quality conditions for resident fish. It also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O12. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers’ ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby project
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)

- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, an end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. This measure reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allow for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O13. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and to reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby
- **Implementation:** Operational change: modify SRDs for Libby.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure may reduce the need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March-April timeframe.

O14. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.

- **Purpose:** Allow Libby project to better adapt local operations to dry water year needs when system FRM is less of a concern.

- **Measure Location:** Libby project

- **Implementation:** At Libby project, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan-Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9

MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.

- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure would result in water management operations (e.g., beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O15. Decrease the Grand Coulee project draft rate used in planning drawdown (in the SRD) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee project draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee project
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, however this measure is anticipated to reduce the probability of landslides. This is expected to have an ancillary benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O16. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee project. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of possible hydraulic capacity during maintenance activities. This more aggressive maintenance schedule on the Third, Left and Right

Power Houses assumes a greater limit on hydraulic capacity. For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[5]) depending on head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.

- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee project. Over the next 20-yrs, Grand Coulee project and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee project; Third Power Plant, Left Power Plant, Right Power Plant
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure will improve safety, reliability and capacity of power plants and spillways at Grand Coulee project, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O17. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations. . Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.

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[5] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

- **Purpose of the measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs snow.
- **Measure Location:** Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at Libby, Hungry Horse, and Dworshak projects.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure is anticipated to reserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

1.12.18 Alternative: Multi-Objective Integration 2 Detailed Description

Summary: The Multi-Objective Integration Alternative 2 is intended to address multiple objectives. This alternative modifies spill, increases operational flexibility and hydropower production, and incorporates measures to improve fish passage at the projects.

Context: Multi-objective integrated alternatives attempt to incorporate measures that would address more than one objective. These alternatives do not necessarily attempt to balance all of the objectives but explore operational changes in order to determine impacts and trade-off of combining objectives under one alternative.

CRSO Objective(s):

This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

The following measures address the objective(s):

Structural Measures:

S1. Construct additional powerhouse sluiceway passage.

- **Purpose:** Provide additional powerhouse passage route for outmigrating juvenile salmonids.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor and McNary projects.
- **Implementation:** Add deep powerhouse passage (orifices to spillway) at Lower Granite, Little Goose and Lower Monumental projects. Install sluiceway surface passage through Ice Harbor and McNary powerhouses.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S2. Upgrade and increase the number of spillway weirs to provide additional surface passage routes.

- **Purpose:** Provide more surface passage routes for smolt passage and upgrade existing top spillway weirs and removable spillway weirs to adjustable spillway weirs (ASW's) for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day projects.
- **Implementation:** Add additional and improve existing spillway weirs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (LSN projects: June 20; LCOL projects: June 15), 7 kcfs per weir discharge during summer spill operations (LSN projects: June 21-August 31; LCOL projects: June 16-August 31).
    - **Lower Granite.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7kcfs.
    - **Little Goose.** One additional ASW (2 total) at 7-11 kcfs.
    - **Lower Monumental.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **Ice Harbor.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **McNary.** Replace the two existing spillway weirs with ASW's and add an additional ASW (3 ASW's total) at 7-10 kcfs.
    - **John Day.** Replace the two existing spillway weirs with ASW's and add an additional ASW in a skeleton bay (3 ASW's total). 7-10 kcfs.
- **Frequency and Duration:** NA

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S3. Improve adult ladder passage through modification of adult trap and adult bypass loop at Lower Granite project.

- **Purpose:** Reduce passage time for migrating adults as they move upstream through the fish ladders.
- **Measure Location:** Lower Granite project.
- **Implementation:** Reconfigure to reduce head, thus reducing the height diverted adults must re-ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move adults from the handling facility over the dam.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may improve adult fish survival.

S4. Add and improve adult fish ladders.

- **Specific measure:** Add new or improve existing adult fish ladders.
- **Purpose:** To reduce adult salmonid upstream passage time through improved or additional ladders and ensure reliable upstream fish passage, including monitoring with PIT detection at ladder entrances for real-time adaptive management of passage delays. Ensure reliable year-round upstream passage capability for bull trout at dams on the lower Snake River.
- **Measure Location:** Lower Granite and Little Goose (additional ladders); all eight fish passage projects (PIT detection at ladder entrances.
- **Implementation:** Instrument all fish ladder entrances with PIT tag detection and add new secondary ladders with less slope than current ladders at Lower Granite and Little Goose projects.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?)** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmonid passage and survival, reduce travel, increase conversion rates, improve real-time adaptive management to reduce passage delays and provide reliable, year round, upstream passage for bull trout and other resident species.

S5. Reconfigure the adult trap at Ice Harbor dam.

- **Specific Measure:** Reconfigure the adult trap at Ice Harbor Dam to enable adult transport upstream past the lower Snake River dams and/or around thermal blockages between Lower Granite Reservoir and the confluence of the mainstem Snake River and the Salmon River.
- **Purpose:** Enable adult transport upstream past the lower Snake dams and/or around thermal blockages in the undammed portions of the middle Snake River and/or Salmon River.
- **Measure Location:** Ice Harbor project
- **Implementation:** Reconfigure the adult trap at Ice Harbor project and include a water chilling system to hold trapped adults to provide infrastructure for adult transport.
- **Frequency and Duration:** June 1 – August 31

  Intended Benefit (why include this measure?): Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult Snake River sockeye and adult summer Chinook salmon survival.

S6. Modify tailrace configuration to reduce spill effects on adult passage.

- **Purpose:** Address current issues where juvenile spill regime results in delays or inefficiencies in adult fish passage. Current configurations result in eddy development and complex flow patterns within trailraces during juvenile spill.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and Bonneville projects.
- **Implementation:** Alternative would include installation of divider walls to channelize spill and powerhouse flow. Specifically, install divider walls between the spillway and powerhouse at all but John Day and Bonneville projects. At Little Goose, tailrace fill would be required for wall installation.
  - **Lower Granite** – Install divider wall between spillway and powerhouse
  - **Little Goose** – Fill in bathymetry and install divider wall, both between spillway and powerhouse.
  - **Lower Monumental** – Install divider wall between spillway and powerhouse.
  - **Ice Harbor** – Install divider wall between spillway and powerhouse.
  - **McNary** – Install divider wall between spillway and powerhouse.
  - **John Day** – Install divider wall between spillway and powerhouse.
- **Frequency and Duration:** Once installed the modification would be permanent.

- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase passage efficiency and reduce delay of adults.

S7. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor projects.

- **Purpose:** Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce temperature differentials between the tailrace and ladder entrance (from surface water warming) to minimize thermal barriers and adult passage delays.

<u>Operational Measures:</u>

O1. Modify juvenile fish passage spill percentages or Total Dissolved Gas (TDG) levels.

- **Specific Measure:**

Project	**Spring** *April 3/10 to* *Mid-June*	**Early Summer**	**Late Summer**
Lower Granite	**⇧40% Spill to 115% TDG forebay and 120% TDG as measured in the tailrace**		**⇩ No Spill**
Little Goose			**⇩ No Spill**
Lower Monumental	**115% TDG forebay and 120% TDG as measured in the tailrace**		**--**
Ice Harbor			**--**
McNary	**50% Spill**		**--**

John Day	**40% Spill**	**40% Spill**	**40% Spill**
The Dalles			**--**
Bonneville	**No Spill**	**No Spill**	**No Spill**

- **Purpose:** Balance adult and juvenile passage
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects
- **Implementation:** Modify juvenile fish passage spill as described above.
- **Frequency and Duration:** Modify juvenile fish passage spill as described above from April 1 through August 31.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure is intended to balance juvenile outmigration and adult passage to improve juvenile and adult anadromous salmonid health and survival.

O2. During juvenile fish passage spill season put more spill over the spillway weir rather than over the spillway.

- **Specific Measure:** During juvenile fish passage spill season put more spill over the spillway weir rather than over the spillway.
- **Purpose:** More spill will be sent through the spillway weir
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor projects
- **Implementation:** When spilling during fish passage season, do not hold projects within 1 foot minimum operating pool (MOP). Bring projects out of MOP will shift more spill to spillway weirs, and this flexibility may assist with adult attraction
- **Frequency and Duration:** When spilling at a project using a spillway weir
- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may improve juvenile anadromous salmon passage.

O3. Measure juvenile fish passage spill total dissolved gas (TDG) levels on a 12-hour rolling average.

- **Specific Measure:** Measure TDG levels on a 12-hour rolling average.
- **Purpose:**
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.

- **Implementation:** Measure TDG levels on a 12-hour rolling average.
- **Frequency and Duration:** Continuously.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however,

O4. Use pumping systems to provide deeper (cooler) water in the fish ladder

- **Purpose:** Attract anadromous adult fish to the fish ladders and forebays so they can pass upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders and forebays by installing pumps that move cooler water into the ladders from depth. Replicate the existing Little Goose design for ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may reduce the temperature differential between the tailrace and ladder entrance (from surface water warming), minimized thermal barrier and adult passage delays.

O5. Implement modified timing of Lower Snake Basin reservoir draft to provide additional cooler water in the Lower Snake River during peak adult migration periods.

- **Purpose:** Provide earlier and later cold water releases for adult sockeye, summer Chinook salmon, Fall Chinook and steelhead that utilize the cool water corridor provided by Dworshak Reservoir through the lower Snake River.
- **Measure:** Dworshak project.
- **Implementation:** Draft earlier (June 21-August 1) for sockeye and summer Chinook salmon and later (September 1- September 30) for Fall chinook and steelhead. From July 16 – August 31, release 5 kcfs flow from Dworshak (surrogate for a higher temperature target like 22°C at lower Granite tailwater that will provide minimal cold water refuge but is not focused on migration).
- **Frequency and Duration:** During sockeye salmon, summer Chinook salmon, fall Chinook salmon and steelhead upstream migration June through September.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may create suitable water temperatures for adult migration and egg viability during the peak adult migration periods for summer Chinook salmon, sockeye salmon, steelhead, and fall Chinook salmon.

O6. Optimize adult fish trap operations.

- **Specific Measure:** Reduce fish trap operations for research purposes an increase trap utilization when temperatures reach or exceed °F.
- **Purpose:** Decrease upstream adult fish travel times and reduce exposure to high water temperatures.
- **Measure Location:** Lower Granite, Ice Harbor and Bonneville projects.
- **Implementation:**
  - Ice Harbor: when lower Snake River water temperatures reach or exceed 72°F, trap and haul adult salmonids upstream and release above Lower Granite project.
  - Bonneville and Lower Granite: Reduce trap operations for research purposes to a maximum of 5 days per week.
- **Frequency and Duration:** March - September.

  Intended Benefit (why include this measure?): Impacts of implementation of this measure will be included in the impact analysis, however; this measure may increase survival of adult salmonids and increased arrival at spawning grounds.

O7. Reservoir drawdown to Minimum Operating Pool (MOP) or lower to further reduce travel times for outmigration.

- **Purpose: R**educe water particle time through the reservoirs.
- **Measure Location:** McNary, John Day and Lower Granite projects.
- **Implementation:** Draw down the reservoir elevation, still allowing turbines to operate sustainable without cavitation issues:
  - Lower Granite: MOP-10’ (forebay elevation 723’ = 1’ operating range above MOP-10’)
  - McNary: MOP (elevation 335” + 1’ operating range above MOP).
  - John Day: MOP (forebay elevation 257’ = 1.5’ operating range above MOP).
- **Frequency and Duration:** April 3 (lower Snake projects)/April 10 (lower Columbia projects) through August 31.
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steehead survival through the lower Snake River and Columbia Rivers projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

O8. Reduce the restriction on turbine operations during the juvenile fish passage season.

O8a. At the lower Snake River projects, relax turbine efficiency restrictions.

- **Specific Measure:** Eliminate/reduce restriction of turbine operation to within 1% peak efficiency resulting in less prescriptive turbine operation peak efficiency restrictions.
- **Purpose:** Provide additional flexibility to hydrogeneration.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** The turbine operation peak efficiency restrictions would be lifted for operating above peak efficiency.
- **Frequency and Duration:** April through October.
- **Intended Benefit: (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure may provide more efficient power generation.

O8b. At some lower Columbia River projects, eliminate turbine efficiency restrictions.

- **Specific Measure:** Eliminate turbine operation to within 1 percent peak efficiency restriction.
- **Purpose:** Increase hydrogenation flexibility, especially during high flows.
- **Measure Location:** McNary, The Dalles, and Bonneville projects.
- **Implementation:** Increase operating range of turbines in hydromodeling.
- **Frequency and Duration:** Eliminate the restriction during fish passage season.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure increases turbine range and increases turbine capacity. During high flow periods, turbines will be able to operate at maximum turbine limits, increasing generation.

O9. In order to support the establishment of riparian vegetation at Libby project for bull trout, the river stage in fall and winter (October through March) should not exceed max river stage in the previous year

- **Specific Measure:**
- **Purpose:** Support the establishment of riparian vegetation to benefit the establishment of riparian vegetation
- **Measure Location:** Libby project
- **Implementation:** River stage in the fall and winter should not exceed max river stage in the previous year. The reference points will be Bonners Ferry and Columbia Falls.

- **Frequency and Duration:** October through March every 5 years. It is unclear if this is feasible from a water management perspective
- **Intended Benefit:** Resident fish, including bull trout

O10. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate forecast for each project, to balance local resident fish priorities with downstream flow augmentation. At Libby project base 10 to 20 foot drafts on appropriate forecast for Libby project. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish.
- **Measure Location:** Libby, Hungry Horse projects
- **Implementation**
    - **Libby:** adjust the end of summer elevation targets (5 to 20 feet from full at Libby, based on forecasts.
    - **Hungry Horse:**
        - Use the May Final April-August forecast for Hungry Horse to determine the end of September draft.
            - For the 10th percentile forecast and drier draft 20 feet.
            - For the 20th percentile forecast and wetter draft 10 feet Use a graduated draft between 10th and 20th percentile, for example:

Table 1-32. Hungry Horse Summer Flow Augmentation Draft

Percentile (forecast)	HGH April-Aug FC	Feet draft	Draft elevation
10th	<=1203.3	20	3540
12th	1203.5-1239.1	18	3542
14th	1239.2-1273.93	16	3544
16th	1274-1324.2	14	3546
18th	1324.3-1349.8	12	3548
20th	>1349.8	10	3550

Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.

- **Frequency and Duration:** All years
- **Intended Benefit (why is this measure included?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure may enable better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O11. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the measure:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit:** This measure increases the available capacity of hydrogenation. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O12. Zero generation operations may occur.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)

- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.

- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

O13. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May–June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management. Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby project
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May-June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby).
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, local FRM operations may be improved by having fewer instances of filling before the end of spring runoff ("fill and spill"). This is anticipated to improve water quality conditions for resident fish. It also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O14. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby project
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft.
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, an end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. This measure reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allow for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O15. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and to reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby project
- **Implementation:** Operational change: modify SRDs for Libby.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure may reduce the need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March-April timeframe.

O16. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.
- **Purpose:** Allow Libby project to better adapt local operations to dry water year needs when system FRM is less of a concern.
- **Measure Location:** Libby project
- **Implementation:** At Libby project, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan-Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9 MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure would result in water management operations (e.g., beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O17. Decrease the Grand Coulee project draft rate used in planning drawdown (in the SRD) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee project draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee project
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, however this measure is anticipated to reduce the probability of landslides. This is expected to have an ancillary

benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O18. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee project. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of possible hydraulic capacity during maintenance activities. This more aggressive maintenance schedule on the Third, Left and Right Power Houses assumes a greater limit on hydraulic capacity. For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[6]) depending on head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.
- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee project. Over the next 20-yrs, Grand Coulee project and Powerplant facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee; Third Power Plant, Left Power Plant, Right Power Plant
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure will improve safety, reliability and capacity of power plants and spillways at Grand Coulee project, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

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[6] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

O19. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose of the measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs snow.
- **Measure Location:** Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at Libby, Hungry Horse, and Dworshak projects.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impacts analysis; however, this measure is anticipated to reserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

1.12.19 Alternative: Multi-Objective Integration 3 Detailed Description

Summary: The Multi-Objective Integration Alternative 3 is intended to address multiple objectives. This alternative modifies spill, increases operational and hydropower production flexibility, and incorporates measures to improve fish passage at the projects.

Context: Multi-objective integrated alternatives attempt to incorporate measures that would address more than one objective. These alternatives do not necessarily attempt to balance all of the objectives but explore operational changes in order to determine impacts and trade-off of combining objectives under one alternative.

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

The following measures address the objective(s):

<u>Structural Measures:</u>

S1. Construct additional powerhouse sluiceway passage.

- **Purpose:** Provide additional powerhouse passage route for outmigrating juvenile salmonids.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor and McNary projects.
- **Implementation:** Add deep powerhouse passage (orifices to spillway) at Lower Granite, Little Goose and Lower Monumental projects. Install sluiceway surface passage through Ice Harbor and McNary powerhouses.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S2. Upgrade and increase the number of spillway weirs to provide additional surface passage routes.

- **Purpose:** Provide more surface passage routes for smolt passage and upgrade existing top spillway weirs and removable spillway weirs to adjustable spillway weirs (ASW's) for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day projects.
- **Implementation:** Add additional and improve existing spillway weirs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (LSN projects: June 20; LCOL projects: June 15), 7 kcfs per weir discharge during summer spill operations (LSN projects: June 21-August 31; LCOL projects: June 16-August 31).
    - **Lower Granite.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7kcfs.
    - **Little Goose.** One additional ASW (2 total) at 7-11 kcfs.
    - **Lower Monumental.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **Ice Harbor.** Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - **McNary.** Replace the two existing spillway weirs with ASW's and add an additional ASW (3 ASW's total) at 7-10 kcfs.

  - **John Day.** Replace the two existing spillway weirs with ASW's and add an additional ASW in a skeleton bay (3 ASW's total). 7-10 kcfs.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S3. Improve adult ladder passage through modification of adult trap and adult bypass loop at Lower Granite project.

- **Purpose:** Reduce passage time for migrating adults as they move upstream through the fish ladders.
- **Measure Location:** Lower Granite project.
- **Implementation:** Reconfigure to reduce head, thus reducing the height diverted adults must re-ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move adults from the handling facility over the dam.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may improve adult fish survival.

S4. Add and improve adult fish ladders.

- **Specific measure:** Add new or improve existing adult fish ladders.
- **Purpose:** To reduce adult salmonid upstream passage time through improved or additional ladders and ensure reliable upstream fish passage, including monitoring with PIT detection at ladder entrances for real-time adaptive management of passage delays. Ensure reliable year-round upstream passage capability for bull trout at dams on the lower Snake River.
- **Measure Location:** Lower Granite and Little Goose (additional ladders); all eight fish passage projects (PIT detection at ladder entrances.
- **Implementation:** Instrument all fish ladder entrances with PIT tag detection and add new secondary ladders with less slope than current ladders at Lower Granite and Little Goose projects.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?)** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmonid passage and survival, reduce travel, increase

conversion rates, improve real-time adaptive management to reduce passage delays and provide reliable, year round, upstream passage for bull trout and other resident species.

S5. Reconfigure the adult trap at Ice Harbor dam.

- **Specific Measure:** Reconfigure the adult trap at Ice Harbor Dam to enable adult transport upstream past the lower Snake River dams and/or around thermal blockages between Lower Granite Reservoir and the confluence of the mainstem Snake River and the Salmon River.
- **Purpose:** Enable adult transport upstream past the lower Snake dams and/or around thermal blockages in the undammed portions of the middle Snake River and/or Salmon River.
- **Measure Location:** Ice Harbor project
- **Implementation:** Reconfigure the adult trap at Ice Harbor project and include a water chilling system to hold trapped adults to provide infrastructure for adult transport.
- **Frequency and Duration:** June 1 – August 31
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult Snake River sockeye and adult summer Chinook salmon survival.

S6. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor projects.

- **Purpose:** Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce temperature differentials between the tailrace and ladder entrance (from surface water warming) to minimize thermal barriers and adult passage delays.

S7. Modify position of entrance weirs to act as orifices to reduce shad in adult fish ladders.

- **Specific Measure:**

- **Purpose:** This measure would reduce the number of shad in the ladders, which in turn would reduce adult salmonid passage delays.
- **Measure Location:** Ice Harbor and Bonneville projects
- **Implementation:** Telescoping weirs would be positioned higher in the water column allowing flow to pass between bottom of stack and sill.
- **Frequency and Duration:** During high volume shad passage perios (May 1 – August 31
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce passage delays for adult anadromous salmonids.

<u>Operational Measures:</u>

O1. Decrease fish passage spill by setting spill as described in the 2014 BiOp, but limiting total dissolved gas (TDG) to the 110 percent TDG cap (water quality standard without waivers), as measured in the tailrace, at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects. Spill associated with high flow and flood events and lack-of-market spill would continue as needed.

- **Specific Measure:** Decrease fish passage spill at all Lower Snake River and Lower Columbia River dams.
- **Purpose:** increase hydropower production
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** . Set spill as described in the 2014 BiOp, except limit TDG to no more than 110% TDG. Spill during high flow and flood events would not be constrained to a cap of 110% TDG, but rather, set to levels necessary for safety. Lack-of-market spill would be contrained to a cap of 110% TDG. Measure fish passage spill levels on 12-hour rolling average, instead of hourly.
- **Frequency and Duration:** Annually from beginning April 3 at the lower Snake River projects and April 10 at the lower Columbia River projects. Fish passage spill ends midnight July 31.
- **Intended Benefit:** Reduce the carbon footprint of the Northwest by reducing the need for fossil-fuel power generation to meet power demand. Increase the generation of affordable, non-fossil fuel sources through increased hydropower production and increased integration of non-hydropower renewable power sources such as wind and solar.,

O2. Implement modified timing of reservoir draft of Dworshak

- **Specific Measure:** Draft from Dworshak project earlier.
- **Purpose:** Provide earlier and later cold water releases for adult sockeye, Fall Chinook and steelhead and utilize the cool water corridor provided by Dworshak Reservoir.
- **Measure:** Dworshak project.
- **Implementation:** Draft earlier (June 15-July 15) for sockeye and later (September 1-September 30). From July 16 – August 31, release 5 kcfs flow from Dworshak.
- **Frequency and Duration:** June through September.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may improve conditions for adult sockeye, fall chinook, and steelhead migration.

O3. Partially lift flow and pool elevation restrictions as listed below to increase hydropower generations and increase hydropower flexibility to integrate renewable resources. Safety-related restrictions would continue, including meeting flood risk management (FRM) elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability.

O3.a. Ramping rate limitations at all projects will be defined for the purpose of safety or engineering.

- **Specific Measure:** *Incorporated into O2 per BPA comment 30 June 2017.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow will be lifted.
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Beneficial to generation if allowed to ramp down much faster than rates. Some restrictions for bank sloughing need to stay - earthen embankment projects (don't ramp @ rate to slough)

O3.b. Operate the four, lower Snake River projects within full reservoir operating range year-round.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (LSN-MOP)
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot of MOP during the fish passage season.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O3.c. At the John Day project, restrict the pool to within 2.5 feet of Minimum Irrigation Pool (MIP) during the juvenile fish passage season (April 10-August 1).

- **Specific Measure:** Reduce restrictions on seasonal pool elevations (JDA-MIP)

- **Purpose:** A larger operating range at the run-of-river project will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day
- **Implementation:** John Day pool will not be restricted to within 1 ½ feet of MIP.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O3.d. The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak), may be drafted for hydropower and the maximum pool elevation is limited to upper rule curves (for FRM). On April 10, the projects shall be within 10 feet of the flood risk management elevation.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations
- **Purpose:** A larger operating range will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak
- **Implementation:** At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O3.e. At Lake Roosevelt (Grand Coulee pool), lower pool elevation would not be limited for ferry operation.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation.
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

O3.f. At John Day, allow project to operate up to full pool (268 feet) except as needed for FRM.

- **Specific Measure:** Expand range of operating pools, esp at LCOL and LSN (Maybe at JDA? Probably not anywhere else. Do not surcharge due to dam safety
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping of generation.
- **Measure Location:** John Day Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand.

O4. Operate turbines across their full range of capacity by eliminating the restriction to only operate within their range of 1 percent of peak efficiency during the fish migration season (approximately April-October). Elimination of 1 percent peak efficiency restriction would increase ability to meet power demand fluctuations from primarily hydropower generation from Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville projects.

- **Specific Measure:** Eliminate turbine operations (restrictions) to within 1% peak efficiency (not universal +/-1%) (No longer restrict turbine operations to within 1% of peak efficiency.)
- **Purpose:** increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** increase operating range of turbines in hydromodeling
- **Frequency and Duration:** restriction applied during fish passage season.
- **Intended Benefit:** The primary benefit is increase turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water can pass through the turbines, reducing involuntary spill and high TDG.

O5. Use pumping systems to provide deeper (cooler) water in the fish ladder

- **Purpose:** Attract anadromous adult fish to the fish ladders and forebays so they can pass upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders and forebays by installing pumps that move cooler water into the ladders from depth. Replicate the existing Little Goose design for ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit:** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may reduce the temperature differential between the tailrace and ladder entrance (from surface water warming), minimized thermal barrier and adult passage delays.

O6. Optimize adult fish trap operations.

- **Specific Measure:** Reduce fish trap operations for research purposes an increase trap utilization when temperatures reach or exceed °F.
- **Purpose:** Decrease upstream adult fish travel times and reduce exposure to high water temperatures.
- **Measure Location:** Lower Granite, Ice Harbor and Bonneville projects.
- **Implementation:**
    - Ice Harbor: when lower Snake River water temperatures reach or exceed 72°F, trap and haul adult salmonids upstream and release above Lower Granite project.
    - Bonneville and Lower Granite: Reduce trap operations for research purposes to a maximum of 5 days per week.
- **Frequency and Duration:** March - September.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis, however; this measure may increase survival of adult salmonids and increased arrival at spawning grounds.

O7. Hold contingency reserves within fish passage spill at the lower Snake River and lower Columbia River projects (infrequent deployment risk).

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the measure:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit:** This measure increases the available capacity of hydrogenation. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O8. Zero generation operations may occur on lower Snake River projects November - February.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.
- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

O9. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May–June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management.

  Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May-June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real

time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby).
- **Intended Benefit (why include this measure?):** Local FRM operations are improved by having fewer instances of filling before the end of spring runoff ("fill and spill"). This would improve water quality conditions for resident fish. Also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O10. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** End-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir

inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O11. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and to reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby
- **Implementation:** Operational change: modify SRDs for Libby.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Reduced need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March-April timeframe.

O12. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.
- **Purpose:** Allow Libby project to better adapt local operations to dry water year needs when system FRM is less of a concern.
- **Measure Location:** Libby
- **Implementation:** At Libby Dam, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan-Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9 MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Water management operations (e.g., beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved

likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O13. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD and the computation of the Initial Controlled Flow (ICF) outlined in the current Flood Control Operating Plan (FCOP).

- **Specific Measure:** Update Grand Coulee storage reservation diagram (SRD) and upstream adjustment to better reflect benefit of upstream storage. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To ensure flood risk drafts are used as efficiently as possible, and that GCL operations are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Expected revisions to FCOP Chart 1, Chart 2, and Chart 3, and to each parameter applied to the Grand Coulee SRD to determine FRM draft. This could also include revised Grand Coulee FRM space calculation methodology.
- **Frequency and Duration:** December-August
- **Intended Benefit (why include this measure?):** Fully documented process that better reflects changes in upstream storage and hydrology, with built-in mechanism to adapt to possible future changes in how reservoir space upstream of Grand Coulee is managed. Ultimately, this will preserve the ability to operate Grand Coulee for FRM purposes, with the goal of maintaining a similar level of flood risk.

O14. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.

- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Reduce the probability of landslides. This is expected to have an ancillary benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O15. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of possible hydraulic capacity during maintenance activities. This more aggressive maintenance schedule, only limited by plant space restrictions to conduct maintenance on the Third Power Plant and the Left and Right Power plants (units 1-18) assumes three units out in the Third Power plant, three out in the Left Power plant, and three out in the Right Power plant (3/3/3). For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[7]) depending on head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.
- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee; Third Power Plant, Left Power Plant, Right Power Plant
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over

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[7] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.

- **Intended Benefit (why include this measure?):** Improved safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O16. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations. . Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose of the measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs snow.
- **Measure Location:** Grand Coulee, Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at GCL, LIB, HGH, and DWR.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under as wide variety of conditions.

1.12.20 Alternative: Multi-Objective Integration 4 Detailed Description

Summary: The Multi-Objective Integration Alternative 4 is intended to address multiple objectives. This alternative modifies spill, increases operational flexibility, and incorporates measures to improve fish passage at the projects.

Context: Multi-objective integrated alternatives attempt to incorporate measures that would address more than one objective. These alternatives do not necessarily attempt to balance all of the objectives but explore operational changes in order to determine impacts and trade-off of combining objectives under one alternative.

CRSO Objective(s):

This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

The following measures address the objective(s):

Structural Measures:

S1. Construct additional surface passage

- **Specific Measure:** Additional surface passage (powerhouse passage)
- **Purpose:** Provide a surface passage route for outmigrating juvenile salmonids
- **Measure Location:** McNary and John Day
- **Implementation:** Install sluiceway surface passage over the McNary powerhouse. Install additional passage at John Day using one or two of the powerhouse skeleton bays.
- **Frequency and Duration:** NA - structural
- **Intended Benefit:** Juvenile salmonids

S2.Drawdown John Day to minimum operating pool (MOP), and maintain forebay elevation within the range 257 feet to 259 feet.

- **Specific Measure:** NOTE: The John Day drawdown measure was not evaluated on the original long form,
- **Purpose:** Ability to retain capacity to move cool water and reduce the need to spill when unit 3 is out of service or when the reservoir must be drafted for flood risk management
- **Measure Location:** John Day project
- **Implementation:**
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Juvenile Snake River fall Chinook salmon health and survival

S3. Improve juvenile bypass facilities by enlarging orifices/pipes, which would reduce juvenile salmon and steelhead injuries caused by collision with debris.

- **Specific Measure:** Improve JBS facilities by enlarging orifices/pipes for debris management, similar to existing condition at Lower Granite. NOTE: Workshop discussions identified this action as the main action with potential to improve JBS survival.
- **Purpose:** Reduce the collision of debris and juvenile salmonids at John Day. This may also improve the condition of fish exiting the bypass (reduce strike/abrasion, if it is an issue at John Day).
- **Measure Location:** John Day Dam
- **Implementation:** Enlarge JBS orifices/pipes at John Day to a 14-inch diameter
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Juvenile salmonids at John Day

S4.Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam.

- **Specific Measure:** Improve adult ladder passage through modification of adult trap and/or adult trap bypass loop. NOTE: Fish handling for harvest monitoring at Bonneville is RM&E – mitigation.
- **Purpose:** Reduce adult salmonid upstream passage time through ladders
- **Measure Location:** Lower Granite Dam
- **Implementation:**
    - Reduce deployment of diversion gate in the main ladder
    - Reconfigure trap to reduce required head for operations, which would reduce height diverted adults must re-ascend
    - Use new technology to move handled adults over the dam (e.g., vacuum tube) NOTE: This is an emerging issue, and is currently under study
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Adult salmonid health and survival

S5. Add or improve fish passage

- **Specific Measure:** Fish ladders/passage (add or improve)
- **Purpose:** Reduce adult salmonid upstream passage time through ladders, and ensure reliability/redundancy
- **Measure Location:** Lower Granite, Little Goose. NOTE: Original long form includes actions for John Day South, and Bonneville (A Branch, B Branch, and Cascade Island)
- **Implementation:** NOTE: Differences exist between the original long form and the summary paper that need resolution.
    - Add a second ladder for redundancy during winter maintenance at Little Goose and Lower Granite.
    - Add fish ladders at Grand Coulee/Chief Joseph or Dworshak for trap-and-haul operations (Reintroduction Placeholder)
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Adult salmonid health and survival

S6. Construct additional powerhouse sluiceway passage.

- **Purpose:** Provide additional powerhouse passage route for outmigrating juvenile salmonids.

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor and McNary projects.
- **Implementation:** Add deep powerhouse passage (orifices to spillway) at Lower Granite, Little Goose and Lower Monumental projects. Install sluiceway surface passage through Ice Harbor and McNary powerhouses.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S7. Upgrade and increase the number of spillway weirs to provide additional surface passage routes.

- **Purpose:** Provide more surface passage routes for smolt passage and upgrade existing top spillway weirs and removable spillway weirs to adjustable spillway weirs (ASW's) for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day projects.
- **Implementation:** Add additional and improve existing spillway weirs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (LSN projects: June 20; LCOL projects: June 15), 7 kcfs per weir discharge during summer spill operations (LSN projects: June 21-August 31; LCOL projects: June 16-August 31).
    - Lower Granite. Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7kcfs.
    - Little Goose. One additional ASW (2 total) at 7-11 kcfs.
    - Lower Monumental. Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - Ice Harbor. Replace existing spillway weir with an ASW and add an additional ASW (2 ASW's total) at 7 kcfs.
    - McNary. Replace the two existing spillway weirs with ASW's and add an additional ASW (3 ASW's total) at 7-10 kcfs.
    - John Day. Replace the two existing spillway weirs with ASW's and add an additional ASW in a skeleton bay (3 ASW's total). 7-10 kcfs.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and

Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S8. Improve adult ladder passage through modification of adult trap and adult bypass loop at Lower Granite project.

- **Purpose:** Reduce passage time for migrating adults as they move upstream through the fish ladders.
- **Measure Location:** Lower Granite project.
- **Implementation:** Reconfigure to reduce head, thus reducing the height diverted adults must re-ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move adults from the handling facility over the dam.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may improve adult fish survival.

S9. Add and improve adult fish ladders.

- **Specific measure:** Add new or improve existing adult fish ladders.
- **Purpose:** To reduce adult salmonid upstream passage time through improved or additional ladders and ensure reliable upstream fish passage, including monitoring with PIT detection at ladder entrances for real-time adaptive management of passage delays. Ensure reliable year-round upstream passage capability for bull trout at dams on the lower Snake River.
- **Measure Location:** Lower Granite and Little Goose (additional ladders); all eight fish passage projects (PIT detection at ladder entrances.
- **Implementation:** Instrument all fish ladder entrances with PIT tag detection and add new secondary ladders with less slope than current ladders at Lower Granite and Little Goose projects.
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?)** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmonid passage and survival, reduce travel, increase conversion rates, improve real-time adaptive management to reduce passage delays and provide reliable, year round, upstream passage for bull trout and other resident species..

S10. Reconfigure the adult trap at Ice Harbor dam.

- **Specific Measure:** Reconfigure the adult trap at Ice Harbor Dam to enable adult transport upstream past the lower Snake River dams and/or around thermal blockages between Lower Granite Reservoir and the confluence of the mainstem Snake River and the Salmon River.
- **Purpose:** Enable adult transport upstream past the lower Snake dams and/or around thermal blockages in the undammed portions of the middle Snake River and/or Salmon River.
- **Measure Location:** Ice Harbor project
- **Implementation:** Reconfigure the adult trap at Ice Harbor project and include a water chilling system to hold trapped adults to provide infrastructure for adult transport.
- **Frequency and Duration:** June 1 – August 31
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult Snake River sockeye and adult summer Chinook salmon survival.

S11. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor projects.

- **Purpose:** Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce temperature differentials between the tailrace and ladder entrance (from surface water warming) to minimize thermal barriers and adult passage delays.

S12. Modify position of entrance weirs to act as orifices to reduce shad in adult fish ladders.

- **Specific Measure:**
- **Purpose:** This measure would reduce the number of shad in the ladders, which in turn would reduce adult salmonid passage delays.
- **Measure Location:** Ice Harbor and Bonneville projects
- **Implementation:** Telescoping weirs would be positioned higher in the water column allowing flow to pass between bottom of stack and sill.

- **Frequency and Duration:** During high volume shad passage perios (May 1 – August 31
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce passage delays for adult anadromous salmonids.

Operational Measures:

O1. Adjust spill to optimize juvenile and adult in-river survival. The table below includes DRAFT fish passage spill operations for this alternative, which is still in refinement.

- **Specific Measure:** Alter spill (change timing, duration, frequency) – assumes flexibility to adapt over time to when fish are in the river
- **Purpose:** Increase in-river fish survival
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams
- **Implementation:** Measure fish passage spill levels on 12-hour rolling average, instead of hourly.

Location	Spill Regime (Juvenile-centric levels below)	Description of Constraint
Lower Granite	Gas cap* or constraints?	
Little Goose	30%	Adult passage constraint
Lower Monumental	Gas cap* or constraints?	
Ice Harbor	Gas cap* or constraints?	
McNary	Gas cap* or constraints?	
John Day	45% spill	Juvenile constraint
The Dalles	Gas cap* or constraints?	
Bonneville	100 kcfs	

*Gas cap is defined here as the level set by the Oregon TDG waiver, which is not as restrictive as the Washington 115% forebay/120% tailrace TDG waiver levels.

- **Frequency and Duration:** March 1 through August 31 each year
- **Intended Benefit:** Juvenile salmon and steelhead

O2. Use one or more existing surface passage structures (spillway weirs or sluiceways) for overwintering steelhead and kelt downstream passage from September 1 through December 15 and March 1 through 31

- **Specific Measure:** Additional spillway weir operation for kelts and overwintering steelhead. Note: This is option 1 of 2 for more overwintering steelhead/kelt passage. Can implement using spill, or opening fish bypasses/sluiceways. Are kelts categorized as mitigation?

- **Purpose:** Overwintering steelhead and kelts appear to prefer surface passage routes rather than turbine passage. Measure could increase red counts and productivity or wild/endemic/natural listed DPS and ESU fish. It could also increase steelhead kelt outmigration survival and re-spawner/return productivity (fecundity to the populations), especially B-run steelhead re-spawners to the Clearwater River and all higher age-class re-spawners to the Yakima River.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day. (The Dalles and Bonneville already have non-spill operations in place for overwintering steelhead and kelts. Detail/triggers can be provided, as needed.
- **Implementation:** Open fish bypasses and sluiceways for overwintering steelhead and kelts.
- **Frequency and Duration:** September 1 through December 15 for overwintering steelhead, and March 1 to March 31 for kelts
- **Intended Benefit:** Overwintering steelhead and kelts

O3. Use pumping systems to provide cooling water in the fish ladders from April through August.

- **Specific Measure:** Cooling water pumped through fish ladder as an attractant (existing condition at Lower Granite and Little Goose)
- **Purpose:** Attract adults to the adult ladders so they pass upstream. NOTE: Important to design so adults do not remain in ladders with cooler water. The purpose of this measure is passage through the structure.
- **Measure Location:** Lower Monumental, Ice Harbor, McNary, and John Day
- **Implementation:**
  - Lower Monumental – Replicate Little Goose design
  - Ice Harbor – Replicate Little Goose design
  - McNary – Would likely require system with four times the capacity of Lower Snake River projects (200 cfs) for a spray-only configuration
  - John Day - ????
- **Frequency and Duration:** April through August
- **Intended Benefit:** Adult salmonids

O4. In dry years, target maintaining minimum 220 kcfs flow at McNary (2014 NOAA BiOp target flow) in May through the use of US storage and Canadian reservoirs. NOTE: No change to Canadian operations in this measure.

- **Specific Measure:** Maintain minimum 220 kcfs flow at McNary (NOAA BiOp target flow) from April 3 through June 15 through the use of US storage reservoirs, up to a maximum of 2.0 million acre-feet (MAF) flow augmentation from US and Canadian projects. In effect, this is flow augmentation for juvenile anadromous fish in dry years.

  - NOTE 1: This action is beyond the existing condition (1 MAF flow augmentation from Columbia River Treat + 0.5 MAF flow augmentation in Non-consecutive dry years from non-Treaty storage).
  - NOTE 2: The ability to store water in US reservoirs for flow augmentation diminishes in high water years due to drafting of the reservoirs for flood risk management. Providing flow augmentation water from US reservoirs may implicitly mean drafting reservoirs deeper than where flood risk management requirements may otherwise have them. This may introduce the risk of reservoirs being unable to meet refill targets for spring/summer fish operations.

- **Purpose:** Augment flows for quicker water travel time through system in low water years
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak
- **Implementation:** Remove resident fish constraints (minimum project flows for resident species).
- **Frequency and Duration:** April 3 through June 15 each year
- **Intended Benefit:** Juvenile salmonids

O5. Additional flow augmentation (seasonal, summer) from Dworshak for temperature operations in the Lower Snake River.

- **Specific Measure:** Additional flow augmentation (seasonal, summer) as a temperature operation at Dworshak, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Flows above 25 kcfs flood in Ahsahka, Dworshak current capacity with 3 units (2 small, 1 large) is 10.5 kcfs and would be around 15 kcfs with an additional large unit. The volume of cold water available varies by year. Drafting more and earlier during the warmest time of the year to beneficial, but we may risk refill if we draft deeper than 1520 feet. NOTE: Steve Hall should weigh in on this measure.
- **Purpose:** Provide more water from Dworshak to benefit adult sockeye and other adults using the cooler water corridor through the Lower Snake River projects.
- **Measure Location:** Dworshak
- **Implementation:** Draft deeper to provide more and longer cold water releases, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Need to evaluate what volume of cold water would be accessible with deeper draft and how existing condition temperature management operations would change.
- **Frequency and Duration:** During sockeye upstream migration, through July/August

- **Intended Benefit:** Adult salmonids

O6. Hold contingency reserves within fish passage spill at the lower Snake River and lower Columbia River projects (infrequent deployment risk).

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the measure:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit:** This measure increases the available capacity of hydrogenation. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O7. Zero generation operations may occur on lower Snake River projects November - February.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.

- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

O8. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May–June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management.

  Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.

- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May-June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.
- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby).
- **Intended Benefit (why include this measure?):** Local FRM operations are improved by having fewer instances of filling before the end of spring runoff ("fill and spill"). This would improve water quality conditions for resident fish. Also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O9. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than

forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** End-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O10. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and to reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby
- **Implementation:** Operational change: modify SRDs for Libby.
- **Frequency and Duration:** January-February and March-April

- **Intended Benefit (why include this measure?):** Reduced need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March-April timeframe.

O11. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.
- **Purpose:** Allow Libby project to better adapt local operations to dry water year needs when system FRM is less of a concern.
- **Measure Location:** Libby
- **Implementation:** At Libby Dam, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan-Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9 MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.
- **Frequency and Duration:** January-February and March-April
- **Intended Benefit (why include this measure?):** Water management operations (e.g., beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O12. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD and the computation of the Initial Controlled Flow (ICF) outlined in the current Flood Control Operating Plan (FCOP).

- **Specific Measure:** Update Grand Coulee storage reservation diagram (SRD) and upstream adjustment to better reflect benefit of upstream storage. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To ensure flood risk drafts are used as efficiently as possible, and that GCL operations are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam

- **Implementation:** Expected revisions to FCOP Chart 1, Chart 2, and Chart 3, and to each parameter applied to the Grand Coulee SRD to determine FRM draft. This could also include revised Grand Coulee FRM space calculation methodology.
- **Frequency and Duration:** December-August
- **Intended Benefit (why include this measure?):** Fully documented process that better reflects changes in upstream storage and hydrology, with built-in mechanism to adapt to possible future changes in how reservoir space upstream of Grand Coulee is managed. Ultimately, this will preserve the ability to operate Grand Coulee for FRM purposes, with the goal of maintaining a similar level of flood risk.

O13. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Reduce the probability of landslides. This is expected to have an ancillary benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O14. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of possible hydraulic capacity during maintenance activities. This more aggressive maintenance schedule, only limited by plant space restrictions to conduct maintenance on the Third Power Plant and the Left and Right Power plants (units 1-18) assumes three units out in the Third Power plant, three out in the Left Power plant, and three out in the Right Power plant (3/3/3). For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[8]) depending on head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.

- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee; Third Power Plant, Left Power Plant, Right Power Plant
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Improved safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O15. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford

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[8] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

greater flexibility and adaptability in reservoir operations. . Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.

- **Purpose of the measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs snow.
- **Measure Location:** Grand Coulee, Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at GCL, LIB, HGH, and DWR.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under as wide variety of conditions.

1.12.21 Alternative: Multi-Objective Integration 5 Detailed Description

Summary: The Multi-Objective Integration Alternative 5 is intended to address multiple objectives. This alternative modifies spill, increases operational and hydropower flexibility, and incorporates measures to improve fish passage at the projects, including breaching of the four lower Snake River Dams.

Context: Multi-objective integrated alternatives attempt to incorporate measures that would address more than one objective. These alternatives do not necessarily attempt to balance all of the objectives but explore operational changes in order to determine impacts and trade-offs of combining objectives under one alternative.

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated Columbia River Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

The following measures address the objectives:

<u>Structural Measures:</u>

S1. Construct additional surface passage

- **Specific Measure:** Additional surface passage (powerhouse passage)
- **Purpose:** Provide a surface passage route for outmigrating juvenile salmonids
- **Measure Location:** McNary and John Day
- **Implementation:** Install sluiceway surface passage over the McNary powerhouse. Install additional passage at John Day using one or two of the powerhouse skeleton bays
- **Frequency and Duration:** NA - structural
- **Intended Benefit (why include this measure?):** Juvenile salmonids

S2. Construct additional powerhouse sluiceway passage.

- **Purpose:** Provide additional powerhouse passage route for out migrating juvenile salmonids
- **Measure Location:** McNary project
- **Implementation:** Add deep powerhouse passage (orifices to spillway) at the McNary powerhouse
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the McNary project, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S3. Upgrade and increase the number of spillway weirs to provide additional surface passage routes.

- **Purpose:** Provide more surface passage routes for smolt passage and upgrade existing top spillway weirs and removable spillway weirs to adjustable spillway weirs (ASWs) for greater operational flexibility based on flows.
- **Measure Location:** McNary and John Day projects
- **Implementation:** Add additional and improve existing spillway weirs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of spring spill operations (June 15), 7 kcfs per weir discharge during summer sill operations (June 16-August 31).
    - McNary: Replace the two existing spillway weirs with ASWs and add an additional ASW (3 ASWs total) at 7-10 kcfs.
    - John Day: Replace the two existing spillway weirs with ASWs and add an additional ASW in a skeleton bay (3 ASWs total). 7-10 kcfs.

- **Frequency and Duration:** NA
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S4. Modify position of entrance weirs to act as orifices to reduce shad in adult fish ladders.

- **Specific Measure:**
- **Purpose:** This measure would reduce the number of shad in the ladders, which in turn would reduce adult salmonid passage delays
- **Measure Location:** Bonneville project
- **Implementation:** Telescoping weirs would be positioned higher in the water column allowing flow to pass between bottom of stack and sill.
- **Frequency and Duration:** During high volume shad passage periods (May 1 – August 31).
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce passage delays for adult anadromous salmonids.

S5: Drawdown John Day to minimum operating pool (MOP), and maintain forebay elevation within the range 257 feet to 259 feet.

- **Specific Measure:** NOTE: The John Day drawdown measure was not evaluated on the original long form
- **Purpose:** Ability to retain capacity to move cool water and reduce the need to spill when unit 3 is out of service or when the reservoir must be drafted for flood risk management.
- **Measure Location:** John Day project
- **Implementation:**
- **Frequency and Duration:** NA - Structural
- **Intended Benefit:** Juvenile Snake River fall Chinook salmon health and survival

S6. Improve Juvenile bypass facilities by enlarging orifices/pipes, which would reduce juvenile salmon and steelhead injuries caused by collision with debris.

- **Specific Measure:** Improve JBS facilities by enlarging orifices/pipes for debris management, similar to existing condition at Lower Granite. NOTE: Workshop discussions identified this action as the main action with potential to improve JBS survival.

- **Purpose:** Reduce the collision of debris and juvenile salmonids at John Day. This may also improve the condition of fish exiting the bypass (reduce strike/abrasion, if it is an issue at John Day)
- **Measure Location:** John Day Dam
- **Implementation:** Enlarge JBS orifices/pipes at John Day to a 14-inch diameter
- **Frequency and duration:** NA-Structural
- **Intended Benefit:** Juvenile salmonids at John Day

S7. Add or improve fish passage

- **Specific Measure:** Fish ladders/passage (add or improve)
- **Purpose:** Reduce adult salmonid upstream passage time through ladders, and ensure reliability/redundancy
- **Measure Location:** NOTE: Original long form includes actions for John Day South, and Bonneville (A Branch, B Branch, and Cascade Island).
- **Implementation:**
    - Add fish ladders at Grand Coulee/Chief Joseph or Dworshak for trap-and-haul operations (Reintroduction Placeholder)
- **Frequency and** Duration**:** NA
- **Intended Benefit:** Adult salmonid health and survival

S8. Add and improve adult fish ladders

- **Specific Measure:** Add or improve existing adult fish ladders.
- **Purpose:** To reduce adult salmonid upstream passage time through improved or additional ladders and ensure reliable upstream fish passage, including monitoring with PIT detection at ladder entrances for real-time adaptive management of passage delays.
- **Measure Location:** all eight (four) fish passage project (PIT detection at ladder entrances)
- **Implementation:** Instrument all fish ladder entrances with PIT tag detection
- **Frequency and Duration:** NA
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmonid passage and survival, reduce travel, increase conversion rates, improve real-time adaptive management to reduce passage delays and provide reliable, year round, upstream passage for bull trout and other resident species.

S9. Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown.

- **Specific Measure:** Remove earthen embankments and portions of existing structure to evacuate the reservoirs.
- **Purpose:** Return the river to a more natural hydraulic condition for ESA-listed fish passage.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** The earthen embankments, abutments, and structures at each dam would be removed as needed to provide a 140-mile stretch of river without impoundment. To control sediment inputs and maintain safe conditions at downstream dams, breaching would be accomplished in phases, starting with Lower Granite and Little Goose dams, followed by Lower Monumental and Ice Harbor dams. Water control structures such as cofferdams and levees would be installed at breach locations to direct and control flows near the powerhouse, spillways, and navigation locks to facilitate safe drawdown of the reservoirs and provide fish passage. It has been calculated that a drawdown of 2 feet per day, beginning in August and continuing through the end of December, would safely evacuate the reservoirs and minimize damage to adjacent infrastructure.
- **Frequency and Duration:** Dam breaching activities would be conducted only once at each location. Work would be coordinated with the agencies and scheduled to minimize negative effects to Snake River ESA-listed fish.
- **Intended Benefit (why include this measure?):** Removal of earthen embankments would be a means to return this portion of the river to a more natural riverine condition in terms of water depth, local sediment movement, and habitats at river margins. However, because these dams are run-of-river projects, breaching would not appreciably affect the volume and timing of flows. These conditions could contribute to more natural migration, spawning, and rearing conditions for ESA-listed fish.

S10. Modify existing equipment and dam infrastructure to adjust to drawdown conditions. Existing equipment would not be used for hydropower generation, but would instead be used as low--level outlets for drawdown below spillway elevations. Depending on the outcome of additional analysis, turbines would be modified or operated at Speed No Load to support controlled drawdown.

- **Specific Measure:** Modify existing equipment to support controlled reservoir drawdown.
- **Purpose:** To use all available outlets at the dam to provide controlled drawdown conditions.

- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** Existing equipment and infrastructure at the dams would be modified so that both spillways and powerhouse outlets may be used to evacuate the reservoir at various elevations.
- **Frequency and Duration:** Modifications and a required decommissioning would take place prior to initiation of drawdown at each location.
- **Intended Benefit (why include this measure?):** Modifications would be undertaken to allow use of existing facilities and outlets for a controlled reservoir evacuation. This would facilitate outflows with minimal creation of total dissolved gas.

Operational Measures:

O1. Decrease fish passage spill by setting spill as described in the 2014 Biological Opinion (BiOp), but limiting total dissolved gas (TDG_ to the 110 percent TDG cap (water quality standard without waivers), as measured in the tailrace at McNary, John Day, The Dalles, and Bonneville projects. Spill associated with high flow and flood events and lack-of-market spill would continue as needed.

- **Specific Measure:** Decrease fish passage sill at all Lower Columbia River dams.
- **Purpose:** Increase hydropower production
- **Measure Location:** McNary, John Day, The Dalles, Bonneville projects
- **Implementation:** Set spill as described in the 2014 BiOp, except limit TDG to no more than 110% TDG. Spill during high flow and flood events would not be constrained to a cap of 110% TDG, but rather set to levels necessary for safety. Lack-of-market spill would be constrained to a cap of 110% TDG. Measure fish passage spill levels on a 12 hour rolling average, instead of hourly.
- **Frequency and Duration:** Annually from beginning April 10 at the lower Columbia River projects. Fish passage spill would end at midnight July 31.
- **Intended Benefit:** Reduce the carbon footprint of the Northwest by reducing the need for fossil-fuel sources through increased hydropower prosecution and increased integration of non-hydropower renewable power sources such as wind and solar.

O2. Zero generation operations may occur on lower Snake River projects November - February.

- **Specific Measure:** Allow the projects to shut off generation at night at the four Lower Snake Projects unless limited by grid stability requirements.
- **Purpose:** Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, and Ice Harbor projects.
- **Implementation:** Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impact models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam.)
- **Frequency and Duration:** Currently, the projects are allowed to go to zero generation mid-Dec through February. This measure extends that period to begin in early November.

- **Intended Benefit:** Increases flexibility to shape generation to meet the shape of load (i.e., demand for power) by reducing water flow at night leaving more water for the daytime.

O3. Additional flow augmentation (seasonal, summer) from Dworshak for temperature operations in the Lower Snake River.

- **Specific Measure:** Additional flow augmentation (seasonal, summer) as a temperature operation at Dworshak, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Flows above 25 kcfs flood in Ahsahka, Dworshak current capacity with 3 units (2 small, 1 large) is 10.5 kcfs and would be around 15 kcfs with an additional large unit. The volume of cold water available varies by year. Drafting more and earlier during the warmest time of the year to beneficial, but we may risk refill if we draft deeper than 1520 feet. NOTE: Steve Hall should weigh in on this measure.
- **Purpose:** Provide more water from Dworshak to benefit adult sockeye and other adults using the cooler water corridor through the Lower Snake River projects.
- **Measure Location:** Dworshak
- **Implementation:** Draft deeper to provide more and longer cold water releases, especially when forecasted temperatures and river levels indicate a potential for warm water conditions. Need to evaluate what volume of cold water would be accessible with deeper draft an how existing condition temperature management operations would change.
- **Frequency and Duration:** During sockeye upstream migration, through July/August
- **Intended Benefit:** Adult salmonids

O4. Implement modified timing of reservoir draft of Dworshak

- **Specific Measure:** Draft water from Dworshak project earlier in the season
- **Purpose:** Provide earlier and later cold water releases for adult sockeye, Fall Chinook, and steelhead and utilize the cool water corridor provided by Dworshak Reservoir.
- **Measure Location:** Dworshak project
- **Implementation:** Draft earlier (June 15 – July 15) for sockeye and later (September 1 – September 30). From July 16 – August 31, release 5 kcfs flow from Dworshak.
- **Frequency and Duration:** Annually June through September
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may improve conditions for adult sockeye, fall chinook, and steelhead migration.

O5. Partially lift flow and pool elevation restrictions as listed below to increase hydropower generation and increase hydropower flexibility to integrate renewable resources. Safety-related restrictions would continue, including meeting flood risk management (FRM) elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability.

O5.a. Ramping rate limitation at all projects will be defined for the purpose of safety or engineering.

- **Specific Measure:** *Incorporated into O2 per BPA comment 30 June 2017
- **Purpose:** To increase flexibility of flows to allow water to be shaped for hydropower production
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, McNary, John Day, The Dalles, Bonneville projects
- **Implementation:** where restrictions are not for safety (e.g. flood risk management or erosion, or grid reliability), restrictions on flow would be lifted
- **Frequency and Duration:** current restrictions vary seasonally in some places.
- **Intended Benefit:** Beneficial to generation if allowed to ramp down much faster than rates. Some restrictions for bank sloughing need to be maintained due to earthen embankments (don’t ramp at rate to slough).

O5.b. At the John Day project, restrict the pool to within 2.5 feet of Minimum Irrigation Pool (MIP) during the juvenile fish passage season (April 10 – August 1).

- **Specific Measure:** Reduce restrictions on seasonal pool elevation (JDA-MIP)
- **Purpose:** A larger operating range at the run-of-river project will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day project
- **Implementation:** John Day pool would not be restricted to within 1.5 feet of MIP
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O5.c. The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak) may be drafted for hydropower and the maximum pool elevation is limited to upper rule curves (for FRM). On April 10, the projects shall be within 10 feet of the flood risk management elevation.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations

- **Purpose:** A larger operating range will allow more operating flexibility for hourly and daily shaping of hydropower generation
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak
- **Implementation:** At the storage projects, variable draft limits (VDLs) will not be enforced, allowing for deeper draft when optimal for power.
- **Frequency and Duration:** Restrictions that can be lifted will be lifted for the whole year.
- **Intended Benefit:** Larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O5.d. At Lake Roosevelt (Grand Coulee pool), lower pool elevation would not be limited for ferry operation.

- **Specific Measure:** Expand range of operating pools, especially at LCOL and LSN (Maybe at JDA? Probably not anywhere else). Do not surcharge due to dam safety.
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation.
- **Frequency and Duration:** Year round
- **Intended Benefit:** More flexibility to shape hydropower to meet demand.

O5.e. At John Day, allow project to operate up to full pool (268 feet) except as needed for FRM.

- **Specific Measure:** Expand range of operating pools, especially at LCOL and LSN (Maybe at JDA? Probably not anywhere else). Do not surcharge due to dam safety.
- **Purpose:** deeper draft at Grand Coulee permits more shaping to seasonal demand for power. Larger operating pool at John Day would allow for more daily and hourly shaping for generation.
- **Measure Location:** John Day Dam
- **Implementation:** At Lake Roosevelt (Grand Coulee pool) do not limit lower pool elevation due to the ferry operation. At John Day, allow project to operate to full pool (268 ft) except as needed for FRM. Anywhere else?
- **Frequency and Duration:** year round
- **Intended Benefit:** more flexibility to shape hydropower to meet demand

O9. Operate turbines across their full range of capacity by eliminating the restriction to only operate within their range of 1 percent of peak efficiency during the fish migration season (approximately April – October). Elimination of 1 percent peak efficiency restriction would increase ability to meet power demand fluctuations form primarily hydropower generation from McNary, John Day, The Dalles, and Bonneville projects.

- **Specific Measure:** Eliminate turbine operations (restrictions) to within 1% peak efficiency (no universal +/- 1%) (No longer restrict turbine operations to within 1% of peak efficiency.)
- **Purpose:** Increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. IN those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** McNary, John Day, The Dalles, Bonneville
- **Implementation:** increase operating range of turbines in hydromodeling
- **Frequency and Duration:** restriction applied during fish passage season.
- **Intended Benefit:** The primary benefit is increase turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water can pass through the turbines, reducing involuntary spill and high TDG.

O10. Optimize adult fish trap operations.

- **Specific Measure:** Reduce fish trap operations for research purposes an increase trap utilization when temperatures reach or exceed °F.
- **Purpose:** Decrease upstream adult fish travel times and reduce exposure to high water temperatures.
- **Measure Location:** Bonneville project
- **Implementation:** Reduce trap operations for research purposes to a maximum of 5 days a week.
- **Frequency and Duration:** March – September
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure may increase survival of adult salmonids and increased arrival at spawning grounds.

O11. Hold contingency reserves within fish passage spill at the lower Columbia River projects (infrequent deployment risk).

- **Specific Measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the Measure:** Enables turbines to operate at a higher capacity

- **Measure Location:** Lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season
- **Intended Benefit:** This measure increases the available capacity of hydrogenation. Because contingency reserves are rarely deployed, it would increase hydropower generation to to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O12. Shift the Libby Storage Reservation Diagram (SRD) to evacuate FRM space to appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). Then during refill period (generally Apr/May – June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.

- **Specific Measure:** Update VarQ procedure at Libby to improve local water management. Implementation details of this will be coordinated with BPA as the "model-ready" description of this measure is developed.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** Operational: modify SRD and VarQ refill flow calculation. Specifically use SRD that incorporate local basin FRM space needs during reservoir drawdown months (generally Jan – Apr). Then during refill period (generally Apr/May – June), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; and (3) changes duration over which VarQ flows are determined so that local flood duration along with the start of refill is tied to the Kootenai River Basin.
- **Frequency and Duration:** All years, from Jan – June (greatest change would be seen in water years where the water supply forecast was less than 6.9 million acre feet (MAF) for Libby.
- **Intended Benefit (why include this measure?):** Local FRM operations are improved by having fewer instances of filling before the end of spring runoff ("fill and spill"). This would improve water quality conditions for resident fish. Also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation. The local operations would allow for greater flexibility in FRM operations for Bonners Ferry, ID, refill operations, minimizing fill and spill scenarios, and in how best to use water in the spring and summer.

O13. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft. elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January – February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 and 2426.7 ft.
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower).
- **Intended Benefit (why include this measure?):** End-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O14. Implement modified SRD at Libby to target a lower reservoir elevation in January and February than their current end-of-month elevation targets, while maintaining current end-of-month target elevations for March and April.

- **Specific Measure:** Implement modified SRDs at primary storage reservoirs to draft deeper earlier in the season. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further refined.
- **Purpose:** To reduce likelihood of heavy spring spill in March and April due to need to evacuate FRM and reduce likelihood of trapped storage, which is water that remains when the reservoir cannot be fully drafted down to its flood control elevation.
- **Measure Location:** Libby
- **Implementation: Operational change:** modify SRDs for Libby
- **Frequency and Duration:** January – February and March – April
- **Intended Benefit (why include this measure?):** Reduced need for trade-off between meeting FRM draft limits and maintaining spill within desired ranges during the March – April timeframe.

O15. When the water supply forecast is approximately 6.9 MAF or less, allow transition of refill timing and approach at Libby project to be based on hydrologic conditions in the local

tributary basins rather than tied to the Columbia River System's Initial Controlled Flow (ICF) date and control flow approach.

- **Specific Measure:** In years where the water supply forecast is approximately 6.9 MAF or less (dry years), operate for local basin needs (FRM, fish, etc.) rather than system FRM requirements.
- **Purpose:** Allow Libby project to better adapt to local operations to dry water year needs when system FRM is less of a concern.
- **Measure Location:** Libby
- **Implementation:** At Libby Dam, the triggers for local versus system will be which SRD (local or system) has the lower required FRM drawdown elevation from Jan- Apr. Timing of refill will be May 1st in years where the water supply forecast is approximately 6.9 MAF or less and the flood duration used for the VarQ calculation will be the longer of the system or the local duration.
- **Frequency and Duration:** January- February and March – April
- **Intended Benefit (why include this measure?):** Water management operations (e.g. beginning to refill) at Libby project that are in sync with local basin hydrologic conditions. Smoother operations, better temperature management, and improved likelihood of reservoir refill. At Libby, would provide better flexibility for resident and mainstem fish requirements.

O16. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD and the computation of the Initial Controlled Flow (ICF) outlined in the current Flood Control Operating Plan (FCOP).

- **Specific Measure:** Update Grand Coulee storage reservation diagram (SRD) and upstream adjustment to better reflect benefit of upstream storage. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose:** To ensure flood risk drafts are used as efficiently as possible, and that GCL operations are adaptable to a wild range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Expected revision to FCOP Chart 1, Chart 2, and Chart 3, and to each parameter applied to the Grand Coulee SRD to determine FRM draft. This could also include revised Grand Coulee FRM space calculation methodology.
- **Frequency and Duration:** December – August
- **Intended Benefit (why include this measure?):** Fully documented process that better reflects changes in upstream storage and hydrology, with built-in mechanism to adapt to possible future changes in how reservoir space upsteam of Grand Coulee is managed.

Ultimately, this will preserve the ability to operate Grand Coulee for FRM purposes, with the goal of maintain a similar level of flood risk.

O17. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Reduce the probability of landslides. This is expected to have an ancillary benefit of reducing involuntary spill during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O18. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through eacy power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more aggressive than current outages, to represent a fuller range of schedule, only limited by plant space restrictions to conduct maintenance on the Third Power Plant and the Left and Right Power plants (units 1-18) assumes three units out in the Third Power Plant, three out in the Left Power plant, and three out in the Right Power plant (3/3/3). For spill capacity, we have 27 (of 40) regulating gates and/or 8 drumgates available (to represent drumgate recoating[9]) depending on the head. By increasing the number of allowed unit outages to the maximum extent possible due to plant space restrictions, the potential exists to decrease the planned modernization schedule by 4-yrs.

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[9] Drumgate recoating assumes that adjacent gates would be unavailable for operations, the simplifying assumption of 8 gates available does not consider that when maintenance is occurring on Gates 1 and 11 there would actually be 9 available for operations.

- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20 – yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks or equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee; Third Power Plant, Left Power Plant, Right Power Plant
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10 – yrs (FY 19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Improved safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O19. Develop draft requirements or an assessment approach to protect against rain-induced flooding separately from snow melt induced flooding year-round.

- **Specific Measure:** Heavy rain results in high runoff that cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Water management operating rules that more explicitly account for the rain component would afford greater flexibility and adaptability in reservoir operations. Implementation details of this will be coordinated with BPA and Reclamation as this measure is further defined.
- **Purpose of the Measure:** Clarify and define the need for adaptability to changes in hydrology in the basin – i.e., a greater proportion of runoff originating from rain vs. snow.
- **Measure Location:** Grand Coulee, Libby, Hungry Horse, and Dworshak
- **Implementation:** Potential operational change: Develop separate rain and snow draft and refill operations at GCL, LIB, HGH, and DWR.
- **Frequency and Duration:** year-round
- **Intended Benefit (why include this measure?):** Preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under as wide variety of conditions.

O20. Develop procedures to operate existing equipment during reservoir drawdown.

- **Specific Measure: Develop a plan for operation of equipment during reservoir drawdown**
- **Purpose:** To provide information to dam and transmission operators and inspectors regarding how existing equipment would be modified and operated to draw down the four reservoirs on the lower Snake River.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** Equipment to be used in drawdown would be tested and calibrated to establish operational limits. Engineers and powerhouse and transmission operators would establish manual operations and procedures using modified equipment to facilitate controlled and safe reservoir evacuation.
- **Frequency and Duration:** The plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** This measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment.

O21. Develop contingency plans to address unexpected issues with drawdown operations.

- **Specific Measure:** Develop plans for operation or emergency shut down during reservoir drawdown
- **Purpose**: To provide information and training to dam and transmission operators and inspectors regarding how modified equipment would be operated or shut down in the event of an emergency or unanticipated circumstances during reservoir evacuation.
- **Measure Location:** Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, and Lower Granite Dam.
- **Implementation:** Engineers and operators would work together to develop plans for operating existing equipment under drawdown conditions. They would identify risks and required emergency responses should equipment not function as anticipated or expected conditions change.
- **Frequency and Duration:** The contingency plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** This measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment.

1.12.22 Alternative: Multi-Objective 1 Detailed Description

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

Additionally, the following secondary objective was considered during development of this alternative:

- Improve conditions for the lamprey within the CRSO project area through actions potentially including, but not limited to project configurations, flow management, spill operations, and water quality management.

The following measures address the objective(s):

<u>Structural Measures:</u>

S1. Construct additional powerhouse surface passage routes

- **Purpose:** May divert fish away from turbines and into a higher survival route, reduce exposure to screens, and reduce forebay delay.
- **Measure Location:** Ice Harbor and McNary dams
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from March 1 to August 31.
    - Ice Harbor: Install surface passage through the Ice Harbor powerhouse
    - McNary: Install surface passage through the McNary powerhouse
- **Frequency and Duration:** March 1 – August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and lower Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S2. Upgrade spillway weirs to Adjustable Spillway Weirs (ASWs)

- **Purpose:** Upgrade existing spillway weirs that are not adjustable spillway weirs (ASW's) to ASW's for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Lower Monumental, Ice Harbor, McNary, John Day dams
- **Implementation:** Upgrade spillway weirs to ASW's. For modeling, use 11 kcfs per weir discharge for March 1 through the end of spring spill operations (lower Snake River projects: June 20; lower Columbia River projects: June 15), 7 kcfs per weir discharge during summer spill operations (lower Snake River projects: June 21-August 31; lower Columbia River projects: June 16-August 31).
    - **Lower Granite.** Replace existing spillway weir with an ASW.
    - **Lower Monumental.** Replace existing spillway weir with an ASW.
    - **Ice Harbor.** Replace existing spillway weir with an ASW.
    - **McNary.** Replace the two existing spillway weirs with ASW's.
    - **John Day.** Replace the two existing spillway weirs with ASW's.
- **Frequency and Duration:** March 1-August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S3. Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam

- **Purpose:** Reduce passage time for adult salmonid as they move upstream through the fish ladder and allow volitional downstream passage through the ladder.
- **Measure Location:** Lower Granite Dam
- **Implementation:** Reconfigure adult trap bypass to reduce head, thus reducing the height diverted adults must ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move handled adults.
- **Frequency and Duration:** Year round while Lower Granite ladder is in operation
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates.

S4. Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway

- **Purpose:** Reduce passage time for adult salmonids as they move upstream through the fish ladder.
- **Measure Location:** Bonneville Dam
- **Implementation:** Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway. At Bonneville Dam's Bradford Island and Washington Shore ladder flow control sections (the portion of the ladder from the count stations to the ladder exit), remove the baffles from this section of the ladders and replace them with baffles that have in-line vertical slots and orifices. It would also likely involve modifying the auxiliary water supply controls and replacing the ladders' PIT detection systems.
- **Frequency and Duration:** Year round while Bonneville Dam ladders are in operation
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates. A similar modification at John Day Dam, the only other CRS dam to use this type of ladder, resulted in significant passage time reductions for salmon and steelhead.

S5. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor dams

- **Purpose**: Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor dams

- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by reducing the temperature differential between tailrace and ladder entrances (from surface water warming), which may minimize thermal barriers and adult passage delays.

S6. Expand network of Lamprey Passage Structures (LPS) to bypass impediments in existing fish ladders.

- **Specific Measure:** Install new Lamprey Passage Structures (LPS) and add additional LPS at existing locations.
- **Purpose:** The purpose is to help Lamprey pass the project using a different route than the fish ladders.
- **Measure Location:** Additional structures at Bonneville, The Dalles, and John Day projects.
- **Implementation:** Construct new Lamprey Passage Structures as follows:
  - **Bonneville**: Construct additional LPS on the south ladder and at the south entrance to the north ladder.
  - **The Dalles**: Add diffuser grating plating on the diffuser in the north ladder.
  - **John Day**: Add LPS to the south ladder and extend North LPS to the forebay.
- **Frequency and Duration:** Construct once.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult lamprey passage success.

S7. Modify turbine cooling water strainer systems to safely exclude Pacific lamprey and other juvenile fish

- **Specific Measure:** Install prototype hoods over cooling water intakes
- **Purpose:** Exclude lamprey from turbine cooling water systems.
- **Measure Location:** All Lower Columbia and Lower Snake river projects.
- **Implementation:** Install prototype hoods (or refined design) over cooling water intake orifices in the scroll case to prevent lamprey entry.
- **Frequency and Duration:** One time modification.

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to eliminate lamprey mortality caused by impingement in the turbine cooling water strainers.

S8. Modify turbine intake bypass screens that cause juvenile lamprey impingement and entanglement

- **Specific Measure:** Modify or replace fish screens to prevent lamprey impingement
- **Purpose:** Reduce lamprey mortality from impingement in fish screens.
- **Measure Location:** McNary project, Little Goose project, and Lower Granite project (Projects with Extended length submerged bar screens (ESBS)).
- **Implementation:** Modify or replace fish screens at the dams with screens that have tighter spacing to prevent lamprey from being caught in the screens.
- **Frequency and Duration:** Construct once, install annually.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce lamprey mortality from impingement in fish screens.

S9. Modify existing fish ladders, incorporating lamprey passage features and criteria into ladder modifications

- **Specific Measure:** Identify, design, and install modifications to improve adult lamprey passage through existing fish ladders.
- **Purpose:** Aid lamprey in finding, entering, and passing through the adult fish ladders.
- **Measure Location:** Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite
- **Implementation:** Design and install modifications to improve passage through existing fish ladders.
    - **Bonneville**: Install ramps to elevated salmon orifices in south ladder; diffuser grating plating on diffuser in south and Cascade island ladders; refuge boxes in north and south ladders; and wetted wall in north ladder serpentine section.
    - **The Dalles:** Install diffuser grating plating on diffuser in north ladder.
    - **McNary**: Install entrance weir caps at north and south ladders.
    - **Ice Harbor:** Install entrance passage structure at south ladder, and entrance weir caps at north and south ladders.
    - **Lower Monumental:** Install diffuser grating plating in the north and south ladders, and entrance weir caps at the north and south ladders.
    - **Little Goose:** Install entrance weir caps at the south ladder.

  - **Lower Granite project:** Install entrance weir caps at the south ladder.
- **Frequency and Duration:** Construct once.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult lamprey passage through fish ladders.

S10. Install new “fish-friendly” and high-efficiency/capacity turbines at John Day.

- **Purpose:** Improve turbine fish passage conditions and hydropower turbine efficiency and capacity
- **Measure Location:** John Day
- **Implementation:** Replace turbines with new improved units two at a time.
- **Frequency and Duration:** Installation of two units at a time.
- **Intended Benefit (why include this measure?):** Improved turbine fish passage conditions, improved hydropower turbine efficiency and capacity, and improved water quality (TDG).

Operational Measures

O1. Conduct spill test to evaluate latent mortality hypothesis.

- **Specific Measure:** Compare two spring juvenile fish passage spill operations using a 50/50 block design, which alternates spill within a year between a base spill operation and a test spill operation. The base spill operation represents spill at each project informed by the results of performance standard testing that conducted from 2008-2018. The test spill operation is spill to the Total Dissolved Gas (TDG) cap (120 % TDG tailrace/ 115% TDG forebay). The order of each block will alternate between years with the base block occurring first in one year and the test block occurring first in the following year.
- **Purpose:** Evaluate latent mortality hypothesis. This measure also has the potential benefit of spreading the biological risk between the two operational blocks to address the uncertainty associated with increased spill.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:**

Location	Spring Base Spill Operation: (Volume/Percent of Total Flow	Spring Test Spill Operation: (Volume/Percent of Total Flow Routed to Spillway)

	Routed to Spillway)	
Lower Granite	20 kcfs	120/115% Gas Cap*
Little Goose	30%	120/115% Gas Cap*
Lower Monumental	120/115% Gas Cap*	120/115% Gas Cap*
Ice Harbor	30%	120/115% Gas Cap*
McNary	48%	120/115% Gas Cap*
John Day	32%	120/115% Gas Cap*
The Dalles	40%	120/115% Gas Cap*
Bonneville	100 kcfs	120/115% Gas Cap*

*120/115% Gas Cap spill is spill to the maximum level that meets, but does not exceed, the TDG criteria allowed under state law. Manage juvenile fish spill on an hourly basis to meet but not exceed the state water quality standards for WA which specifies TDG measured as an average of the twelve highest consecutive hourly readings in any one day; and OR which specified average TDG concentration of the 12 highest hourly measurements per calendar day.

- **Frequency and Duration:** Annually implemented from April 3 – June 20 for the lower Snake River projects and from April 10 – June 15 for the lower Columbia River projects. The test and base block spill operations would exchange specific dates biannually while holding overall spill dates constant.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to provide information on the relationship between further increases in spill and in-river travel times, the condition and survival of smolts entering the estuary, and adult returns.

O2. Modify summer juvenile fish passage spill operations.

- **Specific Measure:** End spill at each of the Snake River dams (Lower Granite, Little Goose, Lower Monumental, Ice Harbor) when fish collection numbers at that dam remain below 300 juvenile fish for four consecutive days. This may result in ending spill at one or more of the Snake River dams as early as Aug 1 (but spill will not proceed beyond 31 August). Summer spill levels are as listed in the table below.
- **Purpose:** Provide fish passage spill when meaningful numbers of fish are migrating past the dams.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:**

Location	Summer Spill Operation (Volume/Percent of Total Flow Routed to Spillway)
Lower Granite	18 kcfs
Little Goose	30%
Lower Monumental	17 kcfs
Ice Harbor	30%
McNary	57%
John Day	35%
The Dalles	40%
Bonneville	95 kcfs

- **Frequency and Duration:** Annually implemented from June 21 – variable, fish-count-triggered August date for the lower Snake River projects and from June 16 – August 31 for the lower Columbia River projects.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to provide fish passage benefits when fish are present and cease spill (to help preserve energy benefits) when fish numbers are extremely low in exchange for transporting fish during a time when data indicate transported fish have higher SARs than those left in-river.

O3. Change start of juvenile fish transportation during spring juvenile fish passage spill operations at the lower Snake River projects.

- **Specific Measure:** Begin juvenile fish transportation on April 15th.
- **Purpose:** To increase the number of juvenile fish transported.
- **Measure Location:** Lower Granite, Little Goose, and Lower Monumental projects.
- **Implementation:** Start collecting juvenile fish at the fish bypass collectors in the three lower Snake River projects. Collected juvenile fish will be transported on a daily or every-other-day basis, dependent upon numbers of fish, to the release site below Bonneville project.

- **Frequency and Duration:** Begin transport on April 15. End transport operation on September 30 at Lower Monumental project and on October 31 at Lower Granite and Little Goose projects.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure would increase the number of juvenile fish transported and potentially increase adult returns.

O4. Increase forebay operating range flexibility at the lower Snake River and John Day projects.

- **Specific Measure:** Change the operating elevation range restriction at the lower Snake River projects to Minimum Operating Pool (MOP)-plus 1.5 feet and at the John Day project to Minimum Irrigation Pool (MIP)-plus 2 feet.
- **Purpose:** Allow more flexibility for water management and hourly shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor and John Day projects.
- **Implementation:** The reservoir pools will gain operating flexibility from April 3 – August 31 to coincide with the juvenile fish passage season. The operating elevation range restriction at the lower Snake River projects would become MOP-plus 1.5 feet and at the John Day project MIP-plus 2 feet, except during the period April 1 – May 31 when the John Day forebay operating range will remain between 263.5 and 265 feet (per operational measure 17). Safety-related restrictions would continue, including but not limited to maintaining ramp rates for minimizing project erosion and maintaining power grid reliability.
- **Frequency and Duration:** April 3 – August 31 annually
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase flexibility for water management, shaping hydropower production to meet energy demand, maintaining power grid reliability and managing avian predation.

O5. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects

- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure increases the available capacity of hydrogeneration. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O6. When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

- **Specific Measure:** Update the existing Libby local Storage Reservation Diagram (SRD) to evacuate FRM space to an appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). During refill (generally Apr/May–July), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; and (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill will start on May 1st. When forecasts are above 6.9 MAF the proposed local SRD will require a deeper draft in January and February. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin**;** (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

- **Frequency and Duration:** All years, from Jan-June (greatest change would be seen in water years where the water supply forecast was less than 6.9 MAF for Libby).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operations by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. Additionally, placing more of the draft in January and February will reduce the trade-off between meeting FRM needs and maintaining spill within desired ranges. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery, while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements, and improve FRM operations for spring rain events in the Kootenay Basin.

O7. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O8. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD.

- **Specific Measure:** The methodology differs conceptually from the current methodology. Rather than adjusting The Dalles (TDA) forecast to determine GCL FRM requirements as with the current methodology, the methodology utilizes the TDA forecast directly to determine the end of April draft requirement for GCL (figure 1) and requires a correction, in the form of a deeper draft target at GCL, when upstream storage reservoirs that fail to achieve their required drafts for whatever reason. It should be noted that the methodology only affects the FRM draft requirements of GCL and does not change the operation or draft requirements of any other project. The Grand Coulee FRM draft is based on four things: 1) The TDA forecast, 2) upstream storage reservoirs' required FRM draft or draft that is manageable and dependable for system flood risk management (called a Base Draft) 3) the in-season draft (actual) of upstream reservoirs in relation to the Base Draft and 4) the relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (Weighting Curves for certain projects). This is similar to the information used under the current methodology but the process of using it is different. The basic concept of the Grand Coulee upstream storage adjustment methodology is depicted in Figure 1-2 as a two-step process. First, a Grand Coulee unadjusted April 30 FRM requirement is determined using the curve in Figure 1 and TDA forecast. The relationship assumes that each upstream storage project is drafted or projected to be drafted to its Base Draft by April 30. Second, an adjustment is made to the Grand Coulee April 30 required draft only if storage projects upstream of The Dalles have not been drafted to their Base Draft. If upstream projects are drafted deeper than their base draft no adjustments are made to the GCL draft or if all projects are on their base draft no adjustments will be made. Because upstream projects contribute in differing proportions to overall system FRM, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment. The adjustment is then added to the unadjusted GCL required draft based on the April 30 curve to yield the adjusted required April 30th GCL draft target. In addition to the methodology changes proposed in this measure, this measure also removes the "flat spot" from the GCL SRD and replaces it with a consistently increasing flood risk draft for all forecast ranges. The "flat spot" is a portion of the current GCL SRD that targets a maximum draft point to 1220 ft (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 MAF.

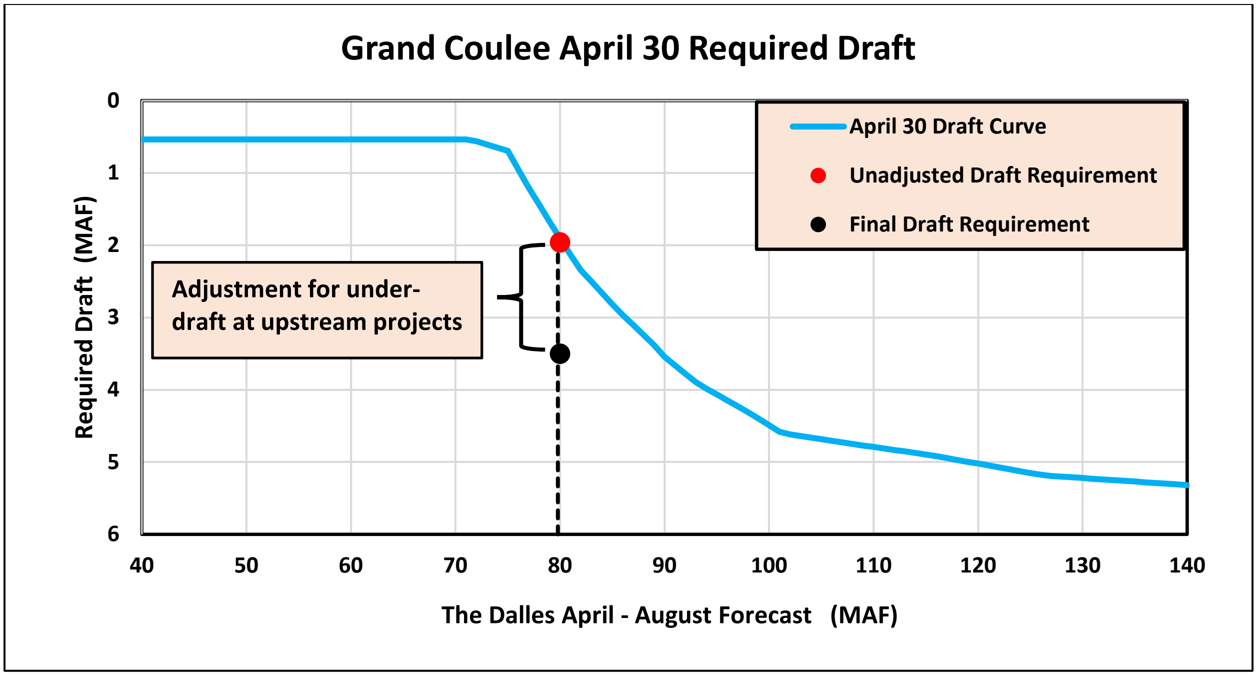

Figure 1-2. Grand Coulee Unadjusted April 30 FRM Requirement

There are a number of specific differences between the No Action operation and this proposed measure.

1. The fixed FRM draft requirements for John Day, SKQ, Noxon, and Albeni Falls are embedded in the new end-of-April draft requirement for GCL and are therefore not necessary in the adjustment process.
2. The 3.6 Maf cap on the Arrow FRM space was removed in the method.
3. Creditable refill checks on project space are not required because those checks are built into the Base Drafts, and the Weighting Factors.
4. The method does not allow adjustments for over-draft conditions.
5. The GCL SRD is modified to remove the non-increasing draft elevation for adjusted forecasts between 80 and 95 MAF, referred to as the “flat spot”.

- **Purpose:** To update GCL operations and ensure they are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** There are four main components that will be used to determine GCL end of month FRM requirements during the drawdown period (Jan-Apr) under the methodology; the GCL Unadjusted April 30 Draft Requirement Curve (GCL Curve), individual project Base Drafts, individual project Weighting Curves, and the GCL SRD. These will be developed, documented and incorporated into the model.
- **Frequency and Duration:** All years, January-April

- **Intended Benefit (why include this measure?):** The measure will provide a fully documented process that allows GCL to better respond to changes in upstream operations. The process will allow adaptation to possible future changes in management of reservoir space upstream of The Dalles Dam. It is the intent that this methodology will maintain a similar level of flood risk compared to the current practice and not significantly alter the magnitude and frequency of GCL water surface elevations given similar operations of upstream reservoirs.

O9. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce the probability of landslides. This is expected to have an ancillary benefit of reducing spill due to lack-of-market or lack-of-turbine-capacity during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O10. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more accelerated than current outages, to represent a broader range of possible hydraulic capacity during maintenance activities.
- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and

Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.

- **Measure Location:** Grand Coulee Dam
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O11. Develop draft requirements to protect against rain-induced flooding.

- **Specific measure:** Increase drafted space available at Grand Coulee for implementing winter operations. Grand Coulee, Albeni Falls and Dworshak Dams will operate to protect against rain-induced flooding at Vancouver and Portland.
- **Purpose of the measure:** Runoff from winter precipitation events associated with atmospheric rivers, that deliver significant amounts of rain over short durations, cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Not only are these events difficult to forecast with long lead times (>5 days), they also can lead to the highest amount of flood damage in the Portland/Vancouver area. Furthermore, there is strong evidence that winter flows and atmospheric river events will increase with climate change. Water management operating rules that more explicitly account for these rain-driven runoff events would offer greater flexibility and adaptability in reservoir operations. Albeni Falls and Dworshak have drafted space already in place for rain-induced flooding and will be adjusted to fill space under the same conditions as Grand Coulee.
- **Measure Location:** Grand Coulee, Albeni Falls, and Dworshak.
- **Implementation:** Grand Coulee will be drafted to provide up to 650 kaf of space for FRM from mid-December through March. All other existing winter operations will remain the same. The winter operations will first rely on the four lower Columbia projects when the stage at Vancouver is forecast to exceed a stage of 16 feet. If the forecast continues to

project a stage exceeding 16 feet with the operation of the four lower Columbia projects then the winter operations will include Albeni Falls, Dworshak and Grand Coulee.

- **Frequency and Duration:** All years Mid-December - March.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

O12. Increase volume of water pumped from Lake Roosevelt via the John W. Keys III Pumping Plant at the Grand Coulee project for increased deliveries to the Columbia Basin Project mostly during the annual irrigation season. The new volume of irrigation water would be calculated by multiplying the 256,475 undeveloped acres by a delivery rate (4.5 acre-feet per acre) estimated by the Project staff to be needed for newly developed acres.

- **Purpose:** To divert water from the Columbia River for irrigation and municipal and industrial (M&I) uses.
- **Measure Location:** Grand Coulee Dam (Lake Roosevelt). This measure focuses only on the diversion of water from the Columbia River via Lake Roosevelt and does not account for increased return flows (i.e. non-consumptively used water that returns to the river) that may occur when delivering this water to the CBP.
- **Implementation:** Pump more water from Lake Roosevelt using the existing John W. Keys Pumping Plant, which was designed and constructed to have the capacity to provide the full water delivery for the original authorization of 1,029,000 acres. The additional pumping would include 1,154,138 acre-feet for irrigation. The total pumped volume wuld be delivered on demand.
- **Frequency and duration:** Annual, mostly during irrigation season which is generally from April 1 through October 30. Table 1-31 shows the estimated monthly and total annual additional pumped water from Lake Roosevelt. **Table 1-32 shows the estimated monthly and total annual pumped water from Lake Roosevelt.**
- **Intended Benefit (why include this measure?):** To provide water supply to an additional 256,475 authorized acres of irrigable land within the CBP for agricultural development.

Table 1-33. Annual additional pumping from Lake Roosevelt.

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
January	8	518
February	59	3,299

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
March	596	36,627
April	2,836	168,724
May	2,983	183,431
June	3,031	180,333
July	3,610	221,983
August	2,290	140,804
September	2,254	134,115
October	1,134	69,725
November	166	9,865
December	77	4,714
Total		1,154,138
Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)

Table 1-34. Total pumping from Lake Roosevelt including current operations, reshaping of Odessa Subarea and the additional water for Columbia Basin Project.

Month	**Diversion Flow Rate (cfs)**	**Diversion Volume (Acre-feet)**
January	32	1,984
February	227	12,627
March	2,282	140,299
April	10,901	648,641
May	11,537	709,384

June	11,784	701,210
July	14,060	864,482
August	8,949	550,235
September	8,722	518,980
October	4,367	268,503
November	634	37,753
December	293	18,042
Total		4,472,138

O13. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish and Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. For years where the flow augmentation draft is 10 feet, the end of September elevation would be 3546 feet. In years where the flow augmentation draft is 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

Frequency and duration: Irrigation season which is generally from April 1 through October 30. Table 1-33 shows the estimated monthly and total annual additional delivered water from the Flathead River.

Table 1-35: Estimated monthly diversion above Flathead Lake.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April		
May		
June		
July	493	30,313
August	493	30,313
September	494	29,395
October		
November	0	0
December	0	0
Total		*90,021*

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure is has the potential to provide 90,000 acre-feet of water for a settlement with CSKT. This water could be used for irrigation or M&I purposes.

O14. Increase water diversion from the Columbia River for the Chief Joseph Dam Project to supply an additional 9,600 acre-feet of irrigation water. Supply irrigation water throughout the irrigation season.

- **Purpose of the measure:** To divert water from the Columbia River for irrigation of authorized acres in the Chief Joseph Dam Project.
- **Measure Location:** On the Columbia River just below Chief Joseph Dam.
- **Implementation:** Deliver 9,600 acre-feet of water to authorized Chief Joseph Dam lands.
- **Frequency and duration:** Annually during the irrigation season.

Table 1-34 shows the monthly estimated and total annual diversion from the Columbia River.

Table 1-36. Total water for additional Chief Joseph Dam Project lands.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April	3	179
May	19	1,168
June	42	2,499
July	50	3,074
August	34	2,091
September	7	417
October	2	123
November	0	0
December	0	0
Total		*9,550*

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to provide irrigation water to authorized acres in the Chief Joseph Dam for agricultural production.

O15. Implement modified timing of Lower Snake Basin reservoir draft to provide cooler water in the Lower Snake River during peak adult migration periods.

- **Purpose:** Provide earlier and later cold water releases for adult sockeye salmon, summer Chinook salmon, Fall Chinook salmon and steelhead that utilize the cool water corridor provided by Dworshak Reservoir through the Lower Snake River.

- **Measure Location**: Dworshak Dam
- **Implementation:** In real time operations, this measure will be tied to water temperatures, however, for the purposes of modeling, shift Dworshak releases to draft earlier (June 21 – August 1) for sockeye salmon and summer Chinook salmon and later (September 1 - September 30) for Fall chinook and steelhead. Earlier releases will provide cooling water earlier in the summer. The end of August target will be set to 1540’ for higher water years (years when the April forecast for April-August Dworshak volume is at or above the 80th percentile) and 1545’ in years when the April forecast for April-August Dworshak volume is below the 80th percentile. August outflows are expected to average 3-8 kcfs depending on inflows and forecast with this operation. The end of September target will remain at 1520’. The Nez Perce Agreement release volume will not change, though releases may increase the total volume of Dworshak releases in September, and Dworshak will continue to operate within state TDG standards.
- **Frequency and Duration:** During sockeye salmon, summer Chinook salmon, fall Chinook salmon and steelhead upstream migration through June - September
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by improving water temperatures for adult migration and egg viability during the peak adult migration periods for summer Chinook salmon, sockeye salmon, steelhead, and fall Chinook salmon.

O16. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate local forecast. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby’s May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking of flows and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of Sept elevation that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout.
    - Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon pulse has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft. For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.

Table 1-37. Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum

Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure O14 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O14.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O17. Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (avian predators).

- **Specific Measure:** Manipulation of lower Columbia reservoir elevations to disrupt juvenile salmonid predator reproduction success (avian predators).
- **Purpose:** Control avian colony success (juvenile salmonid predators).
- **Measure Location:** John Day Dam
- **Implementation:** Raise and maintain John Day Reservoir elevations between 263.5’-265’ (NGVD29) during the months of April and May. FRM operations determined by Vancouver stage are a constraint to this operation but may not be captured operationally in modeling for this measure.
- **Frequency and Duration:** April1 – May 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects by increasing juvenile salmonid predator management.

1.12.23 Errata Sheet - Multi-Objective Alternative 1, V4, January 11, 2019

*Changes to language indicated by *italics*

Measure O1 has been revised with clarifying language in the title of the measure. In addition, under implementation the footnote to the spill table has been modified to indicate a change in frequency of spill management from hourly to daily (24 hours).

Revised Measure (O1): Conduct *spill* test to evaluate latent mortality hypothesis (added the word spill)

- **Implementation:** Revise footnote on table to read,
  *120/115% Gas Cap spill is spill to the maximum level that meets, but does not exceed, the TDG criteria under state law. *Manage fish passage spill on a daily 24-hour basis. Implementation of the daily spill averaging would facilitate integration of renewable power including solar and wind.*

NEPA Policy Team approved this change on December 27, 2018

Measure O6 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

Measure O6: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the s sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change was approved in a call with NEPA Policy staff held on January 3, 2019

Measure O13 has been revised to correctly describe the end of September draft point that will result with the combination of measure *016. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O13. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure O16. Implement sliding Scale summer draft at Libby and Hungry Horse, for example if measure O16 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs.* For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

This change was approved as a change to MO3 in November, and to MOs 1,3, and 4 in January 2019

Measure O16 was changed to correct data in the tables for Libby and Hungry Horse. Corrections were made to the row labeled "Forecast".

O16. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
    - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
    - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

    - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
        - Target 2.5 ft above the end of September elevation on August 31st.
        - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
        - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
    - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
        - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
        - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).

    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.

Table 1-38. Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O*13 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure *O13*.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

1.12.24 Errata Sheet - Multi-Objective Alternative 1, V4, February 21, 2019

*Changes to language (January) indicated by *italics*

*Changes to language (February) indicated in yellow

Measure O1 has been revised with clarifying language in the title of the measure. In addition, under implementation the footnote to the spill table has been modified to indicate a change in frequency of spill management from hourly to daily (24 hours).

Revised Measure (O1): Conduct *spill* test to evaluate latent mortality hypothesis (added the word spill)

- **Implementation:** Revise footnote on table to read,
  *120/115% Gas Cap spill is spill to the maximum level that meets, but does not exceed, the TDG criteria under state law. *Manage fish passage spill on a daily 24-hour basis. Implementation of the daily spill averaging would facilitate integration of renewable power including solar and wind.*

NEPA Policy Team approved this change on December 27, 2018

Measure O6 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

Measure O6: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the s sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts).*

This change was approved in a call with NEPA Policy staff held on January 3, 2019

Measure O13 has been revised to correctly describe the end of September draft point that will result with the combination of measure *016. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O13. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure O16, Implement sliding scale summer draft at Libby and Hungry Horse. For example, if measure O16 determines a summer draft of 14 ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require additional draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs.* For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the

water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

This change was approved as a change to MO3 in November, and to MOs 1,3, and 4 in January 2019

Measure O16 was changed to correct data in the tables for Libby and Hungry Horse. Corrections were made to the row labeled "Forecast" and to the other measure referenced for Hungry Horse.

O16. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before

September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.

- The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
  - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
  - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
  - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
  - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.

Table 1-39. Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

- Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
- Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
- NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O*13 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure *O13*.

- **Frequency and Duration: Applies to all years**
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

1.12.25 Alternative: Multi-Objective 2 Detailed Description

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

Additionally, the following secondary objective was considered during development of this alternative:

- Improve conditions for the lamprey within the CRSO project area through actions potentially including, but not limited to project configurations, flow management, spill operations, and water quality management.

The following measures address the objective(s):

<u>Structural Measures:</u>

S1. Install new “fish-friendly” and high-efficiency/capacity turbines at John Day.

- **Purpose:** Improve turbine fish passage conditions and hydropower turbine efficiency and capacity
- **Measure Location:** John Day
- **Implementation:** Replace turbines with new improved units two at a time.
- **Frequency and Duration:** Installation of two units at a time.
- **Intended Benefit (why include this measure?):** Improved turbine fish passage conditions, improved hydropower turbine efficiency and capacity, and improved water quality (TDG).

S2. Construct powerhouse and/or spill surface passage routes.

- **Purpose:** May divert fish away from turbines and into a higher survival route, reduce exposure to screens, and reduce forebay delay.
- **Measure Location:** Ice Harbor, McNary and John Day projects.
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from April 3 for LSR and April 10 for LCR to July 31 and cease installation of fish screens.
- **Frequency and Duration:** April 3 – July 31 for Ice Harbor and April 10 – July 31 for McNary and John Day
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and lower Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S3. No installation of fish screens at Ice Harbor, McNary and John Day projects.

- **Specific Measure:** Do not install fish screens at specific projects on the lower Snake and lower Columbia Rivers.
- **Purpose:** Not installing fish-screens increases the efficiency of hydropower turbines.
- **Measure Location:** Ice Harbor, McNary and John Day projects.
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from April 3 –July 31 for Ice Harbor and April 10-July 31 for lower Columbia projects and cease installation of fish screens.
- **Frequency and Duration:** April 3 – July 31 for Ice Harbor and April 10 – July 31 for lower Columbia projects.

- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival through the lower Snake River and lower Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S4. Upgrade spillway weirs to Adjustable Spillway Weirs (ASWs).

- **Purpose:** Upgrade existing spillway weirs that are not adjustable spillway weirs (ASWs) to ASWs for greater operational flexibility based on flows.
- **Measure Location:** Lower Granite, Lower Monumental, and Ice Harbor, McNary, and John Day projects.
- **Implementation:** Upgrade spillway weirs to ASWs. For modeling, use 11 kcfs per weir discharge for March 1 through the end of Spring spill operations (lower Snake River projects: June 20; lower Columbia River projects: June 15), 7 kcfs per weir discharge during summer spill operations (lower Snake River projects: April 3-July 31; lower Columbia River projects: April 10-July 31).
  - **Lower Granite.** Replace existing spillway weir with an ASW.
  - **Lower Monumental.** Replace existing spillway weir with an ASW.
  - **Ice Harbor.** Replace existing spillway weir with an ASW.
  - **McNary.** Replace the two existing spillway weirs with ASWs.
  - **John Day.** Replace the two existing spillway weirs with ASWs
- **Frequency and Duration:** April 3 – July 31 for lower Snake and April 10 – July 31 for lower Columbia projects.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.

S5. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor projects.

- **Purpose:** Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor projects.
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from cooler water deeper in the reservoir. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by reducing the temperature

differential between tailrace and ladder entrances (from surface water warming), which may minimize thermal barriers and adult passage delays.

S6. Expand network of Lamprey Passage Structures (LPS) to bypass impediments in existing fish ladders.

- **Specific Measure:** Install new Lamprey Passage Structures (LPS) and add additional LPS at existing locations.
- **Purpose:** The purpose is to help Lamprey pass the project using a different route than the fish ladders.
- **Measure Location:** Additional structures at Bonneville, The Dalles, John Day, and McNary projects.
- **Implementation:** Construct new Lamprey Passage Structures as follows:
    - **Bonneville**: Construct additional LPS on the south ladder and at the south entrance to the north ladder.
    - **The Dalles:** Add diffuser grating plating on the diffuser in the north ladder.
    - John Day: Add LPS to the south ladder and extend North LPS to the forebay.
- **Frequency and Duration:** Construct once.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult lamprey passage success.

S7. Modify turbine cooling water strainer systems to safely exclude Pacific lamprey and other juvenile fish

- **Specific Measure:** Install prototype hoods over cooling water intakes
- **Purpose:** Exclude lamprey from turbine cooling water systems.
- **Measure Location:** All Lower Columbia and Lower Snake river projects.
- **Implementation:** Install prototype hoods (or refined design) over cooling water intake orifices in the scroll case to prevent lamprey entry.
- **Frequency and Duration:** One time modification.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to eliminate lamprey mortality caused by impingement in the turbine cooling water strainers.

S8. Modify turbine intake bypass screens that cause juvenile lamprey impingement and entanglement

- **Specific Measure:** Modify or replace fish screens to prevent lamprey impingement
- **Purpose:** Reduce lamprey mortality from impingement in fish screens.

- **Measure Location:** McNary project, Little Goose project, and Lower Granite project (Projects with Extended length submerged bar screens (ESBS)).
- **Implementation:** Modify or replace fish screens at the dams with screens that have tighter spacing to prevent lamprey from being caught in the screens.
- **Frequency and Duration:** Construct once, install annually.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce lamprey mortality from impingement in fish screens.

S9. Modify existing fish ladders, incorporating lamprey passage features and criteria into ladder modifications

- **Specific Measure:** Identify, design, and install modifications to improve adult lamprey passage through existing fish ladders.
- **Purpose:** Aid lamprey in finding, entering, and passing through the adult fish ladders.
- **Measure Location:** Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite
- **Implementation:** Design and install modifications to improve passage through existing fish ladders.
    - **Bonneville**: Install ramps to elevated salmon orifices in south ladder; diffuser grating plating on diffuser in south and Cascade island ladders; refuge boxes in north and south ladders; and wetted wall in north ladder serpentine section.
    - **The Dalles:** Install diffuser grating plating on diffuser in north ladder.
    - **McNary**: Install entrance weir caps at north and south ladders.
    - **Ice Harbor:** Install entrance passage structure at south ladder, and entrance weir caps at north and south ladders.
    - **Lower Monumental:** Install diffuser grating plating in the north and south ladders, and entrance weir caps at the north and south ladders.
    - **Little Goose:** Install entrance weir caps at the south ladder.
    - **Lower Granite project:** Install entrance weir caps at the south ladder.
- **Frequency and Duration:** Dependent on additional information (see note).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult lamprey passage through fish ladders.

Operational Measures:

O1. Limit fish passage spill to 110 percent total dissolved gas (TDG) (water quality standard without the TDG criteria adjustment or modification). Spill associated with high flow (lack of

capacity) and flood risk management events would continue as needed. Lack-of-market spill would also continue and follow the spill priority list.

- **Specific Measure:** Decrease fish passage spill at all Lower Snake River and Lower Columbia River dams.
- **Purpose:** Increase hydropower production and increase integration of non-hydropower renewable power sources such as wind and solar.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** Limit fish passage spill to no more than 110% TDG, as measured river, including tailraces and downstream forebays. Spill during high flow and flood events would not be constrained to a cap of 110% TDG, but rather, set to levels necessary for safety. Lack-of-market spill would follow the spill priority list.
- **Frequency and Duration:** Annually beginning April 3 at the lower Snake River projects and April 10 at the lower Columbia River projects. Fish passage spill ends midnight July 31.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure would reduce the carbon footprint of the Northwest by reducing the need for fossil-fuel power generation to meet power demand. Increase the generation of affordable, non-fossil fuel sources through increased hydropower production and increased integration of non-hydropower renewable power sources such as wind and solar.

O2. Partially lift flow and pool elevation restrictions as listed below to increase hydropower generation and increase hydropower flexibility to integrate renewable resources. Safety-related restrictions would continue, including meeting flood risk management (FRM) elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability.

O2.a. Ramping rate limitations at all projects will be defined for the purpose of safety or engineering.

- **Specific Measure:** Ramping rate limitations at all projects will be defined only for the purpose of safety or geotechnical concerns such as erosion.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production to meet power demand.
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management, erosion concerns, or grid reliability), restrictions on flow will be lifted. More

flexibility in ramping rates would not increase total generation and would increase ability to shape flows and power generation within-day.

- **Frequency and Duration:** current restrictions vary seasonally and vary by project.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, increased flexibility to raise and lower flows increases the ability for hydropower to meet fluctuations in demand.

O2.b. At the four lower Snake River projects operate within the full reservoir operating range year-round.

- **Specific Measure:** Allow the reservoirs behind the lower Snake River dams to use the full operating pool except as restricted for safety.
- **Purpose:** A larger operating range at the run-of-river projects will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor
- **Implementation:** at the Lower Snake projects, the pools will no longer be restricted to within 1-foot above Minimum Operating Pool operating range during the fish passage season.
- **Frequency and Duration:** Current restrictions apply April to August at Little Goose to Ice Harbor, but continue longer at Lower Granite. With this measure, these restrictions would not apply at any time of the year.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O2.c. At John Day allow project to operate within the full reservoir operating range year-round except as needed for flood risk management.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations at John Day
- **Purpose:** A larger operating range at the run-of-river project will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** John Day
- **Implementation:** John Day pool will not be restricted to within 1 ½ feet above Minimum Irrigation Pool (MIP) operating range during the fish passage season.
- **Frequency and Duration:** Currently, John Day pool is restricted to operating within 1 ½ feet above MIP during the fish passage season (April – September). With this measure, this restriction will not be put into place at any time of the year, so the pool will operate between 257.0 and 266.5 ft all year, except as needed for flood risk management.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, the larger operating ranges will not substantially increase total generation but it will increase flexibility to shape flows and power generation within-day.

O2.d. The storage projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, and Dworshak), may be drafted for hydropower generation, and the maximum pool elevation is limited to upper rule curves for FRM. On April 10, April 30, and May 30 the projects shall be within 10

feet below the flood risk management elevation. Libby may be 20 feet below the flood risk management elevation at the end of December.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations
- **Purpose:** A larger operating range will allow more operating flexibility for hourly and daily shaping of hydropower generation.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak
- **Implementation (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, hydroregulation modeling will operate the storage projects to shape generation to meet demand. This will likely require initial modeling by a hydropower model (HYDSIM) to develop rules that can be implemented by ResSim. Chief drivers will be demand for power (based on load forecasts) and market prices (for shaping surplus power into the high-demand periods).
- **Frequency and Duration:** Current restrictions vary seasonally by project.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to result in larger ranges of operating pools allow for more flexibility to shape power production to meet demand.

O3. Operate turbines across their full range of capacity.

- **Specific Measure:** No longer restrict turbine operations to within 1% of peak efficiency.
- **Purpose:** increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville
- **Implementation:** Allow turbines to operate across the full range of capacity. Operating to a higher capacity would increase generation and would increase turbine flow capacities which reduce the amount of lack-of-turbine spill. These effects will be evident in monthly and daily hydroregulation models. Further, the increased turbine capacity would increase the amount of within-day shaping for hydropower, which will be analyzed in hydropower impact modeling.
- **Frequency and Duration:** Currently, restrictions apply during fish passage season. This measure would not impose restrictions at any time of the year.
- **Intended Benefit:** The primary benefit is increase turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water would be allowed to pass through the turbines, potentially reducing the incidence of high Total Dissolved Gas levels.

O4. Juvenile fish transportation.

- **Purpose:** Transport all juvenile salmonids entering the juvenile fish bypasses at collector projects and at McNary downstream to below Bonneville for release.
- **Measure Location:** McNary, Lower Granite, Little Goose, and Lower Monumental dams
- **Implementation:** Transport all juvenile salmonids entering the juvenile fish bypasses at the collector projects and McNary Power House Surface Passage (PHSP) downstream to the release site below Bonneville Dam.
- **Frequency and Duration:** April 25 - August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase salmon and steelhead adult returns during extreme low water years.

O5. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate local forecast. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
    - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
    - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-May Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking of flows and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of Sept elevation that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
- The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirements for bull trout.
    - Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon pulse has been expended and through September 30th.

- **Implementation - Hungry Horse:**
    - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
        - For the 10th percentile forecast and drier draft 20 feet.
        - For the 20th percentile forecast and wetter draft 10 feet
        - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.

Table 1-40. Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

- Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
- Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.

- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O6. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose of the measure:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure increases the available capacity of hydrogeneration. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O7. When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

- **Specific Measure:** Update the existing Libby local Storage Reservation Diagram (SRD) to evacuate FRM space to an appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). During refill (generally Apr/May–July), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; and (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill will start on May 1st. When forecasts are above 6.9 MAF the proposed local SRD will require a deeper draft in January and February. The VarQ refill flow calculation will

be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin**;** (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

- **Frequency and Duration:** All years, from Jan-July (greatest change would be seen in water years where the water supply forecast was less than 6.9 MAF for Libby).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operations by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery, while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements, and improve FRM operations for spring rain events in the Kootenay Basin

O8. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for

reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O9. Update the upstream Storage Corrections Method as applied to the Grand Coulee (GCL) SRD.

- **Specific Measure:** The methodology differs conceptually from the current methodology. Rather than adjusting The Dalles (TDA) forecast to determine GCL FRM requirements as with the current methodology, the methodology utilizes the TDA forecast directly to determine the end of April draft requirement for GCL (figure 1) and requires a correction, in the form of a deeper draft target at GCL, when upstream storage reservoirs that fail to achieve their required drafts for whatever reason. It should be noted that the methodology only affects the FRM draft requirements of GCL and does not change the operation or draft requirements of any other project. The Grand Coulee FRM draft is based on four things: 1) The TDA forecast, 2) upstream storage reservoirs' required FRM draft or draft that is manageable and dependable for system flood risk management (called a Base Draft) 3) the in-season draft (actual) of upstream reservoirs in relation to the Base Draft and 4) the relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (Weighting Curves for certain projects). This is similar to the information used under the current methodology but the process of using it is different. The basic concept of the Grand Coulee upstream storage adjustment methodology is depicted in Figure 1 as a two-step process. First, a Grand Coulee unadjusted April 30 FRM requirement is determined using the curve in Figure 1 and TDA forecast. The relationship assumes that each upstream storage project is drafted or projected to be drafted to its Base Draft by April 30. Second, an adjustment is made to the Grand Coulee April 30 required draft only if storage projects upstream of The Dalles have not been drafted to their Base Draft. If upstream projects are drafted deeper than their base draft no adjustments are made to the GCL draft or if all projects are on their base draft no adjustments will be made. Because upstream projects contribute in differing proportions to overall system FRM, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment. The adjustment is then added to the unadjusted GCL required draft based on the April 30 curve to yield the adjusted required April 30th GCL draft target. In addition to the methodology changes proposed in this measure, this measure also removes the "flat spot" from the GCL SRD and replaces it with a consistently increasing flood risk draft for all forecast ranges. The "flat spot" is a portion of the current GCL SRD that targets a maximum draft point to 1220 ft (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 MAF.

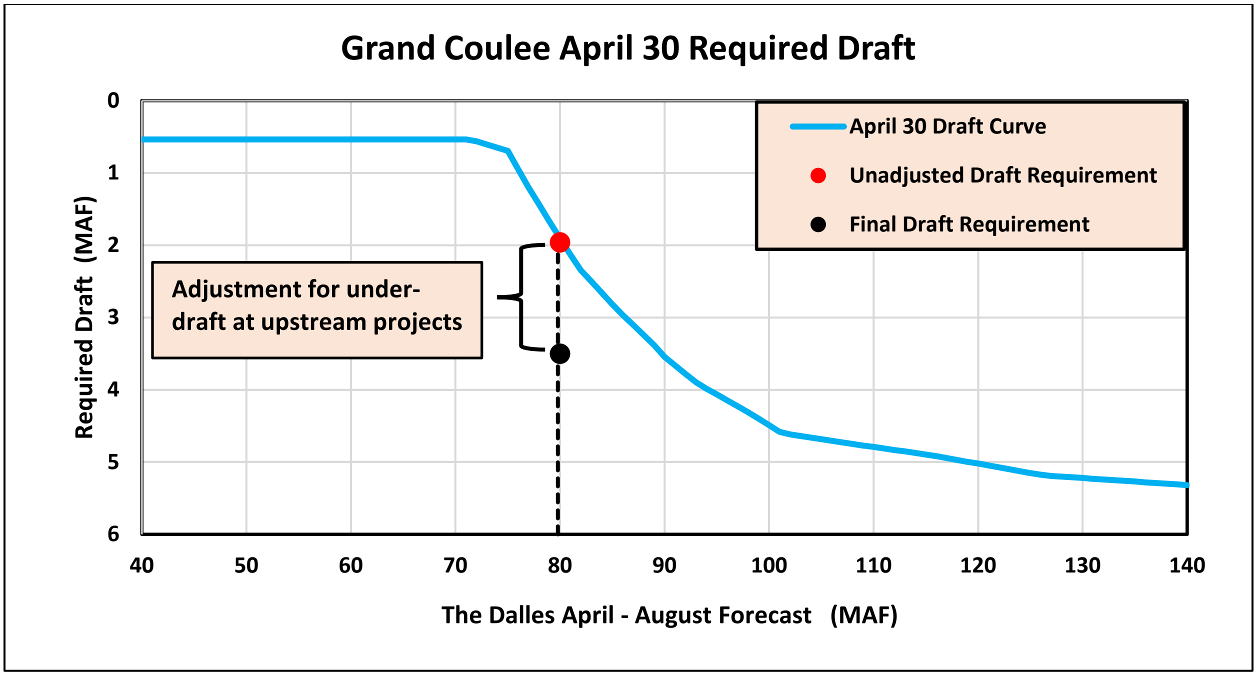

Figure 1 – Grand Coulee Unadjusted April 30 FRM Requirement

There are a number of specific differences between the No Action operation and this proposed measure.

1. The fixed FRM draft requirements for John Day, SKQ, Noxon, and Albeni Falls are embedded in the new end-of-April draft requirement for GCL and are therefore not necessary in the adjustment process.
2. The 3.6 Maf cap on the Arrow FRM space was removed in the method.
3. Creditable refill checks on project space are not required because those checks are built into the Base Drafts, and the Weighting Factors.
4. The method does not allow adjustments for over-draft conditions.
5. The GCL SRD is modified to remove the non-increasing draft elevation for adjusted forecasts between 80 and 95 MAF, referred to as the “flat spot”.

- **Purpose:** To update GCL operations and ensure they are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** There are four main components that will be used to determine GCL end of month FRM requirements during the drawdown period (Jan-Apr) under the methodology; the GCL Unadjusted April 30 Draft Requirement Curve (GCL Curve), individual project Base Drafts, individual project Weighting Curves, and the GCL SRD. These will be developed, documented and incorporated into the model.
- **Frequency and Duration:** All years, January-April

- **Intended Benefit (why include this measure?):** The measure will provide a fully documented process that allows GCL to better respond to changes in upstream operations. The process will allow adaptation to possible future changes in management of reservoir space upstream of The Dalles Dam. It is the intent that this methodology will maintain a similar level of flood risk compared to the current practice and not significantly alter the magnitude and frequency of GCL water surface elevations given similar operations of upstream reservoirs.

O10. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce the probability of landslides. This is expected to have an ancillary benefit of reducing spill due to lack of market or lack of turbine capacity during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O11. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more accelerated than current outages, to represent a broader range of possible hydraulic capacity during maintenance activities.

- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O12. Develop draft requirements or an assessment approach to protect against rain-induced flooding.

- **Specific measure:** Increase drafted space available at Grand Coulee for implementing winter operations. Grand Coulee, Albeni Falls and Dworshak Dams will operate to protect against rain-induced flooding at Vancouver and Portland.
- **Purpose:** Runoff from winter precipitation events associated with atmospheric rivers, that deliver significant amounts of rain over short durations, cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Not only are these events difficult to forecast with long lead times (>5 days), they also can lead to the highest amount of flood damage in the Portland/Vancouver area. Furthermore, there is strong evidence that winter flows and atmospheric river events will increase with climate change. Water management operating rules that more explicitly account for these rain-driven runoff events would offer greater flexibility and adaptability in reservoir operations. Albeni Falls and Dworshak have drafted space already in place for rain-induced flooding and will be adjusted to fill space under the same conditions as Grand Coulee.
- **Measure Location:** Grand Coulee, Albeni Falls, and Dworshak. **Implementation:** Grand Coulee will be drafted to provide up to 650 kaf of space for FRM from mid-December through March. All other existing winter operations will remain the same. The winter operations will first rely on the four lower Columbia projects when the stage at Vancouver is forecast to exceed a stage of 16 feet. If the forecast continues to project a stage exceeding 16 feet with the operation

of the four lower Columbia projects then the winter operations will include Albeni Falls, Dworshak and Grand Coulee.

- **Frequency and Duration:** All years Mid-December - March.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to preserve the ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

1.12.26 Errata Sheet - Multi-Objective Alternative 2, V4, January 11, 2019

*Changes to text indicated with italics.

Measure S3 was modified to remove specific language about diversion volumes from the measure. The measure now reads,

S3. No Installation of fish screens at Ice Harbor, McNary, and John Day projects

Implementation: This measure would cease installation of fish screens at Ice Harbor, McNary, and John Day projects.

This change was approved by NEPA policy.

Measure O1 was modified to include spill operations to levels lower than No Action but high enough to potentially provide a meaningful benefit to fish through surface passage routes. Specific language was added to the Implementation section and the Frequency and Duration Section. The measure now reads:

Measure O1: Limit fish passage spill to 110 percent total dissolved gas (TDG) (water quality standard without the TD G criteria adjustment or modification). Spill associated with high flow (lack of capacity) and flood risk management events would continue as needed. Lack-of-market spill would also continue and follow the spill priority list.

Implementation: Limit fish passage spill to no more than 110% TDG, as measured *in*-river, including tailraces and downstream forebays *except when minimum spill levels are higher including spill needed for the powerhouse surface passage routes, for the spillway weirs, and/or for adult attraction.* Spill during high flow and flood events would not be constrained to a cap of 110% TDG, but rather, set to levels necessary for safety. Lack-of-market spill would follow the spill priority list.

Frequency and Duration: Annually beginning April 3 at the lower Snake River projects and April 10 at the lower Columbia River projects. *Juvenile fish* passage spill ends midnight July 31.

Measure O2d was modified to include modifications to operational elevations in Sept/Oct at Grand Coulee in the measure title, and removes limitations on maximum pool elevation to the upper rule curve for FRM. The change also includes modifications to the Implementation section and the Frequency and Duration section, which now read:

Measure O2d The storage projects (Libby, Hungry Horse, Grand Coulee, and Dworshak) may be drafted *slightly deeper* for hydropower generation. On April 10, April 30, and May 30 the

projects may be 10 feet below the flood risk management elevation. Libby may be 20 feet below the flood risk management elevation at the end of December. ***Grand Coulee will be no lower than 1283 feet at the end of October instead of at the end of September.***

Implementation: Hydroregulation modeling will operate the storage projects *with slightly more flexibility* to shape generation to meet demand. *Libby reservoir may be 20 feet below the end-of- December elevation (from measure O8). The storage projects may be 10 feet below the FRM elevations in April and May. And Grand Coulee may be at elevation 1283 or higher at the end of October, but not necessarily at the end of September. The maximum pool elevations are limited to upper rule curves for FRM.*

Frequency and Duration: Libby end-of-December, Grand Coulee end-of-September, and all storage projects during the drawdown period through April and May.

Measure O5 was changed to correct data in the tables for Libby and Hungry Horse. Corrections were made to the row labeled “Forecast”.

O5. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby’s May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
    - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    -
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
    - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
        - For the 10th percentile forecast and drier draft 20 feet.
        - For the 20th percentile forecast and wetter draft 10 feet
        - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
        - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

- Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
- Outflow would be maximum of outflow required to meet the Columbia Falls

minimum or calculated flow augmentation outflow.

  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O15* which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O15.

- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O7 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

Measure O7: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change was approved in a call with NEPA Policy staff held on January 3, 2019

A **new measure** has been added to MO2, imported from the previous single objective alternative for hydropower. The measure is added as **O13,** and reads as follows:

O13 Zero Generation Operations may occur on the Lower Snake River projects November – February

Specific Measure: *Allow the projects to shut off generation at night at the four Lower Snake River projects unless limited by grid stability requirements*

Purpose: *Reduce generation at night when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for daytime generation*

Measure Location: *Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Projects*

Implementation: *Allowing generation to go to zero at night would allow more water to be stored for generation during the day. This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impacts models. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam).*

Frequency and Duration: *Currently, the projects are allowed to go to zero generation mid-December through February. This measure extends that period to begin in early November.*

Intended Benefit: *Increases flexibility to shape generation to meet the shape of load (i.e. demand for power) by reducing water flow at night leaving more water for the daytime.*

1.12.27 Errata Sheet - Multi-Objective Alternative 2, V4, February 21, 2019

*Changes to text indicated with italics (January 11 Version)

*Changes indicated in yellow highlight (February 21 Version)

Measure S3 was modified to remove specific language about diversion volumes from the measure. The measure now reads,

S3. No Installation of fish screens at Ice Harbor, McNary, and John Day projects

Implementation: This measure would cease installation of fish screens at Ice Harbor, McNary, and John Day projects.

This change was approved by NEPA policy.

Measure O1 was modified to include specific language to the Implementation section and the Frequency and Duration Section to include higher spill levels when the minimum spill is greater than 110%. The measure now reads:

Measure O1: Limit fish passage spill to 110 percent total dissolved gas (TDG) (water quality standard without the TD G criteria adjustment or modification). Spill associated with high flow (lack of capacity) and flood risk management events would continue as needed. Lack-of-market spill would also continue and follow the spill priority list.

Implementation: Limit fish passage spill to no more than 110% TDG, as measured *in*-river, including tailraces and downstream forebays *except when minimum spill levels are higher including spill needed for the powerhouse surface passage routes, for the spillway weirs, and/or for adult attraction.* Spill during high flow and flood events would not be constrained to a cap of 110% TDG, but rather, set to levels necessary for safety. Lack-of-market spill would follow the spill priority list.

Frequency and Duration: Annually beginning April 3 at the lower Snake River projects and April 10 at the lower Columbia River projects. *Juvenile fish* passage spill ends midnight July 31.

Measure O2c was modified to change the lower limit elevation for John Day Pool to Minimum Operating Pool elevation. The lower limit operation was changed from 257.0 to 262.5.

Frequency and Duration: Currently, John Day pool is restricted to operating within 1.5 feet above MIP during the fish passage season (April – September). With this measure, this restriction will not be put into place at any time of year, so the pool will operate between elevations *262.5 – 266.5* ft. all year, except as needed for flood risk management.

This change was approved by NEPA Policy Team on February 7, 2019

Measure O2d The February 21 change corrects a misstatement in the characterization of the January errate by removing the phrase “and removes limitation on maximum pool elevation to the upper rule curve for FRM” from the change summary in the errata. This is an error. Measure O2d does not remove limitation on FRM restrictions.

Measure O2d was modified to include modifications to operational elevations in Sept/Oct at Grand Coulee in the measure title The change also includes modifications to the Implementation section and the Frequency and Duration section, which now read:

Measure O2d The storage projects (Libby, Hungry Horse, Grand Coulee, and Dworshak) may be drafted *slightly deeper* for hydropower generation. On April 10, April 30, and May 30 the projects may be 10 feet below the flood risk management elevation. Libby may be 20 feet below the flood risk management elevation at the end of December. *Grand Coulee will be no lower than 1283 feet at the end of October instead of at the end of September*.

Implementation: Hydroregulation modeling will operate the storage projects *with slightly more flexibility* to shape generation to meet demand. *Libby reservoir may be 20 feet below the end-of- December elevation (from measure O8). The storage projects may be 10 feet below the FRM elevations in April and May. And Grand Coulee may be at elevation 1283 or higher at the end of October, but not necessarily at the end of September. The maximum pool elevations are limited to upper rule curves for FRM.*

Frequency and Duration: Libby end-of-December, Grand Coulee end-of-September, and all storage projects during the drawdown period through April and May.

Measure O5 was changed to correct data in the tables for Libby and Hungry Horse. Corrections were made to the row labeled “Forecast”.

O5. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for

resident fish and balance these needs with flow augmentation.

- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.
- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.

  - For the 10th percentile forecast and drier draft 20 feet.
  - For the 20th percentile forecast and wetter draft 10 feet
  - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
  - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O15* which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O15.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O7 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

Measure O7: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change was approved in a call with NEPA Policy staff held on January 3, 2019

A **new measure** has been added to MO2, imported from the previous single objective alternative for hydropower. The measure is added as **O13,** and reads as follows:

Additional changes to measure **O13** were made following review of revised language originally approved in December. The previously approved language should have read as below.

The February 21, 2019 changes include a change to the dates for implementation from November – February. Recommended implementation period is now September – March. In addition, the change removes the restriction for implementing this operation only at night, and allows this operation any time. This change is reflected in deletion of the designation "at night" under the **Specific Measure, Purpose, Implementation**, and **Intended Benefits** section, and with the deletion of "daytime" under the **Purpose** section of the Alternative description. The change also includes the deletion of the sentence under the Implementation section that reads, "This will not be evident in monthly or daily hydroregulation modeling but will be evident in other hydropower impacts models." This was an erroneous cut/paste error and did not belong in this measure.

O13 Zero Generation Operations may occur on the Lower Snake River projects September – March

Specific Measure: *Allow the projects to shut off generation at the four Lower Snake River projects unless limited by grid stability requirements*

Purpose: *Reduce generation when there is little demand for hydropower and lower Snake River inflow is low enough to permit storage for later generation*

Measure Location: *Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Projects*

Implementation: *Allowing generation to go to zero would allow more water to be stored for generation during peak demand hours. (Zero generation without spill reduces the flow to zero, but the tailwater below the dam does not dry out since each of the dams has a reservoir downstream that extends to the base of the upstream dam).*

Frequency and Duration: *Currently, the projects are allowed to go to zero generation mid-December through February. This measure extends that period to begin in September and extend through March.*

Intended Benefit: *Increases flexibility to shape generation to meet the shape of load (i.e. demand for power) by reducing water flow in low demand periods leaving more water for high demand periods.*

1.12.28 Alternative: Multi-Objective 3 Detailed Description

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

Additionally, the following secondary objective was considered during development of this alternative:

- Improve conditions for the lamprey within the CRSO project area through actions potentially including, but not limited to project configurations, flow management, spill operations, and water quality management.

The following measures address the objective(s):

<u>Structural Measures:</u>

S1. Remove earthen embankments and adjacent structures, as required, at each dam to facilitate reservoir drawdown.

- **Specific Measure:** Remove earthen embankments and portions of existing structure to evacuate the reservoirs.
- **Purpose:** Return the river to a more natural hydraulic condition for ESA-listed fish passage.
- **Measure Location:** Ice Harbor, Lower Monumental, Little Goose, and Lower Granite projects.
- **Implementation:** The earthen embankments, abutments, and structures at each dam would be removed as needed to provide a 140-mile stretch of river without impoundment. To control sediment inputs and maintain safe conditions at downstream dams, breaching would be accomplished in phases, starting with Lower Granite and Little Goose dams, followed by Lower Monumental and Ice Harbor dams. Water control structures such as cofferdams and levees would be installed at breach locations to direct and control flows near the powerhouse, spillways, and navigation locks to facilitate safe drawdown of the reservoirs and provide fish passage. It has been calculated that a drawdown of 2 feet per day, beginning in August and continuing through the end of December, would safely evacuate the reservoirs and minimize damage to adjacent infrastructure.
- **Frequency and Duration:** Dam breaching activities would be conducted only once at each location. Work would be coordinated with the agencies and scheduled to minimize negative effects to Snake River ESA-listed fish.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, removal of earthen embankments would be a means to return this portion of the river to a more natural riverine condition in terms of water depth, local sediment movement, and habitats at river margins. However, because these dams are run-of-river projects, breaching would not appreciably affect the volume and timing of flows. These conditions could contribute to more natural migration, spawning, and rearing conditions for ESA-listed fish in this stretch of the Snake River.

S2. Modify existing equipment and dam infrastructure to adjust to drawdown conditions. Existing equipment would not be used for hydropower generation, but would instead be used as low-level outlets for drawdown below spillway elevations. Depending on the outcome of additional analysis, turbines would be modified or operated at Speed No Load to support controlled drawdown.

- **Specific Measure:** Modify existing equipment to support controlled reservoir drawdown.

- **Purpose:** To use all available outlets at the dam to provide controlled drawdown conditions.
- **Measure Location:** Ice Harbor, Lower Monumental, Little Goose, and Lower Granite projects.
- **Implementation:** Existing equipment and infrastructure at the dams would be modified so that both spillways and powerhouse outlets may be used to evacuate the reservoir at various elevations.
- **Frequency and Duration:** Modifications and a required decommissioning would take place prior to initiation of drawdown at each location.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, modifications would be undertaken to allow use of existing facilities and outlets for a controlled reservoir evacuation. This would facilitate outflows with minimal creation of total dissolved gas.

S3. Construct additional powerhouse and/or spill surface passage routes at McNary project.

- **Purpose:** May divert fish away from turbines and into a higher survival route, reduce exposure to screens, and reduce forebay delay.
- **Measure Location:** McNary project
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from March 1 to August 31 and cease installation of fish screens.
- **Frequency and Duration:** March 1 – August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and lower Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S4. No installation of fish screens at McNary project.

- **Specific Measure:** Do not install fish screens at McNary.
- **Purpose:** Not installing fish-screens increases the efficiency of hydropower turbines.
- **Measure Location:** McNary project.
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from April 10-July 31 and cease installation of fish screens.
- **Frequency and Duration:** April 10 – July 31.

- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead fish passage survival McNary, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S5. Upgrade spillway weirs to Adjustable Spillway Weirs (ASWs)

- **Purpose:** Upgrade existing spillway weirs that are not adjustable spillway weirs (ASWs) to ASWs for greater operational flexibility based on flows.
- **Measure Location:** McNary and John Day projects
- **Implementation:** Upgrade spillway weirs to ASWs. For modeling, use 11 kcfs per weir discharge for April 10 – June 15 Spring spill operations, 7 kcfs per weir discharge for June 16 - July 31 Summer spill operations.
    - **McNary.** Replace the two existing spillway weirs with ASWs.
    - **John Day.** Replace the two existing spillway weirs with ASWs.
- **Frequency and Duration:** March 1-August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S6. Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway.

- **Purpose:** Reduce passage time for adult salmonids as they move upstream through the fish ladder.
- **Measure Location:** Bonneville Dam
- **Implementation:** Modify the upper ladder serpentine flow control ladder sections at Bonneville Dam to an Ice Harbor-style vertical slot fishway. At Bonneville Dam's Bradford Island and Washington Shore ladder flow control sections (the portion of the ladder from the count stations to the ladder exit), remove the baffles from this section of the ladders and replace them with baffles that have in-line vertical slots and orifices. It would also likely involve modifying the auxiliary water supply controls and replacing the ladders' PIT detection systems.
- **Frequency and Duration:** Year round
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the

potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates. A similar modification at John Day Dam, the only other CRS dam to use this type of ladder, resulted in significant passage time reductions for salmon and steelhead.

S7. Expand network of Lamprey Passage Structures (LPS) to bypass impediments in existing fish ladders.

- **Specific Measure:** Install new Lamprey Passage Structures (LPS) and add additional LPS at existing locations.
- **Purpose:** The purpose is to help Lamprey pass the project using a different route than the fish ladders.
- **Measure Location:** Additional structures at Bonneville, The Dalles, John Day, and McNary projects.
- **Implementation:** Construct new Lamprey Passage Structures as follows:
    - **Bonneville**: Construct additional LPS on the south ladder and at the south entrance to the north ladder.
    - **The Dalles:** Add diffuser grating plating on the diffuser in the north ladder.
    - John Day: Add LPS to the south ladder and extend North LPS to the forebay.
- **Frequency and Duration:** Construct once.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult lamprey passage success.

S8. Modify turbine cooling water strainer systems to safely exclude Pacific lamprey and other juvenile fish

- **Specific Measure:** Install prototype hoods over cooling water intakes
- **Purpose:** Exclude lamprey from turbine cooling water systems.
- **Measure Location:** All Lower Columbia River projects.
- **Implementation:** Install prototype hoods (or refined design) over cooling water intake orifices in the scroll case to prevent lamprey entry.
- **Frequency and Duration:** One time modification.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to eliminate lamprey mortality caused by impingement in the turbine cooling water strainers.

S9. Modify turbine intake bypass screens that cause juvenile lamprey impingement and entanglement

- **Specific Measure:** Modify or replace fish screens to prevent lamprey impingement
- **Purpose:** Reduce lamprey mortality from impingement in fish screens.
- **Measure Location:** McNary project.
- **Implementation:** Modify or replace fish screens at the dams with screens that have tighter spacing to prevent lamprey from being caught in the screens.
- **Frequency and Duration:** Construct once, install annually.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce lamprey mortality from impingement in fish screens.

S10. Modify existing fish ladders, incorporating lamprey passage features and criteria into ladder modifications

- **Specific Measure:** Identify, design, and install modifications to improve adult lamprey passage through existing fish ladders.
- **Purpose:** Aid lamprey in finding, entering, and passing through the adult fish ladders.
- **Measure Location:** Bonneville, The Dalles, John Day and McNary
- **Implementation:** Design and install modifications to improve passage through existing fish ladders.
    - **Bonneville**: Install ramps to elevated salmon orifices in south ladder; diffuser grating plating on diffuser in south and Cascade island ladders; refuge boxes in north and south ladders; and wetted wall in north ladder serpentine section.
    - **The Dalles:** Install diffuser grating plating on diffuser in north ladder.
    - **McNary**: Install entrance weir caps at north and south ladders.
- **Frequency and Duration:** Dependent on additional information (see note).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult lamprey passage through fish ladders.

S11. Install new “fish-friendly” and high-efficiency/capacity turbines at John Day.

- **Purpose:** Improve turbine fish passage conditions and hydropower turbine efficiency and capacity
- **Measure Location:** John Day
- **Implementation:** Replace turbines with new improved units two at a time.

- **Frequency and Duration:** Installation of two units at a time.
- **Intended Benefit (why include this measure?):** Improved turbine fish passage conditions, improved hydropower turbine efficiency and capacity, and improved water quality (TDG).

Operational Measures:

O1. Develop procedures to operate existing equipment during reservoir drawdown.

- **Specific Measure:** Develop a plan for operation of equipment during reservoir drawdown
- **Purpose:** To provide information to dam and transmission planners regarding how existing equipment would be modified and operated to draw down the four reservoirs on the lower Snake River.
- **Measure Location:** Ice Harbor project, Lower Monumental project, Little Goose project, and Lower Granite project.
- **Implementation:** Equipment to be used in drawdown would be tested and calibrated to establish operational limits. Engineers and powerhouse and transmission operators would establish manual operations and procedures using modified equipment to facilitate controlled and safe reservoir evacuation.
- **Frequency and Duration:** The plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment.

O2. Develop contingency plans to address unexpected issues with drawdown operations.

- **Specific Measure:** Develop plans for operation or emergency shut down during reservoir drawdown
- **Purpose**: To provide information and training to dam and transmission operators and inspectors regarding how modified equipment would be operated or shut down in the event of an emergency or unanticipated circumstances during reservoir evacuation.
- **Measure Location:** Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, and Lower Granite Dam.
- **Implementation:** Engineers and operators would work together to develop plans for operating existing equipment under drawdown conditions. They would identify risks and required emergency responses should equipment not function as anticipated or expected conditions change.

- **Frequency and Duration:** Impacts of implementation of this measure will be included in the impact analysis; however, the contingency plans and procedures would be developed prior to initiation of drawdown and implemented at each location of dam breaching.
- **Intended Benefit (why include this measure?):** This measure is intended to support safe, informed, and controlled evacuation of the reservoir using existing equipment.

O3. Modify spring spill in the lower Columbia River

- **Specific Measure:** Modify spring juvenile fish passage spill by applying the results of performance standard testing conducted from 2008-2018 to inform spill operations.
- **Purpose:** Implement juvenile fish spring passage spill by applying the best available science
- **Measure Location:** McNary, John Day, The Dalles, and Bonneville projects
- **Implementation:**
- **Frequency and Duration:** Annually implemented from April 10 – June 15 for the lower Columbia River projects.

Location	Spring Spill Operation Volume/Percent of Total Flow Routed to Spillway
McNary	48%
John Day	32%
The Dalles	40%
Bonneville	100 kcfs

"Manage fish passage spill on a daily 24-hour basis. Implementation of the daily spill averaging would facilitate integration of renewable power including solar and wind."

- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

O4. Reduce the duration of summer juvenile fish passage spill.

- **Specific Measure:** Reduce the period for which summer juvenile fish passage spill is provided.

- **Purpose:** To increase hydropower production during periods of low juvenile fish passage.
- **Measure Location:** McNary, John Day, The Dalles, and Bonneville projects.
- **Implementation:** Modify the duration of the summer spill period.
- **Frequency and Duration:** Summer spill will end midnight July 31.
- **Intended Benefit (why include this measure?):** Impacts of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase power production flexibility in the month of August during periods of low juvenile fish passage.

O5. Partially lift flow and pool elevation restrictions as listed below to increase hydropower generation and increase hydropower flexibility to integrate renewable resources. Safety-related restrictions would continue, including meeting flood risk management (FRM) elevations and flows, maintaining ramp rates for minimizing dam erosion, and maintaining grid reliability.

O5.a. Ramping rate limitations at all projects will be defined for the purpose of safety or engineering.

- **Specific Measure:** Ramping rate limitations at all projects will be defined only for the purpose of safety or geotechnical concerns such as erosion.
- **Purpose:** To increase flexibility in flows to allow water to be shaped for hydropower production to meet power demand.
- **Measure Location:** All projects (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joe, Dworshak, McNary, John Day, The Dalles, Bonneville)
- **Implementation:** where restrictions are not for safety (e.g. flood risk management, erosion concerns, or grid reliability), restrictions on flow will be lifted. More flexibility in ramping rates would not increase total generation and would increase ability to shape flows and power generation within-day.
- **Frequency and Duration:** current restrictions vary seasonally and vary by project.
- **Intended Benefit (why include this measure?):** Increased flexibility to raise and lower flows increases the ability for hydropower to meet fluctuations in demand.

O5.b. At John Day allow project to operate within the full reservoir operating range year-round except as needed for flood risk management.

- **Specific Measure:** Reduce restrictions on seasonal pool elevations at John Day
- **Purpose:** A larger operating range at the run-of-river project will allow more operating flexibility for hourly and daily shaping of hydropower generation.

- **Measure Location:** John Day
- **Implementation:** John Day pool will not be restricted to within 1 ½ feet above Minimum Irrigation Pool (MIP) operating range during the fish passage season.
- **Frequency and Duration:** Currently, John Day pool is restricted to operating within 1 ½ feet above MIP during the fish passage season (April – September). With this measure, this restriction will not be put into place at any time of the year, so the pool will operate between 257.0 and 266.5 ft all year, except as needed for flood risk management.
- **Intended Benefit (why include this measure?):** The larger operating ranges will not substantially increase total generation but it will increase flexibility to shape flows and power generation within-day.

O6. Operate turbines within and above 1% of peak efficiency during juvenile fish passage season.

- **Specific Measure:** Allow turbine operation within and above 1% of peak efficiency.
- **Purpose:** Increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** McNary, John Day, The Dalles, and Bonneville projects
- **Implementation:** Allow turbines to operate within and above 1% of peak efficiency. Operating to a higher capacity would increase generation and would increase turbine flow capacities which reduce the amount of lack-of-turbine spill. These effects will be evident in monthly and daily hydroregulation models. Further, the increased turbine capacity would increase the amount of within-day shaping for hydropower, which will be analyzed in hydropower impact modeling.
- **Frequency and Duration:** Currently, restrictions apply during fish passage season. This measure would not impose restrictions during juvenile fish passage season.
- **Intended Benefit (why include this measure?):** The primary benefit is increased turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water would be allowed to pass through the turbines, potentially reducing the incidence of high Total Dissolved Gas levels.

O7. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation.

At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.

- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of Sept target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meeting the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)

    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure O17 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O17.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O8. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.
- **Purpose:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Columbia River projects
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit (why include this measure?):** This measure increases the available capacity of hydrogeneration. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O9. When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

- **Specific Measure:** Update the existing Libby local Storage Reservation Diagram (SRD) to evacuate FRM space to an appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). During refill (generally Apr/May–July), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; and (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam
- **Implementation:** From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill will start on May 1st. When forecasts are above 6.9 MAF the proposed local SRD will require a deeper draft in January and February. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so

that local flood duration, along with the start of refill, is tied to the Kootenai River Basin**;** (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

- **Frequency and Duration:** All years, from Jan-July (greatest change would be seen in water years where the water supply forecast was less than 6.9 MAF for Libby).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operations by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery, while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements, and improve FRM operations for spring rain events in the Kootenay Basin.

O10. Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure**: Eliminate end-of-December variable draft at Libby and replace with single draft target (2,420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2,420, with allowance for additional draft of 20 feet below FRM elevation (2,400 feet elevation), instead of the current end of December variable target between 2,411 ft and 2,426.7 ft.
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O11. Update the upstream Storage Corrections Method as applied to the Grand Coulee (GCL) SRD.

- **Specific Measure:** The methodology differs conceptually from the current methodology. Rather than adjusting The Dalles (TDA) forecast to determine GCL FRM requirements as with the current methodology, the methodology utilizes the TDA forecast directly to determine the end of April draft requirement for GCL (figure 1) and requires a correction, in the form of a deeper draft target at GCL, when upstream storage reservoirs that fail to achieve their required drafts. It should be noted that the methodology only affects the FRM draft requirements of GCL and does not change the operation or draft requirements of any other project. The Grand Coulee FRM draft is based on four things: 1) The TDA forecast, 2) upstream storage reservoirs' required FRM draft or draft that is manageable and dependable for system flood risk management (called a Base Draft) 3) the in-season draft (actual) of upstream reservoirs in relation to the Base Draft and 4) the relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (Weighting Curves for certain projects). This is similar to the information used under the current methodology but the process of using it is different.

The basic concept of the Grand Coulee upstream storage adjustment methodology is depicted in Figure 1 as a two-step process. First, a Grand Coulee unadjusted April 30 FRM requirement is determined using the curve in Figure 1 and TDA forecast. The relationship assumes that each upstream storage project is drafted or projected to be drafted to its Base Draft by April 30. Second, an adjustment is made to the Grand Coulee April 30 required draft only if storage projects upstream of The Dalles have not been drafted to their Base Draft. If upstream projects are drafted deeper than their base draft no adjustments are made to the GCL draft or if all projects are on their base draft no adjustments will be made. Because upstream projects contribute in differing proportions to overall system FRM, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment. The adjustment is then added to the unadjusted GCL required draft based on the April 30 curve to yield the adjusted required April 30th GCL draft target.

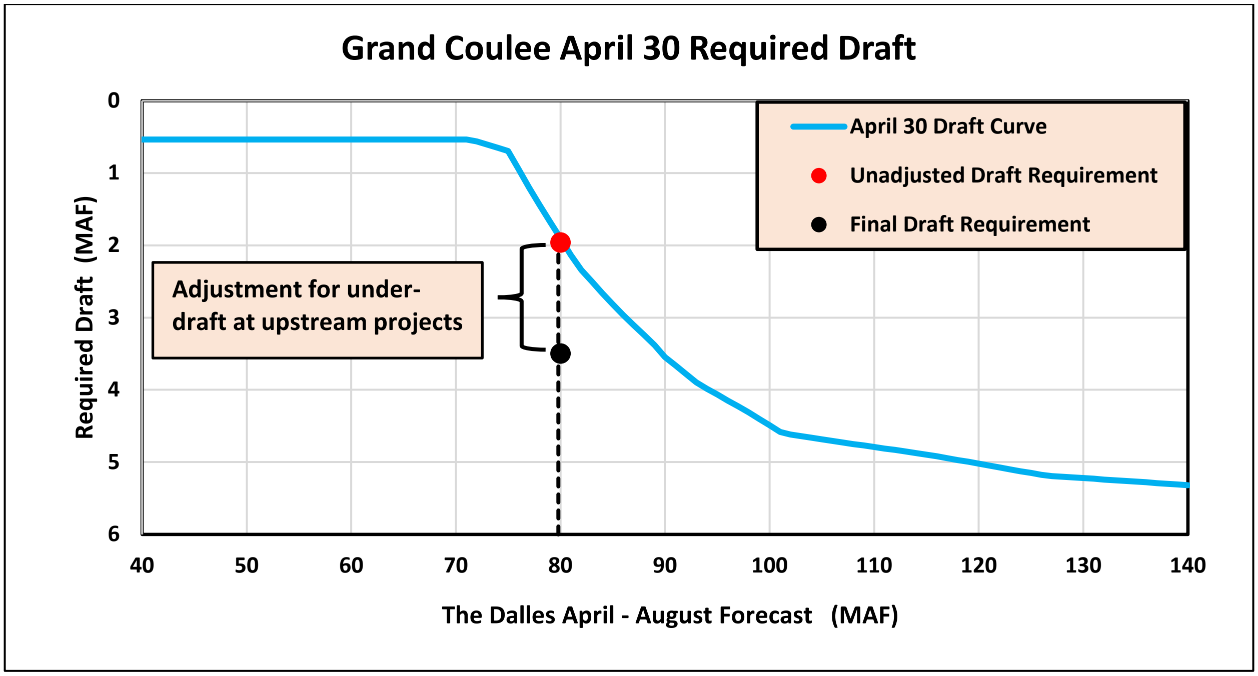

Figure 1 – Grand Coulee Unadjusted April 30 FRM Requirement

There are a number of specific differences between the current and proposed methods.

1. The fixed FRM draft requirements for John Day, SKQ, Noxon, and Albeni Falls are embedded in the new end-of-April draft requirement for GCL and are therefore not necessary in the adjustment process.
2. The 3.6 Maf cap on the Arrow FRM space was removed in the method.

3. Creditable refill checks on project space are not required because those checks are built into the Base Drafts, and the Weighting Factors.
4. The method does not allow adjustments for over-draft conditions.

- **Measure Location:** Grand Coulee Dam
- **Purpose:** To update GCL operations and ensure they are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** There are four main components that will be used to determine GCL end of month FRM requirements during the drawdown period (Jan-Apr) under the methodology; the GCL Unadjusted April 30 Draft Requirement Curve (GCL Curve), individual project Base Drafts, individual project Weighting Curves, and the GCL SRD. These will be developed, documented and incorporated into the model.
- **Frequency and Duration:** All years, January-April
- **Intended Benefit (why include this measure?):** The measure will provide a fully documented process that allows GCL to better respond to changes in upstream operations. The process will allow adaptation to possible future changes in management of reservoir space upstream of The Dalles Dam. It is the intent that this methodology will maintain a similar level of flood risk compared to the current practice and not significantly alter the magnitude and frequency of GCL water surface elevations given similar operations of upstream reservoirs.

O12. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce the probability of landslides. This is expected to have an ancillary benefit of reducing spill due to lack-of-market or lack-of-turbine-capacity during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O13. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more accelerated than current outages, to represent a broader range of possible hydraulic capacity during maintenance activities.
- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee Dam;
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O14. Increase volume of water pumped from Lake Roosevelt via the John W. Keys III Pumping Plant at the Grand Coulee project for increased deliveries to the Columbia Basin Project mostly during the annual irrigation season. The new volume of irrigation water would be

calculated by multiplying the 256,475 undeveloped acres by a delivery rate (4.5 acre-feet per acre) estimated by the Project staff to be needed for newly developed acres.

- **Purpose:** To divert water from the Columbia River for irrigation and municipal and industrial (M&I) uses.
- **Measure Location:** Grand Coulee Dam (Lake Roosevelt). This measure focuses only on the diversion of water from the Columbia River via Lake Roosevelt and does not account for increased return flows (i.e. non-consumptively used water that returns to the river) that may occur when delivering this water to the CBP.
- **Implementation:** Pump more water from Lake Roosevelt using the existing John W. Keys Pumping Plant, which was designed and constructed to have the capacity to provide the full water delivery for the original authorization of 1,029,000 acres. The additional pumping would include 1,154,138 acre-feet for irrigation. The total pumped volume wuld be delivered on demand.
- **Frequency and duration:** Annual, mostly during irrigation season which is generally from April 1 through October 30. Table 1 shows the estimated monthly and total annual additional pumped water from Lake Roosevelt. **Table 2 shows the estimated monthly and total annual pumped water from Lake Roosevelt.**
- **Intended Benefit (why include this measure?):** To provide water supply to an additional 256,475 authorized acres of irrigable land within the CBP for agricultural development.

Table 1-41: Annual additional pumping from Lake Roosevelt.

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
January	8	518
February	59	3,299
March	596	36,627
April	2,836	168,724
May	2,983	183,431
June	3,031	180,333
July	3,610	221,983
August	2,290	140,804

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
September	2,254	134,115
October	1,134	69,725
November	166	9,865
December	77	4,714
Total		1,154,138
Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)

Table 2: Total pumping from Lake Roosevelt including current operations, reshaping of Odessa Subarea and the additional water for Columbia Basin Project.

Month	**Diversion Flow Rate (cfs)**	**Diversion Volume (Acre-feet)**
January	32	1,984
February	227	12,627
March	2,282	140,299
April	10,901	648,641
May	11,537	709,384
June	11,784	701,210
July	14,060	864,482
August	8,949	550,235
September	8,722	518,980
October	4,367	268,503

November	634	37,753
December	293	18,042
Total		4,472,138

O15. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. . The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. For years where the flow augmentation draft is 10 feet, the end of September elevation would be 3546 feet. In years where the flow augmentation draft is 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.
- **Frequency and duration:** Irrigation season which is generally from April 1 through October 30. Table 4 shows the estimated monthly and total annual additional delivered water from the Flathead River.

Table 1-42: Estimated monthly diversion above Flathead Lake.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April		

May		
June		
July	493	30,313
August	493	30,313
September	494	29,395
October		
November	0	0
December	0	0
Total		*90,021*

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to provide 90,000 acre-feet of water for a settlement with CSKT. This water could be used for irrigation or municipal purposes.

O16. Increase water diversion from the Columbia River for the Chief Joseph Dam Project to supply an additional 9,600 acre-feet of irrigation water. Supply irrigation water throughout the irrigation season.

- **Purpose:** To divert water from the Columbia River for irrigation of authorized acres in the Chief Joseph Dam Project.
- **Measure Location:** On the Columbia River just below Chief Joseph Dam.
- **Implementation:** Deliver 9,600 acre-feet of water to authorized Chief Joseph Dam Project lands.
- **Frequency and duration:** Annually during the irrigation season. Table 5 shows the monthly estimated and total annual diversion from the Columbia River.

Table 1-43: Total water for additional Chief Joseph Dam Project lands.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0

Month	**Diversion Flow Rate (cfs)**	**Diversion Volume (acre-feet)**
February	0	0
March	0	0
April	3	179
May	19	1,168
June	42	2,499
July	50	3,074
August	34	2,091
September	7	417
October	2	123
November	0	0
December	0	0
Total		*9,550*

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to provide irrigation water to authorized acres in the Chief Joseph Dam Project for agricultural production.

1.12.29 Errata Sheet - Multiple Objective Three (MO3) Alternative, V4, November 1, 2018

Measure O7 has been revised to correctly reference measure O15. Currently measure O7 references O17 which does not exist in MO3.

O7. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has

been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:

  - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
  - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
  - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
  - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure O15 which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O15.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the

potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

Measure O15 has been revised to correctly describe the end of September draft point that will result with the combination of measure *07. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O15. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure *07. Implement sliding Scale summer draft at Libby and Hungry Horse*, for example if measure 07 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs. For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

Updates to measures were approved by CRSO NEPA Policy.

1.12.30 Errata Sheet - Multi-Objective Alternative 3, V4 January 11, 2019

*Changes to text indicated in *italics*.

Measure O3 was renamed (brought over from the Juvenile Focus SO) so that spill to 120% is analyzed, and is focused on the lower Columbia projects following the breaching of the four lower Snake River Dams. The measure now reads,

Measure O3 Manage Juvenile fish passage spill to not exceed 120% tailrace gas cap at all lower Columbia River Projects

- ***Specific Measure:*** *Increase juvenile fish passage spill.*
- ***Purpose:*** *Increase fish in-river and long-term survival.*
- ***Measure Location:*** *The four lower Columbia Dams*
- ***Implementation:*** *Spill would be as shown in the table below. The dams would spill to the gas cap to maximize spill passage efficiency (SPE) since the spillway is typically one of the highest survival routes. Although there may be areas where increasing SPE may negatively affect passage survival, any potential negative effects will be documented in the effects analysis.*

Location	***Spill Regime***
McNary	*120% tailrace Spill Cap**
John Day	*120% tailrace Spill Cap**
The Dalles	*120% tailrace Spill Cap**
Bonneville	*120% tailrace Spill Cap*, not to exceed 150 kcfs spill*

**The term "spill cap" refers to the maximum spill level at each project that is estimated to meet, but not exceed, the gas cap in the tailrace unless the spill cap is constrained (e.g.150 kcfs maximum spill for Bonneville Dam). In this measure, spill caps will be set to meet, but not exceed, the gas cap of 120% TDG as measured at the tailrace fixed monitoring stations. This gas cap is consistent with the current Oregon TDG water quality standard modification and with the Washington TDG water quality standard criteria adjustment as measure at the tailrace. This measure is not consistent with the Washington TDG water quality criteria adjustment for measuring TDG at the forebay, which is 115% TDG. For the analysis of this measure, the spill caps will be set in a manner that accounts for the different methodologies the states of Washington and Oregon use to ascertain compliance with their respective standards.*

This change approved by the NEPA Policy team on Dec. 27, 2018

Measure O9 was changed to remove language related to drafting deeper in January – February at Libby. The measure now reads:

Measure O9: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change approved in a call with the NEPA Policy Team held January 3, 2019

Measure O7 has been revised to correctly reference measure O15. Currently measure O7 references O17 which does not exist in MO3. In addition, numbers in the Forecast Line of each table (Libby and Hungry Horse) have been updated.

O7. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
    - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
    - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
- The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum

    ramp down rate for this period)

    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April- August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O15* which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure *O15*.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O11 was modified to **remove the figure**. The text of the measure reads the same, but the figure is removed.

Measure O15 has been revised to correctly describe the end of September draft point that will result with the combination of measure *07. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O15. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure 07. Implement sliding Scale summer draft at Libby and Hungry Horse, for example if measure 07 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs.* For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

1.12.31 Errata Sheet - Multi-Objective Alternative 3, V4 February 21, 2019

*Changes to text (January 2019) indicated in *italics*.

*Changes to text (February 2019) indicated in yellow

Measure S3 Construct powerhouse surface passage at McNary was changed to remove specific dates of spill (an operation) for a measure that proposes construction. The **Frequency and Duration** section now reads:

Frequency and Duration: In operation during fish spill season.

Measure O3 was renamed (brought over from the Juvenile Focus SO) so that spill to 120% is analyzed, and is focused on the lower Columbia projects following the breaching of the four lower Snake River Dams. The measure now reads,

Measure O3 Manage Juvenile fish passage spill to not exceed 120% tailrace gas cap at all lower Columbia River Projects

- ***Specific Measure:*** *Increase juvenile fish passage spill.*
- ***Purpose:*** *Increase fish in-river and long-term survival.*
- ***Measure Location:*** *The four lower Columbia Dams*
- ***Implementation:*** *Spill would be as shown in the table below. The dams would spill to the gas cap to maximize spill passage efficiency (SPE) since the spillway is typically one of the highest survival routes. Although there may be areas where increasing SPE may negatively affect passage survival, any potential negative effects will be documented in the effects analysis.*

Location	Spill Regime
McNary	120% tailrace Spill Cap*
John Day	120% tailrace Spill Cap*
The Dalles	120% tailrace Spill Cap*
Bonneville	120% tailrace Spill Cap*, not to exceed 150 kcfs spill

**The term "spill cap" refers to the maximum spill level at each project that is estimated to meet, but not exceed, the gas cap in the tailrace unless the spill cap is constrained (e.g.150 kcfs maximum spill for Bonneville Dam). In this measure, spill caps will be set to meet, but not exceed, the gas cap of 120% TDG as measured at the*

> *tailrace fixed monitoring stations. This gas cap is consistent with the current Oregon TDG water quality standard modification and with the Washington TDG water quality standard criteria adjustment as measure at the tailrace. This measure is not consistent with the Washington TDG water quality criteria adjustment for measuring TDG at the forebay, which is 115% TDG. For the analysis of this measure, the spill caps will be set in a manner that accounts for the different methodologies the states of Washington and Oregon use to ascertain compliance with their respective standards.*
>
> This change approved by the NEPA Policy team on Dec. 27, 2018

Measure O5b was modified to change the lower limit elevation for John Day Pool to Minimum Operating Pool elevation. The lower limit operation was changed from 257.0 to 262.5.

Frequency and Duration: Currently, John Day pool is restricted to operating within 1.5 feet above MIP during the fish passage season (April – September). With this measure, this restriction will not be put into place at any time of year, so the pool will operate between elevations *262.5* – 266.5 ft. all year, except as needed for flood risk management.

This change approved by the NEPA Policy team on February 7, 2019

Measure O9 was changed to remove language related to drafting deeper in January – February at Libby. The measure now reads:

Measure O9: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change approved in a call with the NEPA Policy Team held January 3, 2019

Measure O7 has been revised to correctly reference measure O15. Currently measure O7 references O17 which does not exist in MO3. In addition, numbers in the Forecast Line of each table (Libby and Hungry Horse) have been updated.

O7. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
  - Target 2.5 ft above the end of September elevation on August 31st.
  - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
  - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
- The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
  - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
  - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
  - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
  - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.

- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April- August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O15* which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure *O15*.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O9 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill timing will be tied to Kootenai River Basin runoff. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the s sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. (Removes reference to January and February drafts).

This change was approved in a call with NEPA Policy staff held on January 3, 2019

Measure O11 was modified to **remove the figure**. The text of the measure reads the same, but the figure is removed.

Measure O15 has been revised to correctly describe the end of September draft point that will result with the combination of measure *07. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O15. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure 07, Implement sliding scale summer draft at Libby and Hungry Horse. For example, if measure 07 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs.* For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water

released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

1.12.32 Alternative: Multi-Objective 4 Detailed Description

CRSO Objective(s): This alternative is included to evaluate its ability to meet all or part of the following objectives:

- Improve ESA-listed anadromous salmonid juvenile fish rearing, passage, and survival within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management.
- Improve ESA-listed anadromous salmonid adult fish migration within the CRSO project area, through actions including but not limited to project configuration, flow management, spill operations, and water quality management
- Improve ESA-listed resident fish survival and spawning success at CRSO projects through actions including but not limited to, project configuration, flow management, improving connectivity, project operations, and water quality management.
- Provide an adequate, efficient, economical, and reliable power supply that supports the integrated CR Power System.
- Minimize greenhouse gas emissions from power production in the Northwest by generating carbon-free power through a combination of hydropower and integrations of other renewable energy sources.
- Maximize operating flexibility by implementing updated, adaptable water management strategies to be responsive to changing conditions, including hydrology, climate, and environment.
- Meet existing contractual water supply obligations and provide for authorized additional regional water supply.

Additionally, the following secondary objective was considered during development of this alternative:

- Improve conditions for the lamprey within the CRSO project area through actions potentially including, but not limited to project configurations, flow management, spill operations, and water quality management.

The following measures address the objective(s):

<u>Structural Measures:</u>

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S1. Construct additional powerhouse surface passage routes to meet system-wide PITPH target.

- **Purpose:** May divert fish away from turbines and into a higher survival route, reduce exposure to screens, and reduce forebay delay. May also support kelt downstream passage.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and/or John Day dams.
- **Implementation:** This measure would require diversion of 4-20 kcfs flow from powerhouse routes for operation of the new structures from March 1 to August 31.
    - Lower Granite: Install surface passage through the Lower Granite powerhouse by 2025.
    - Little Goose: Install surface passage through the Little Goose powerhouse by 2023 (Priority project for PITPH reduction)
    - Lower Monumental: Install surface passage through the Lower Monumental powerhouse, by 2029
    - Ice Harbor: Install surface passage through the Ice Harbor powerhouse, by 2031 if at all.
    - McNary: Install surface passage through the McNary powerhouse, by 2023
    - John Day: Install surface passage through the John Day powerhouse, by 2025
- **Frequency and Duration:** March 1 – August 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce juvenile powerhouse encounter rate, allow increased kelt downstream passage, increase juvenile salmon and steelhead survival through the lower Snake river and lower Colmbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

S2. Improve adult ladder passage through modification of adult trap and adult trap bypass loop at Lower Granite Dam

- **Purpose:** Reduce passage time for adult salmonid as they move upstream through the fish ladder and allow volitional downstream passage through the ladder.
- **Measure Location:** Lower Granite Dam
- **Implementation:** Reconfigure adult trap bypass to reduce head, thus reducing the height diverted adults must ascend; reduce deployment of the main ladder diversion gate; and use a vacuum tube to move handled adults.
- **Frequency and Duration:** Year round while ladder in operation

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by reducing upstream travel times and higher conversion rates.

S3. Install pumping systems to provide deeper (cooler) water in adult fish ladders at Lower Monumental and Ice Harbor dams

- **Purpose**: Reduce passage delays at the fish ladders so adults pass more quickly upstream.
- **Measure Location:** Lower Monumental and Ice Harbor dams
- **Implementation:** Provide cooler water to the fish ladders by installing pumps and pipe systems that move cooler water into the ladders from depth. Replicate the existing Little Goose design for Ice Harbor and Lower Monumental.
- **Frequency and Duration:** June 15 through September 15
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult salmon and steelhead survival by reducing the temperature differential between tailrace and ladder entrances (from surface water warming), which may minimize thermal barriers and adult passage delays.

S4. Install new “fish-friendly” and high-efficiency/capacity turbines at John Day.

- **Purpose:** Improve turbine fish passage conditions and hydropower turbine efficiency and capacity
- **Measure Location:** John Day
- **Implementation:** Replace turbines with new improved units two at a time.
- **Frequency and Duration:** Installation of two units at a time.
- **Intended Benefit (why include this measure?):** Improved turbine fish passage conditions, improved hydropower turbine efficiency and capacity, and improved water quality (TDG).

S5. Expand network of Lamprey Passage Structures (LPS) to bypass impediments in existing fish ladders

- **Specific Measure:** Install new Lamprey Passage Structures (LPS) and add additional LPS at existing locations.
- **Purpose:** The purpose is to help Lamprey pass the project using a different route than the fish ladders.

- **Measure Location:** Additional structures at Bonneville, The Dalles, and John Day, projects.
- **Implementation:** Construct new Lamprey Passage Structures as follows:
    - **Bonneville**: Construct additional LPS on the south ladder and at the south entrance to the north ladder.
    - **The Dalles:** Add diffuser grating plating on the diffuser in the north ladder.
    - John Day: Add LPS to the south ladder and extend North LPS to the forebay.
- **Frequency and Duration:** Construct once.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase adult lamprey passage success.

S6. Modify turbine intake bypass screens that cause juvenile lamprey impingement and entanglement

- **Specific Measure:** Modify or replace fish screens to prevent lamprey impingement
- **Purpose:** Reduce lamprey mortality from impingement in fish screens.
- **Measure Location:** McNary project, Little Goose project, and Lower Granite project (Projects with Extended length submerged bar screens (ESBS)).
- **Implementation:** Modify or replace fish screens at the dams with screens that have tighter spacing to prevent lamprey from being caught in the screens.
- **Frequency and Duration:** Construct once, install annually.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce lamprey mortality from impingement in fish screens.

S7. Modify existing fish ladders, incorporating lamprey passage features and criteria into ladder modifications

- **Specific Measure:** Identify, design, and install modifications to improve adult lamprey passage through existing fish ladders.
- **Purpose:** Aid lamprey in finding, entering, and passing through the adult fish ladders.
- **Measure Location:** Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite
- **Implementation:** Design and install modifications to improve passage through existing fish ladders.

  - **Bonneville**: Install ramps to elevated salmon orifices in south ladder; diffuser grating plating on diffuser in south and Cascade island ladders; refuge boxes in north and south ladders; and wetted wall in north ladder serpentine section.
  - **The Dalles:** Install diffuser grating plating on diffuser in north ladder.
  - **McNary**: Install entrance weir caps at north and south ladders.
  - **Ice Harbor:** Install entrance passage structure at south ladder, and entrance weir caps at north and south ladders.
  - **Lower Monumental:** Install diffuser grating plating in the north and south ladders, and entrance weir caps at the north and south ladders.
  - **Little Goose:** Install entrance weir caps at the south ladder.
- **Lower Granite project:** Install entrance weir caps at the south ladder.
- **Frequency and Duration:** Dependent on additional information (see note).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve adult lamprey passage through fish ladders.

S8. Addition of spillway weir notch gate inserts.

- **Specific Measure:** Addition of spillway weir notch gate inserts.
- **Purpose:** Increase survival of adult steelhead overshoots, overwintering steelhead, and steelhead kelts as they move downstream through the projects, spilling more efficiently (2-3 kcfs) than an entire spillway weir amount of flow (approx. 8-10 kcfs).
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day dams**.**
- **Implementation:** Modify one existing spillway weir per dam with notch gate inserts (see locations above). In each notch gate insert, water passes through a picture frame shaped gate that is opened in the top 22’ of the gate (versus the entire gate). The notch gate measures 12’ wide x 22’ tall, and gates provide 1.8-2.6 kcfs of flow (assume an average 2.2 kcfs flow for modeling purposes).
- **Frequency and Duration:**
  - Lower Columbia River dams: October 1 – November 31
  - Lower Snake River dams: October 1 – November 31
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by decreasing downstream passage mortality of adult steelhead while minimizing the effect on hydropower generation.

Operational Measures:

O1. Use spill through existing surface passage structures for steelhead overshoots, overwintering steelhead and kelt downstream passage

- **Purpose:** Increase survival of adult steelhead overshoots, overwintering steelhead, and steelhead kelts as they move downstream through the projects.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day dams
- **Implementation:** Modify one existing spillway weir per dam (see locations above) with a spillway weir insert to provide efficient downstream passage, assuming approximately 2 kcfs spill at each dam with the addition of these spillway weir inserts (See also Structural Measure S8 above).
- **Frequency and Duration: October 1 – November 31**
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase adult salmon and steelhead survival by decreasing downstream passage mortality of adult steelhead while minimizing the effect on hydropower generation.

O2. Low powerhouse encounter rate (high spill) during spring emigration period.

- **Specific Measure**: Allow variable spillway and powerhouse surface passage efficiencies at individual projects, that collectively achieve a low system-wide powerhouse encounter rate, targeting increased SARs. Implement under an experiemental context (spring spill test) to validate Comparative Survival Study (CSS) life cycle modeling. Compare two spring juvenile fish passage spill operations, between a base spill operation and reduced powerhouse encounter rate operation. The base spill operation represents spill operations realized between 2008 and 2017 operations. The reduced powerhouse encounter rate (PITPH) operation is spill and/or powerhouse surface passage at each project sufficient to achieve a system-wide PITPH of 0.44 (system-wide SPE of 0.945). A consensus experimental design will establish frequency, duration, pattern, sample size, and analytical framework (e.g. before/after, blocked, etc).
- **Purpose:** Increase SARs to meet regional goals. In addition, validate CSS life cycle model predictions associated with powerhouse encounter rate (PITPH) in a manner that provides for robust statistical results.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville dams.
- **Implementation:** This operation is not meant to supercede other operations in this alternative. When measures O2 or O3 are in effect, O1 is a subset of that spill. Coordination should occur to make sure the timing of this operation is consistent with other operations in the alternative.

Location	Spring Reduced Powerhouse Encounter Rate Operation: system-wide spill passage efficiency of 0.44 (project specific Spill Passage Efficiency)*
Lower Granite	0.945
Little Goose	0.945
Lower Monumental	0.945
Ice Harbor	0.945
McNary	0.945
John Day	0.945
The Dalles	0.945
Bonneville	0.945

*Current Oregon and Washington water quality standards of 120% or 120/115% TDG restrict this operation; temporary/experimental standards should be requested to manage TDG up to 125% in tailrace and eliminate forebay standards.

- **Frequency and Duration:** Annually implemented from March[10] 1st – June 10th for the Lower Snake River projects and from March 25th – June[11] 20th for the Lower Columbia River projects. Duration of paired operational conditions contingent upon consensus study design and result-based adaptive management decisions (likely implementation year 10 or 14). Transition to reduced powerhouse encounter rate (PITPH) operation annually over entire spring migration period after completion of evaluation, assuming positive fish results.
- **Intended Benefit (why include this measure?)**: Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to quantify the effectiveness of reducing powerhouse encounters and likelihood of increasing adult abundance. Regional entities have established abundance-based escapement goals that meet ESA-delisting minimum abundance thresholds, sustainable harvest, and/or ecological escapement. Meeting the abundance goals requires an average SAR of 4% (NPCC FWP Goal 2-6%). The CSS 2017 report estimated Snake Basin populations would achieve an average SAR of 4% when emigrating juveniles experienced a PITPH of 0.44 (approximately 125% TDG level in an average flow year). Achieving a system-wide PITPH of 0.44 requires an average project specific spill passage efficiency (SPE) of 0.945 (individual project SPE can vary). NOAA's blocked spill power analysis showed an affect size of at least 75% was needed in order to detect a statistical difference after approximately 6 years of treatments. CSS modeling of 125% spill level indicated approximately 78% increase in SARs over 2008/14 BiOp conditions.

O3. Transitional summer juvenile fish passage spill operations.

- **Specific Measure:** Initiate summer spill consistent with 2014 BiOp operations at end of spring spill period (~June 10th for Snake River projects and ~ June[12] 20th for lower Columbia River projects), reduce spill at Snake River project to RSW/TSW and/or pending powerhouse surface passage collectors August ~ 15th.
- **Purpose:** Provide fish surface passage route alternative for summer migrants, with decreased spill volume for Snake and Lower Columbia projects after August 15th. Increased power generation flow.

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[10] Adjust based on 2018 injunctive early operations data to capture 99% of spring migrant emigration period.

[11] Adjust based on applied block study emigration timing.

[12] Adjust based on applied block study emigration timing.

- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville dams.
- **Implementation:** This operation is not meant to supercede other operations in this alternative. When measures O2 or O3 are in effect, O1 is a subset of that spill. Coordination should occur to make sure the timing of this operation is consistent with other operations in the alternative.

Location	Initial Summer Spill Operation: Volume/Percent of Total Flow Routed to Spillway	Late Summer Transitional Spill Operation: Volume/Percent of Total Flow Routed to Spillway*
Lower Granite	18 kcfs	RSW 7-10 kcfs
Little Goose	30%	ASW 7-10 kcfs
Lower Monumental	17 kcfs	RSW 7-10 kcfs
Ice Harbor	30%	RSW 8-11 kcfs
McNary	57%	Two non-RSW spillbays
John Day	35%	Two TSW ~20 kcfs
The Dalles	40%	Sluiceway and 30% spill
Bonneville	95 kcfs	Conner Collector and 50kcfs

*Allocation of non-powerhouse flows between spillway and powerhouse surface passage collectors to be determined.

- **Frequency and Duration:** Annually implemented from ~June 10th – August 31st for the Lower Snake River projects and from June 20th – August 31st for the Lower Columbia River projects.
- **Intended Benefit (why include this measure?)**: Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to maintain fall Chinook survival rates and increase power generation.

O4. Allow contingency reserves to be carried within juvenile fish passage spill.

- **Specific measure:** Hydropower operations may count unused turbine capacity as contingency reserves even if the water needed for that contingent generation would come from water that is used for fish passage spill.

- **Purpose:** Enables turbines to operate at a higher capacity.
- **Measure Location:** Lower Snake River and lower Columbia River project.
- **Implementation:** Incremental and decremental reserves which are deployed routinely would be maintained without any reliance on fish passage spill. However, contingency reserves could be held by generation that relies on water allocated to juvenile fish passage spill.
- **Frequency and Duration:** Juvenile fish passage season.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure increases the available capacity of hydro-generation. Because contingency reserves are rarely deployed, it would increase hydropower generation not to require contingency reserves to be carried only with capacity that does not rely on using the water for fish passage spill. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place.

O5. Implement juvenile fish transportation during spring and fall periods

- **Purpose:** Transport all juvenile salmonids entering the juvenile fish bypasses at collector projects downstream to below Bonneville for release.
- **Measure Location:** Lower Granite, Little Goose, and Lower Monumental dams.
- **Implementation:** Transport all fish entering fish bypasses at the collector projects past the downstream hydrosystem to the below Bonneville release site.
- **Frequency and Duration:** April 25 - June 14, August 16 – November 15
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase juvenile salmon and steelhead survival under spill conditions designed for adult salmon and steelhead passage.

O6. Cease juvenile transport during portions of summer spill period.

- **Specific Measure:** Do not operate the juvenile transport facilities June 15 to August 15.
- **Purpose:** Reduce cost of transportation program during periods that show little to no benefit to adult returns.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental dams
- **Implementation:** No juvenile fish transportation at Lower Granite, Little Goose, or Lower Monumental. All juvenile fish entering the fish bypasses are returned to the river to migrate and are not transported.
- **Frequency and Duration:** June 15 – August 15

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to decrease cost of transportation program and either maintain or increase adult fall Chinook abundance.

O7. Strive to maintain minimum 220 kcfs spring flow objective at McNary from May 1 – June 15 and minimum 200 kcfs summer flow objective at McNary from June 16 – July 31 through the use of four U.S. storage reservoirs, up to a maximum of 2.0 Million acre-feet (Maf).

- **Specific Measure:** Discharge up to 2.0 Maf additional water from U.S. storage reservoirs between May 1 – June 15 to meet spring flow objective at McNary dam. If the additional flow augmentation from U.S. reservoirs has not reached Maf by June 15th, use the remaining volume to try to achieve the summer flow objective at McNary dam until July 31.
- **Purpose:** Lessen the impact of drier-than-normal juvenile salmon and steelhead outmigration periods by raising flows in the lower Columbia River during outmigration.
- **Measure Location:** Libby, Hungry Horse, Albeni Falls, and Grand Coulee Dams.
- **Implementation:** This measure would be implemented in years when the April issued April-August water supply forecast for The Dalles is below 87.5 Maf. This measure would be accomplished by operating Grand Coulee to target McNary Dam outflows described below. Grand Coulee will be allowed to draft to meet the target, but can only go as deep as minimum pool. Libby, Albeni Falls and Hungry Horse will backfill water to Grand Coulee by targeting a reduced fill elevation (i.e. this measure will result in a change in end-of-refill period reservoir elevations). To conserve the volume of water available, no more than 40 kcfs of flow augmentation shall be released on a given day. Current Canadian operations will be maintained (flow augmentation in Treaty and Non-Treaty agreements). Local resident fish ops will be maintained (e.g. minimum flows for resident fish, sturgeon pulse) unless they are maximum flows or minimum reservoir elevations, which could conflict with this measure and would be removed. Projects providing summer flow augmentation in the No Action alternative will operate with same draft targets, but those targets will be adjust lower by the augmentation volume provided by this measure, meaning they may end the summer at a lower elevation. If the 2.0 Maf of flow augmentation specified in this measure is not fully used during the spring, the projects may provide summer flow augmentation in addition to flows specified in the No Action Alternative. Projects will provide a percentage of the flow augmentation based on their total storage capacity.
- **Frequency and Duration:** This measure would be implemented in years when the April issued April-August water supply forecast for The Dalles is below 87.5 Maf. Between May 1 - July 31, strive to maintain minimum flows at McNary of 220 kcfs spring (May 1-June 15) and 200 kcfs summer (June 16-July 31) using up to 2.0 Maf additional volume discharged from four U.S. reservoirs.

- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, and reduce in-river travel times.

O8. Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for outmigration

- **Purpose:** Reduce water particle time through the reservoirs.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams
- **Implementation:** Draw down the reservoir elevation, still allowing turbines to operate sustainably without cavitation issues and adjusting for safe navigation:
    - Bonneville: MOP (forebay elevation 71.5’ + 1.5’ operating range above MOP)
    - The Dalles: MOP (forebay elevation 155’ + 1.5’ operating range above MOP) John Day: MOP (forebay elevation 257’ + 1.5’ operating range above MOP)
    - McNary: MOP (forebay elevation 335’ + 1’ operating range above MOP)
    - Ice Harbor: MOP (forebay elevation 437’ + 1.5” operating range above MOP)
    - Lower Monumental: MOP (forebay elevation 540’ + 1.5’ operating range above MOP)
    - Little Goose: MOP (forebay elevation 638’ + 1.5’ operating range above MOP)
    - Lower Granite: MOP (forebay elevation 738’ + 1.5’ operating range above MOP)
- **Frequency and Duration:** March 15 (lower Snake River Dams)/March 25 (lower Columbia River Dams) through August 15
- **Intended Benefit:** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survival of smolts entering the estuary, and increase adult returns.

O9. Operate turbines within and above 1% of peak efficiency during juvenile fish passage season.

- **Specific Measure:** Allow turbine operation within and above 1% of peak efficiency.
- **Purpose:** Increase hydro flexibility. This is particularly valuable during high flow periods when flow exceeds turbine capacity. In those situations, it will be possible to generate more by operating to the maximum turbine limits.
- **Measure Location:** Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville dams
- **Implementation:** Allow turbines to operate within and above 1% of peak efficiency. Operating to a higher capacity would increase generation and would increase turbine flow capacities which reduce the amount of lack-of-turbine spill. These effects will be evident in monthly and daily hydroregulation models. Further, the increased turbine capacity would increase the amount of within-day shaping for hydropower, which will be analyzed in hydropower impact modeling. Implementation would be integrated/balanced with 1% exceedance for contingency reserves.
- **Frequency and Duration:** Currently, restrictions apply during juvenile fish passage season. This measure would not impose restrictions during juvenile fish passage season.
- **Intended Benefit (why include this measure?):** The primary benefit is increased turbine range and increased turbine capacity. A secondary benefit is that during high flows, more water would be allowed to pass through the turbines, potentially reducing the incidence of high Total Dissolved Gas levels.

O10. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate local forecast. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
  - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
  - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (maf)	<4.8	<=4.8	5.1	7.2	>=7.7	>7.7
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking of flows and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of Sept elevation that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before Sept 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout.
    - Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon pulse has been expended and through September 30th.
- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum

Forecast (maf)	<1203.3	<=1203.3	1349.8	>1349.8
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure O7 and O19, which are intended to represent an additive draft from Hungry Horse for augmenting flow in the spring and summer at McNary and for the purposes of water supply, respectively. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of up to ~250 kaf for McNary Augmentation measure O7 and 90 kaf for water supply measure O20.
- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

O11. When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

- **Specific Measure:** Update the existing Libby local Storage Reservation Diagram (SRD) to evacuate FRM space to an appropriate depth based upon local, Kootenai River Basin forecast during reservoir drawdown months (generally Jan-Apr). During refill (generally Apr/May–July), modify VarQ refill flow calculation so that it (1) modifies past release calculation to occur in real time; (2) takes into account planned sturgeon volume release before it occurs, thereby eliminating "double-accounting;" (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; and (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Purpose:** Improved management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility in releases in the spring and summer.
- **Measure Location:** Libby Dam

- **Implementation:** From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill will start on May 1st. When forecasts are above 6.9 MAF the proposed local SRD will require a deeper draft in January and February. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin**;** (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.
- **Frequency and Duration:** All years, from Jan-July (greatest change would be seen in water years where the water supply forecast was less than 6.9 MAF for Libby).
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operations by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery, while providing better management of outflow temperature desired for the sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements, and improve FRM operations for spring rain events in the Kootenay Basin

O12.Eliminate end-of-December variable draft at Libby and replace with single draft target to mitigate for potential over-drafting of reservoir in years that become more dry than forecasted and increase water managers' ability to adapt to a wide range of runoff conditions during remainder of water year. Single draft target elevation would be elevation 2,420 feet.

- **Specific Measure:** Eliminate end-of-December variable draft at Libby and replace with single draft target (2420 ft elev.)
- **Purpose:** Mitigate for potential over-drafting of reservoir in years that turn out to be more dry than forecasted. For most years, would allow the timing of the draft to be shifted from November-December into January-February instead.
- **Measure Location:** Libby Dam
- **Implementation:** Operational change: target a single end of December FRM elevation of 2420 instead of the current end of December variable target between 2411 ft and 2426.7 ft
- **Frequency and Duration:** All years, affects flows in December (could be higher or lower) and January (could be higher or lower)
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, end-of-December reservoir elevation of 2420 ft, when coupled with proposed SRD for Libby that drafts deeper in

dry years, positions the reservoir to be adaptable to a wide range of runoff conditions during remainder of water year. Reduces frequency of spill which negatively impacts resident fish with high TDG levels. Deeper drafts in below average years also allows for reduced residence time of reservoir to support nutrient delivery and availability in reservoir inflow and better management of outflow temperature during sturgeon flow augmentation operation.

O13. Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD.

- **Specific Measure:** The methodology differs conceptually from the current methodology. Rather than adjusting The Dalles (TDA) forecast to determine GCL FRM requirements as with the current methodology, the methodology utilizes the TDA forecast directly to determine the end of April draft requirement for GCL (figure 1) and requires a correction, in the form of a deeper draft target at GCL, when upstream storage reservoirs that fail to achieve their required drafts for whatever reason. It should be noted that the methodology only affects the FRM draft requirements of GCL and does not change the operation or draft requirements of any other project. The Grand Coulee FRM draft is based on four things: 1) The TDA forecast, 2) upstream storage reservoirs' required FRM draft or draft that is manageable and dependable for system flood risk management (called a Base Draft) 3) the in-season draft (actual) of upstream reservoirs in relation to the Base Draft and 4) the relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (Weighting Curves for certain projects). This is similar to the information used under the current methodology but the process of using it is different. The basic concept of the Grand Coulee upstream storage adjustment methodology is depicted in Figure 1 as a two-step process. First, a Grand Coulee unadjusted April 30 FRM requirement is determined using the curve in Figure 1 and TDA forecast. The relationship assumes that each upstream storage project is drafted or projected to be drafted to its Base Draft by April 30. Second, an adjustment is made to the Grand Coulee April 30 required draft only if storage projects upstream of The Dalles have not been drafted to their Base Draft. If upstream projects are drafted deeper than their base draft no adjustments are made to the GCL draft or if all projects are on their base draft no adjustments will be made. Because upstream projects contribute in differing proportions to overall system FRM, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment. The adjustment is then added to the unadjusted GCL required draft based on the April 30 curve to yield the adjusted required April 30th GCL draft target. In addition to the methodology changes proposed in this measure, this measure also removes the "flat spot" from the GCL SRD and replaces it with a consistently increasing flood risk draft for all forecast ranges. The "flat spot" is a portion of the current GCL SRD that targets a maximum draft point to 1220 ft (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 MAF.

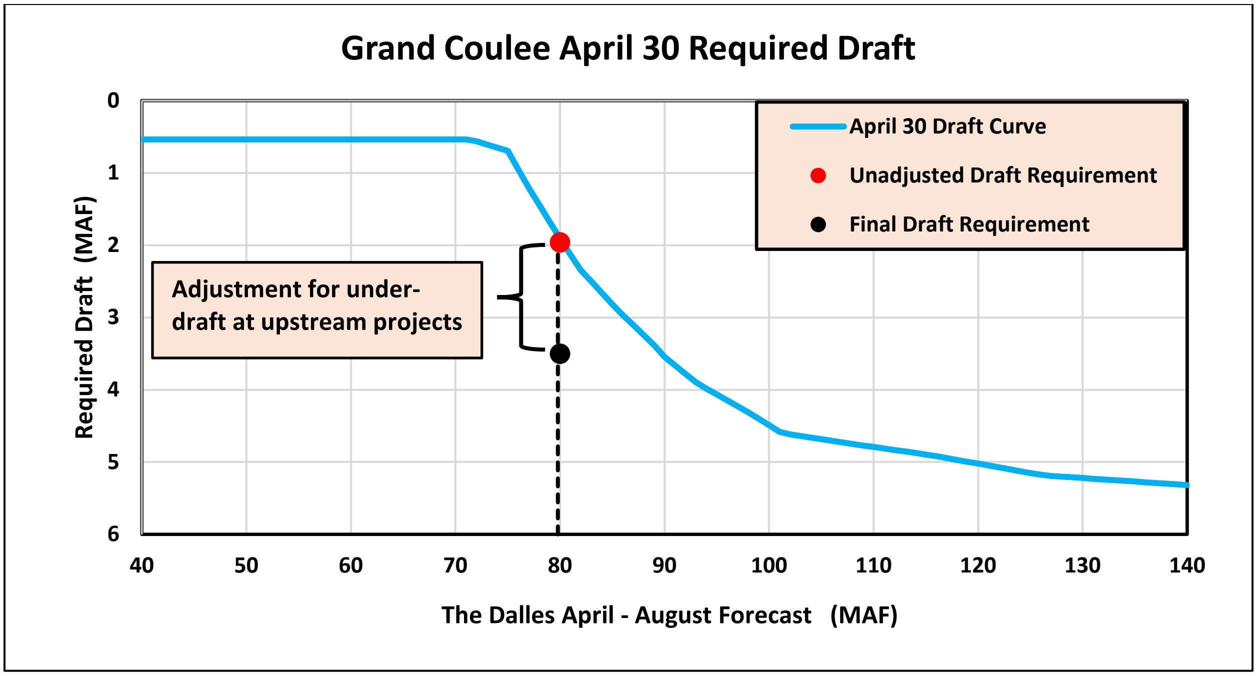

Figure 1 – Grand Coulee Unadjusted April 30 FRM Requirement

There are a number of specific differences between the No Action operation and this proposed measure.

1. The fixed FRM draft requirements for John Day, SKQ, Noxon, and Albeni Falls are embedded in the new end-of-April draft requirement for GCL and are therefore not necessary in the adjustment process.
2. The 3.6 Maf cap on the Arrow FRM space was removed in the method.
3. Creditable refill checks on project space are not required because those checks are built into the Base Drafts, and the Weighting Factors.
4. The method does not allow adjustments for over-draft conditions.
5. The GCL SRD is modified to remove the non-increasing draft elevation for adjusted forecasts between 80 and 95 MAF, referred to as the “flat spot”.

- **Purpose:** To update GCL operations and ensure they are adaptable to a wide range of upstream storage conditions.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** There are four main components that will be used to determine GCL end of month FRM requirements during the drawdown period (Jan-Apr) under the methodology; the GCL Unadjusted April 30 Draft Requirement Curve (GCL Curve), individual project Base Drafts, individual project Weighting Curves, and the GCL SRD. These will be developed, documented and incorporated into the model.
- **Frequency and Duration:** All years, January-April

- **Intended Benefit (why include this measure?):** The measure will provide a fully documented process that allows GCL to better respond to changes in upstream operations. The process will allow adaptation to possible future changes in management of reservoir space upstream of The Dalles Dam. It is the intent that this methodology will maintain a similar level of flood risk compared to the current practice and not significantly alter the magnitude and frequency of GCL water surface elevations given similar operations of upstream reservoirs.

O14. Decrease the Grand Coulee Dam draft rate used in planning drawdown (in the Storage Reservation Diagram (SRD)) to 0.8 feet/day. This will result in drawdown to meet flood risk drafts to begin a few weeks earlier. This measure is not intended to change the current maximum draft rate limits of 1 to 1.5 feet/day, but rather, by decreasing the rate at which the reservoir is planned to draft, will reduce the likelihood of real-time exceedances of the maximum draft rate of 1 to 1.5 feet/day.

- **Specific Measure:** Decrease the Grand Coulee Dam draft rate applied to the SRD to 0.8 ft/day.
- **Purpose:** To reduce the risk of landslide activity around Lake Roosevelt due to rapid drawdowns.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Modify the SRD to plan for a 0.8 ft/day draft rate at Grand Coulee. This does not imply that the real-time operational drawdown limit will change; it will remain at 1 to 1.5 ft/day.
- **Frequency and Duration:** This will be implemented as part of the SRD and will therefore apply from winter to spring.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to reduce the probability of landslides. This is expected to have an ancillary benefit of reducing spill due to lack-of-market or lack-of-turbine-capacity during drawdown by starting draft earlier and reducing the need to discharge large amounts of water late in the drawdown period to reach flood risk management draft elevations.

O15. Operational constraints for ongoing Grand Coulee maintenance of power plants and spillways.

- **Specific Measure:** This measure is a limitation on available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam. The maintenance measure described here is more accelerated than current outages, to represent a broader range of possible hydraulic capacity during maintenance activities.

- **Purpose:** Represent hydraulic capacity limitations associated with maintenance activities at Grand Coulee Dam. Over the next 20-yrs, Grand Coulee Dam and Powerplant Facilities will require replacement or modernization of aging equipment to mitigate increasing risks of equipment failure, reduced unit availability and reliability. These efforts will require extended outages (>1-yr) for multiple generating units across the project.
- **Measure Location:** Grand Coulee Dam
- **Implementation:** Hydraulic capacity is assumed to be limited for the period of analysis. While in reality, as maintenance occurs, there will be improved reliability and hydraulic capacity.
- **Frequency and Duration:** Continuous limitation of hydraulic capacity for the period of analysis. The modernization period for Grand Coulee power plants will extend to over 10-yrs (FY19-30) during which time increasing equipment condition degradation will increase the likelihood of forced unit outages and reduced hydraulic capacity through the units.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to improve safety, reliability and capacity of power plants and spillways at Grand Coulee Dam, which are facing increasing risks of equipment failure, reduced unit availability and reliability due to age and wear-and-tear.

O16. Develop draft requirements or an assessment approach to protect against rain-induced flooding.

- **Specific measure:** Increase drafted space available at Grand Coulee for implementing winter operations. Grand Coulee, Albeni Falls and Dworshak Dams will operate to protect against rain-induced flooding at Vancouver and Portland.
- **Purpose:** Runoff from winter precipitation events associated with atmospheric rivers, that deliver significant amounts of rain over short durations, cannot be forecasted in the same way as runoff that is predominantly caused by snowmelt. Not only are these events difficult to forecast with long lead times (>5 days), they also can lead to the highest amount of flood damage in the Portland/Vancouver area. Furthermore, there is strong evidence that winter flows and atmospheric river events will increase with climate change. Water management operating rules that more explicitly account for these rain-driven runoff events would offer greater flexibility and adaptability in reservoir operations. Albeni Falls and Dworshak have drafted space already in place for rain-induced flooding and will be adjusted to fill space under the same conditions as Grand Coulee. **Measure Location:** Grand Coulee, Albeni Falls, and Dworshak.
- **Implementation:** Grand Coulee will be drafted to provide up to 650 kaf of space for FRM from mid-December through March. All other existing winter operations will remain the same. The winter operations will first rely on the four lower Columbia projects when the

stage at Vancouver is forecast to exceed a stage of 16 feet. If the forecast continues to project a stage exceeding 16 feet with the operation of the four lower Columbia projects then the winter operations will include Albeni Falls, Dworshak and Grand Coulee.

- **Frequency and Duration:** All years Mid-December - March.
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to preserve ability to operate reservoirs for FRM purposes, with goal of maintaining similar level of flood risk under a wide variety of conditions.

O17. Increase volume of water pumped from Lake Roosevelt via the John W. Keys III Pumping Plant at the Grand Coulee project for increased deliveries to the Columbia Basin Project mostly during the annual irrigation season. The new volume of irrigation water would be calculated by multiplying the 256,475 undeveloped acres by a delivery rate (4.5 acre-feet per acre) estimated by the Project staff to be needed for newly developed acres.

- **Purpose:** To divert water from the Columbia River for irrigation and municipal and industrial (M&I) uses.
- **Measure Location:** Grand Coulee Dam (Lake Roosevelt). This measure focuses only on the diversion of water from the Columbia River via Lake Roosevelt and does not account for increased return flows (i.e. non-consumptively used water that returns to the river) that may occur when delivering this water to the CBP.
- **Implementation:** Pump more water from Lake Roosevelt using the existing John W. Keys Pumping Plant, which was designed and constructed to have the capacity to provide the full water delivery for the original authorization of 1,029,000 acres. The additional pumping would include 1,154,138 acre-feet for irrigation. The total pumped volume wuld be delivered on demand.
- **Frequency and duration:** Annual, mostly during irrigation season which is generally from April 1 through October 30. Table 1 shows the estimated monthly and total annual additional pumped water from Lake Roosevelt. **Table 2 shows the estimated monthly and total annual pumped water from Lake Roosevelt.**
- **Intended Benefit (why include this measure?):** To provide water supply to an additional 256,475 authorized acres of irrigable land within the CBP for agricultural development.

Table 1-44: Annual additional pumping from Lake Roosevelt.

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
–	–	–

Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)
January	8	518
February	59	3,299
March	596	36,627
April	2,836	168,724
May	2,983	183,431
June	3,031	180,333
July	3,610	221,983
August	2,290	140,804
September	2,254	134,115
October	1,134	69,725
November	166	9,865
December	77	4,714
Total	–	1,154,138
Month	Diversion Flow Rate (cfs)	Diversion Volume (Acre-feet)

Table 2: Total pumping from Lake Roosevelt including current operations, reshaping of Odessa Subarea and the additional water for Columbia Basin Project.

Month	**Diversion Flow Rate (cfs)**	**Diversion Volume (Acre-feet)**
–	–	–
January	32	1,984
February	227	12,627
March	2,282	140,299

April	10,901	648,641
May	11,537	709,384
June	11,784	701,210
July	14,060	864,482
August	8,949	550,235
September	8,722	518,980
October	4,367	268,503
November	634	37,753
December	293	18,042
Total	–	4,472,138

O20. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish and Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. For years where the flow augmentation draft is 10 feet, the end of September elevation would be 3546 feet. In years where the flow augmentation draft is 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.
- **Frequency and duration:** Irrigation season which is generally from April 1 through October 30.

Table 4 shows the estimated monthly and total annual additional delivered water from the Flathead River.

Table 1-45: Estimated monthly diversion above Flathead Lake.

Month	Diversion Flow Rate (cfs)	Diversion Volume (acre-feet)
January	0	0
February	0	0
March	0	0
April		
May		
June		
July	493	30,313
August	493	30,313
September	494	29,395
October		
November	0	0
December	0	0
Total		*90,021*

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure is has the potential to provide 90,000 acre-feet of water for a settlement with CSKT. This water could be used for irrigation or M&I purposes.

O21. Increase water diversion from the Columbia River for the Chief Joseph Dam Project to supply an additional 9,600 acre-feet of irrigation water. Supply irrigation water throughout the irrigation season.

- **Purpose of the measure:** To divert water from the Columbia River for irrigation of authorized acres in the Chief Joseph Dam Project.

- **Measure Location:** On the Columbia River just below Chief Joseph Dam.
- **Implementation:** Deliver 9,600 acre-feet of water to authorized Chief Joseph Dam lands.
- **Frequency and duration:** Annually during the irrigation season.

  Table 5 shows the monthly estimated and total annual diversion from the Columbia River.

Table 5: Total water for additional Chief Joseph Dam Project lands.

Month	**Diversion Flow Rate (cfs)**	**Diversion Volume (acre-feet)**
January	**0**	**0**
February	**0**	**0**
March	**0**	**0**
April	**3**	**179**
May	**19**	1,168
June	**42**	2,499
July	**50**	3,074
August	**34**	2,091
September	**7**	417
October	**2**	123
November	**0**	0
December	**0**	0
		9,550

- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to provide irrigation water to authorized acres in the Chief Joseph Dam for agricultural production.

O22. Limit Bonners Ferry stage to a maximum of 1753 ft from November through March to aid in the survival of riparian vegetation downstream of Libby Dam.

- **Specific Measure:** Limit Bonners Ferry stage to a maximum of 1753 ft from November through March to aid in the survival of riparian vegetation downstream of Libby Dam.
- **Purpose:** Increase survival of newly established riparian habitat to benefit Kootenai River White Sturgeon and bull trout. The increased survival of riparian habitat would additionally benefit riparian communities and wildlife, especially the threatened yellow-billed cuckoo. High flows out of Libby Dam in June and July, followed by a gradually receding hydrograph, allow for seed deposition in riparian zones. This measure, when combined with measures O1 and O2 earlier in this alternative, improves the survival of these riparian plants by reducing the number of years when winter stages are higher than late June stages, thus allowing these plants to become more firmly established.
- **Measure Location:** Libby Dam
- **Implementation:** Limit flows to not exceed an elevation of 1753 ft at Bonners Ferry from November through March. This can be modeled in a similar manner to the 1764 ft flood elevation at Bonners Ferry, and is intended to keep the river stage downstream of Libby Dam at a lower winter stage relative to the previous June 15th to July 15th period (peak stage) in more years.
- **Frequency and Duration:** November through March
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival by operating to support riparian habitat recruitment, which may shade and cool the adjacent water. The biological inputs from riparian vegetation also contributes to food production, nutrient input, and habitat for forage, benthic species, and juvenile fish, including Kootenai River white sturgeon and bull trout.

1.12.33 Errata Sheet - Multi-Objective Alternative 4, V4, January 14, 2018

*Changes to text indicated in *italics*.

Measure O2 was changed to include and describe spill not to exceed 125%, as it was described in the Single Objective Alternative for Spill to 125% TDG. **Inclusion of this measure with implementation through August has necessitated removal of measure O3, Summer Spill (see below)**

Measure O2: Set juvenile fish passage spill to not exceed 125% TDG, as measured in the tailrace, at all Lower Snake River and Lower Columbia River Projects.

- ***Specific Measure:*** *Alter the current fish passage spill regime.*
- ***Purpose:*** *Analyze the impacts to affected resources from increasing juvenile fish passage spill to not exceed 125 percent TDG.*
- ***Measure Location:*** *Lower Snake and Lower Columbia River projects: Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville.*
- ***Implementation:*** *In order to meet minimum generation requirements, spill to not exceed 125 percent TDG would be dependent upon availability of sufficient flow and upstream storage reservoirs would not be drafted specifically to reach 125 percent TDG. For modeling purposes, there is not a forebay target for TDG and will calculate a 12 hour running average.*
- ***Frequency and Duration:*** *Start date of March 1 and end date August 31 at all projects.*
- ***Intended Benefit (why include this measure?):*** *Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.*

This change was approved by the Executive Committee on Jan. 4, 2019

Measure O3 Transitional summer juvenile fish passage spill operations *was* ***deleted*** *following decision to adopt measure O2 as described above, which includes implementation of spill to 125% from March 1 to August 31.*

Measure O8 was changed to reflect accurate purpose and MOP elevations at John Day, McNary, and the Snake River projects. The measure now reads:

Measure O8 Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for outmigration

- **Purpose:** Minimize water particle time through the reservoirs *while providing slightly increased operating range flexibility at the lower Snake River Projects*.
- **Implementation:** Draw down the reservoir elevation, still allowing turbines to operate sustainably without cavitation issues and adjusting for safe navigation:
    - Bonneville: MOP (forebay elevation 71.5' + 1.5' operating range above MOP)
    - The Dalles: MOP (forebay elevation 155.0' + 1.5' operating range above MOP)
    - John Day: MOP (forebay elevation *261.0'* + 1.5' operating range above MOP)
    - McNary: MOP (forebay elevation *337.0'* + 1' operating range above MOP)
    - Ice Harbor: MOP (forebay elevation *437.0'* + 1.5' operating range above MOP)
    - Lower Monumental: MOP (forebay elevation *537.0'* + 1.5' operating range above MOP)
    - Little Goose: MOP (forebay elevation *633.0'* + 1.5' operating range above MOP)
    - Lower Granite: MOP (forebay elevation *733.0'* + 1.5' operating range above MOP)

Measure O11 was changed to remove language related to drafting deeper in January – February at Libby. The measure now reads:

Measure O11: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions.

Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill *timing will be tied to Kootenai River Basin runoff.* The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff ("fill and spill incidents") by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF.

This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the s sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. *(Removes reference to January and February drafts)*.

This change approved by the NEPA Policy Team January 3, 2019

Measure O10 has been revised to correct numbers in the Forecast Line of each table (Libby and Hungry Horse).

O10. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with downstream flow augmentation. At Libby Dam base 5 to 20 foot drafts on appropriate forecast for Libby Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
    - Use Libby's May Final April-August Water Supply forecast to set the end of Sept target.
    - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*
September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

- Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.

    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.
- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April-August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measure *O15* which is intended to represent an additive draft from Hungry Horse for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional

draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O15.

- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O20 has been revised to correctly describe the end of September draft point that will result with the combination of measure *010. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O20. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure O10. Implement sliding Scale summer draft at Libby and Hungry Horse, for example if measure O10 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target plus 493 cfs.* For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

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1.12.34 Errata Sheet - Multi-Objective Alternative 4, V4, February 21, 2018

*Changes (January 2019) to text indicated in *italics*.

*Changes (February 2019) to text indicated in yellow.

Measure O2 was changed to include and describe spill not to exceed 125%, as it was described in the Single Objective Alternative for Spill to 125% TDG. **Inclusion of this measure with implementation through August has necessitated removal of measure O3, Summer Spill (see below)**

Measure O2: Set juvenile fish passage spill to not exceed 125% TDG, as measured in the tailrace, at all Lower Snake River and Lower Columbia River Projects.

- ***Specific Measure:*** *Alter the current fish passage spill regime.*
- ***Purpose:*** *Analyze the impacts to affected resources from increasing juvenile fish passage spill to not exceed 125 percent TDG.*
- ***Measure Location:*** *Lower Snake and Lower Columbia River projects: Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville.*
- ***Implementation:*** *In order to meet minimum generation requirements, spill to not exceed 125 percent TDG would be dependent upon availability of sufficient flow and upstream storage reservoirs would not be drafted specifically to reach 125 percent TDG. For modeling purposes, there is not a forebay target for TDG and will calculate a 12 hour running average.*
- ***Frequency and Duration:*** *Start date of March 1 and end date August 31 at all projects.*
- ***Intended Benefit (why include this measure?):*** *Impact of implementation of this measure will be included in the impact analysis; however, this measure has the potential to increase juvenile salmon and steelhead survival through the lower Snake River and Columbia River projects, reduce in-river travel times, improve condition and survivability of smolts entering the estuary, and increase adult returns.*

This change was approved by the Executive Committee on Jan. 4, 2019

***Measure O3 Transitional summer juvenile fish passage spill operations** was **deleted** following decision to adopt measure O2 as described above, which includes implementation of spill to 125% from March 1 to August 31.*

Measure O8 was changed to reflect accurate purpose and MOP elevations at John Day, McNary, and the Snake River projects. The measure now reads:

Measure O8 Reservoir drawdown to Minimum Operating Pool (MOP) to further reduce travel times for outmigration

- **Purpose:** Minimize water particle time through the reservoirs *while providing slightly increased operating range flexibility at the lower Snake River Projects.*
- **Implementation:** Draw down the reservoir elevation, still allowing turbines to operate sustainably without cavitation issues and adjusting for safe navigation:
  - Bonneville: MOP (forebay elevation 71.5' + 1.5' operating range above MOP)
  - The Dalles: MOP (forebay elevation 155.0' + 1.5' operating range above MOP)
  - John Day: MOP (forebay elevation *261.0'* + 1.5' operating range above MOP)
  - McNary: MOP (forebay elevation *337.0'* + 1' operating range above MOP)
  - Ice Harbor: MOP (forebay elevation *437.0'* + 1.5' operating range above MOP)
  - Lower Monumental: MOP (forebay elevation *537.0'* + 1.5' operating range above MOP)
  - Little Goose: MOP (forebay elevation *633.0'* + 1.5' operating range above MOP)
  - Lower Granite: MOP (forebay elevation *733.0'* + 1.5' operating range above MOP)

Measure O11 was changed to remove language referring to drafting deeper in January – February at Libby. The measure now reads:

Measure O11: When Libby's water supply forecast is approximately 6.9 million acre feet (MAF) or less, implement a draft and refill operation at Libby that is modified for local forecasts and conditions. Additionally, modify the existing SRD above 6.9 MAF to provide more flexibility during the draft.

Implementation: From Jan-Apr, when forecasts are approximately 6.9 MAF or less, the proposed local SRD will require deeper drafts than the proposed System VarQ SRD and refill timing will be tied to Kootenai River Basin runoff. The VarQ refill flow calculation will be modified so that it (1) modifies past release calculation to occur in real time; (2) takes into account the planned sturgeon volume release before it occurs, thereby eliminating "double-accounting"; (3) changes the duration over which VarQ flows are determined so that local flood duration, along with the start of refill, is tied to the Kootenai River Basin; (4) adjusts the initial VarQ flows to be appropriate to the applied SRD.

Intended Benefit (why include this measure): Impact of implementation of this measure will be included in the impact analysis; however, this measure improves local FRM operation by having fewer instances of filling before the end of spring runoff (“fill and spill incidents”) by providing more FRM space for local high spring flows with a water supply forecast of less than 6.9 MAF. This would improve water quality conditions for resident fish by having less spill. During the spring this measure will reduce residence time of reservoir to support nutrient delivery while providing better management of outflow temperature desired for the s sturgeon flow augmentation operation. The local operations would allow for greater flexibility for resident fish and mainstem fish requirements and improve FRM operations for spring rain events in the Kootenay Basin. (Removes reference to January and February drafts).

This change was approved in a call with NEPA Policy staff held on January 3, 2019

Measure O10 has been revised to correct numbers in the Forecast Line of each table (Libby and Hungry Horse).

O10. Implement sliding scale summer draft at Libby and Hungry Horse

- **Specific Measure:** Implement a sliding scale summer draft at Libby and Hungry Horse to provide flexibility to operate to local water supply conditions. The sliding scale will adjust the end of summer elevation targets (5 to 20 feet from full at Libby and 10 to 20 feet at Hungry Horse as an example) based off of the most appropriate local forecast for each Dam, to balance local resident fish priorities with Dam. At Hungry Horse instead of using the May final April-August forecast at The Dalles, use the May Final April-August Forecast for Hungry Horse basin to determine the end of September draft.
- **Purpose:** Allow Libby and Hungry Horse to operate more locally for resident fish and balance these needs with flow augmentation.
- **Measure Location:** Libby and Hungry Horse Dams
- **Implementation – Libby**
    - Use Libby’s May Final April-August Water Supply forecast to set the end of Sept target.
    - The drafts will be 5 to 20 feet from full, linearly interpolated from the criteria in the table below.

Percentile of Libby April-August Water Supply	Minimum	<=15	25	75	>=85	Maximum
Forecast (kaf)	*<4656*	*<=4656*	*5007*	*6782*	*>=7328*	*>7328*

September Elevation Target (ft)	2439	2439	2449	2449	2454	2454

  - Operational target elevations for the summer draft that are intended to minimize double peaking and create flows of about 9 kcfs in September are below:
    - Target 2.5 ft above the end of September elevation on August 31st.
    - Calculate a release to target the end of September target that is below the end of August release, preferably around 9 kcfs.
    - During the month of September, if the end of Sept target is reached before September 30th or on August 31st decrease releases to 6 kcfs until the end of the month.
  - The following limits to flow fluctuation during summer at Libby Dam shall be implemented after the tiered flow volume for Kootenai River white sturgeon has been released through the end of August. If the forecast is increasing after the summer flat flow has been set and an increase in releases from the Dam are needed to meet the criteria above, limit increase as described below:
    - Outflows at or below 9kcfs - Maintain existing instream flow requirement for bull trout. Minimize fluctuation.
    - Flows between 9 kcfs and 16 kcfs - Maximum increase of 2 kcfs (corresponds to daily maximum ramp down rate for this period).
    - Flows between 16 kcfs and Power House Capacity - Maximum increase of 5 kcfs or one unit (corresponds to daily maximum ramp down rate for this period)
    - Maximum of one allowable increase within the above flow bands after the sturgeon volume has been expended and through September 30th.
- **Implementation - Hungry Horse:**
  - Use the May Final April-August forecast for Hungry Horse basin to determine the end of September draft.
    - For the 10th percentile forecast and drier draft 20 feet.
    - For the 20th percentile forecast and wetter draft 10 feet
    - Linearly interpolated between 10th and 20th percentile, a 20 to 10 foot draft. For example, a 16th percentile would have a 14 foot draft.
    - Table 1: Hungry Horse Summer Flow Augmentation Draft

Percentile of Hungry Horse April- August Water Supply	Minimum	<=10	20	Maximum
Forecast (kaf)	*<1407*	*<=1407*	*1579*	*>1579*
September Elevation Target (ft)	3540	3540	3550	3550

  - Flow Augmentation discharges from Hungry Horse during the summer months should be even or gradually declining.
  - Outflow would be maximum of outflow required to meet the Columbia Falls minimum or calculated flow augmentation outflow.
  - NOTE: The above table that determines the sliding scale draft at Hungry Horse for summer flow augmentation does not account for the effect of measures O7

and *O20* which are intended to represent an additive draft from Hungry Horse for augmenting flow in the spring and summer at McNary and for the purposes of water supply. The combination of the measures will result in a draft between 10 and 20ft (based on forecast representing local water supply condition) plus an additional draft of approximately 4ft to document the delivery of 90 kaf for water supply measure O20.

- **Frequency and Duration:** Applies to all years
- **Intended Benefit (why include this measure?):** Impact of implementation of this measure will be included in the impact analysis. However, this measure has the potential to increase resident fish survival through better temperature management, higher reservoir productivity in summer, and improved likelihood of instream flows downstream of the projects for resident fish.

This change was approved in a call with NEPA Policy staff on January 3, 2019.

Measure O20 has been revised to correctly describe the end of September draft point that will result with the combination of measure *010. Implement sliding Scale summer draft at Libby and Hungry Horse.* No changes made to purpose or location sections.

O20. Increase water managers' flexibility to store and release water from Hungry Horse Reservoir and divert water downstream for the Confederated Salish Kootenai Tribes (CSKT) water rights settlement for irrigation or M&I purposes.

- **Purpose:** To release water from Hungry Horse to deliver 90,000 acre-feet downstream.
- **Measure Location:** Hungry Horse Reservoir and diversion from within Flathead Lake. The exact diversion location is unknown at this time; however, it is anticipated that reservoir operations downstream of Hungry Horse will not change to deliver this water.
- **Implementation:** Ensure enough water is stored and released at certain times to comply with the settlement. The way to determine if the water has been released is to ensure that the end of September elevation is such that it includes the draft for flow augmentation plus the 90,000 acre feet. *For most years the end of September elevation would be approximately 4 feet lower than the summer flow augmentation elevation target that results from measure O10, Implement sliding scale summer draft at Libby and Hungry Horse. For example, if measure O10 determines a summer draft of 14ft then the end of September elevation will be approximately 3542 feet to ensure the additional release of the 90,000 acre feet. In some years conditions may require addition draft of Hungry Horse during the summer period to meet minimum flows, this will result in flows at Columbia Falls that meet the minimum flow target*

plus 493 cfs. For example, in years where the flow augmentation results in a draft of 20 feet, two objectives will need to be met; (1) an end of September elevation of 3535.8 (or lower) and (2) flow at Columbia Falls should be a minimum of the Columbia Falls minimum plus 493 cfs. The exact location and purpose of the water released from Hungry Horse has not yet been defined, so the assumption is to remove all of the 90,000 acre-feet from the river and assume that it is all consumptively used to cover the most extreme impact of using the water.

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Draft Columbia River System Operations Environmental Impact Statement

Appendix B, Part 1

Hydrology and Hydraulics Data Analysis

EXECUTIVE SUMMARY

PURPOSE OF TECHNICAL APPENDIX B, PART 1

This technical appendix documents the analysis of results from the Columbia River System hydroregulation modeling (Appendix AB, Part 3 – ResSim/WAT Documentation) of the CRSO alternatives including the No Action Alternative. The analysis presents some results in terms of water levels via use of the flow-stage relationship tool (Appendix B, Part 5 – Flow-Stage Relationship). This report provides more detailed discussion to supplement content in Chapter 3.2 of the EIS main report, and it presents much of the plotted and tabulated results summaries.

ORGANIZATION OF APPENDIX B, PART 1

This appendix is comprised of three parts. It includes 1) a brief overview of hydroregulation modeling and the approach used for alternatives evaluation, 2) a description of the study area and the baseline hydrologic conditions (e.g., regulated stream outflow, reservoir levels, and water levels in the rivers between the projects) using result from the No Action Alternative, and 3) a presentation of alternative model results highlighting the changes in hydrologic conditions. Additional discussion on topics including power considerations, draft rate changes, and gate maintenance are included toward the end of the document. Summary results are provided in the form of various plots and comparison tables, included at the end of this document. Alternatives analysis and results are organized by CRSO Region and generally proceed from upstream to downstream.

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ACRONYMS AND ABBREVIATIONS

AEP	annual exceedance probability
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRS	Columbia River System
CRSO	Columbia River System Operations
EIS	environmental impact statement
FRM	flood risk management
ft/sec	feet per second
H&H	hydrology and hydraulics
HEC-RAS	Hydrologic Engineering Center River Analysis System
kaf	thousand acre-feet
kcfs	thousand cubic feet per second
M&I	municipal and industrial
Maf	million acre-feet
M-C	Monte Carlo
mi^2	square miles
MIP	minimum irrigation pool
MO	Multiple Objective Alternative
MOP	minimum operating pool
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
ResOps	reservoir operations
ResSim	Reservoir System Simulation
RM	river mile
SKQ	Seli’š Ksanka Qlispe’ Dam
SRD	Storage Reservation Diagram
SWS	selective withdrawal system
TDG	total dissolved gas
URC	upper rule curve
WAT	Watershed Analysis Tool

CHAPTER 1 - INTRODUCTION

This section of the Hydrology and Hydraulics (H&H) Appendix, "Part 1 – Hydrology and Hydraulics Data Analysis," documents the results from the Columbia River System (CRS) hydroregulation modeling (Appendix B, Part 3 – ResSim/WAT Documentation) of the Columbia River System Operations (CRSO) alternatives including the No Action Alternative, and the comparison of alternatives evaluated within this CRSO Environmental Impact Statement (EIS). The analysis presents some results in terms of water levels via use of the flow-stage relationship tool (Appendix B, Part 5 – Flow-Stage Relationship).

CHAPTER 2 - PURPOSE OF TECHNICAL APPENDIX

This appendix is intended to serve multiple purposes, including providing an overview of the reservoir operations (ResOps) modeling approach, to document No Action Alternative results in greater detail than is allowed in the main EIS report, and to present the alternatives analyses in which the H&H conditions of each alternative are compared to those of the No Action Alternative. It is also intended to serve as a concise resource on background H&H data for impact teams, as well as provide an upfront explanation of H&H changes for each alternative, which has been requested in order to help focus impact teams and their analyses. Added discussion on model limitations, model anomalies, and differences between modeled results and actual expected changes to H&H conditions is included, as are discussion on non-modeled measures that would impact H&H conditions.

This appendix consists of several parts, which are (1) a brief overview of hydroregulation modeling and the approach used for alternatives evaluation, (2) a description of the study area and the baseline H&H conditions (e.g., regulated stream outflow, reservoir levels, and water levels in the rivers between the projects) using results from the No Action Alternative, (3) a presentation of alternative model results highlighting the changes in H&H conditions, and (4) additional discussion on other, non-modeled changes.

Effects of the alternatives on river mechanics (e.g., sediment transport), groundwater, power, fish passage, etc., all of which may generally fall under the H&H umbrella, are covered in separate appendices.

Hydroregulation modeling results have been used by various impact teams in the preparation of the CRSO EIS. In the event that an impact team's attribution of a flow or reservoir condition to a particular operational measure (or measures) conflicts with information presented in the H&H Environmental Consequences sections of the EIS, the information presented in the H&H Environmental Consequences sections should be taken as the governing explanation. Information and results presented here (in the H&H Data Analysis section of the H&H Appendix) provide greater detail supporting the results presented in the H&H Environmental Consequences sections of Chapter 3 of the EIS.

CHAPTER 3 - HYDROLOGY AND HYDRAULICS ANALYSIS APPROACH

3.1 OVERVIEW OF MODELING TOOLS

The ResOps model of the No Action Alternative was established as a baseline condition. The ResOps model is described in Appendix B, Part 3 – ResSim/WAT Documentation. The hydrologic inputs used in the model are described in Appendix B, Part 4 – Hydrologic Data Development. Water levels between projects (dams and their associated reservoirs), i.e., at mid-reach locations, are estimated using the flow-stage transform developed from Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic models of each reach, described in Appendix B, Part 5 – Flow-Stage Development.

The ResOps model samples forecast uncertainty within a Monte Carlo (M-C) modeling scheme and the model output is 5,000 years of daily data at reservoir forebays and project outflow. This data is summarized using a suite of standard analyses that summarize the M-C output. The model output is also delivered to technical specialists (fisheries managers, water quality scientists, economists, etc.) who use the datasets for a variety of impact assessments, which may use qualitative or quantitative methods.

The Corps ResOps and hydraulic models are used as the primary tools for quantifying the changes to dam outflow and water levels in the reservoirs and rivers resulting from implementation of the various alternatives. Alternatives rule sets within the ResOps model are developed to reflect measures that impact ResOps in order to estimate changes in reservoir levels and project outflow that would occur from a given alternative. A flow chart is provided in Figure 3-1.

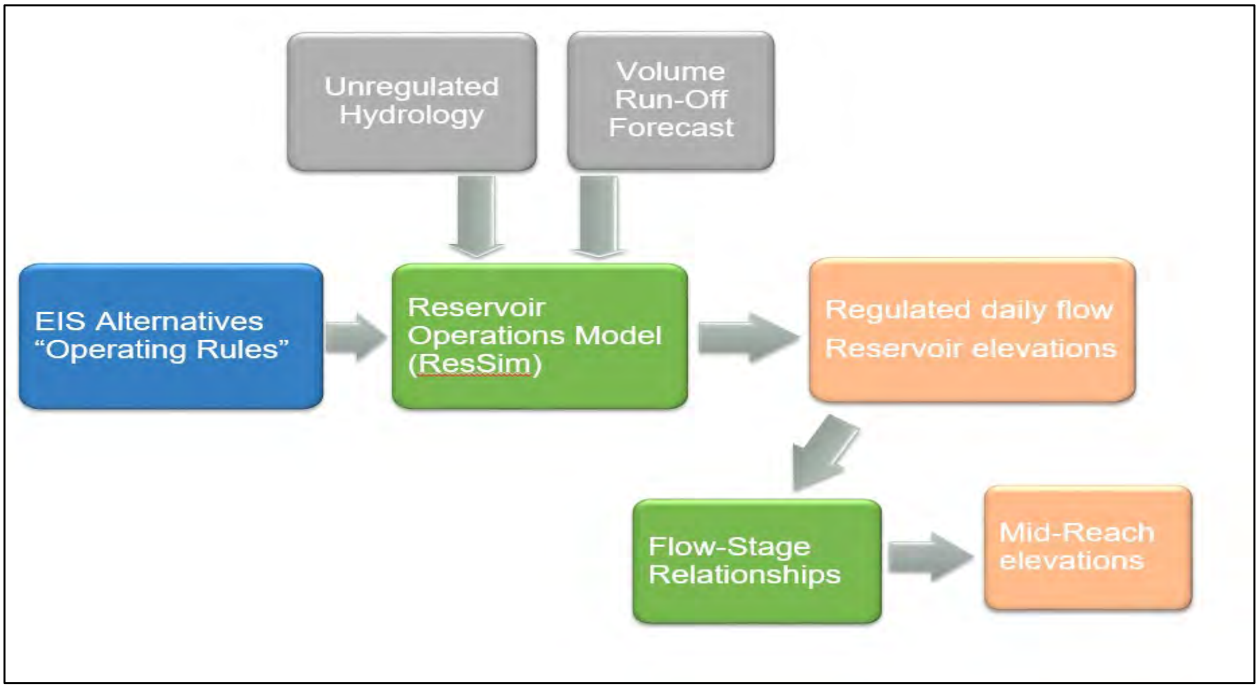


Figure 3-1. Simplified Hydrology and Hydraulics Data and Modeling Process

The effects that various alternatives will have on hydrology (flow and water level conditions) within the study area are quantified by comparing the alternative results with the No Action Alternative results. Alternatives are evaluated throughout the detailed study reaches but evaluations are targeted around the major CRSO dams where rule changes are actually being made. The objective of the H&H reservoir modeling is to describe the effect of operational changes under a given alternative to the H&H through the system, and to supply H&H data to facilitate further investigation of effects of potential H&H changes to other resources (e.g., economics, water quality, etc.)

3.1.1 Reservoir Operations Modeling

Hydroregulation (regulating water) is the process planners and operators use to make decisions about routing water through a series of dams in a river system. Computer hydroregulation modeling is used to simulate operations for the system of dams which can operate for multiple purposes including flood risk management (FRM), hydropower, irrigation, navigation, recreation, water supply, and fish and wildlife purposes.

A hydroregulation model was developed for the CRS using the Hydrologic Engineering Center Reservoir System Simulation (ResSim) model. Details on the hydroregulation modeling approach employed for this EIS are provided in Appendix B, Part 3 – ResSim/WAT Documentation, but a brief summary is included here. The CRS Model was designed to meet the following objectives:

- Represent multipurpose operations of dams in the system, including local flood storage and refill operations, CRS flood storage and refill operations, and other operations described in biological opinions.
- Represent an interpretation of current Columbia River hydropower operations under the Columbia River Treaty and incorporate the effects of power drafts in Canadian reservoirs on FRM.
- Include and be able to model year-round detailed operations of all major Columbia River Basin projects in the system which affect water levels at reservoirs and river reaches in the system.
- Function efficiently in a M-C framework, allowing M-C simulation of the system's reservoir operations with varying water supply forecasts and synthetic hydrographs that represent extreme events.
- Provide output in a daily timestep format, which is useful in estimating a variety of impacts associated with water conditions (reservoir elevations and river flows) in the basin.

The CRS Model is designed as a planning model to represent rule-based reservoir operations. All rules in the model are explicitly defined and do not include the range of decisions that might be made in real time, which rely on information that may not be available to the model. These decisions also include a level of subjectivity (i.e., human decisions) that cannot inherently be replicated by a model or can only be approximated using assumptions. Model reviewers agree that this assumption is acceptable given the purpose of the model itself (to quantify and compare various impacts associated with proposed operating scenarios) and do not expect modeling results to match real-time reservoir operations in the observed period-of-record.

3.1.2 Water Levels Estimation Between Projects

Hydraulic models of the reaches throughout the Columbia River Basin were created to estimate the water surface profile between projects. Results from these hydraulic models were used to develop flow-stage relationships to efficiently produce water level data within the M-C framework described in the previous section.

The flow-stage relationships are developed for about 2,000 locations throughout the Columbia River Basin to create the annual peak water surface profiles to an acceptable accuracy level. Flow-stage relationships were also developed to produce daily time series data throughout the entire M-C compute to describe typical and annual conditions at specific locations. About 200 of these locations are queried and evaluated as part of the H&H analysis or used for other analyses. More information about development of the flow-stage relationship tool is described in Appendix B, Part 5 – Flow-Stage Relationship.

3.2 MONTE CARLO DATA SUMMARIZATION

Model output includes 5,000 years of daily time series data at numerous locations through the basin. To summarize model data, a suite of statistical operations are performed, and the reduced data and plots are available for alternative comparison. Water conditions at locations of interest are summarized using several different statistical analyses. With each of these, either tabulated data, plots, or both are created. A description of the different statistical products follows.

3.2.1 Summary Hydrographs

Plots that have time of year on the x-axis and either water surface elevation or discharge on the y-axis. X-axis and y-axis are both linear. This plot displays the 1st, 25th, 50th (median), 75th, and 99th percentiles from the daily time-series for each calendar day of the year. The 1 percent series represents the highest and the 99 percent the lowest, and the range between the 25 and 75 percent represents the flow or water level conditions that occur 50 percent of the time. The summary hydrograph is not a plot of individual water years, but the probability of the elevation or flow on any given day. Example summary flow and water surface elevation plots are below (Figure 3-2 and Figure 3-3) .

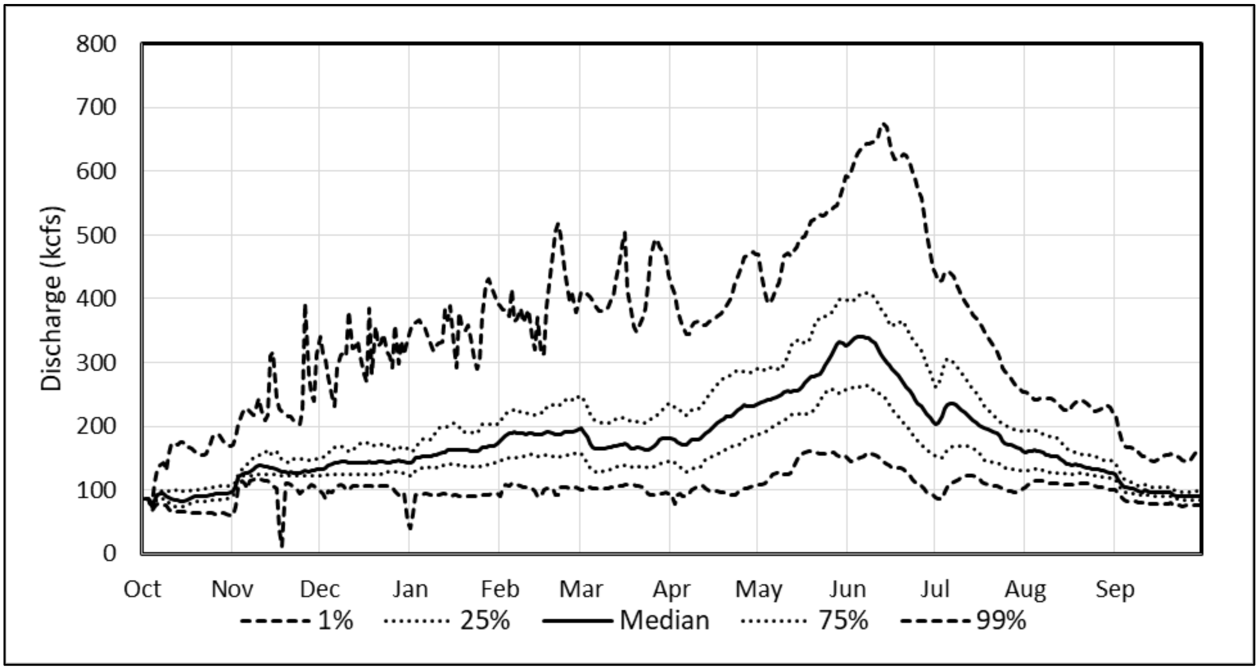


Figure 3-2. Example of Summary Flow Hydrographs

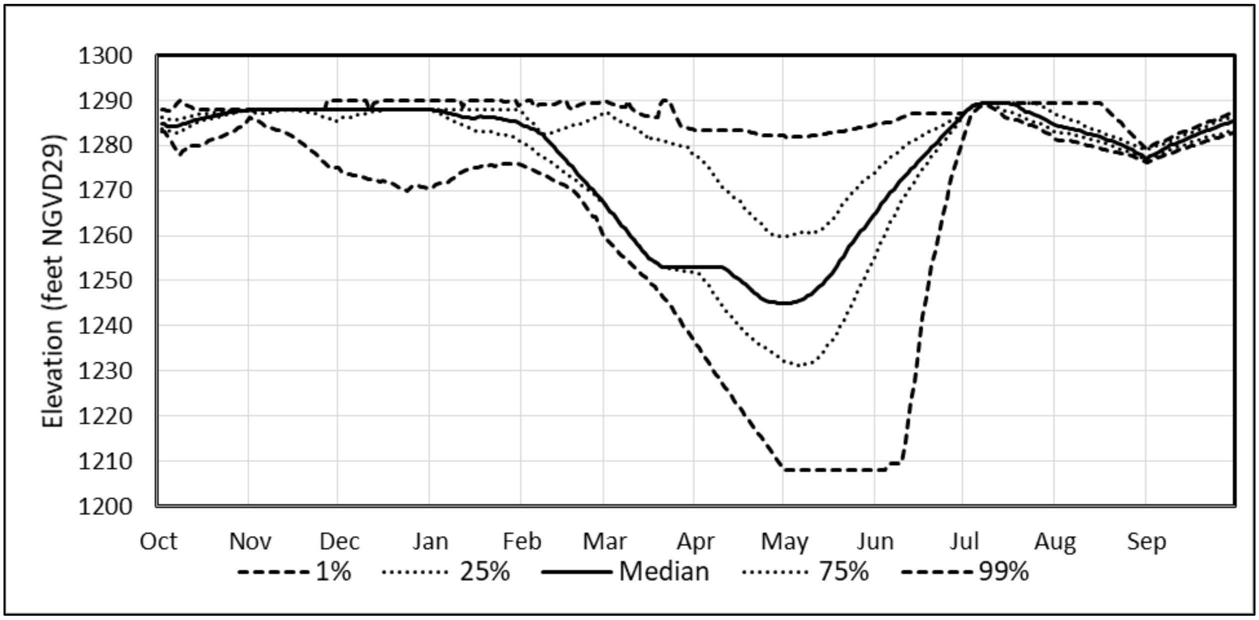


Figure 3-3. Example of Summary Elevation Hydrographs

3.2.2 Dry, Average, Wet Water Years Hydrographs

These plots group water years into “dry,” “average,” or “wet” years based on the May 1 April–August water supply forecast, then take the median flow or elevation for each day within the group. Water years are categorized with respect to the forecasted runoff volume percentile: dry years represent the lowest 20 percent, average years represent forecasts between 20 and 80 percent, and wet years represent greater than 80 percent. Libby, Hungry Horse, Dworshak, and The Dalles used their own forecast volumes to develop the water year categorization.

Grand Coulee, McNary, and Albeni Falls use The Dalles forecast volumes. While these plots look similar to the summary hydrographs, they provide different, useful information. Summary hydrographs analyze all years together and so provide the probability of a specific occurrence, on a specific day, over all modeled hydrologic events. The median hydrographs of dry, average, and wet years plots group years by the May forecast value and so can give an indication of how a measure affects different types of years. An example plot is shown in Figure 3-4.

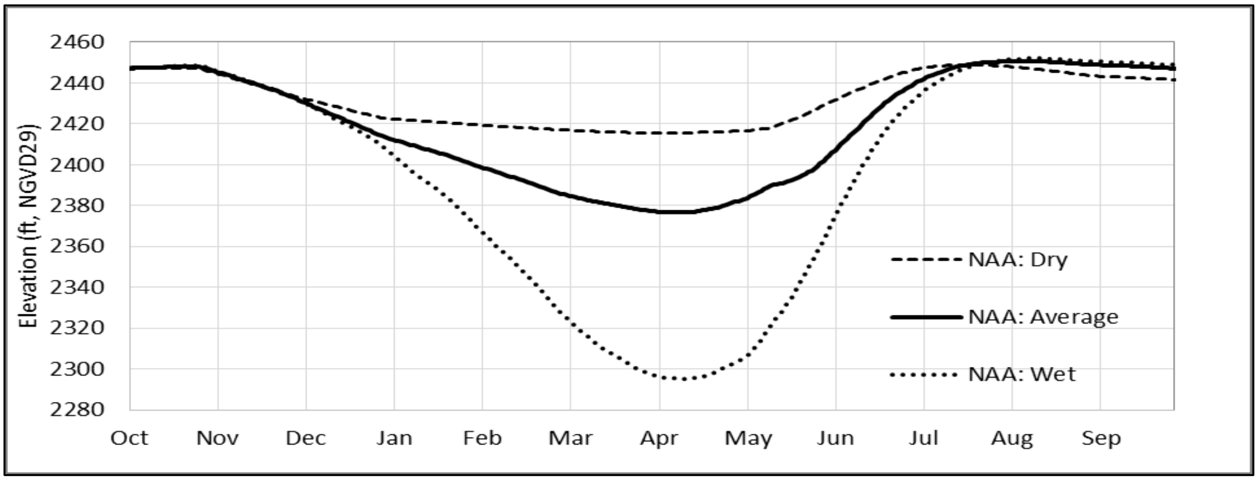


Figure 3-4. Example of Water Year Plot

3.2.3 Duration Plots

A duration plot has the percent of time exceeded on the x-axis and either water surface elevation or discharge on the y-axis. The x-axis and y-axis are both linear. Created from the daily time series for the defined period, the data represents the percent of time that an elevation or flow rate is exceeded in that period. Duration plots are created for individual months and the entire year and may be created for specific time periods (e.g., growing season.) An example plot is shown in Figure 3-5.

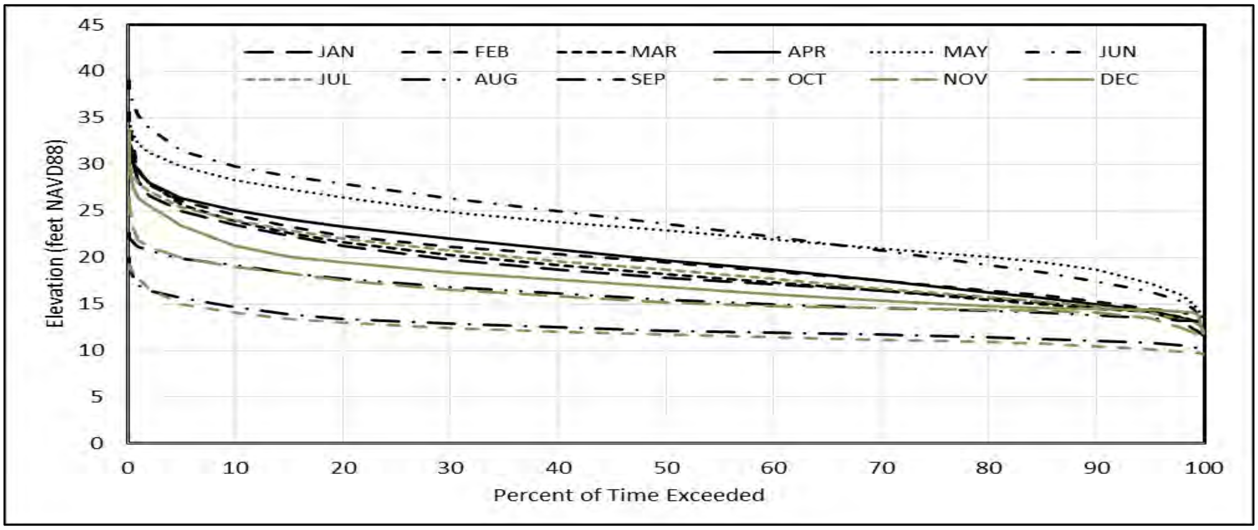


Figure 3-5. Example Monthly Elevation-Duration Plots

3.2.4 Target Date Probability Plot

A target date probability plot has exceedance probability on the x-axis and water surface elevation on the y-axis. The x-axis is normal probability scale, and y-axis is linear. Calculated from the daily time series record, the data represents the likelihood of a water surface elevation being exceeded on a specific day for any given year. These are used most commonly with reservoir pool targets with dates at the end of a given month. Tabulated data are available with the plots.

3.2.5 Average Monthly Discharge Table

The average monthly discharge table shows the 1, 25, 50 (median), 75, and 99 percent discharge for each month at a given site. These summary statistics are calculated using the average monthly discharge values from the daily time series and represent the exceedance probability for each month in a given year.

3.2.6 Peak Frequency Plot

Similar to the target date plots, peak frequency plots have exceedance probability on the x-axis and water surface elevation or discharge on the y-axis, but the data represents the likelihood of a water surface elevation or discharge being exceeded in any given year (as opposed to on a specific day of the year). Peaks are calculated for annual, winter, and spring maximums, where winter is defined as the period from November through March and spring is from April through July.

3.2.7 Annual Exceedance Probability Profiles and Inundation Polygons

Water surface profiles and inundation maps are created for the detailed hydraulic reaches for various annual exceedance probability (AEP) conditions, based on analysis of annual maximum data at a representative number of cross sections.

For each of these requiring an annual exceedance probability (peak frequency, target date, and average monthly discharge), the daily values from all simulations are queried, and the returning single value for each of the 5,000 years of the M-C simulation are ranked and the percentiles are developed using Weibull plotting position.

For duration plots, each of the daily values within a defined time period are used in the series. Like the annual probability series, the duration series are ranked, and percentiles developed using Weibull plotting position. The number of values included in the series is number of days within the defined time period multiplied by 5,000. For example, the December duration summary includes 31 days × 5,000 = 155,000 values.

For peak elevation-frequency plots at mid-reach locations, the flow-stage transforms calibrated on maximum annual water surface are used. Conversely, the “daily” flow-stage transforms are used for all other plots, as they were calibrated for a wider range of flow conditions. Similar to the peak-frequency plots, the water surface elevation used to calculate the AEP profiles and spatial mapping products are based on the peak flow-stage transforms.

3.3 ALTERNATIVES ANALYSIS

3.3.1 Analysis Approach

Under the CRSO EIS project, various alternatives to the current hydroregulation scheme are developed and evaluated for potential impacts to the hydrologic regime and water levels throughout the study area, and to a variety of other resources (e.g., economics, recreation, fish habitat, etc.) via changes to the H&H regime. The objective of the alternatives analysis as presented in this Part 1 of Appendix B is to identify changes to a wide array of hydrologic metrics that may have relevance to a given impact group, in addition to the metrics relevant to water managers. The impact groups are looking at topics from fish, water quality, and wildlife, to economics, flood risk, and cultural resources.

Each CRSO alternative contains a variety of measures, some of which are incorporated into an alternative ResOps rule set. By comparing the results from alternative ResOps simulations with those of the existing conditions model (No Action Alternative), the changes to H&H throughout the study area can be quantified.

With each alternative, there are several measures that are not included in the operations model, either because the measures are not operational in nature or because the reservoir operations model is not configured to simulate a given measure. Because not all measures are modeled, discussion is provided on any potential H&H impacts of non-modeled measures or measures that are only partially modeled.

3.3.2 Presentation of Results

The alternatives analysis is presented by regions, with all of the multiple objective alternatives (MOs) discussed together for a given location. A summary of major changes is provided at the beginning of each location, followed by a more detailed discussion of changes resulting from the specific alternatives and measures. Narrative discussion of changes is provided, summarizing the major or notable changes and linking changes to specific measures wherever possible. Comparisons between alternatives often proves helpful in describing relative effects on reservoir elevations, project outflows, etc.

The summarized M-C data is primarily used for comparison to determine effects on various H&H metrics. The effects of the alternatives on ***reservoir levels*** are evaluated using a variety of metrics including summary elevation hydrographs, refill curves water control project, and other metrics relevant to the individual projects. To quantify the impacts on ***project outflow***, the summary outflow hydrographs, monthly duration-curves, average monthly flows, and AEP flow-frequency curves from the ResOps model at critical projects are compared to the No Action Alternative results. Changes ***in water levels at mid-reach locations*** resulting from changes in upstream outflow and/or downstream pool are quantified using differences in summary elevation hydrographs or monthly duration curves.

Comparison plots and tables are developed from the standard M-C output. The plots show the model results for both a given alternative and the No Action Alternative. Comparison tables include the difference in tabulated alternative results to the No Action Alternative results. Percent change is also included for comparisons of discharge results. Custom plots and tables may be used to summarize results from multiple locations. Example comparison plots and tables are provided below (Table 3-1 and Table 3-2; Figure 3-6).

Table 3-1. Example Comparison Table: Change in Average Monthly Flow Data

	Change in Average Monthly Outflow (kcfs)											
Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
1%	0.6	0.4	-1.8	-1.4	0.8	0.2	-1.1	-1.0	0.9	0.3	-2.3	0.5
25%	0.0	1.2	-4.9	1.1	1.5	3.2	0.4	-0.9	-0.6	0.0	-0.8	-0.1
50%	**0.0**	**0.2**	**-4.4**	**1.7**	**3.3**	**1.6**	**-0.6**	**-0.7**	**-0.3**	**0.0**	**-0.7**	**-0.2**
75%	0.0	-0.4	2.7	0.2	0.5	0.2	0.1	-2.2	-0.2	0.0	0.0	-0.2
99%	0.0	-0.4	3.5	0.5	0.0	0.0	0.0	-5.5	0.9	0.7	0.7	0.1

Note: kcfs = thousand cubic feet per second.

Table 3-2. Example Comparison Table: Percent Change in Average Monthly Flow Data

	Percent Change in Average Monthly Outflow											
Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
1%	12%	2%	-8%	-5%	3%	1%	-5%	-4%	4%	1%	-13%	4%
25%	0%	7%	-26%	6%	7%	26%	4%	-5%	-3%	0%	-7%	-1%
50%	0%	2%	-25%	19%	52%	29%	-8%	-4%	-2%	0%	-7%	-3%
75%	0%	-4%	27%	3%	12%	4%	1%	-16%	-1%	0%	0%	-2%
99%	0%	-5%	43%	12%	0%	0%	0%	-47%	10%	10%	9%	1%

Changes in flow, water levels, and probabilities as compared to the No Action Alternative are summarized using ranges in values when possible, but because a major intent of this document is to present results so that further analysis by impact teams can be focused on areas of change, precise quantification of results is not always necessary, particularly when summarizing basinwide effects. Data is generally not presented for locations where no noticeable change in flow or water levels is found.

A broad selection of summary plots and tables are provided at the end of this appendix, as opposed to within the body of the report. The selected data for inclusion in the report focuses on the major CRSO projects and water level impacts in the lower Columbia River. Additional H&H results may be provided within the various other Impact Teams' technical appendices.

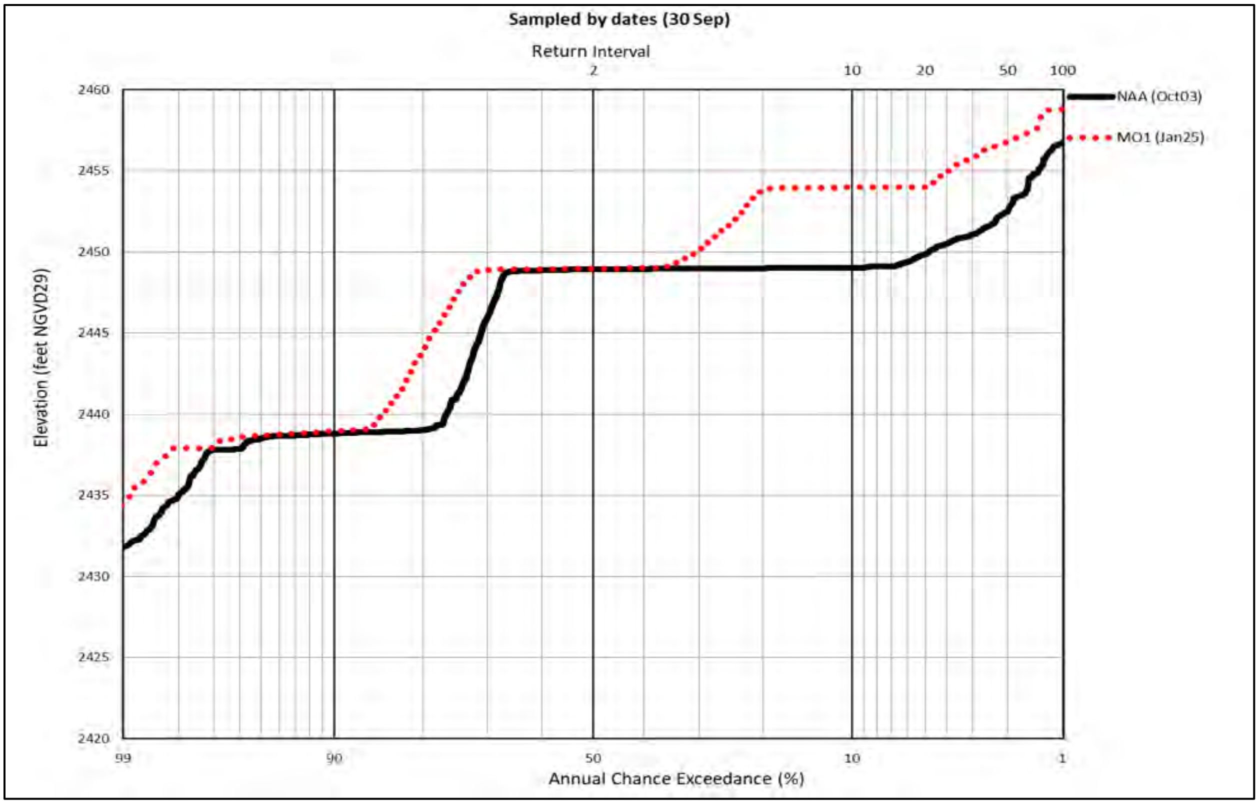


Figure 3-6. Example Plot: Comparison of Target Date Elevation-Frequency Results

3.4 CAVEATS AND DISCLAIMERS RELATED TO THE RESERVOIR OPERATIONS MODELING

3.4.1 Reservoir Operations Modeling

The purpose of the CRSO computer hydroregulation models are for planning studies in which operational scenarios, or rules, are tested over many years of data. The planning models used for CRSO simulate on a daily timestep and have a fixed rule set for each alternative. This is so that when the model is computed, each event is handled with the same rule conditions without human interference to preference different conditions. Real-world reservoir operation is very complex, affected by input uncertainty (imprecision in forecast inflow, seepage and evaporation losses, etc.), filtered by the reservoir operator's experience and natural risk-aversion, while considering the different physical and legal/institutional constraints to meet the different demands and system requirements. In addition, each season the agencies responsible for reservoir operations work with the regional management teams to adapt normal operations to something that might be a better result for all the interested parties given the specific conditions of that particular water year, habitat restoration work, and other factors. Operations changes of this nature are not possible to represent in a planning model. Nor would they necessarily be desirable as it would make comparing different alternatives significantly more challenging and likely skew the results toward the personal/professional opinions of what should happen. Examples of real-time operation flexibility can include how the system may operate for chum spawning and incubation by changing Bonneville Dam downstream stage levels, or summer drawdown patterns at Libby Dam for restoration work downstream of the dam on the Kootenai River.

3.4.2 Considerations for Simulation of Power Operations

Real-time operations at many Federal projects within the Columbia River Basin operate at an hourly timestep or finer due to power demands and other factors. This is referred to as load shaping and is done throughout the system. In real-time operations, there are seasonal hourly and daily ramping rate restrictions at some projects. In CRSO reservoir models, hourly ramping rates can only be simplified as daily restrictions, ignoring the effects that hourly ramping rates may have on real-time daily volume releases. This affects downstream river stages due to the hourly changes in dam releases. With no load shaping and only minimal operation rules to mimic power operations at Grand Coulee in the CRSO reservoir models, sub-season operations for power are largely not captured in this study. Effects of the alternatives on power generation are evaluated in Appendix B, Part 2: Spill Analysis, and the power generation evaluation (included in Chapter 3 of the main EIS, Section 3.8.). In the CRSO model, most storage projects will have steady releases, day to day and week to week, with the most common changes because of new monthly reservoir draft or fill targets. Less frequent changes can be for FRM or biological operations.

Dams can also vary their releases by using specific turbines in real-time releases to meet differing objectives such as fish passage or unit servicing. CRSO reservoir modeling does not cover turbine priority nor unit efficiencies. These operational decisions are based on information that is not available for a planning model study and are typically handled only in real time.

3.4.3 Operations for Other Purposes

In CRSO reservoir modeling, there is no feedback loop from reservoir modeling to other types of modeling such as hydraulics, hydropower, water quality and fisheries modeling. This is beyond the model’s capability at current time. For example, this means that there are no daily fluctuating releases from Dworshak Dam for temperature management, but only steady releases to meet fixed monthly draft targets. While qualitative comparisons can be done between the alternatives, the alternatives themselves are unlikely to produce directly comparable modeled results to actual observations. Similarly, these issues of daily operations in the planning models and real-time feedback are not available to affect daily spill operations and thus total dissolved gas (TDG). Also, by modeling the reservoir releases at a daily timestep, instead of hourly, there is not a method to properly model changing water quality metrics throughout the day, such as rising TDG as the temperature rises in the afternoon or falling TDG as the barometric pressure increases in the atmosphere.

3.4.4 General Modeling Constraints

Some factors of the CRSO study are beyond the currently available modeling capabilities or just have too much variability to include. All Federal dams have required maintenance that can take turbines or spillways out of service. These maintenance activities can affect projects operations by reducing hydraulic capacity through power plants and requiring spill, and this can result in a diminished ability to draft for the spring freshet and water quality impacts with respect to TDG. For the most part, maintenance issues are ignored for CRSO modeling, except for Grand Coulee Dam drum gate maintenance, which is Section 6.2 of this document. Annual unit service and unit overhauls are not modeled in ResSim but are included in the spill post-process of the ResSim results (Part 2 of this appendix). One exception to this is a reduction to hydraulic capacity that was simulated in ResSim to reflect additional maintenance under the **Grand Coulee Maintenance Operations** measure. Many of these maintenance projects on the turbines are included in the process used by Bonneville Power Administration and the Corps to develop spill numbers for water quality modeling. Additionally, most recreation operations were excluded as they vary from year to year and have limited impact on reservoir modeled releases.

The CRSO reservoir models will produce a plethora of data, some of which can be taken at face value and compared to observations that were actually observed in the river. Modeled results of streamflow at the projects will look very realistic for non-climate change streamflows; however, other metrics will not have the same level of accuracy and should be treated differently. For example, reservoir elevation at run-of-river projects does not represent realistic operations and so is typically plotted with a range of possible elevations. Also, for the M-C analysis, the model requires some “spin-up” time at the beginning of the water year, so October flows and elevations are often not reliable and spiky. This information may still be valuable to the study, however some metrics will need to be dealt with in a more qualitative manner.

CHAPTER 4 - REACH SUMMARIES INCLUDING NO ACTION RESULTS

4.1 OVERVIEW

In order to describe potential changes to the hydrologic and hydraulic regime throughout the Columbia River System resulting from the various alternatives evaluated in this study, it is necessary to create an adequate characterization of a baseline condition for each of the unique model reaches. This section contains necessary background information on the rivers and reservoirs within the study area which are evaluated for changes under the CRSO H&H modeling framework. This includes all of the hydraulic modeling reaches and bounding projects as defined in the Section 4.2, Study Area. Information is presented on a reach-by-reach basis, with some of the minor reaches grouped together. These “reach summaries” include general information on location and associated projects, inflow to the reach including major tributaries, basic reservoir operations ***as defined in the ResOps model***, and water level dynamics within a given reach, including water surface profiles.

No Action Alternative results are used to describe the pertinent hydrologic and hydraulic information for each reach. Due to a number of limitations associated with the modeling process, the baseline conditions established by the No Action Alternative results are not to be assumed to characterize the actual conditions. That being said, the No Action Alternative results do adequately describe the hydrology and hydraulics as required for a general description of the study area. By using the No Action Alternative results to describe the H&H environment, the reader is both introduced to the M-C data summaries and is familiarized with the reaches as defined by the baseline to which subsequent alternatives will be compared.

Reservoir operations are not discussed in detail in this appendix. Operations at the major storage projects are generally described in Chapter 3 of the EIS, and a more detailed description of how operations are modeled in ResSim is provided in Part 3 of this appendix – ResSim/WAT Documentation. Differences between simulated ResSim operations and the operations as described in Chapter 2 of the EIS are discussed in the ResSim appendix as well and are mentioned in this appendix as needed to support evaluation of specific measures within the various alternatives.

Location information used to describe where dams, confluences, cities, etc., in these reach summaries is based on river mile alignment; however, the level of precision is reduced to align with the narrative format of the section. Index point locations are presented in greater precision because they are generally referring to a specific hydraulic model cross-section at which data is produced. The purposes of assessing results at the index point throughout the basin are to understand potential impacts of changes in flow on changes in water levels in specific reaches.

4.2 STUDY AREA

While the entire Columbia River Basin is represented in the hydrologic modeling, flow and water levels evaluated in this study are limited to the major storage projects and the mainstem rivers downstream. This includes over 1,400 miles of reservoirs and rivers, 5 major storage projects, and over 20 other dams in the Columbia River System reservoir network that are modeled and evaluated. For many of the river reaches, detailed hydraulic models were developed to produce water surface profiles. Figure 4-1 shows the H&H study area including all of the CRSO and non-CRSO dams simulated, along with the location of the detail study reaches.

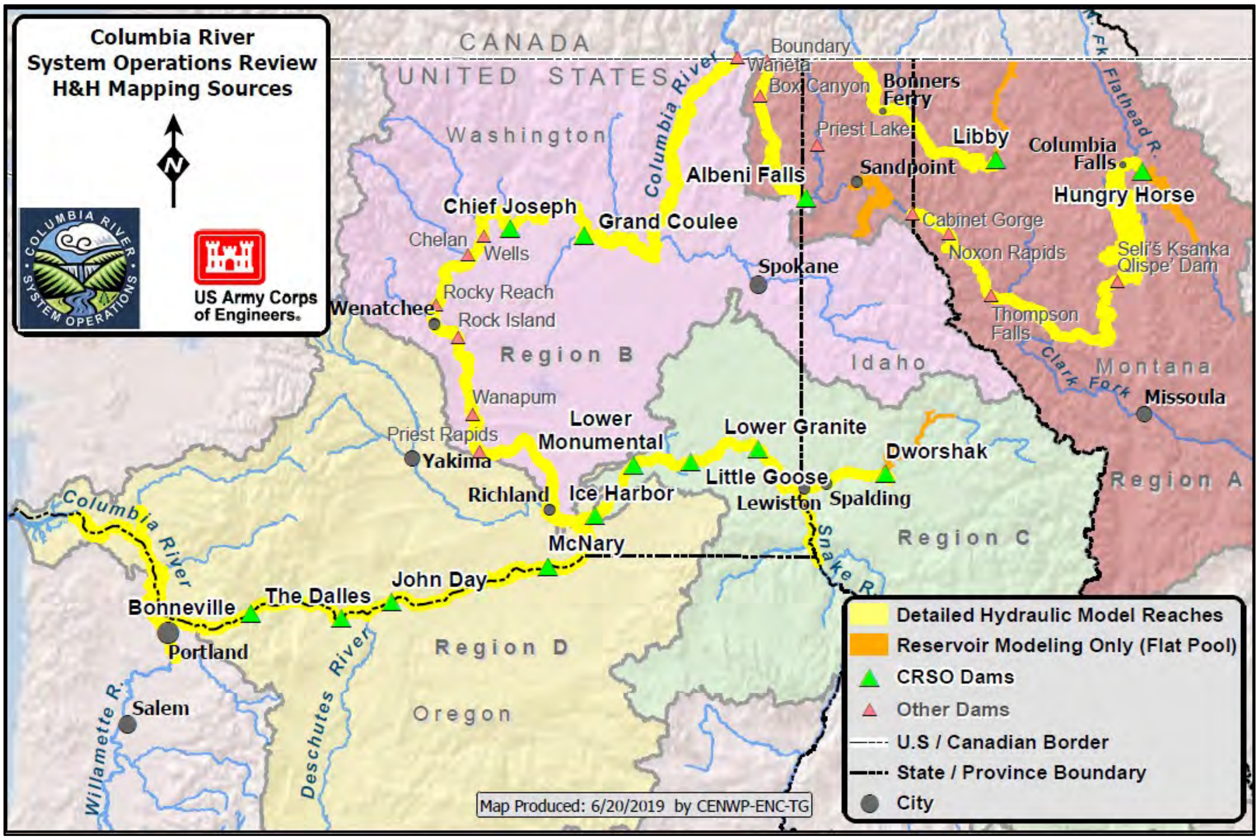


Figure 4-1. Map of Columbia River System Operations Regions, Projects, and Modeling Reaches

Water levels throughout this system are influenced by the many dams, to the extent that the water surface profile can be described as a series of steps at each of the major dams with reservoirs upstream. There are only a handful of steeper reaches that are above the influence of a downstream dam and/or reservoir. Figure 4-2 shows water surface profiles for all of the hydraulic reaches evaluated in this study. Each reach has an assigned reach number, and they are shown here to introduce the reader to the numbering convention and geographic extent of each reach. Several impact teams involved with CRSO environmental consequences evaluations use this reach numbering system to describe effects that would be associated with the various CRSO alternatives.

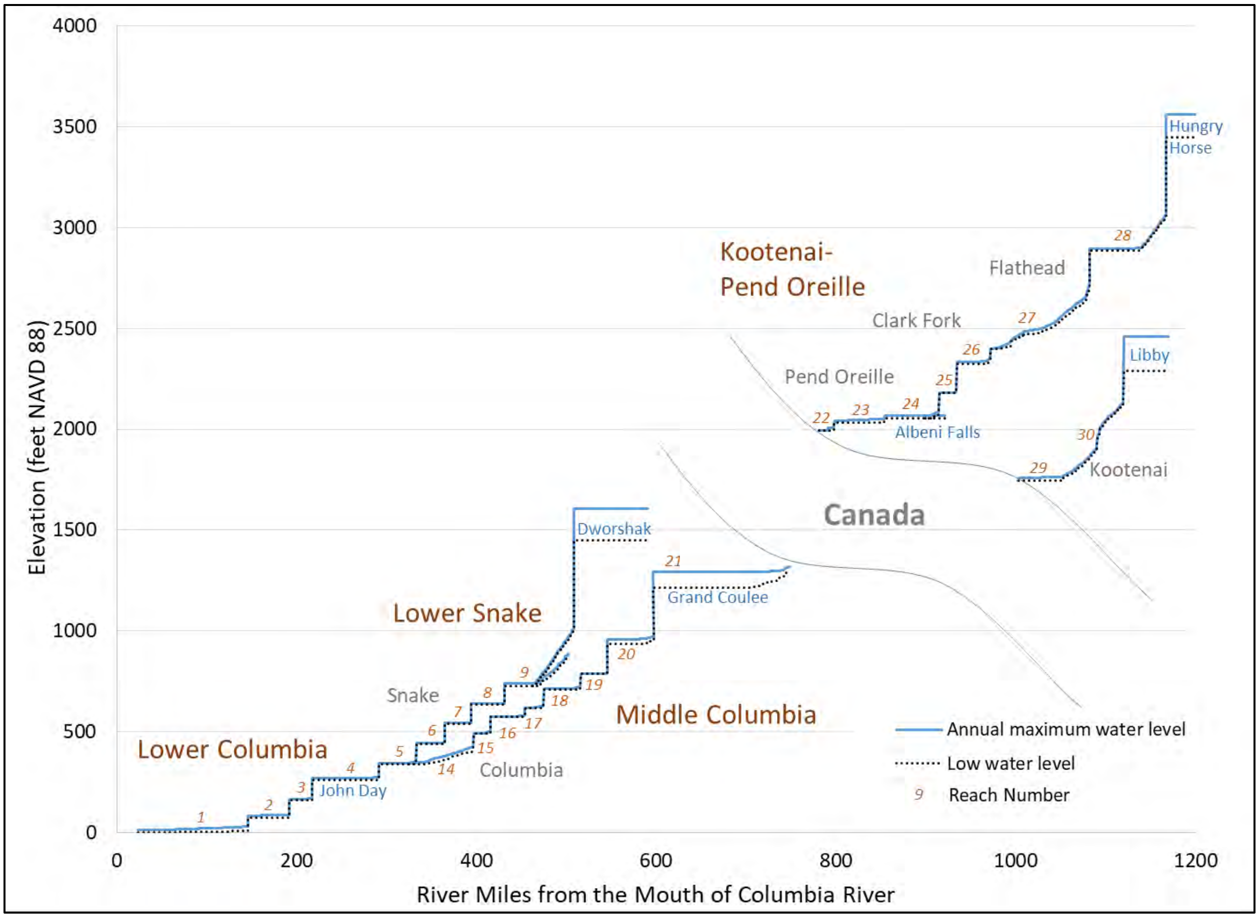


Figure 4-2. Water Surface Profiles for the Columbia River System Operations Hydraulic Model Reaches and Reservoirs

Water levels at a given location will fluctuate seasonally with the hydrologic cycle, dominated by high flows during the spring and early summer freshet with reservoir levels that are lower in the winter months and higher following the freshet. Depending on the location within a given reach, the water level will be influenced by either the forebay elevation held at the downstream dam, the outflow from the upstream project, or a combination of the two. For the purposes of this report and describing water level effects, these zones are occasionally referred to as “flat pool” or reservoir sections, “free-flowing,” or “transitional.” Index points are typically available for each of these zones within a given reach, and the largest flow-related changes happen within the free-flowing zones, often immediately downstream of dams, and the flat-pool zones show no sensitivity to changes in flow. Figure 4-3 depicts the typical location of these different zones within a reach, and Section 4.3, Reach Summaries, describes in greater detail the water levels and the driving factors associated for the different hydraulic reaches. Figure 4-4 shows a map of the hydraulic reaches and approximate boundaries for the various zones.

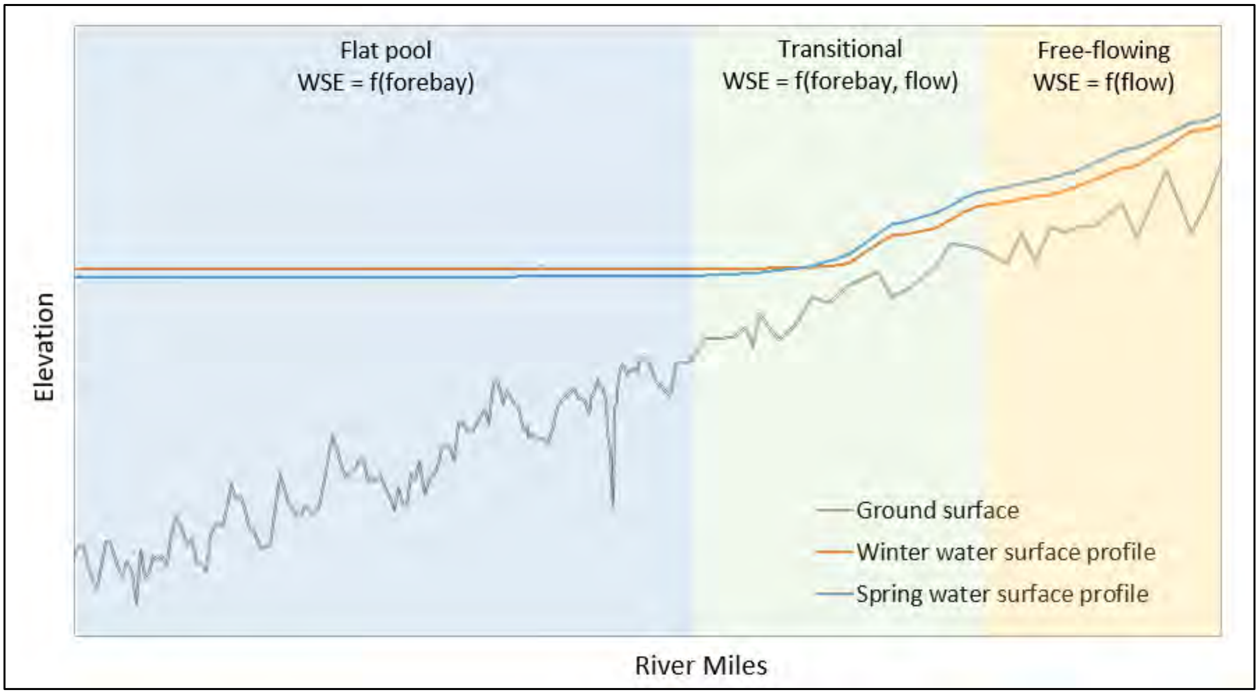


Figure 4-3. Depiction of the Different Hydraulic Zones Within a Reach

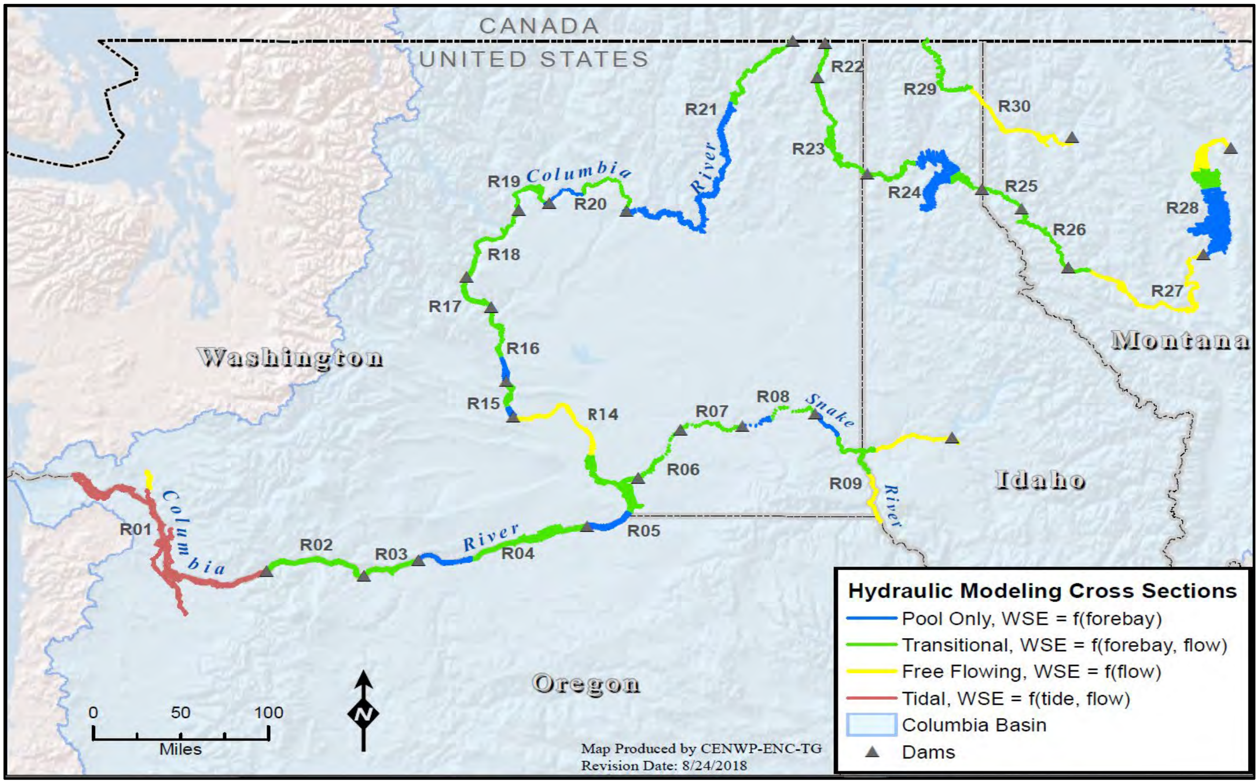


Figure 4-4. Map of Hydraulic Reaches (labeled RXX) and Approximate Boundaries for the Different Hydraulic Zones

4.3 REACH SUMMARIES

4.3.1 Region A – Kootenai, Flathead, and Pend Oreille Basins

4.3.1.1 Libby Dam and Lake Koocanusa

Libby Dam is located on the Kootenai River in northwestern Montana, creating Lake Koocanusa, a 90-mile long reservoir that extends across the border into Canada. Libby Dam is a major storage project and is a CSRO dam.

The summary hydrographs for Lake Koocanusa and Libby Dam outflow are shown in Figure 4-5 and Figure 4-6. Discussion of reservoir operations and No Action Alternative results for the major storage project is included Chapter 3.4 of the main EIS, and reservoir modeling details are provided in Part 3 of this appendix, ResSim/WAT Documentation.

Water levels in the Kootenai River above Libby Dam, including the Libby Reservoir, were not calculated using detailed hydraulic modeling.

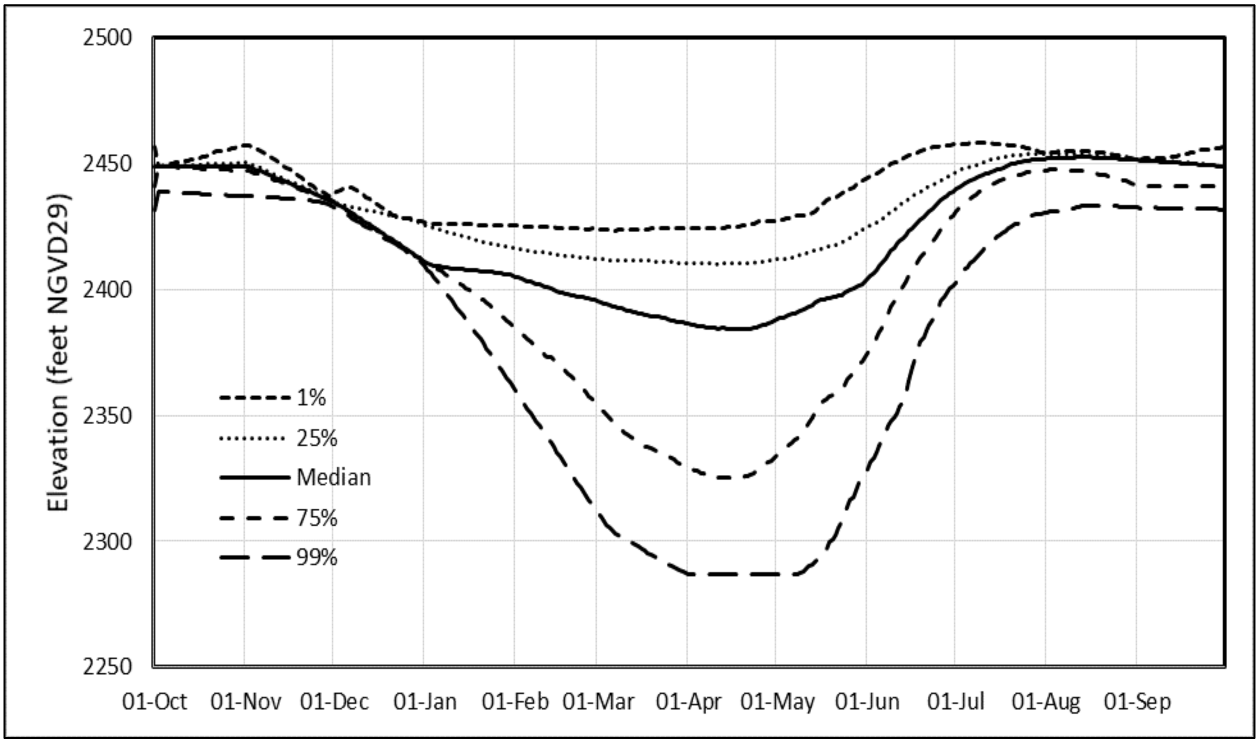


Figure 4-5. Libby Summary Elevation Hydrograph

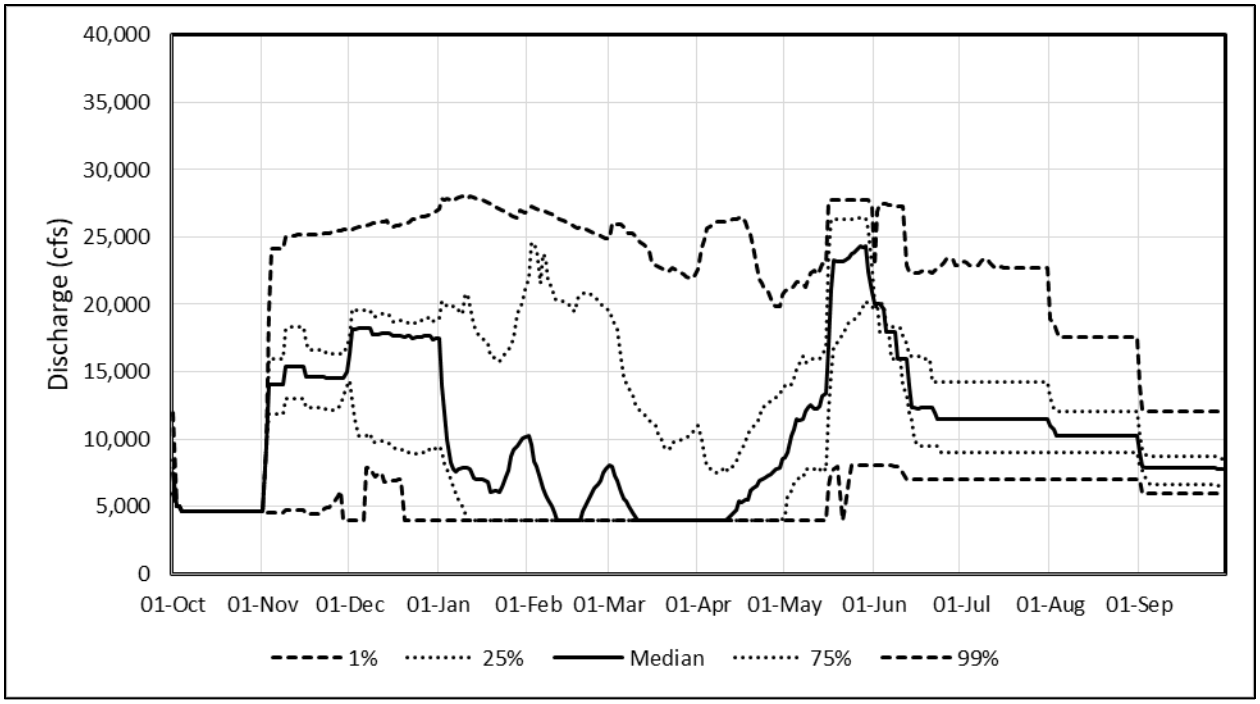


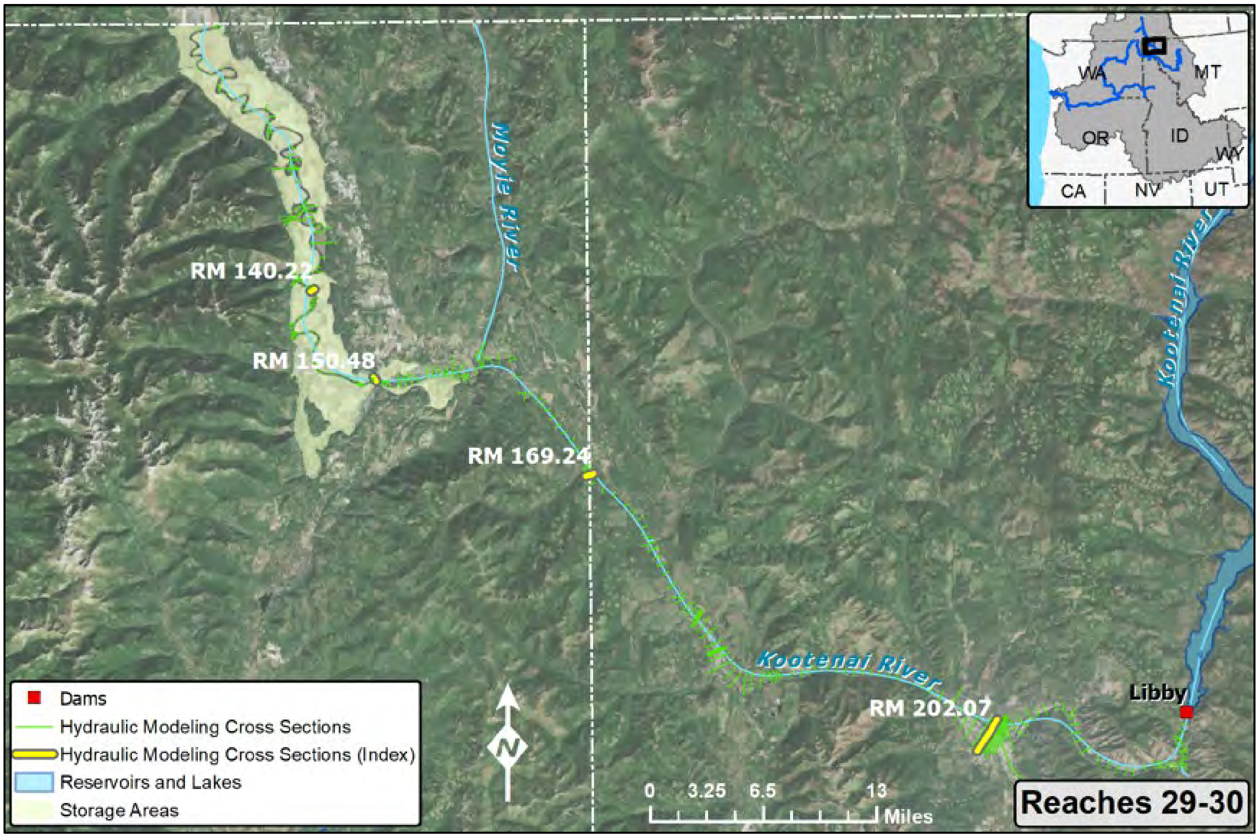
Figure 4-6. Libby Summary Outflow Hydrographs

4.3.1.2 Reach 29_30 – Kootenai River from Libby Dam to the U.S.-Canada Border

The Kootenai River below Libby Dam in northwestern Montana and northern Idaho is modeled in Reach 29_30 (originally two separate hydraulic models). The reach extends from Libby Dam down to the Corra Linn Dam in Canada, although the CRSO study area stops at the U.S.-Canada border. The reach includes the heavily leveed Bonners Ferry, Idaho, and the agricultural area between Bonners Ferry and the U.S.-Canada border. See Figure 4-7 for a map of the reach.

Inflow to the reach includes outflow from Libby Dam at the upper end of the model and several tributaries including the Fisher, Yaak, Moyie, Goat, and the Kuskunook Rivers. Outflow from Duncan Reservoir in Canada also flows into Kootenay Lake from the north.

Corra Linn Dam in Canada downstream of the Grohman Narrows partially controls Kootenay Lake, providing limited storage to support flood control and power generation. The profile for Reach 29_30 can be divided into two distinct reaches. The backwater influence of Kootenay Lake extends all the way to and slightly past Bonners Ferry (to approximately River Mile [RM] 160). Above RM 160, the reach is free flowing. There is a major natural constriction near RM 190 that creates a roughly 100-foot step in the water surface profile. Figure 4-8 shows the water surface profiles for the reach, and Figure 4-9 shows summary hydrographs at index locations in the lower part of the reach.



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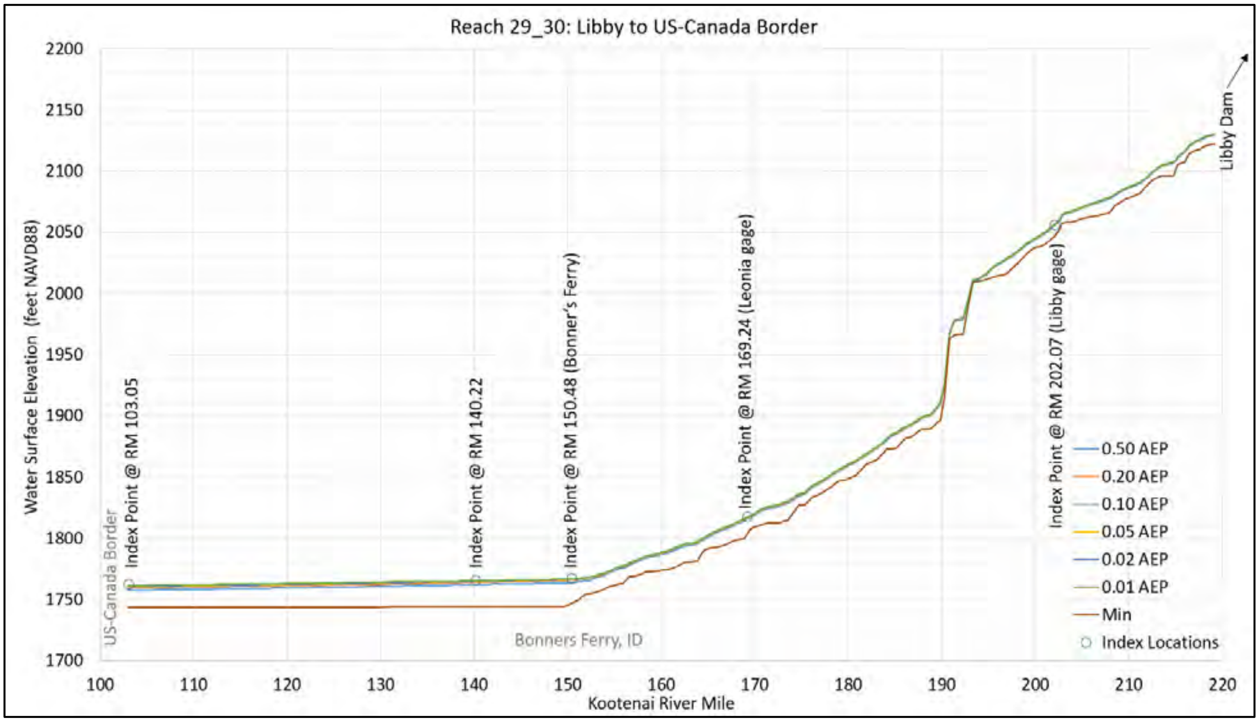
1058 **Figure 4-7. Reach 29_30 Location Map**



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1060 **Figure 4-8. Annual Exceedance Probability Profiles for Reach 29_30**

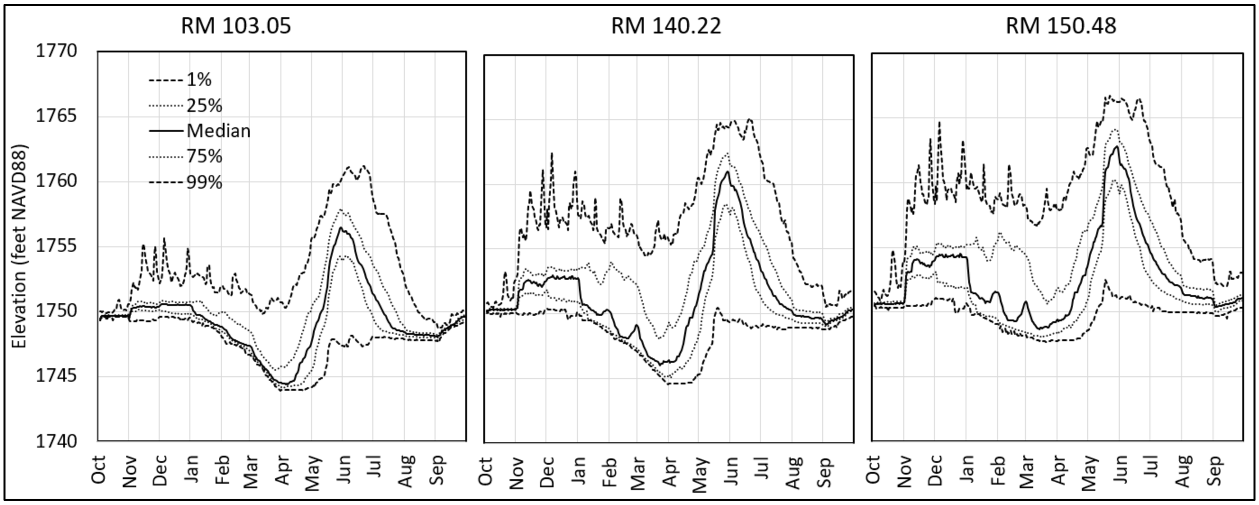


Figure 4-9. Summary Elevation Hydrographs for the Lower Kootenai River above the border (RM 103) to Bonner's Ferry, Idaho (RM 150)

4.3.1.3 Hungry Horse Dam and Reservoir

Hungry Horse Dam and Reservoir are located on the South Fork Flathead River in northwestern Montana. Hungry Horse has approximately 2.9 million acre-feet (Maf) of active space, and the reservoir extends upstream about 34 miles with over 170 miles of shoreline. Water levels in the South Fork Flathead River above Hungry Horse Dam including the Hungry Horse Reservoir were not calculated using detailed hydraulic modeling. Summary hydrographs for Hungry Horse outflow are shown in Figure 4-10 and Figure 4-11.

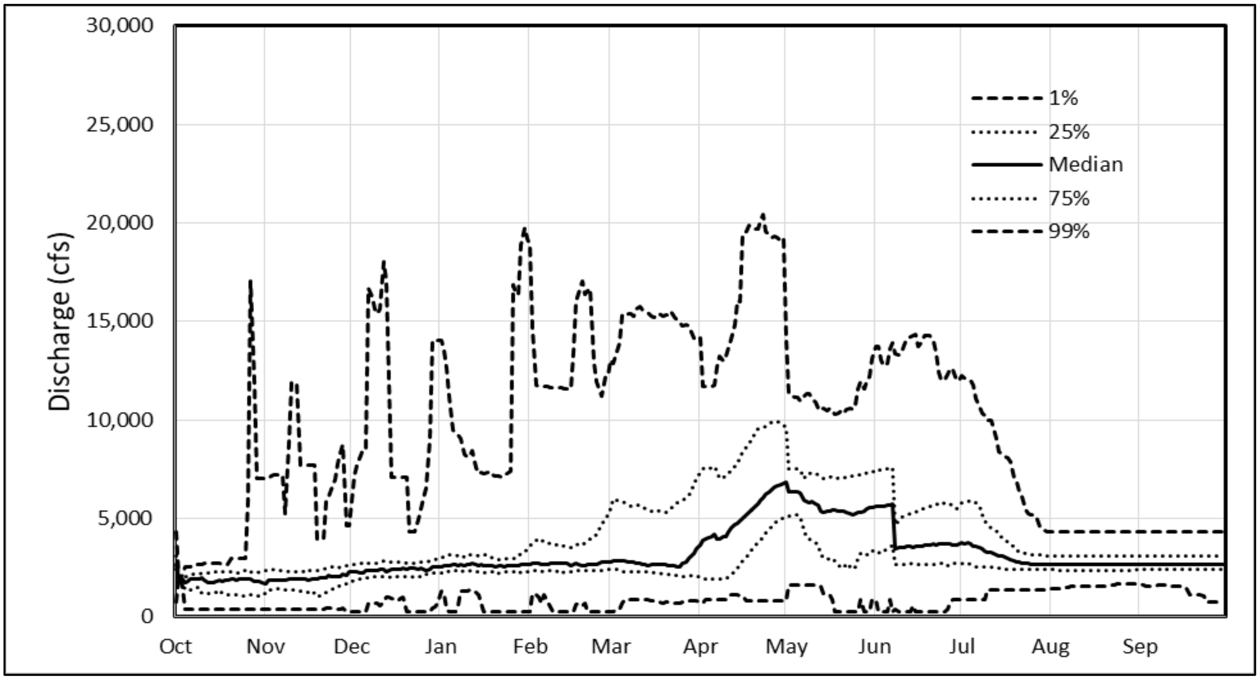


Figure 4-10. Summary Discharge Hydrographs for Hungry Horse Dam Outflow

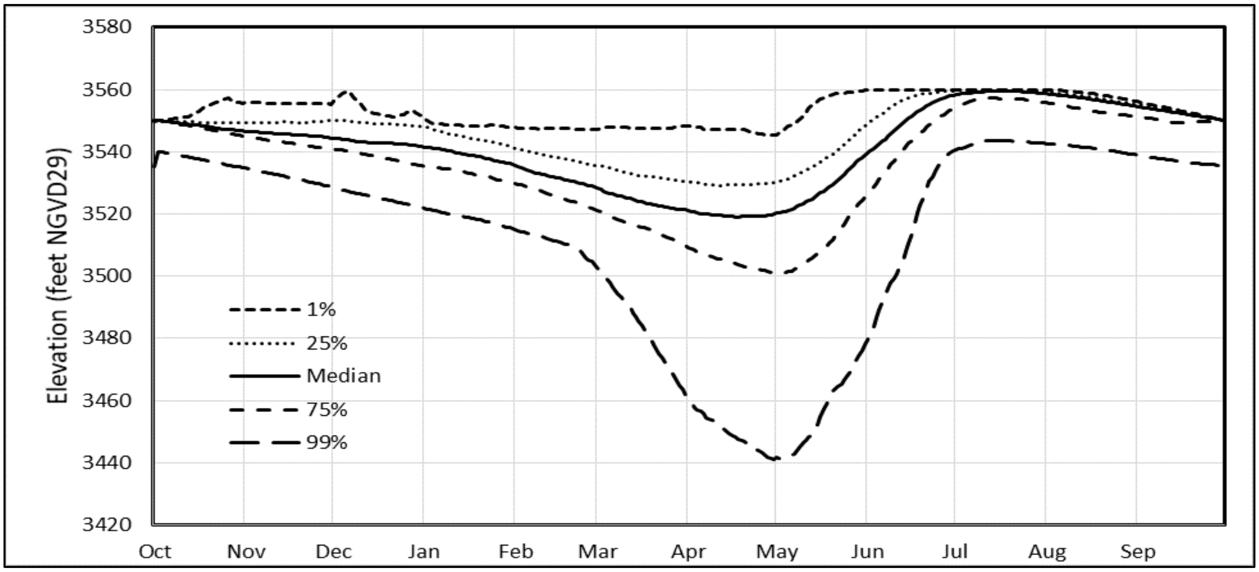


Figure 4-11. Hungry Horse Summary Elevation Hydrographs

4.3.1.4 Reach 28 – Flathead River and Flathead Lake (Hungry Horse Dam to Seli'š Ksanka Qlispe' Dam)

Reach 28 (Figure 4-12) is located in northwest Montana near Kalispell, Montana. It extends from Seli'š Ksanka Qlispe' (SKQ) Dam (Flathead RM 74) to just below Hungry Horse Dam (RM 160). It includes the entirety of Flathead Lake, starting at just above SKQ Dam (RM 74), and includes the Whitefish River(s) west of the Flathead River.

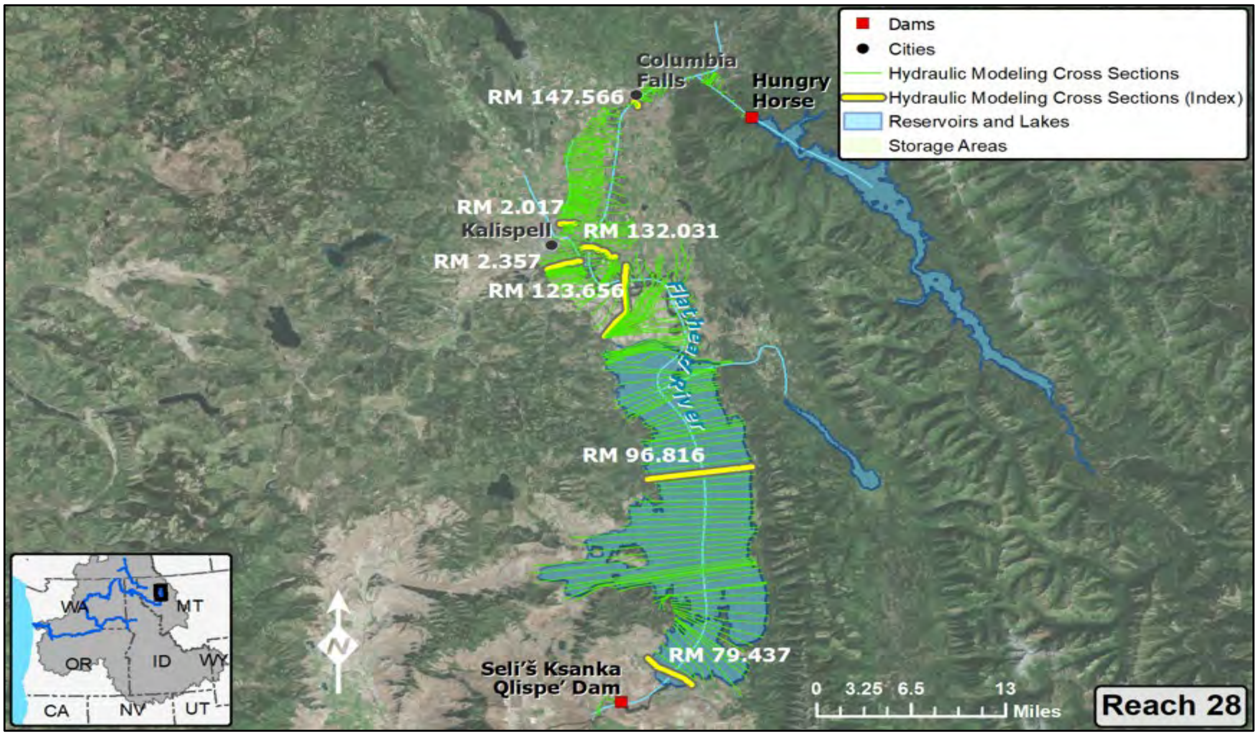


Figure 4-12. Reach 28 Location Map

The majority of the inflow to Reach 28 comes from unregulated Flathead River that combines with releases from Hungry Horse Dam on the South Fork Flathead River at the confluence near RM 153. Below Columbia Falls, there are only minor additional local inflows, including the Whitefish River, therefore Columbia Falls flow adequately represents the shape and magnitude of inflow to Flathead Lake. Because SKQ Dam operates Flathead Lake for storage and has a natural channel constriction, the flow hydrographs for SKQ Dam outflow is different than those at Columbia Falls.

Summary hydrographs for Hungry Horse outflow, the Flathead River (calculated as the difference between Columbia Falls and Hungry Horse), and Columbia Falls (a control point below the confluence) are shown in Figure 4-13 through Figure 4-15.

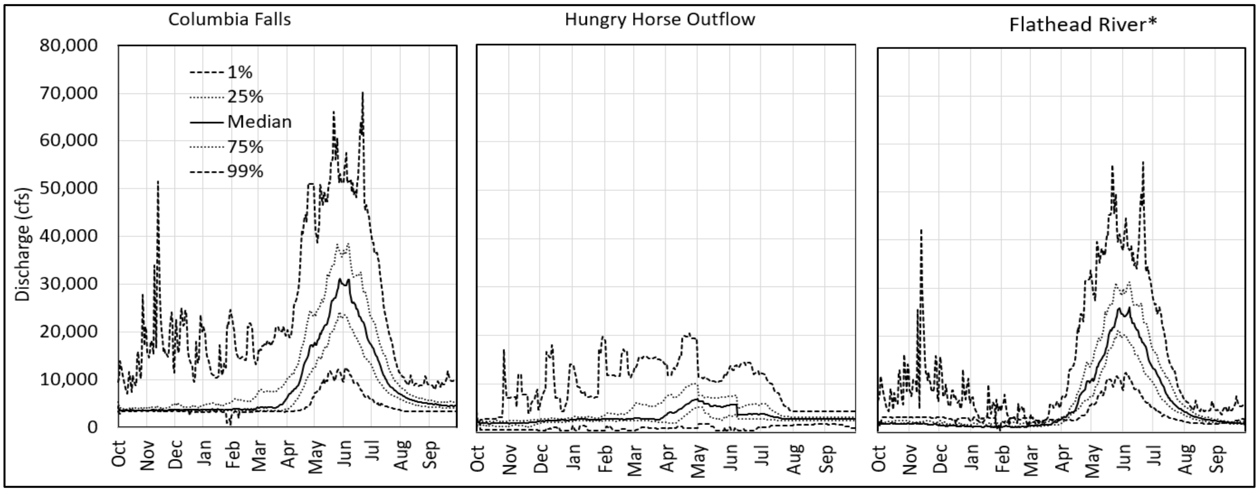


Figure 4-13. Summary Discharge Hydrographs for Hungry Horse Dam Outflow, Columbia Falls, and the Unregulated Flathead River above Columbia Falls

Note: Flathead River is the estimated flow on the Flathead River above the South Fork confluence, calculated as the difference between Columbia Falls flow and Hungry Horse outflow.

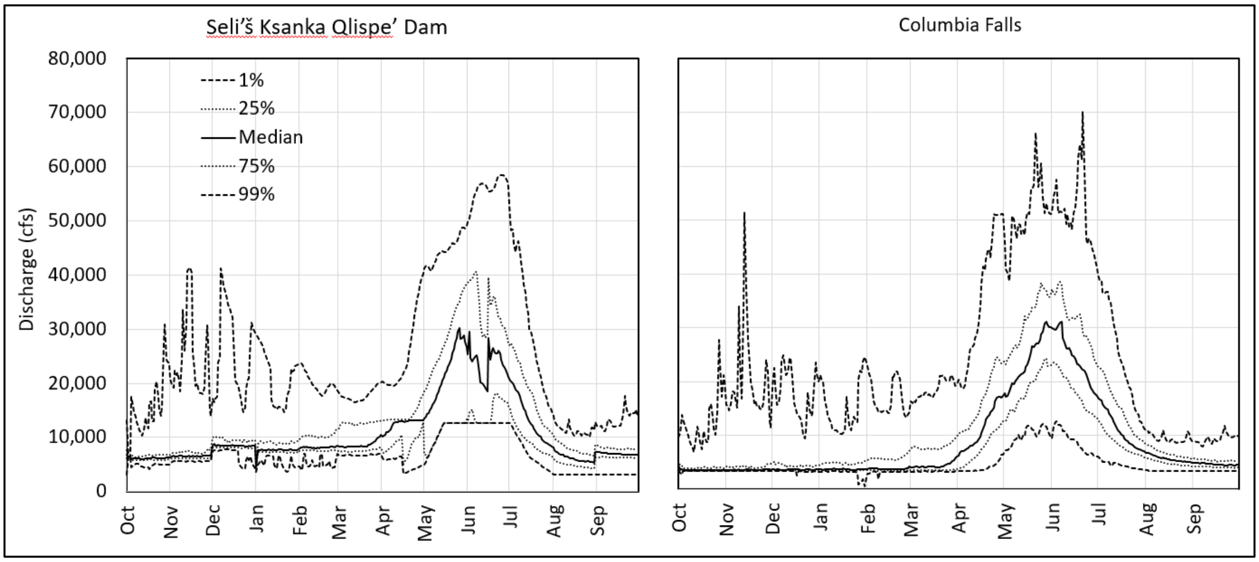


Figure 4-14. Summary Flow Hydrographs for Columbia Falls and SKQ Dam Outflow

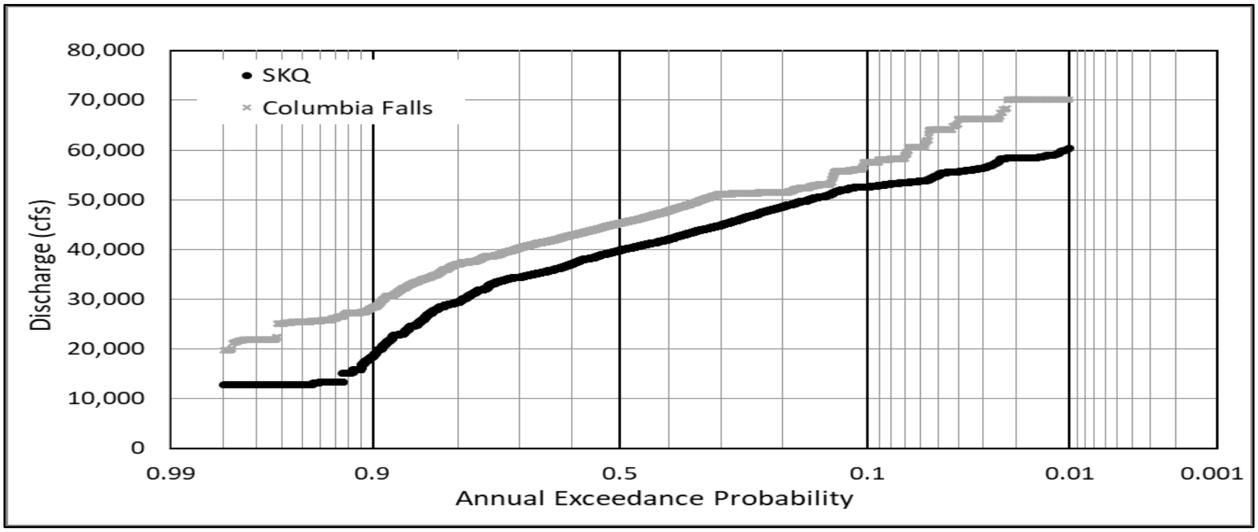


Figure 4-15. Annual Peak Discharge-Frequency Data at Columbia Falls and SKQ Dam Outflow

SKQ Dam is located just downstream of the roughly 50-mile-long Flathead Lake. The hydraulic model used as the basis of the flow-stage relationship tables has the elevation of Flathead Lake just above the natural constriction as the boundary condition that drives upstream hydraulics. For this reason, the water surface profile below RM 79.437 is not calculated.

SKQ Dam is operated for storage between a minimum pool in Flathead Lake of 2,883 feet NGVD29 (mid-April), and 2,893 feet NGVD29 during the summer months (Figure 4-16). During the winter draft and refill during large water years, the outflows can be restriction by a natural channel constriction just upstream of SKQ Dam.

The lake is mostly flat from RM 79 to 110 (Figure 4-17). Above RM 112, a slight increase in water surface elevation can be seen during higher flows coincident with lower lake levels. The reach quickly turns to free flowing along the Flathead River at about RM 133 as the water surface profile roughly parallels the bed slope (Figure 4-18).

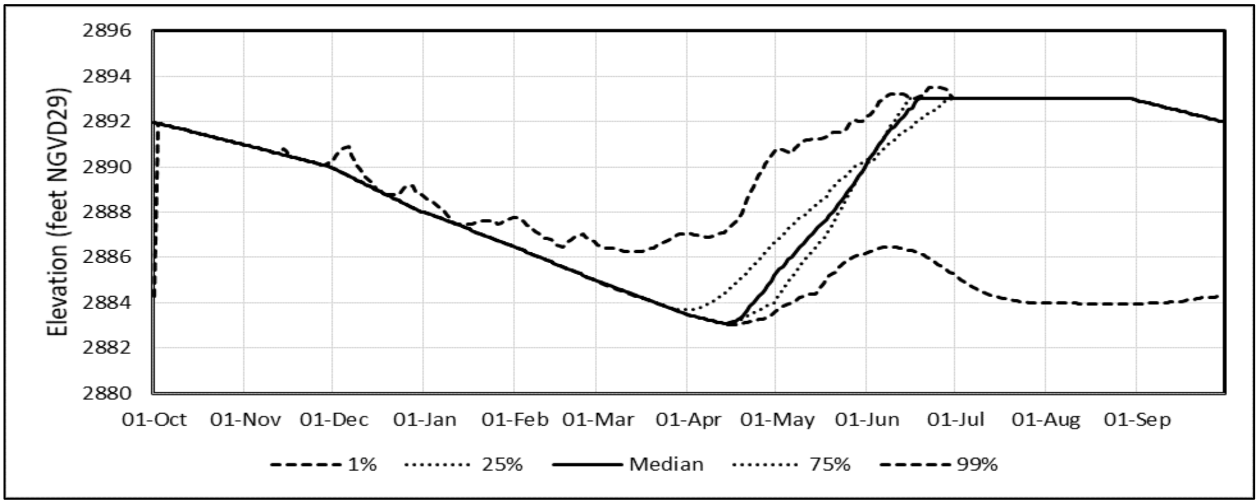


Figure 4-16. Summary Elevation Hydrograph for Flathead Lake

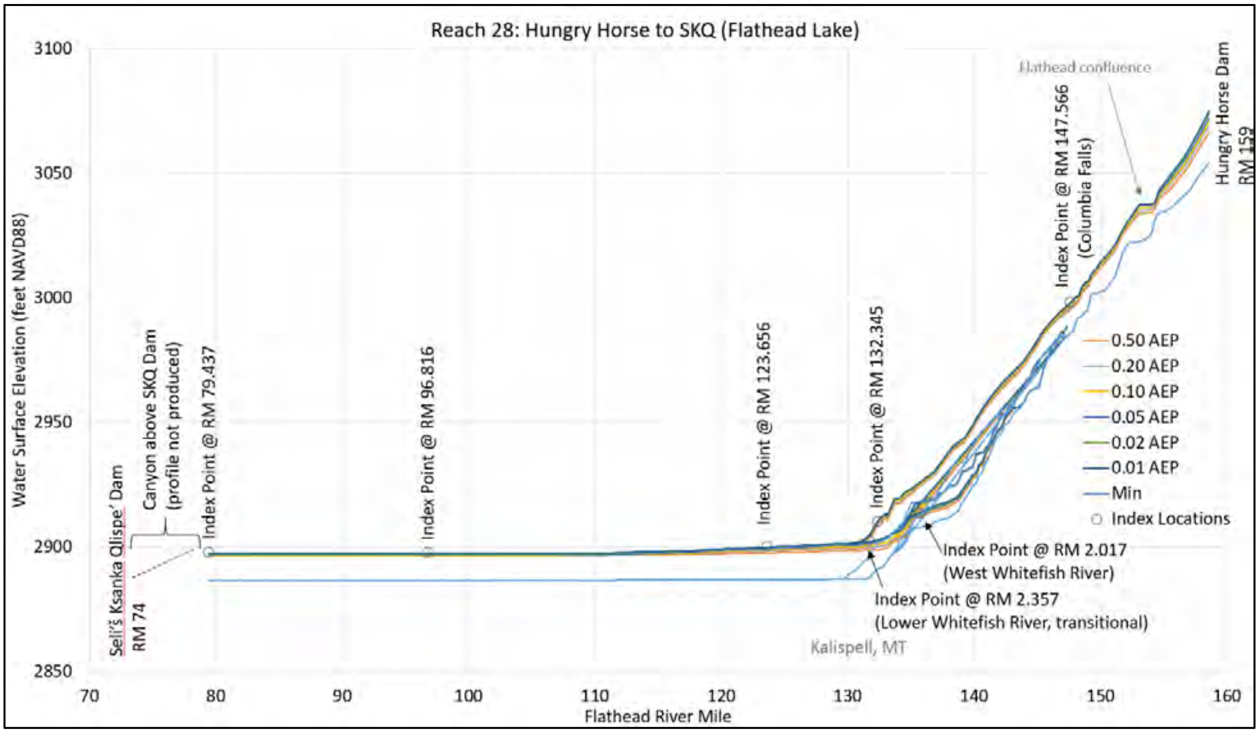


Figure 4-17. Annual Exceedance Probability Profiles for Reach 28

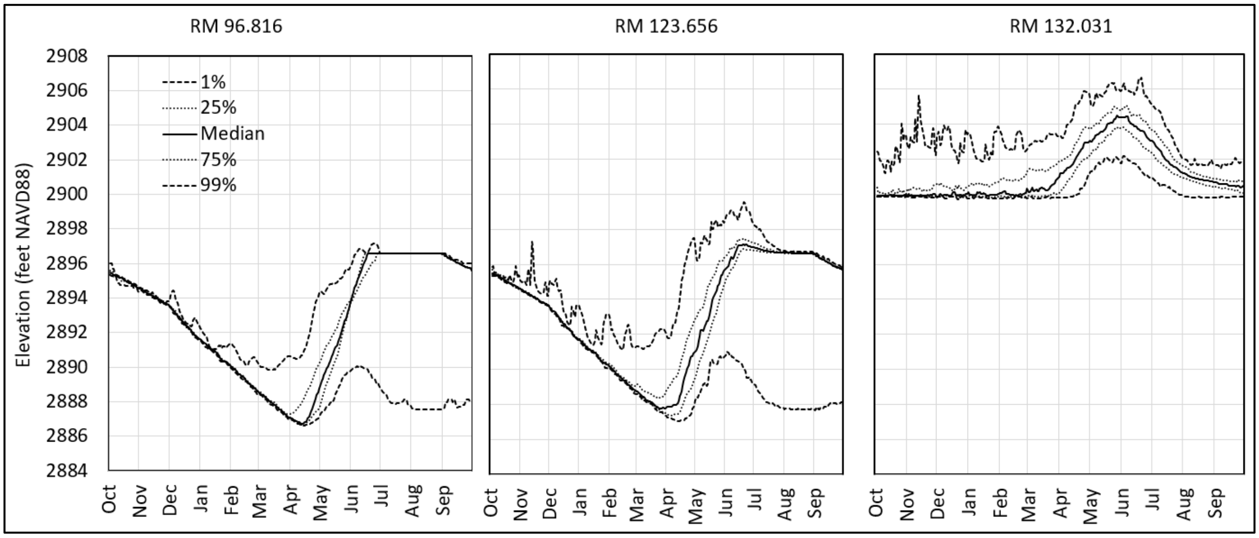


Figure 4-18. Summary Elevation Hydrographs for the Lower Index Locations in Reach 28

4.3.1.5 Reaches 25 to 27 – Lower Flathead and Clark Fork Rivers from SKQ Dam to Cabinet Gorge Dam

Reaches 25 to 27 (Figure 4-19) include the Flathead River below SKQ Dam to the confluence with the Clark Fork River, and then downstream through three run-of-river projects: Thompson Falls, Noxon Rapids, and Cabinet Gorge Dams.

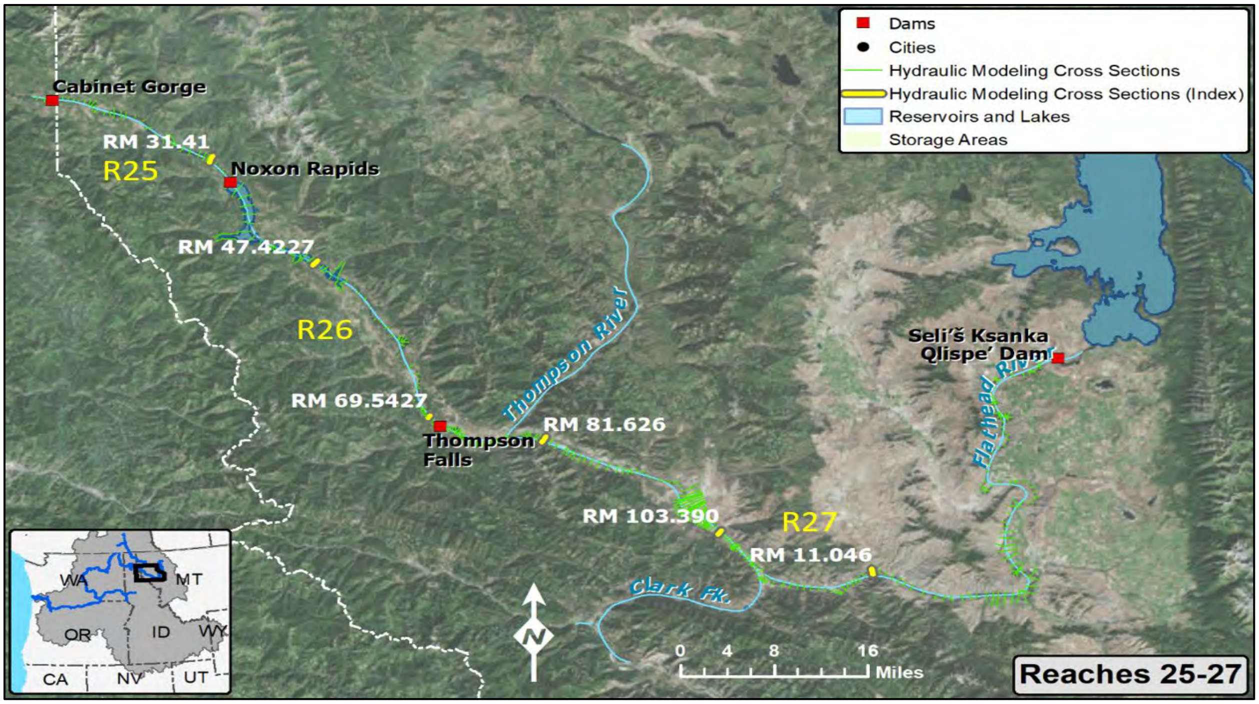


Figure 4-19. Reaches 25 to 27 Location Map

More than half of the inflow to Reach 27 comes from SKQ Dam at the upstream end of the model; however, the Clark Fork River above the Flathead River confluence at RM 109 can contribute more during the freshet months. Inflow to the shorter, downstream reaches are dominated by outflow from the Thompson Falls Dam at the upstream end, but other smaller tributaries between Thompson Falls and Cabinet Gorge Dam can contribute notably to the seasonal and annual peak flows.

Both the Cabinet Gorge and Thompson Falls Dams are run-of-river projects in the model; therefore, the summary hydrographs and annual frequency curves at the project forebays are both flat. Noxon Rapids Dam does operate as a storage project with an operating pool between 2,321 and 2,331 feet NGVD29 for all water years (Figure 4-20). (Note there are no differences between the median, 1, 25, 75, and 99 percent.)

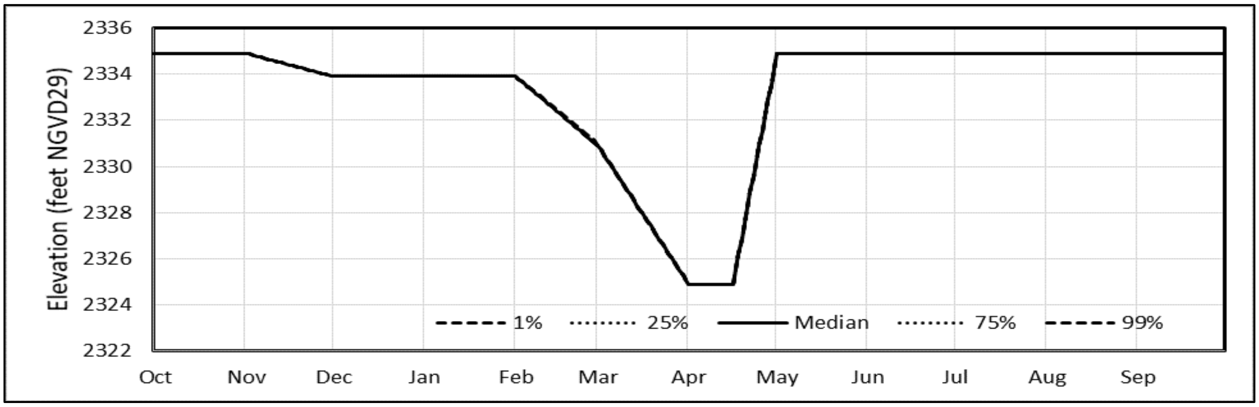


Figure 4-20. Summary Elevation Hydrographs for Noxon Rapids Dam

Reach 27 is considered free flowing due to its relatively steep slope and the fact that the Thompson Falls Dam is operated as a run-of-river project. The profile flattens notably just above the Clark Fork confluence at RM 109, but then increases as it approaches SKQ Dam. The water surface profile is not modeled for the Clark Fork River above the Flathead River confluence. The profile for Reach 26 is mostly flat over the lower 20 miles but can climb over 15 feet in the 10 miles below Thompson Falls Dam. Reach 25 between Cabinet Gorge and Noxon Rapids Dams is relatively flat but is considered transitional due to the hydraulic grade that can develop across nearly the entire reach during high-flow periods (Figure 4-21). Figure 4-22 shows summary hydrographs at index locations in Reach 26.

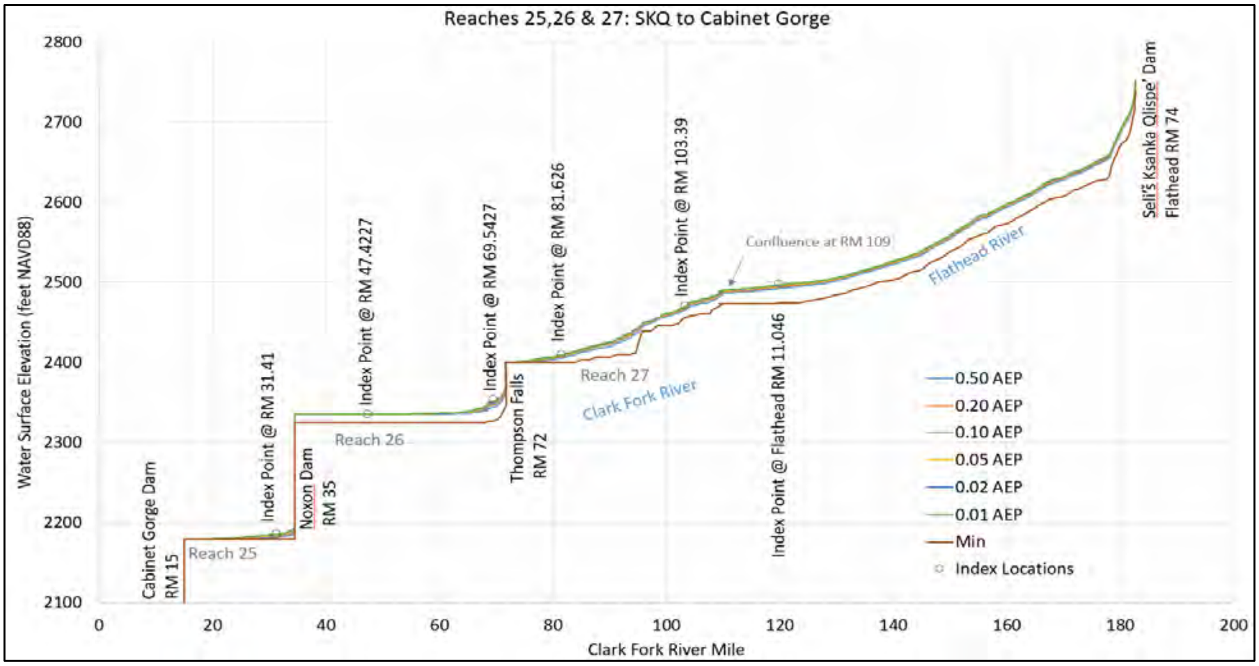


Figure 4-21. Annual Exceedance Probability Profiles for Reaches 25, 26, and 27

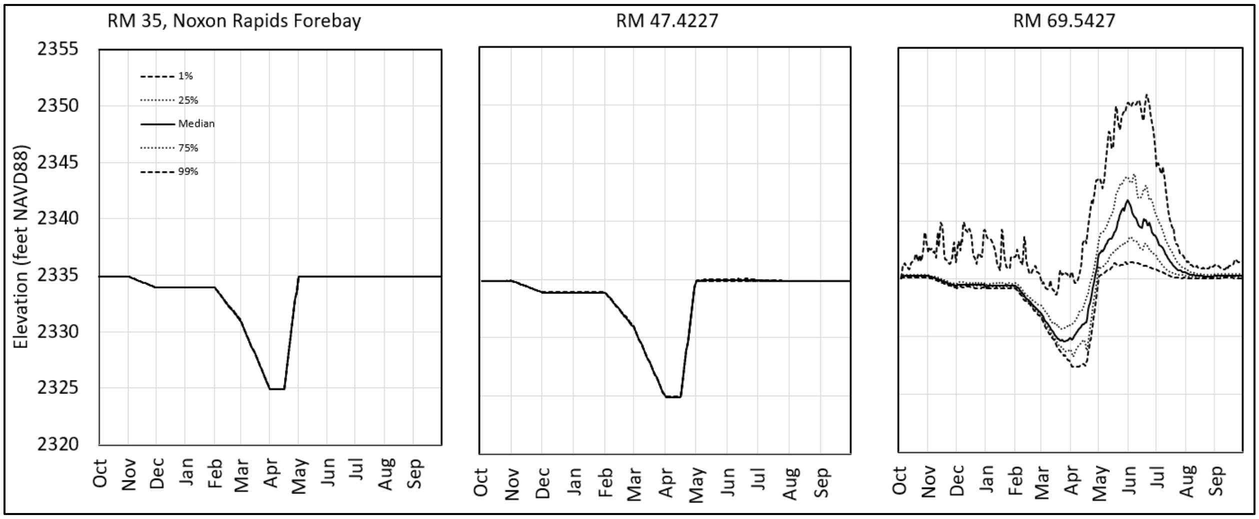


Figure 4-22. Summary Elevation Hydrographs for Reach 26 Forebay and Index Locations

4.3.1.6 Albeni Falls Dam and Lake Pend Oreille

Albeni Falls Dam and Lake Pend Oreille are in the northern Idaho Panhandle near Sandpoint. Lake Pend Oreille is over 43 miles long and is one of the deepest lakes in the nation. It was a naturally formed lake due to a natural channel constriction at the downstream (northwest) end of the lake, near Dover, Idaho. The lake was made larger and the channel enlarged with the construction of Albeni Falls Dam.

Albeni Falls Dam is at approximately Pend Oreille RM 89, Lake Pend Oreille starts around RM 110, and the upstream boundary of the lake is about 45 miles upstream (RM 156) (Figure 4-23). The lake also extends up the Clark Fork River several miles toward Cabinet Gorge Dam (Clark Fork RM 14.9).

Inflow above Albeni Falls Dam is from the Clark Fork River with notable contribution from the Priest River, which comes in at RM 95 below Lake Pend Oreille. The summary outflow hydrograph for Albeni Falls differs from the Cabinet Gorge outflow due to the natural lake constriction near Dover, Idaho, where Lake Pend Oreille becomes the Pend Oreille River and the Albeni Falls Dam regulates Lake Pend Oreille levels. Figure 4-24 shows the 50 percent and 1 percent summary hydrographs for Cabinet Gorge and Albeni Falls Dams outflow.

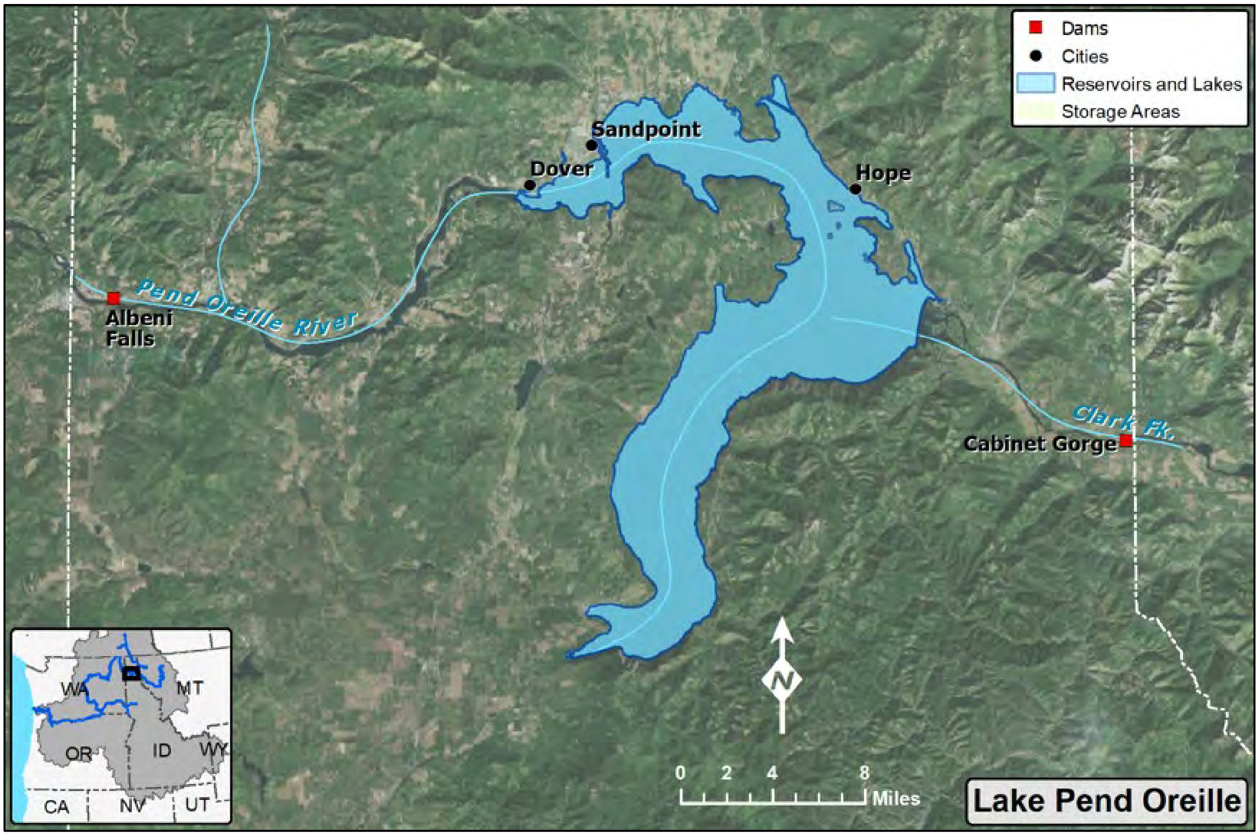


Figure 4-23. Map of Albeni Falls Dam and Lake Pend Oreille

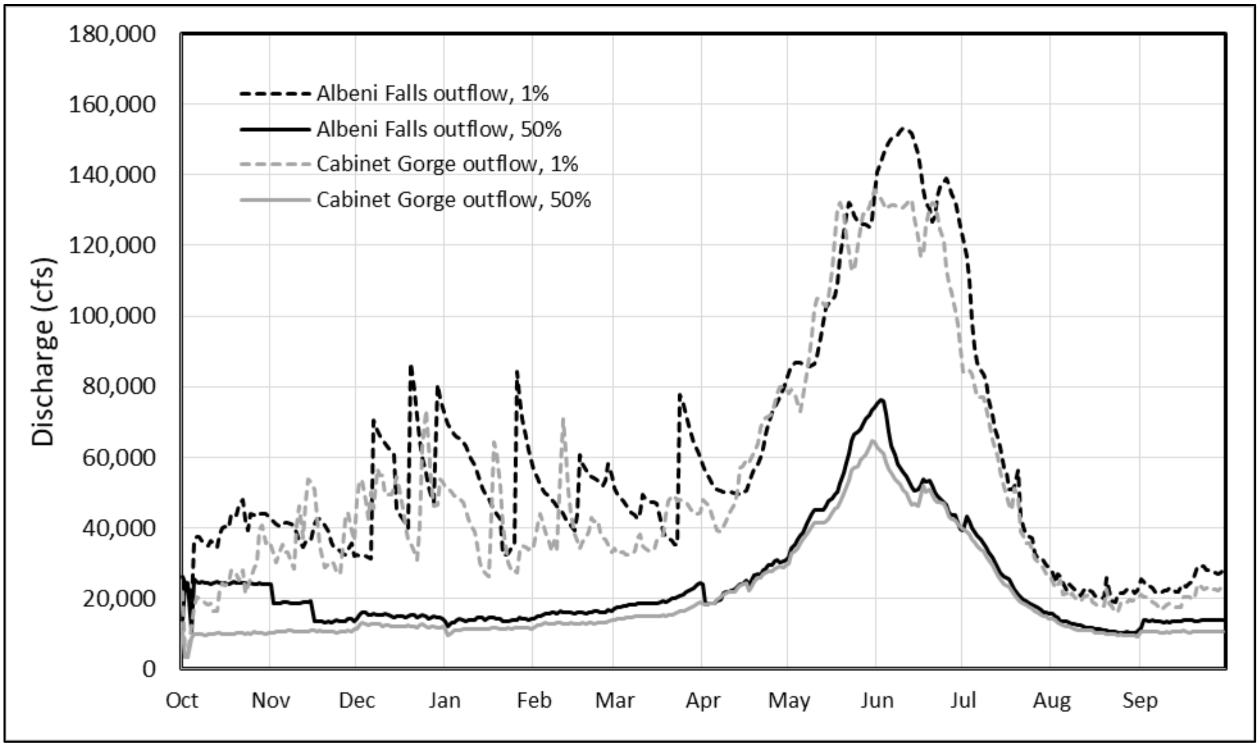


Figure 4-24. Median (50 percent) and 1 percent Summary Outflow Hydrographs for Albeni Falls and Cabinet Gorge Dams

It is worth noting that the Albeni Falls Dam forebay is not the same as Lake Pend Oreille water levels. This is due natural hydraulic constriction near the outlet of Lake Pend Oreille near Dover, Idaho, as it transitions to the Pend Oreille River. During high outflows from Albeni Falls Dam, the natural constriction controls how much water is released from the lake and thus the dam. During the rest of the year, the dam controls releases from the lake when that constriction is backwatered. As a result of this constriction, water levels in Lake Pend Oreille can vary according to the flow through Albeni Falls Dam, which is influenced by operations and inflow to the project. In the ResSim model, Albeni Falls Dam's elevation is modeled as the Lake Pend Oreille elevation at the Hope gage. This is done to correctly model the times where the natural constriction is governing releases through the project. In the real world, the elevation on Lake Pend Oreille and the forebay of Albeni Falls Dam are different.

According to the rules used in the ResOps model, the normal operating pool at Albeni Falls Dam is between 2,051.25 and 2,062.25 feet NGVD29. During part of the winter and summer, there are 0.5-foot operating bands, and in the ResSim model this is done by taking the middle of those two respective bands. The elevation of Lake Pend Oreille can exceed the normal pool levels during the spring freshet and approach maximum elevations exceeding 2,068 feet NGVD29. The pool can rise above its normal winter elevation during winter flood events, but only some of those winter FRM operations are incorporated into the ResSim model, and it is unlikely the pool would exceed 2,060 feet NGVD29 during the winter (Figure 4-25).

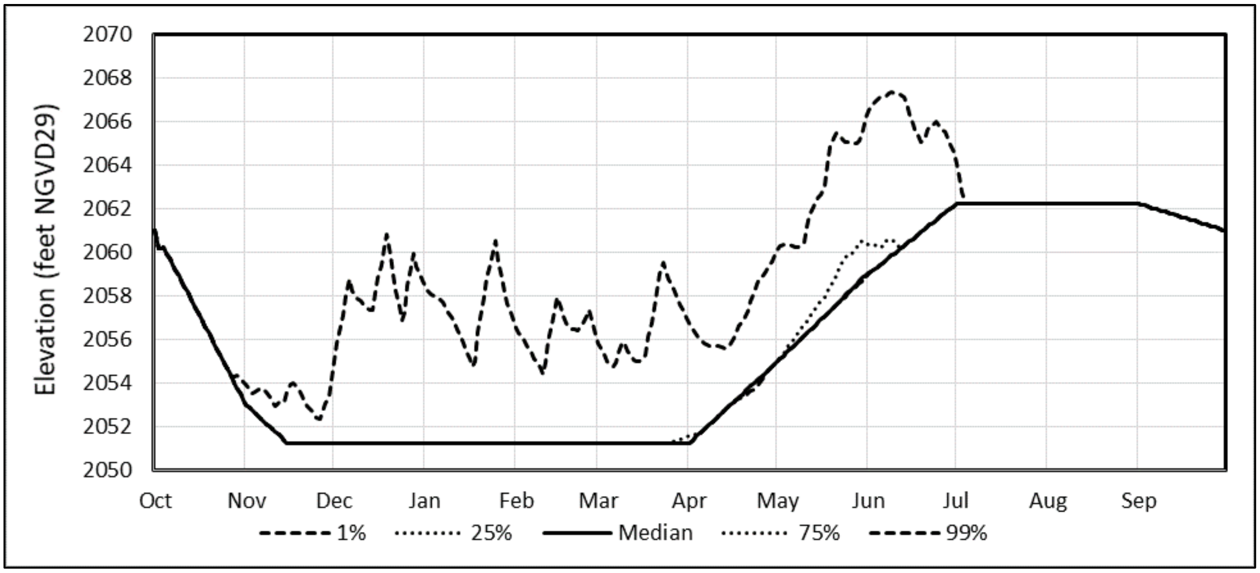


Figure 4-25. Summary Elevation Hydrographs for Lake Pend Oreille

A detailed description of the water surface profile in Reach 24 is not presently available. The elevation of Lake Pend Oreille is higher than the Albeni Falls Dam forebay due to the presence of a natural channel constriction between the lake and Albeni Falls Dam. The lake can be assumed to be flat from above Sand Point, Idaho (approximately RM 110), to the upstream end along the Pend Oreille River throughout the year. The water level down to RM 95 can be assumed to be equal to that of Lake Pend Oreille during low-flow periods.

4.3.1.7 Reaches 22 and 23 – Pend Oreille River from Albeni Falls Dam to Boundary Dam

Reaches 22 and 23 cover the 73 miles of the lower Pend Oreille River from Albeni Falls Dam to the Boundary Dam near the U.S.-Canada border in the northeast corner of Washington (Figure 4-26). Both the Boundary Dam (RM 16) and Box Canyon Dam (RM 33) are non-CRSO dams, but Albeni Falls (RM 89) is a CRSO dam and a major storage project.

Flow through the lower Pend Oreille River reaches is dominated by Albeni Falls outflow. There are no major tributary inflows. Both the Boundary and Box Canyon Dams are run-of-river projects in the model; therefore, the summary hydrographs and annual frequency curves at the project forebays are both flat (Figure 4-27 to Figure 4-29).

Water levels in both Reaches 22 and 23 are more sensitive to changes in discharge due to the notable constrictions in both reaches, one at roughly RM 25, halfway between Box Canyon and Boundary Dams, and one immediately above Box Canyon Dam. Both constrictions result in a substantial step in the water surface profiles during high-flow conditions.

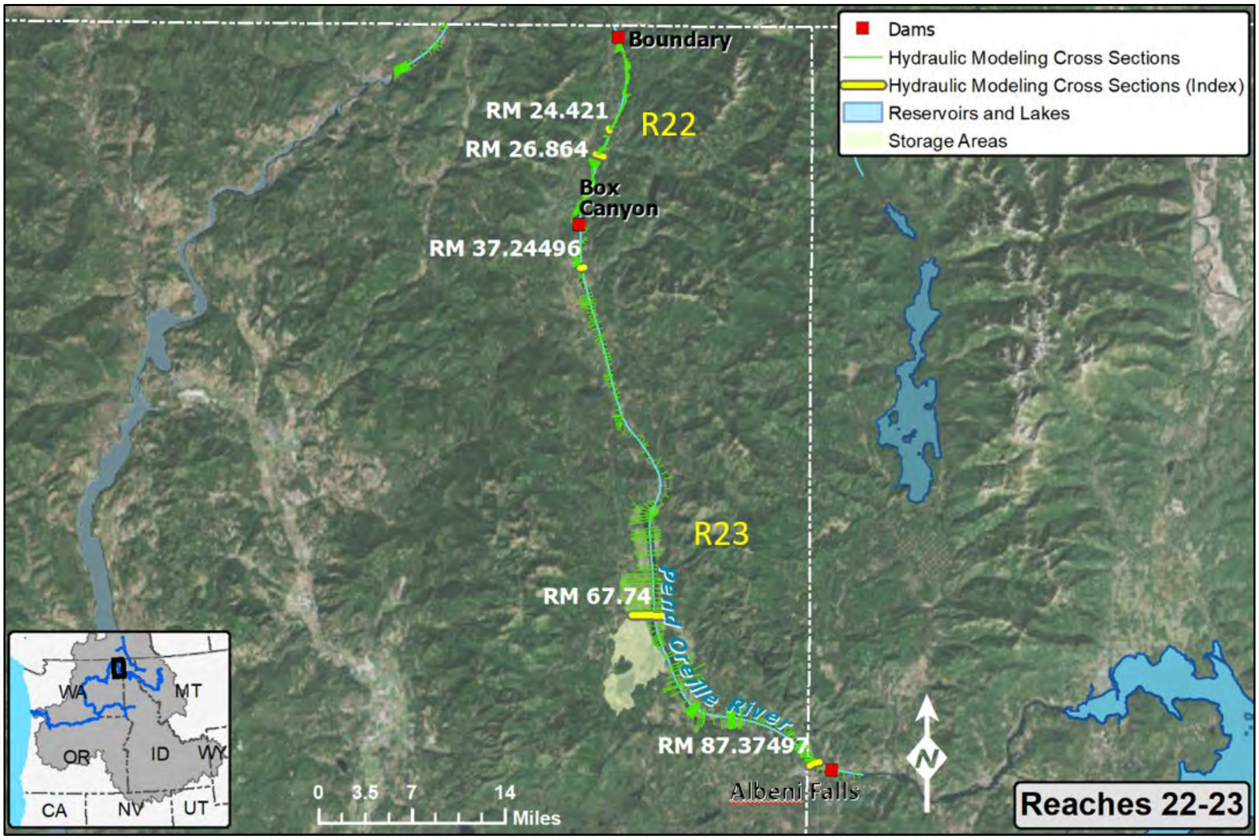


Figure 4-26. Reaches 22 and 23 Location Map

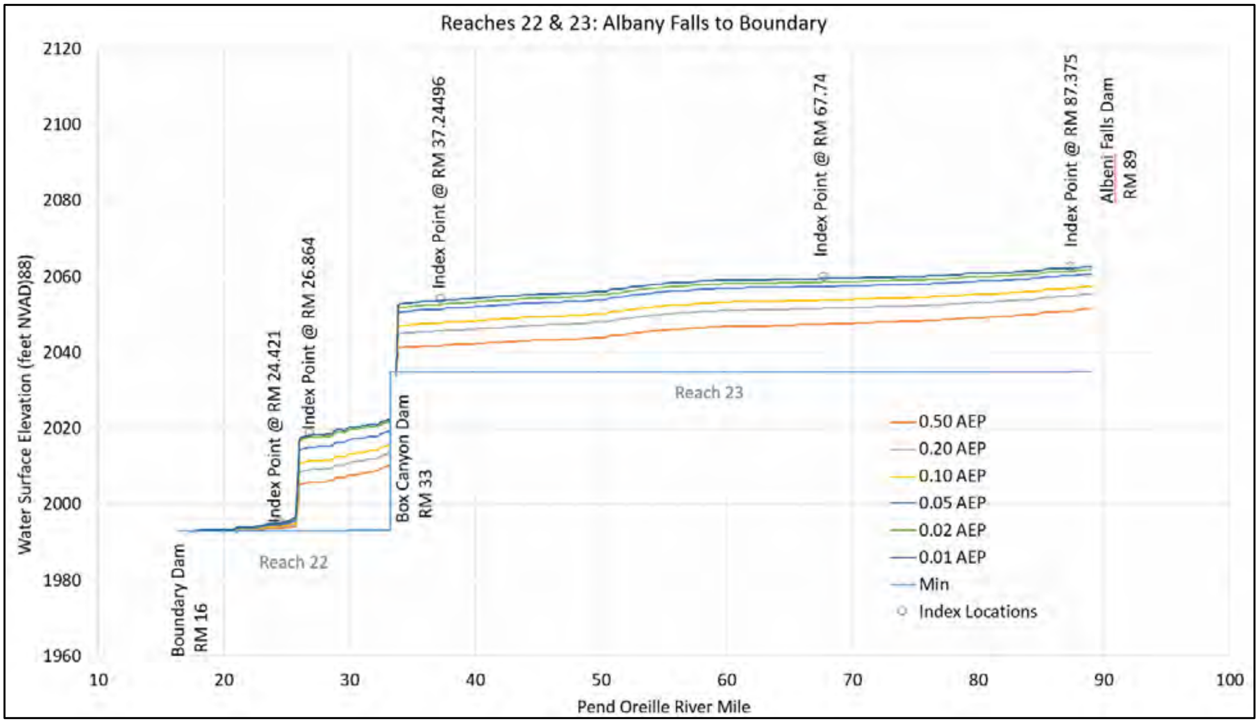


Figure 4-27. Annual Exceedance Probability Profiles for Reaches 22 and 23

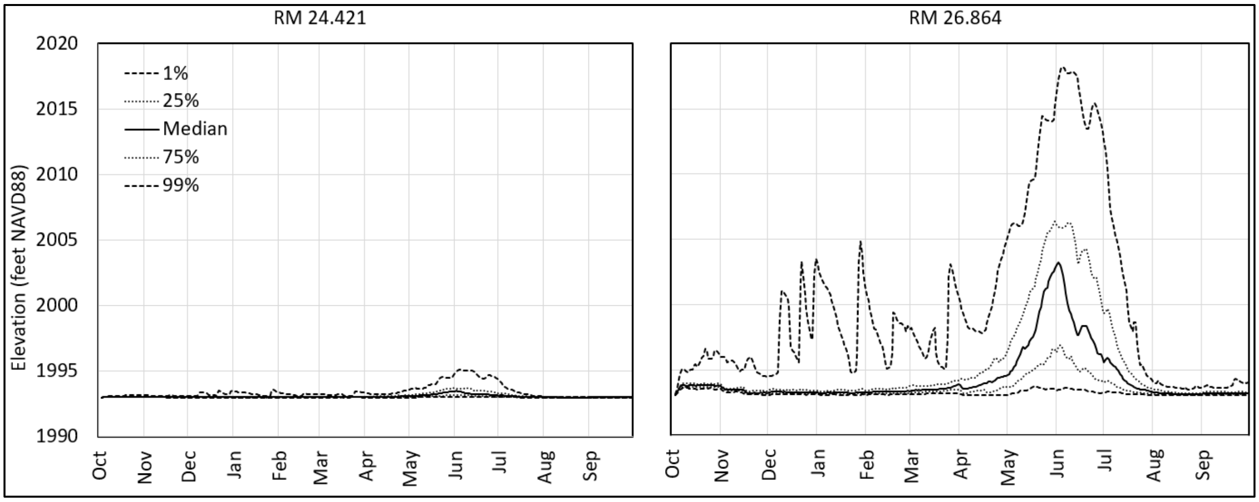


Figure 4-28. Summary Elevation Hydrographs for Index Points in Reach 22

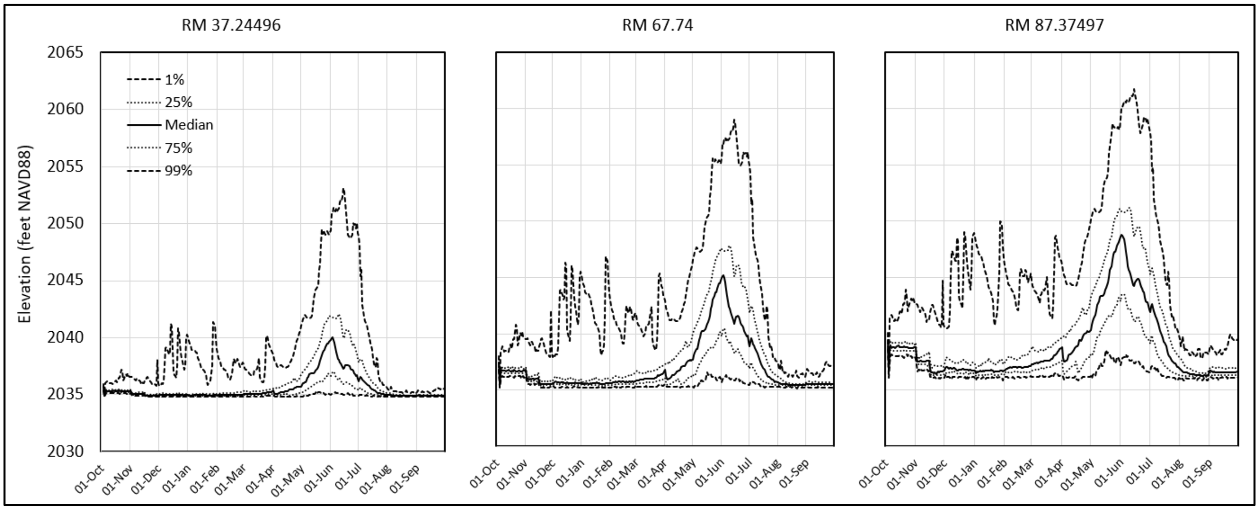


Figure 4-29. Summary Elevation Hydrographs for Index Points in Reach 23

4.3.2 Region B – Grand Coulee and Middle Columbia River

4.3.2.1 Reaches 20 and 21 – Rufus Woods Lake and Lake Roosevelt (U.S.-Canada Border to Grand Coulee and Chief Joseph Dams)

Reach 21 (Figure 4-30) includes the Columbia River in northeast Washington from Grand Coulee Dam in northwest Washington north to the U.S.-Canada border. Lake Roosevelt, the reservoir behind the Grand Coulee Dam, and has approximately 5.2Maf of active space with an additional 3.9 Maf of inactive space. The reservoir is over 100 miles long. It is operated for power, flood control, and irrigation. It is connected to Banks Lake, which has 715,000 acre-feet of active storage, via a feeder canal.

Reach 20 (Figure 4-30) is in central Washington between Grand Coulee Dam and Chief Joseph Dam, Columbia RM 597 to 545. The reservoir above Chief Joseph Dam is named Rufus Woods Lake.

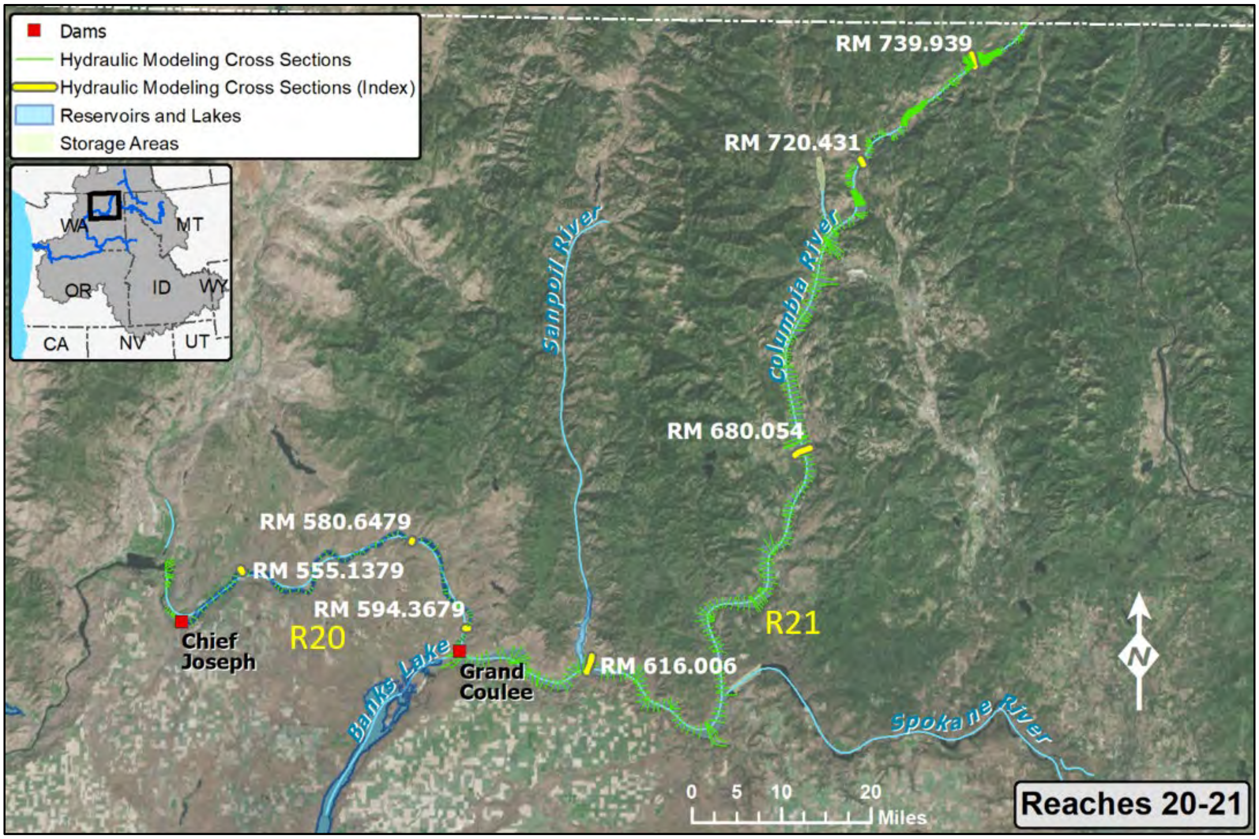


Figure 4-30. Reaches 20 and 21 Location Map

Inflow to Grand Coulee is dominated by mainstem Columbia River flow from across the U.S.-Canada border, which includes outflow from the Arrow Dam on the mainstem Columbia River, Brilliant Dam on the Kootenay River, and outflow from Boundary Dam on the Pend Oreille River. The summary outflow hydrograph is different than the hydrograph of the Columbia River at the upper end of Lake Roosevelt (referred to as "Lake Roosevelt inflow" for the remainder of this report) due to storage operations at Grand Coulee Dam and the pumping from Lake Roosevelt into Banks Lake for water supply. Figure 4-31 shows the median, 1 percent, and 99 percent summary hydrographs for the Lake Roosevelt inflow and the Grand Coulee dam outflow. Flow in Reach 20 is dominated by Grand Coulee outflow. Because Chief Joseph Dam is operated as a run-of-river project and there are no major tributary inflows, project outflow and inflow are similar.

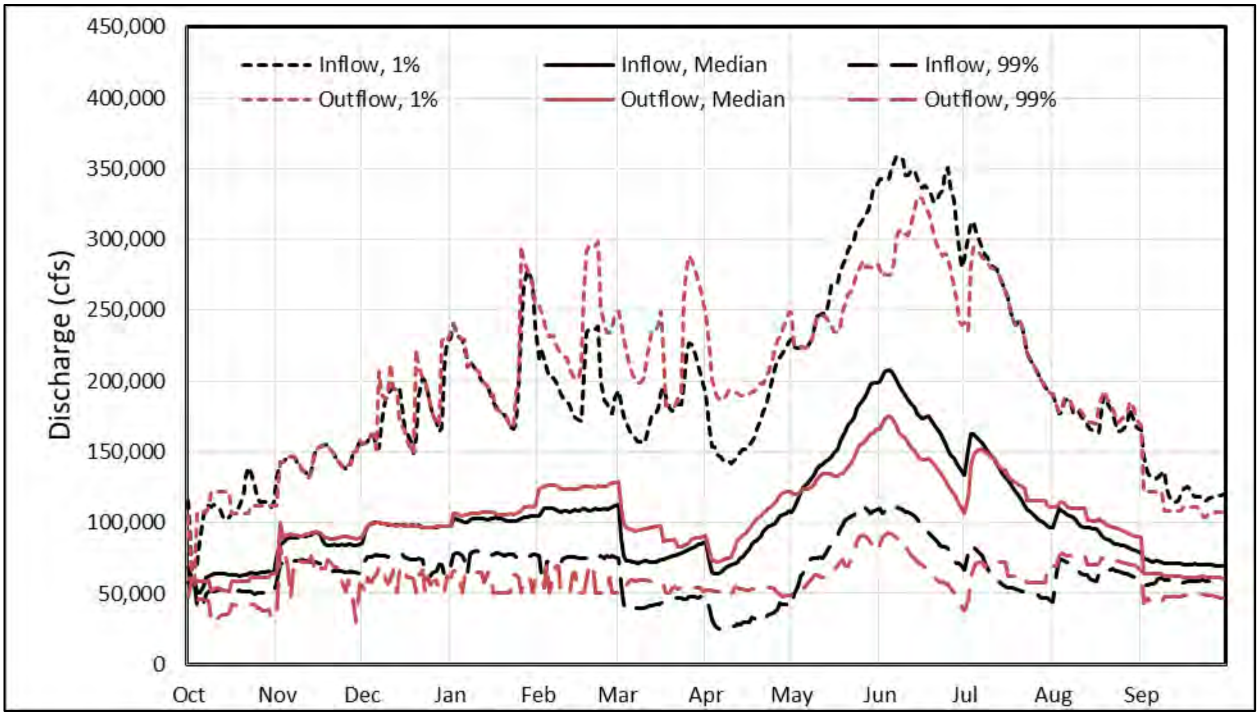


Figure 4-31. Summary Hydrographs of Columbia River Inflow to Lake Roosevelt (Lake Roosevelt inflow) and Grand Coulee Dam Outflow

Grand Coulee is a major storage project. According to the rules used in the ResOps model, the normal operating pool at Grand Coulee is between 1,290 and 1,208 feet NGVD29. The reservoir is drafted in the winter when flows are lower so it can capture higher flows and fill the reservoir during the spring freshet. At Chief Joseph Dam in real-time operations, the pool is fluctuated within its power pool on an hourly to daily timestep. In ResSim, it is operated as a run-of-river project and has no simulated, active storage; therefore, the summary hydrograph and annual frequency curves at the project forebay are both flat (Figure 4-32 to Figure 4-35).

The water surface profile in Reach 20 is relatively flat for the first lower 20 miles, but is increasingly steep as is approaches Grand Coulee Dam. The water surface profile and flat pool extents in Lake Roosevelt will vary depending on the season. A flat pool can be assumed perennially to about RM 665, but it can extend as far as roughly RM 720 during low-flow and high pool conditions. With the exception of the early summer period during large freshets, the summary hydrographs near RM 700 are mostly within a half-foot of those at the Grand Coulee forebay over a hundred miles downstream.

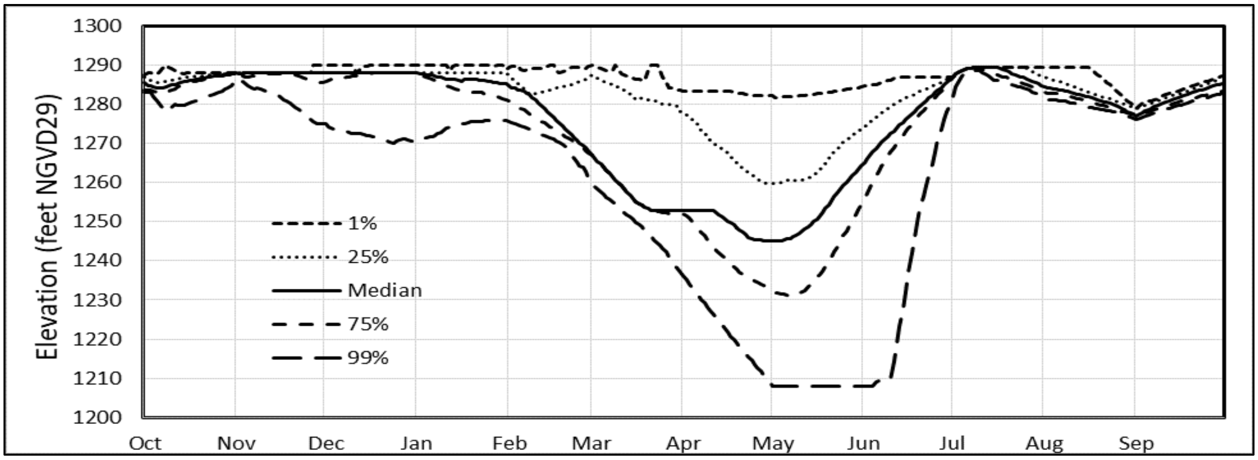


Figure 4-32. Summary Elevation Hydrographs for Grand Coulee Dam Forebay (Lake Roosevelt)

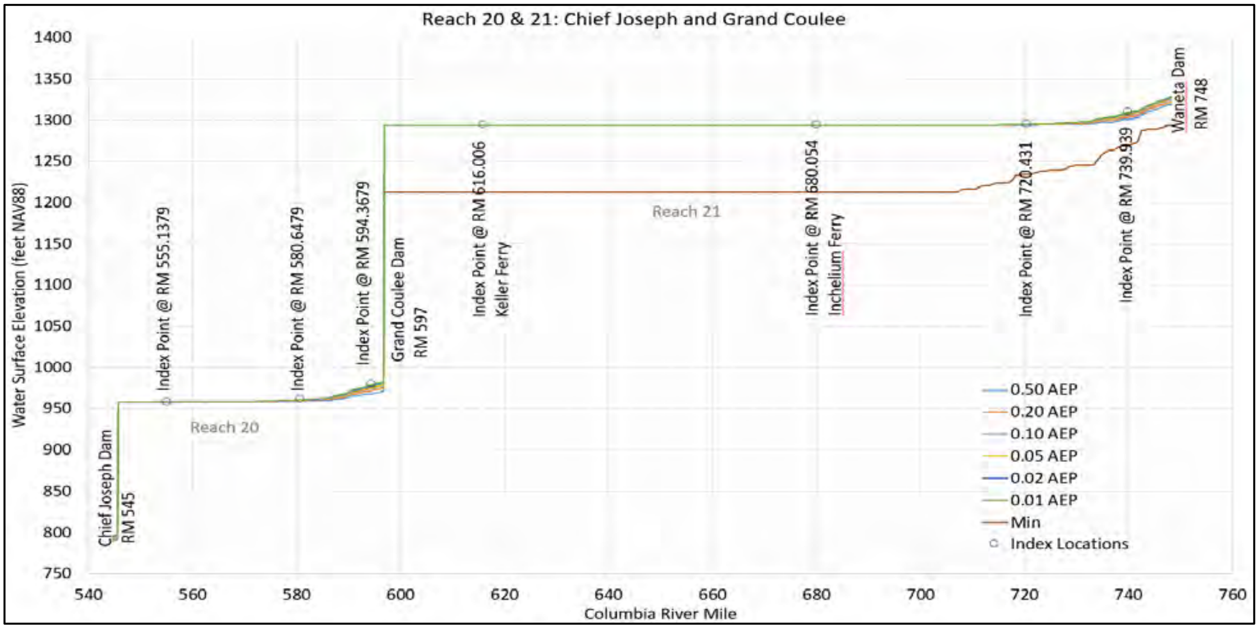


Figure 4-33. Annual Exceedance Probability Profiles for Reaches 20 and 21

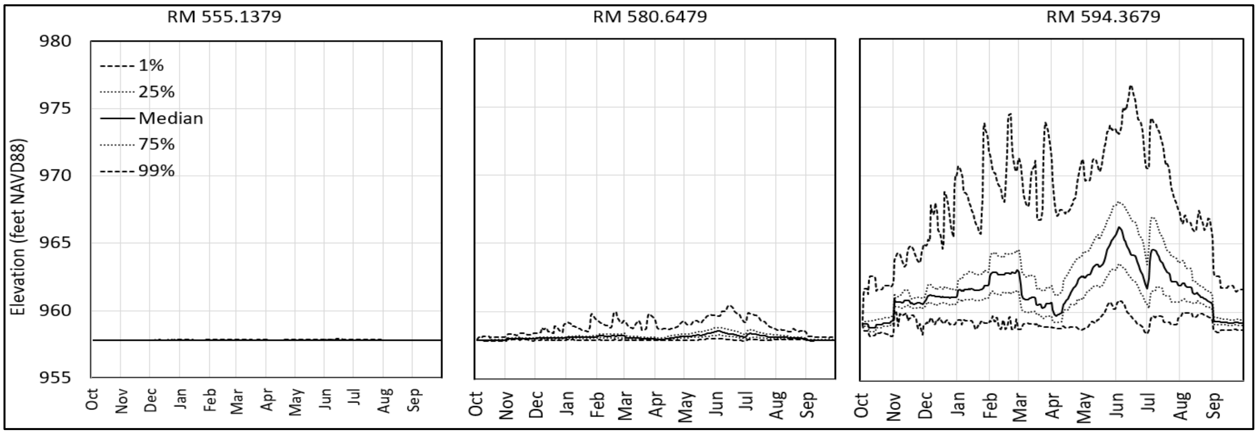


Figure 4-34. Summary Hydrographs at Reach 20 Index Locations

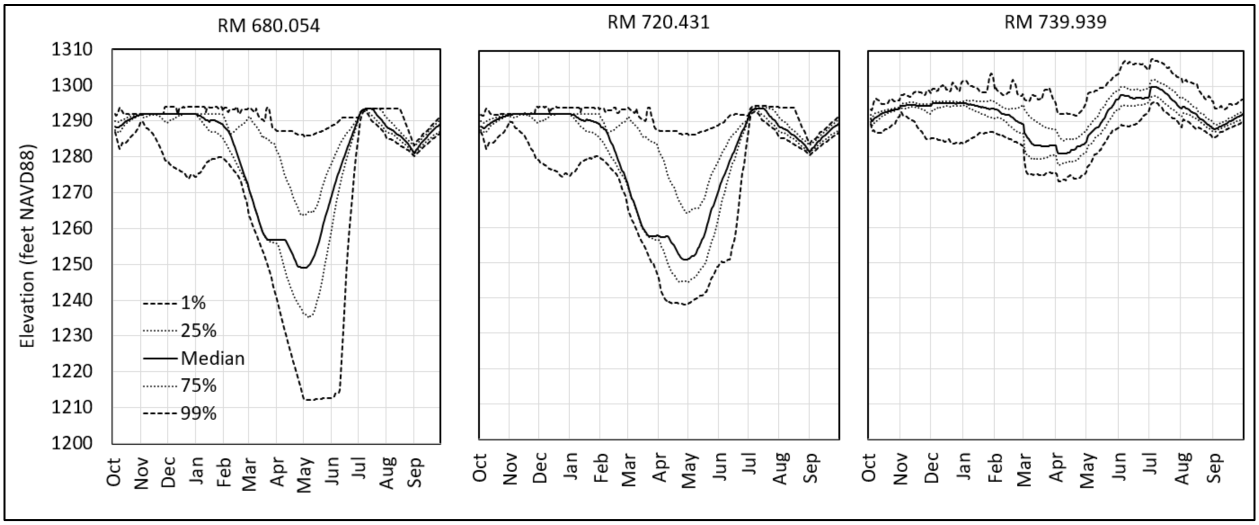


Figure 4-35. Summary Hydrographs at Reach 21 Index Locations

4.3.2.2 Reaches 15 to 19 – Columbia River from Chief Joseph Dam to Priest Rapids Dam

There are five model reaches separating the five non-CRSO dams in the mainstem Columbia River between Chief Joseph Dam and the Hanford Reach above McNary. These reaches (15 through 19) include Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells Dams, spanning from Columbia RM 397 to 545.5 (Figure 4-36).

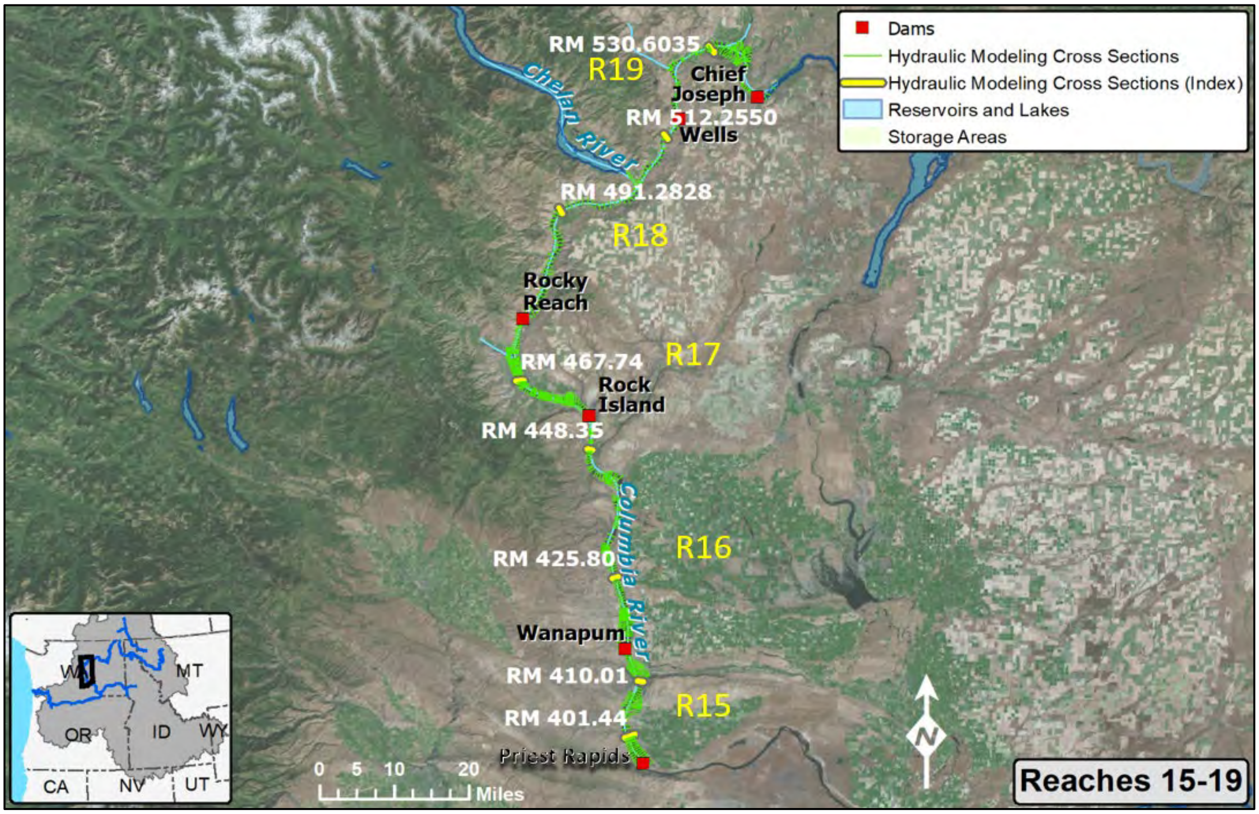


Figure 4-36. Reaches 15 to 19 Location Map

Flow through these reaches is dominated by upstream, mainstem Columbia River flow released from Chief Joseph Dam. There a few major tributary inflows including the Okanogan and Methow Rivers into Reach 19, Lake Chelan outflow into Reach 18, and the Wenatchee River into Reach 17. These inflows comprise over 90 percent of the local inflow along this stretch of the Columbia River.

All of these projects are operated as run-of-river projects with no active storage simulated in the model, so summary hydrographs and annual frequency curves are all flat at the operating pool. In real-time operations, these pools are fluctuated within their power pool on an hourly to daily timestep. The constant elevations in the forebay for each of the projects are shown in Table 4-1.

Table 4-1. Constant Forebay Elevations at each of the Dams in Reaches 15 through 19

Dam	Constant Forebay Elevation (feet NGVD29)
Priest Rapids	486.0
Wanapum	570.0
Rock Island	613.0
Rocky Reach	707.0
Wells	781.0

These reaches are all considered transitional due to having profiles that show notable water surface slope during high-flow periods with the spring freshet. Figure 4-37 shows the AEP profiles for Reaches 15 through 19. Because there is no change in pool elevation through the year, water surface elevations between projects will vary only with flow and mirror the summary flow hydrographs of the upstream project outflow. The largest changes in water level for a given reach will generally be closest to the upstream dam.

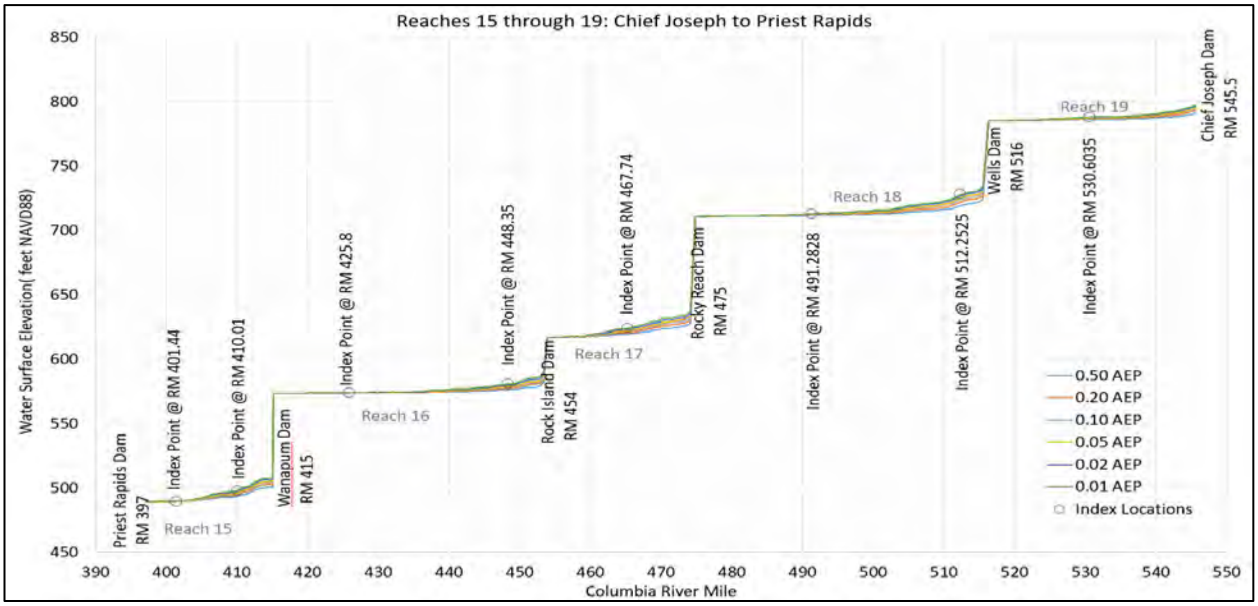


Figure 4-37. Annual Exceedance Probability Profiles for Reaches 15 through 19

4.3.3 Region C – Dworshak and Lower Snake River Basin

4.3.3.1 Dworshak Dam and Reservoir

Dworshak Dam and Reservoir are located on the North Fork Clearwater River in northern Idaho. Operations that control release decisions and outflow from Dworshak Dam are generally described in Chapter 3 of the EIS, and they are described in greater detail in the Part 3 of this appendix. Water levels in the North Fork Clearwater River above Dworshak Dam, including the Dworshak Reservoir, are not calculated using detailed hydraulic modeling. Summary hydrographs for Dworshak outflow are shown in Figure 4-38 and Figure 4-39.

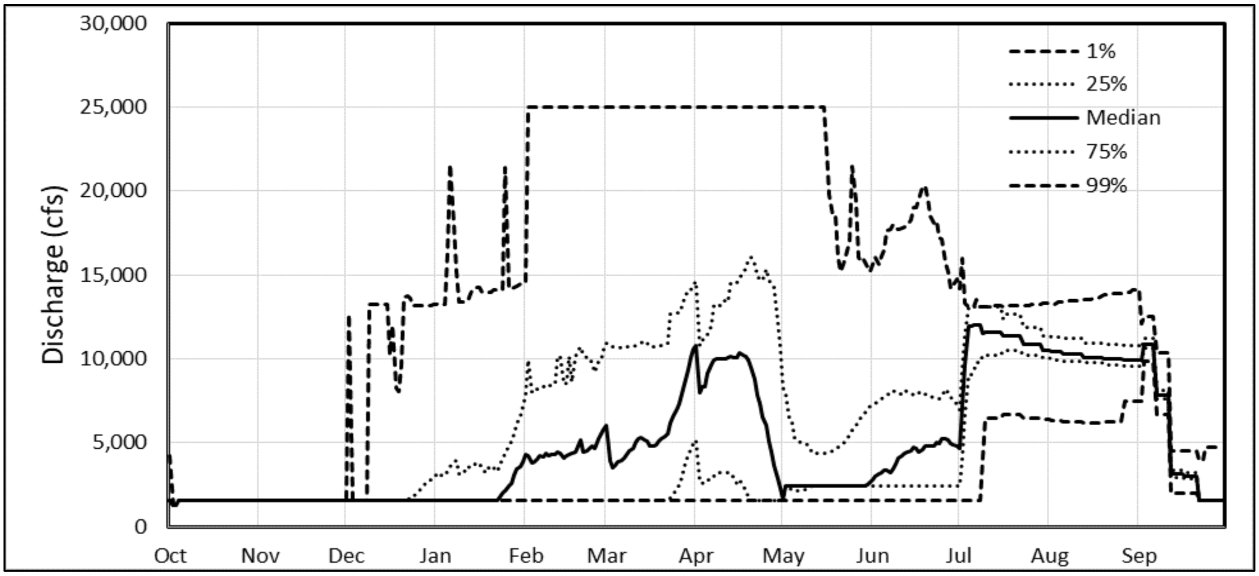


Figure 4-38. Dworshak Dam Summary Outflow Hydrographs

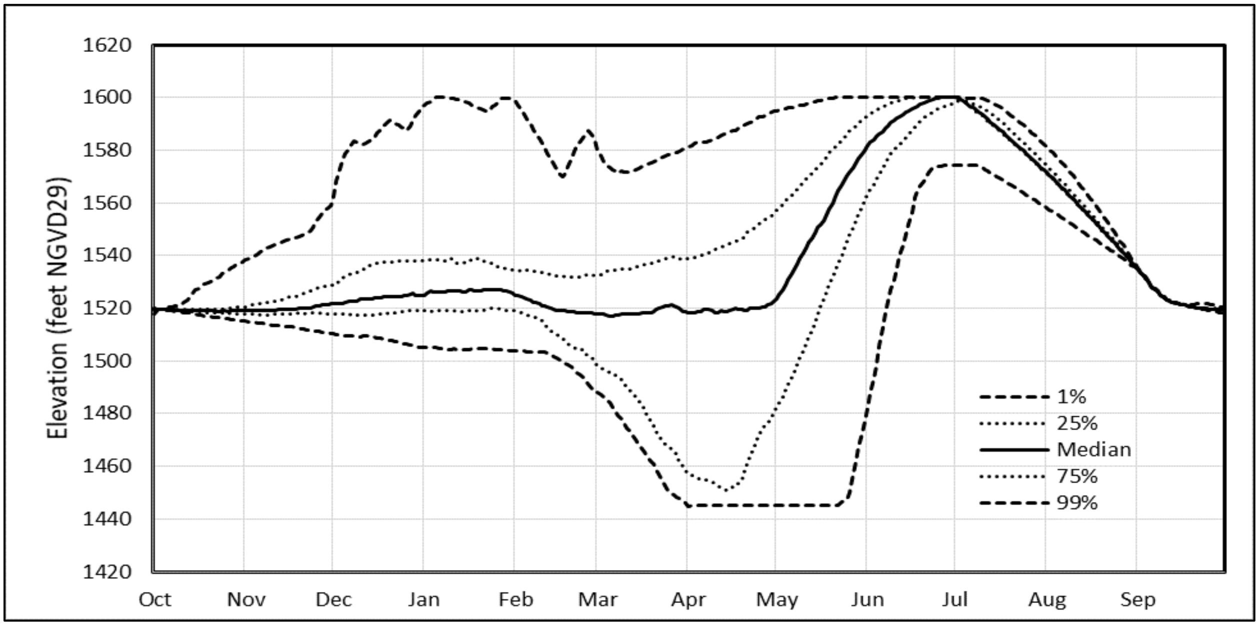


Figure 4-39. Dworshak Dam Summary Elevation Hydrographs

4.3.3.2 Reach 9 – Snake and Clearwater Rivers near Lewiston, Idaho (Dworshak and Snake River above Grand Ronde River to Lower Granite Dam)

Reach 9 includes the Snake and Clearwater Rivers and is centered about the confluence at Lewiston, Idaho. It extends from the Lower Granite Dam (Snake RM 106.6) in southeast Washington up to RM 178 near the Snake-Salmon River confluence along the Oregon-Idaho border, and up the Clearwater River from the confluence at Lewiston (Snake RM 138) to Orofino, Idaho, and the Dworshak Dam.

Figure 4-40 shows a map of this hydraulic modeling reach and shows the major projects, towns and landmarks, and mainstem and tributary inflows. It also shows the general location of the three zone types including flat pool, transitional, and free flowing, along with the locations of the representative index points.

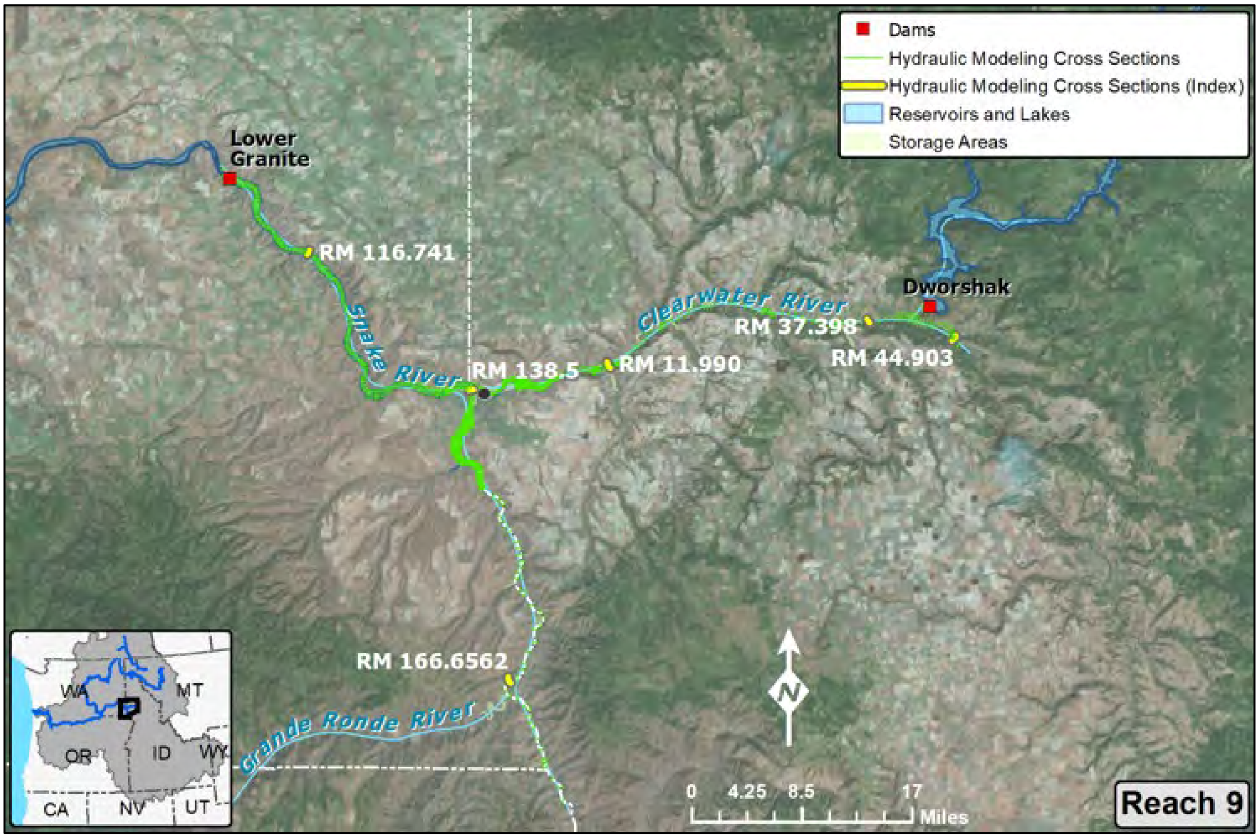


Figure 4-40. Reach 9 Location Map

Inflow to the Lower Granite Reservoir includes outflow from two dams (Dworshak on the North Fork Clearwater River and Hells Canyon on the Snake River) and several large tributaries, including the upper Clearwater River above Orofino, the Salmon River, and the Grande Ronde River. Because it is a run-of-river project, outflow is a reasonable approximation of inflow to the Lower Granite. The median summary outflow hydrographs for Lower Granite and Dworshak are shown in Figure 4-41.

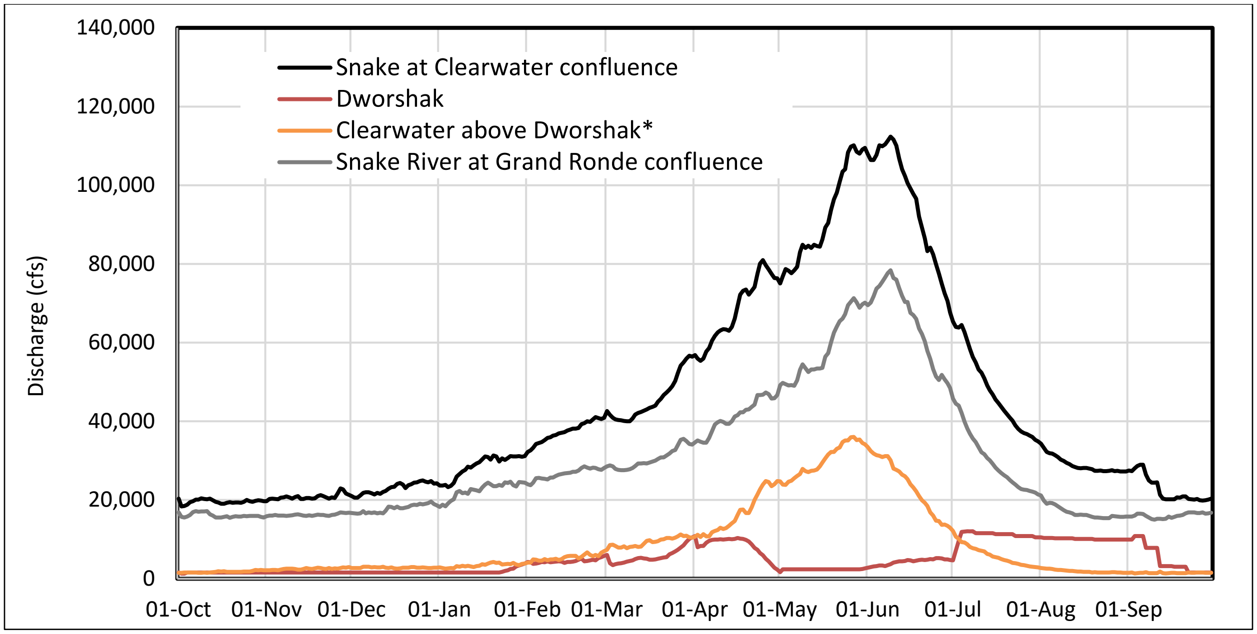
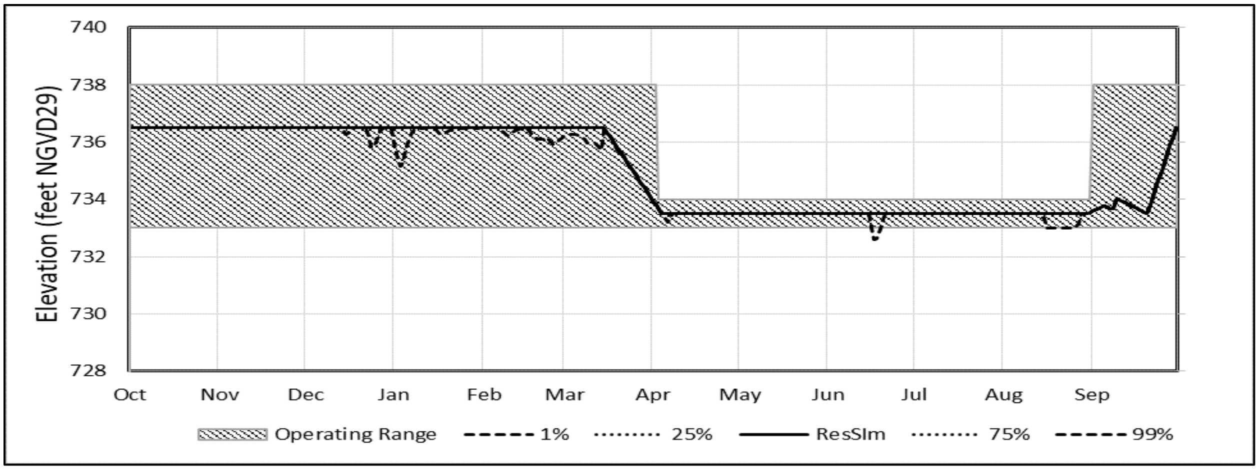


Figure 4-41. Median Summary Discharge Hydrographs for Major Reach 9 Flow Inputs and the Snake-Clearwater Rivers Confluence, which is a Proxy for Flow into the Lower Granite Reservoir

Note: Clearwater above Dworshak is calculated as the difference between the flow at Spalding and Dworshak outflow.

In ResSim, the normal forebay operating range at Lower Granite Dam is modeled between 733.5 and 736.5 feet NGVD29, with a higher pool through the fall and winter and a lower pool April through August to represent minimum operating pool (MOP) operations (Figure 4-42). The reservoir is drafted slightly lower on occasion with a hinge pool operation for FRM that keeps reservoir levels lower near Lewiston, Idaho, during higher flows. Figure 4-42 shows the summary elevation hydrographs at the project. Note there is no difference between the 1 percent, 25 percent, median, and 75 percent hydrographs; the 99 percent hydrograph demonstrates the occasional operations for FRM. In real-time operations, the pool will fluctuate hourly and daily through the entire operating band 732.5 to 738.0 feet NGVD29, and during the summer it operates to a lower operating band; these real-time fluctuations are not modeled in ResSim.

The Reach 9 profile has a mostly flat pool for the lower 30 miles, nearly to Lewiston at roughly RM 140, but differences in water surface elevation can exist during higher flow conditions. Above Lewiston, the slope of both the Snake and Clearwater Rivers increases considerably to 4 feet per mile on the Snake and 6 feet per mile on the Clearwater River. The Snake River is free flowing above RM 145, about 10 miles above the Clearwater River confluence near Lewiston, and the Clearwater River is free flowing above RM 5. Figure 4-43 shows the water surface profiles for this reach and includes the location of the key features. Figure 4-44 shows summary hydrographs at index locations within the Lower Granite Reservoir.



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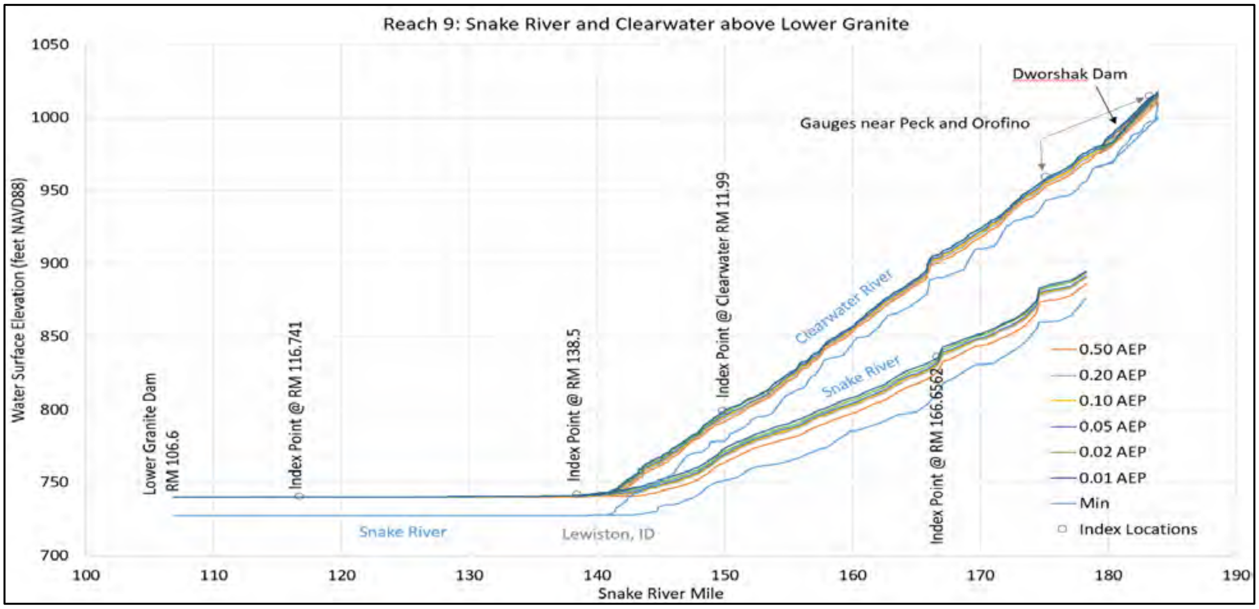
1355 **Figure 4-42. Summary Elevation Hydrographs for Lower Granite Forebay**



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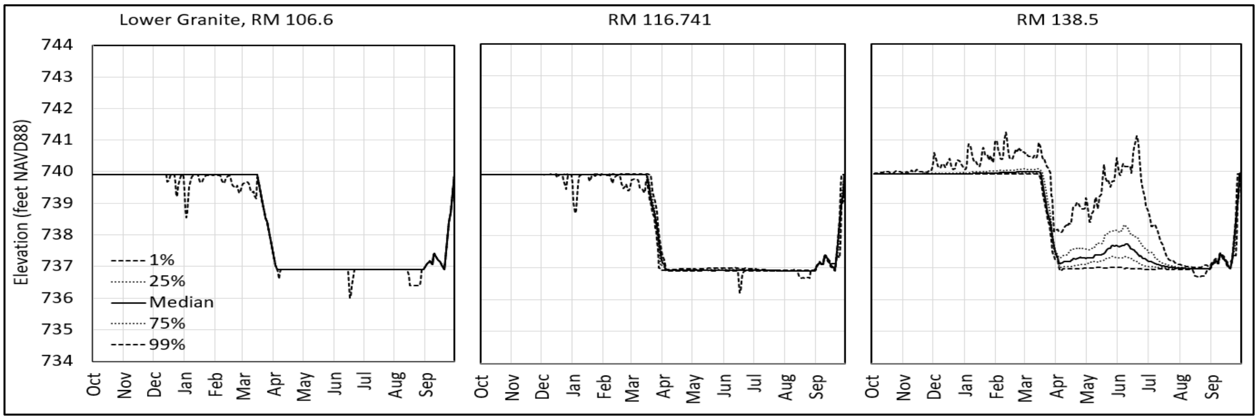
1357 **Figure 4-43. Annual Exceedance Probability Profiles for Reach 9**



1358

1359 **Figure 4-44. Summary Hydrographs at Lower Granite Forebay and Index Points Below**
1360 **Lewiston, Idaho**

4.3.3.3 Reaches 6 to 8 – Lower Snake River from Lower Granite Dam to Ice Harbor Dam

Reaches 6, 7, and 8 are located in southeastern Washington between Lewiston, Idaho, and the Tri-Cities area in Washington (Figure 4-45). The reaches extend from Lower Granite Dam down to Ice Harbor Dam, from Snake RM 106 to 9. The reaches include Lake Sacajawea above Ice Harbor Dam, Lake Herbert G. West above Lower Monumental Dam, and Lake Bryant above Little Goose Dam. The three reservoirs are all considered run-of-river, and they have a combined 94,000 acre-feet of active storage.

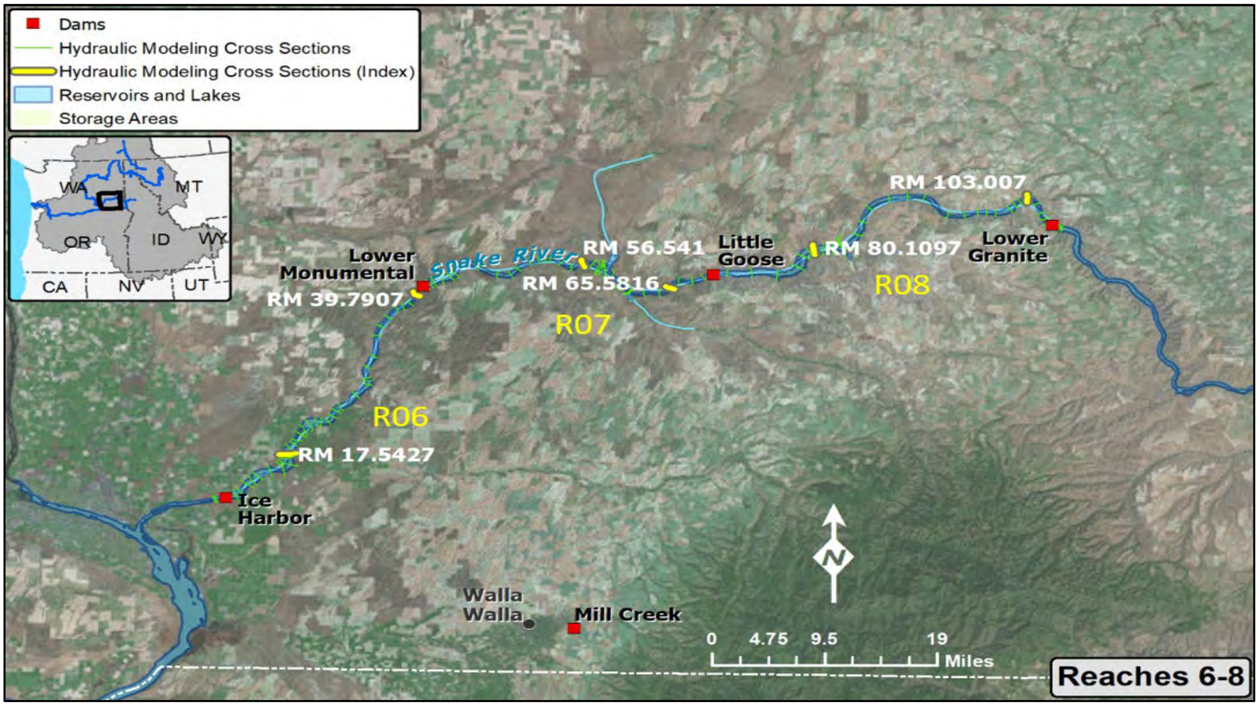


Figure 4-45. Reaches 6, 7, and 8 Location Map

Flow into these reaches is dominated by the releases passed through Lower Granite Dam. The Palouse River drains into the Snake River below Little Goose Dam in Reach 7; otherwise, there are no major tributary inflows to these reaches. The local inflow in Reach 7 is the only major difference between the summary hydrographs.

All three of these lower Snake River projects are modeled according to a rule curve with higher reservoir levels from September through March, and lower levels from April through August, to simulate MOP operations. In actual operations, the pools fluctuate hourly and daily through the full operating range; however, these fluctuations are not modeled in ResSim. The summary hydrographs (Figure 4-46, Figure 4-47, and Figure 4-48)include the actual and the ResSim-modeled operating ranges at Little Goose, Lower Monumental, and Ice Harbor Dams.

The profiles in Reaches 6, 7, and 8 (Figure 4-49) are essentially flat for most of the year, passing from pool to pool through the relatively canyonized stretch of the Snake River; however, they can all develop substantial hydraulic grade at the upper end of the individual reaches during high-flow conditions. While flat for much of the year, flow rate can impact water levels throughout the reaches. These profiles do not account for hourly and daily reservoir fluctuations that occur during real-time operations. It also should be noted that the AEP profiles were calculated based on ResOps-modeled pools, not the slightly larger range of actual operating pools. The actual AEP elevations in the reservoirs would be 1 to 1.5 feet higher than the modeled pools at all four of the Lower Snake River projects.

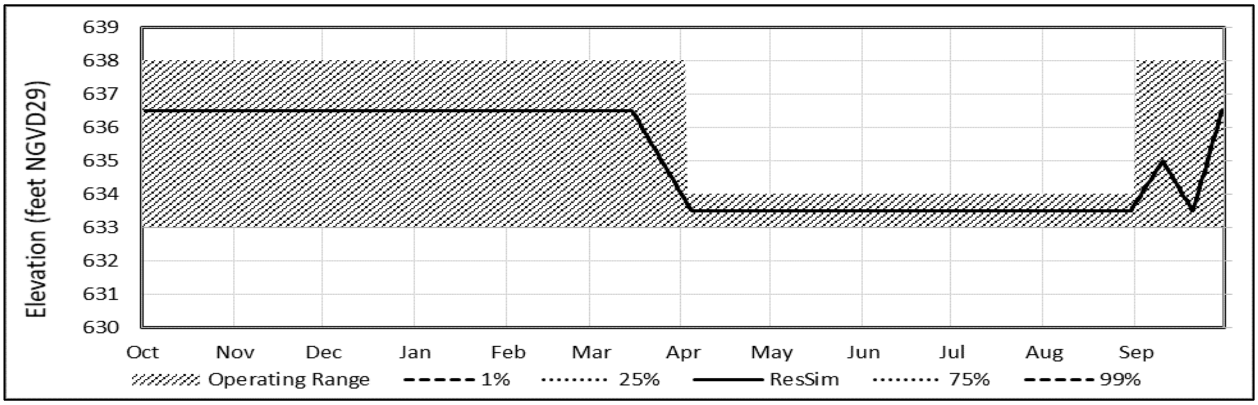


Figure 4-46. Summary Elevation Hydrographs for Little Goose Dam

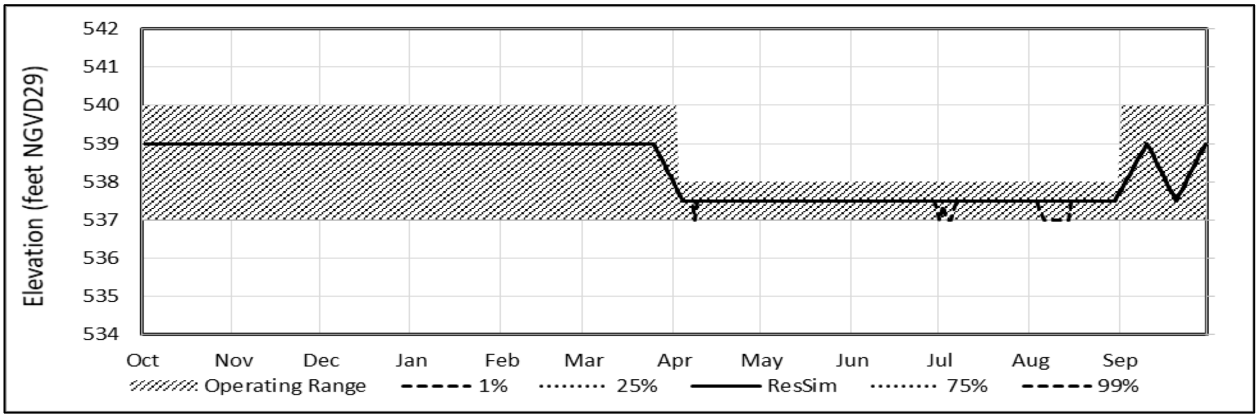


Figure 4-47. Summary Elevation Hydrographs for Lower Monumental Dam

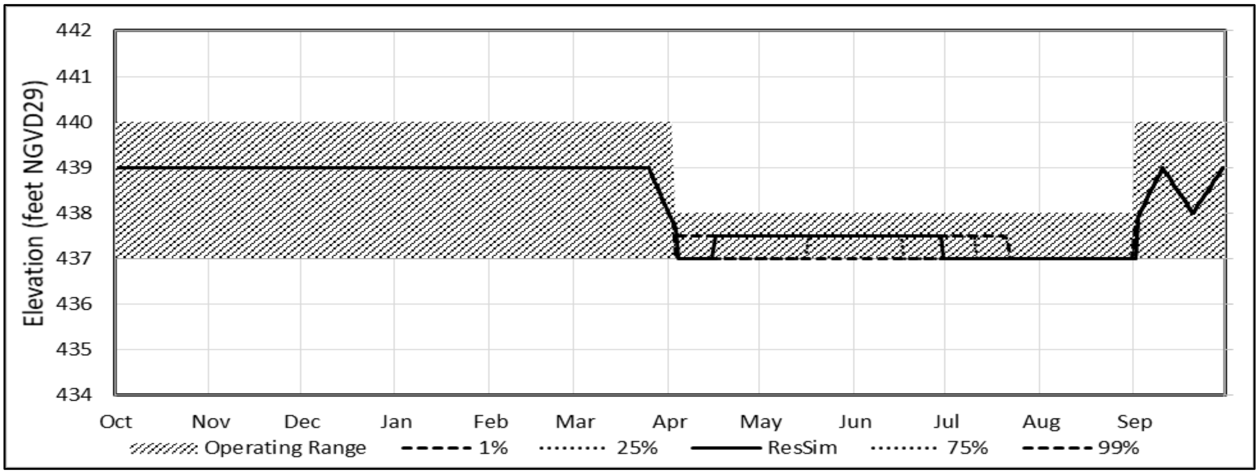


Figure 4-48. Summary Elevation Hydrographs for Ice Harbor Dam

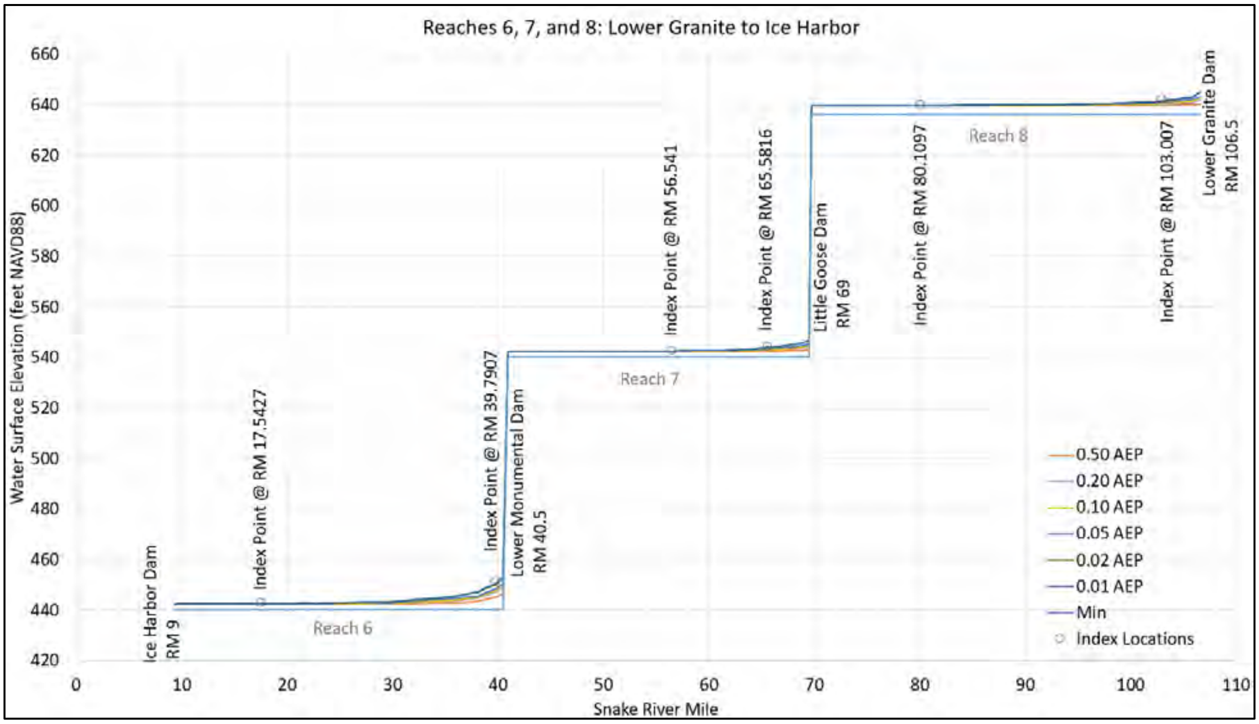


Figure 4-49. Annual Exceedance Probability Profiles for Reaches 6, 7, and 8

4.3.4 Region D – Lower Columbia River

4.3.4.1 Reach 5_14 – Columbia River near Tri-Cities, Washington (Priest Rapids and Ice Harbor Dams to McNary Dam)

Reach 5_14[1] is located in southern Washington on the mainstem Columbia River. It extends from the Priest Rapids Dam (RM 396) to McNary Dam (RM 291). It also includes the lower portion of the Snake River downstream of Ice Harbor (Snake RM 9) and the lower portion of the Yakima River. The reach includes the heavily leveed, Tri-Cities, Washington, area. The reservoir above McNary Dam is Lake Wallula, a run-of-river reservoir with 185,000 acre-feet of active storage in the normal operating range.

Figure 4-50 shows a map of these hydraulic modeling reaches and shows the major projects, towns and landmarks, and mainstem and tributary inflows. It also shows the general location of the three zone types including flat pool, transitional, and free flowing, along with the locations of the representative index points.

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[1] Reach 5_14 combines two earlier hydraulic model reaches (5 and 14). Reach 14, also known as the Hanford Reach, is a free-flowing reach from Priest Rapids Dam down to the Tri-Cities area above the Yakima River confluence. Reach 14 is technically within the bounds of Region B, but it is described in this section for expediency.

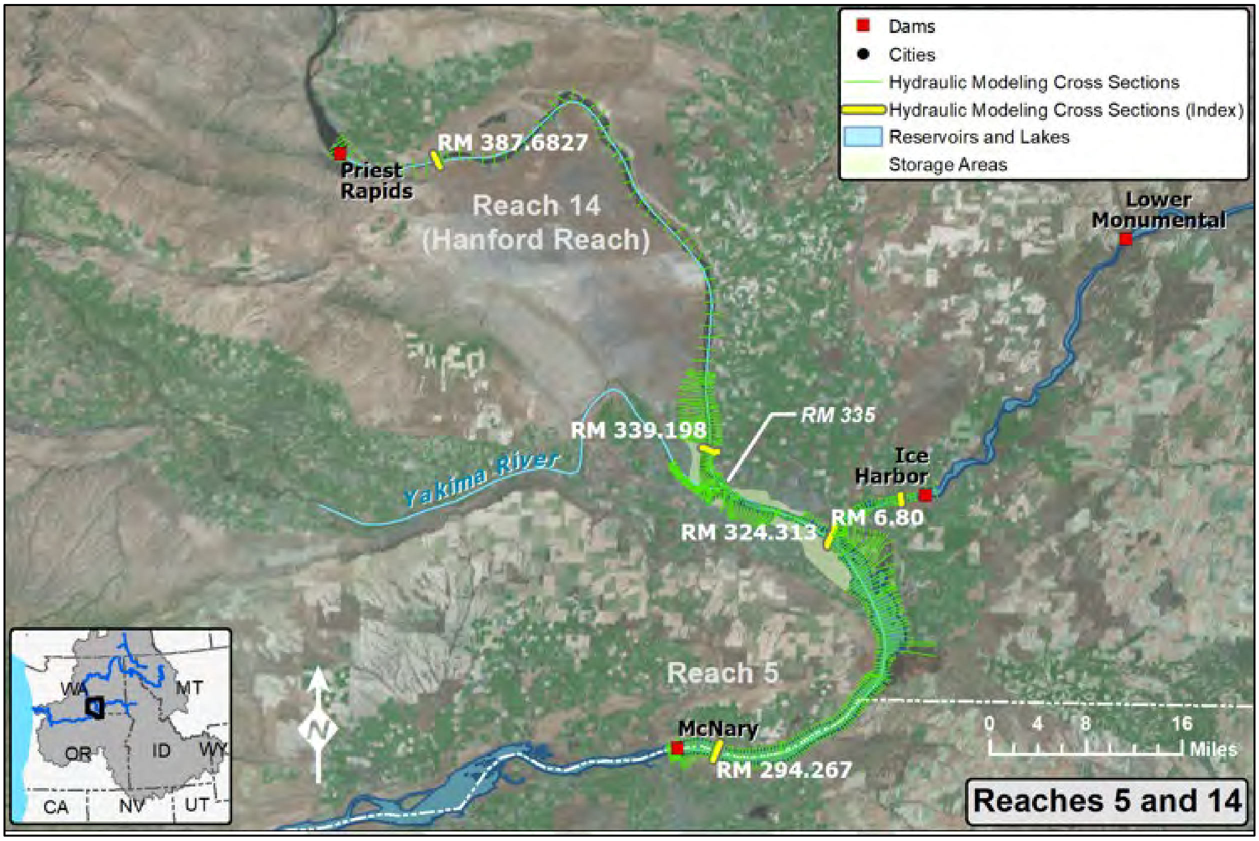

Figure 4-50. Reach 5_14 Location Map

Inflow to the Lake Wallula reservoir above McNary Dam is a combination of Priest Rapids outflow, Ice Harbor outflow, and local inflows from the Yakima River. Because it is a run-of-river project, outflow is a reasonable approximation of the total inflow to the project. The summary flow hydrographs for Priest Rapids, Ice Harbor, and McNary are shown in Figure 4-51.

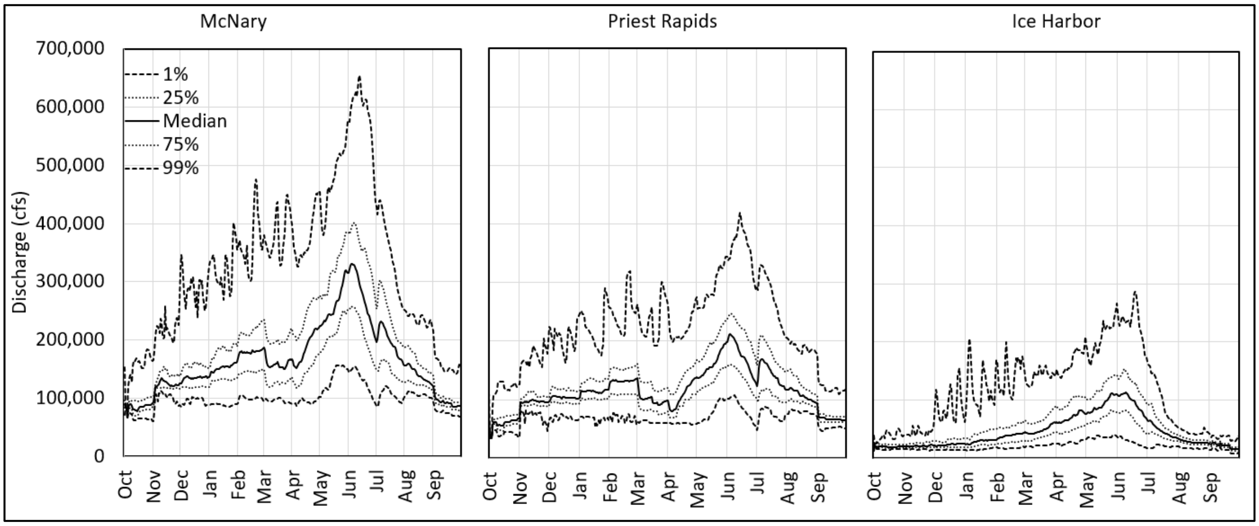

Figure 4-51. Summary Outflow Hydrographs for McNary, Priest Rapids, and Ice Harbor Dams

In the ResSim model, McNary Dam is modeled as a steady pool at 338.7 feet NGVD29, but it will operate between 335.0 and 340.0 feet NGVD29 to assist with flood control downstream during the winter months (Figure 4-52). In actual operations, the pool can fluctuate hourly and daily throughout the full normal operating range from 335.0 to 340.0 feet. However, these real-time fluctuations are not modeled in ResSim.

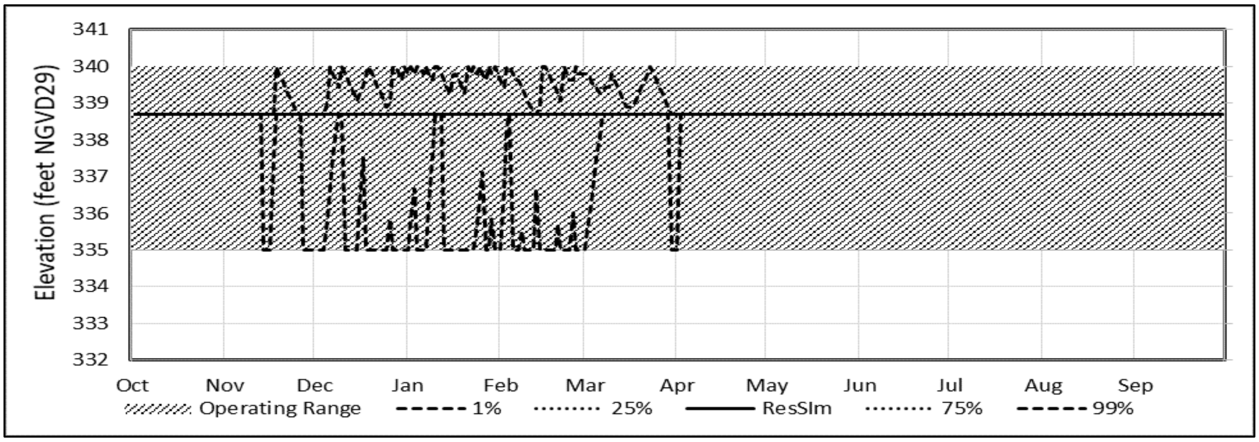

Figure 4-52. Median, 1 Percent, and 99 Percent Summary Hydrographs for McNary Dam Forebay

The profile in Reach 5 (Figure 4-53) can be described as a 30- to 50-mile pool reach followed by a longer, steeper reach up to Priest Rapids Dam. The Hanford Reach downstream of Priest Rapids Dam is the only free-flowing riverine reach in the mainstem Columbia River between the Bonneville and Grand Coulee Dams. The Snake River confluence is at RM 324, and the Snake River profile slopes mildly to the Ice Harbor Dam at Snake RM 9. The Yakima River confluence is at RM 335, above which, the Yakima River is relatively steep. Summary hydrographs at index points (Figure 4-54) show the varying water level dynamics within the reach.

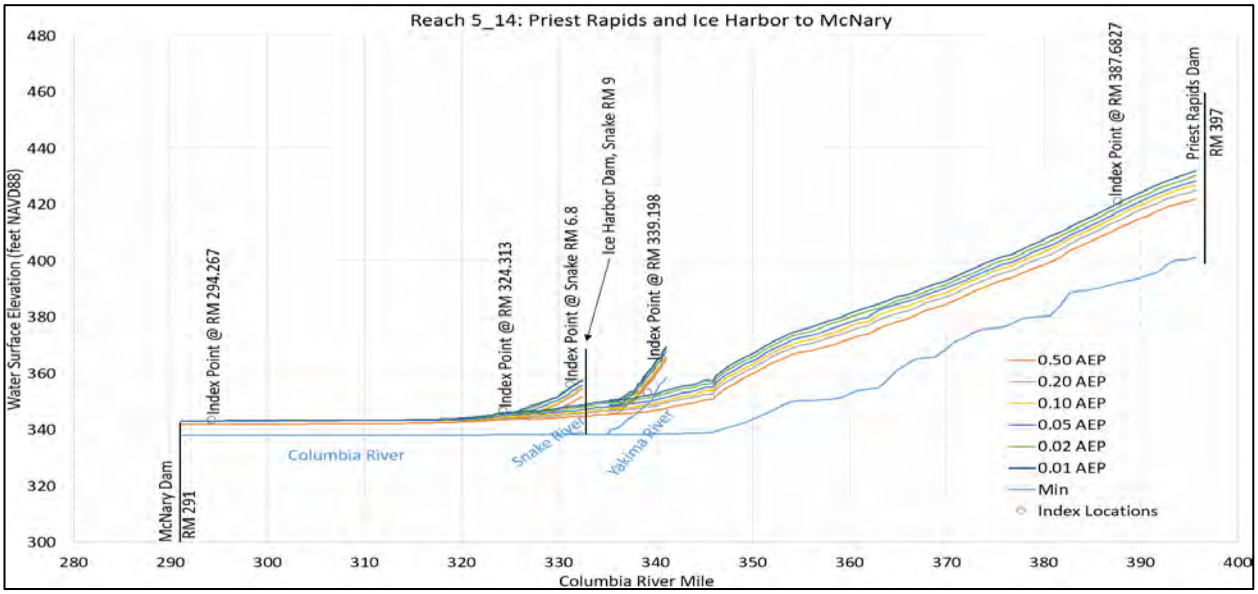

Figure 4-53. Annual Exceedance Probability Profile for Reach 5

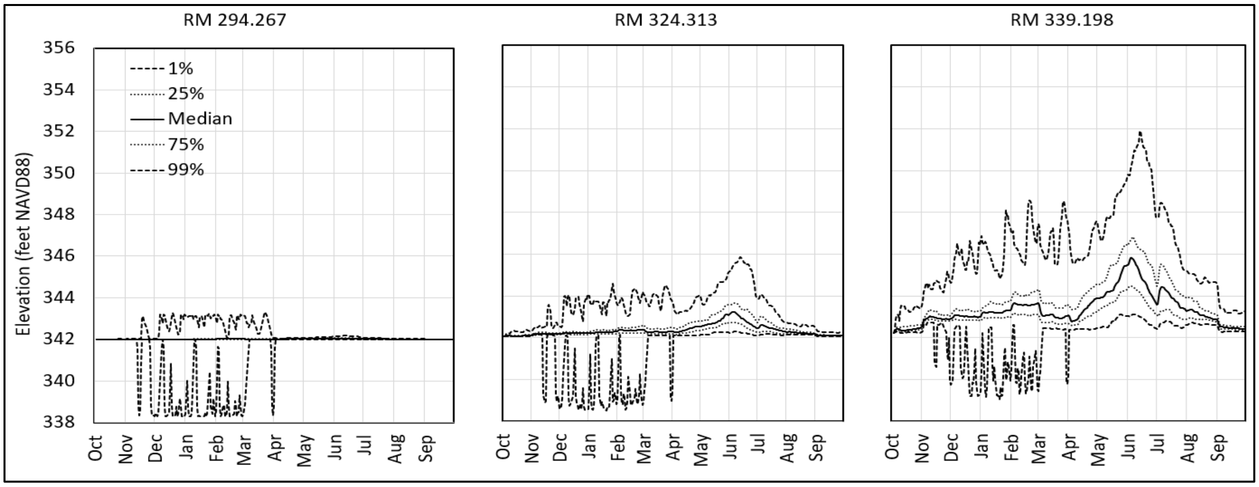

Figure 4-54. Summary Hydrographs at Select Reach 5 Index Points

4.3.4.2 Reaches 2 to 4 – Columbia River from McNary Dam to Bonneville Dam

Reaches 2, 3, and 4 extend from McNary Dam down to Bonneville Dam, Columbia RM 291 to 146. The reaches include Bonneville Reservoir above Bonneville Dam, Lake Celilo Reservoir above The Dalles Dam, and Lake Umatilla Reservoir above John Day Dam.

Figure 4-55 shows a map of these reaches with the major projects, towns and landmarks, and mainstem and tributary inflows. It also shows the general location of the three zone types including flat pool, transitional, and free flowing, along with the locations of the representative index points.

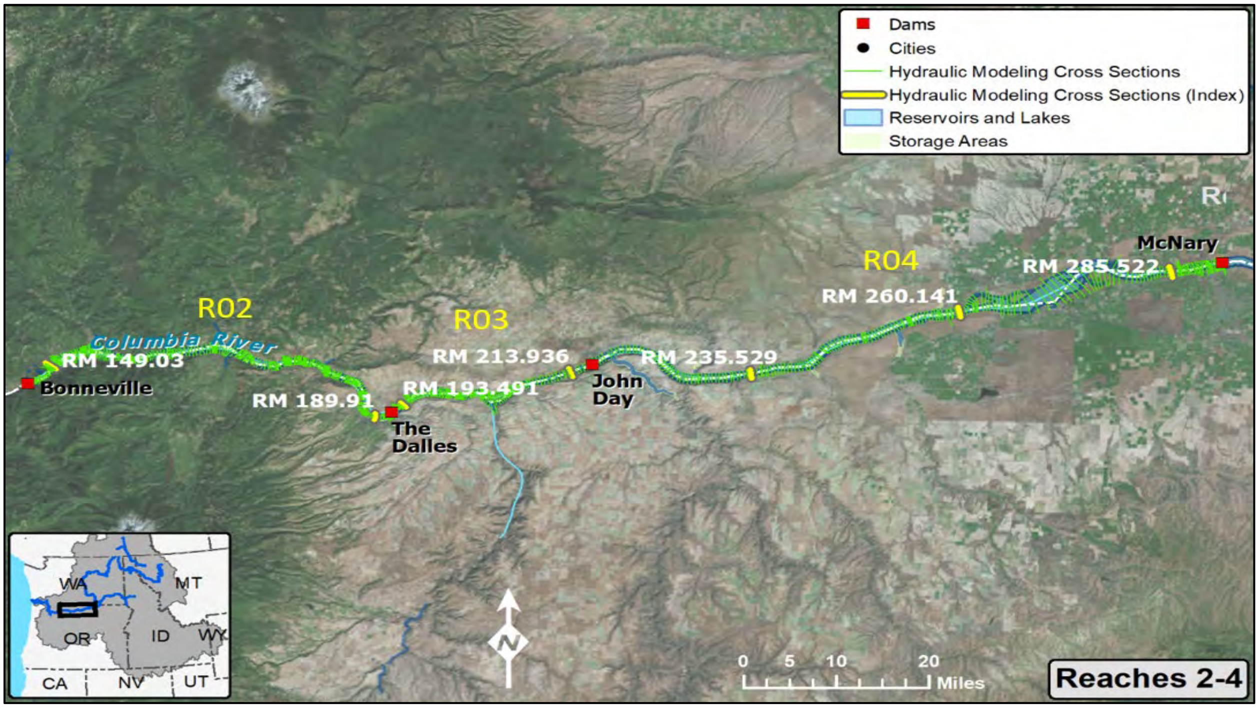

Figure 4-55. Reaches 2, 3, and 4 Location Map

Inflow to these reaches is dominated by the flow passing through McNary Dam. There are several tributaries in this stretch of the mainstem Columbia River including the Klickitat, Hood, and White Salmon Rivers in Reach 2, the Deschutes River in Reach 3, and John Day and Umatilla Rivers in Reach 4. The summary hydrograph does not change dramatically from McNary to Bonneville Dam, but the local inflows in Reaches 2 through 4 can contribute notably to the total flow, particularly in the winter months and in the early spring during lower flow years. Figure 4-56 shows the median and 1 percent summary outflow hydrographs from McNary through Bonneville Dam, and Figure 4-57 compares the annual and winter peak discharge frequency curves from McNary through Bonneville Dam.

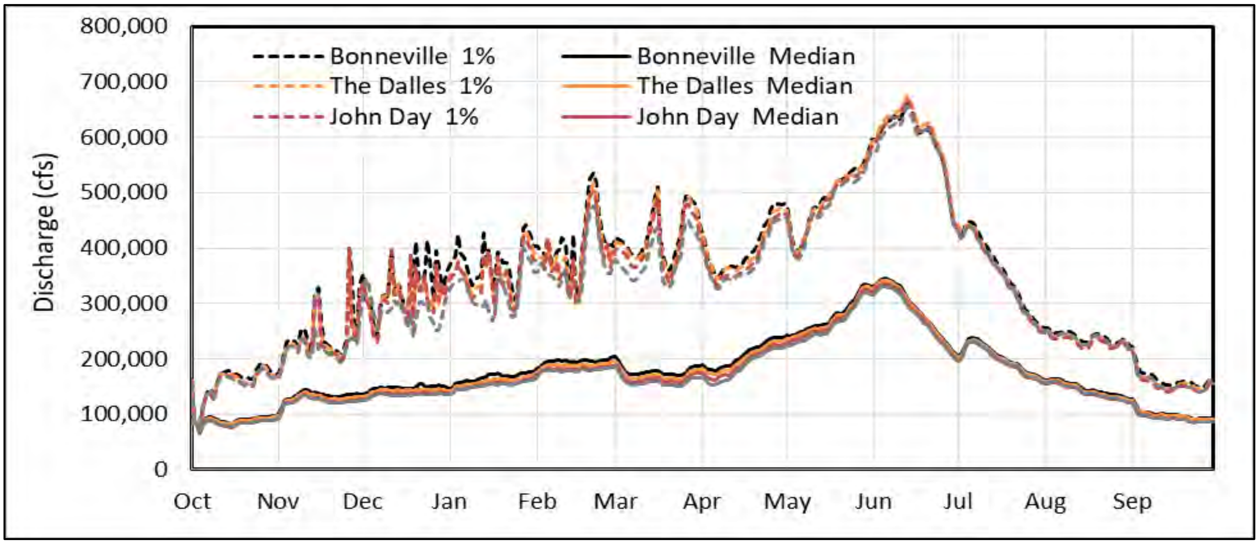

Figure 4-56. Median and 1 Percent Summary Hydrographs for McNary, John Day, The Dalles, and Bonneville Dams Outflow

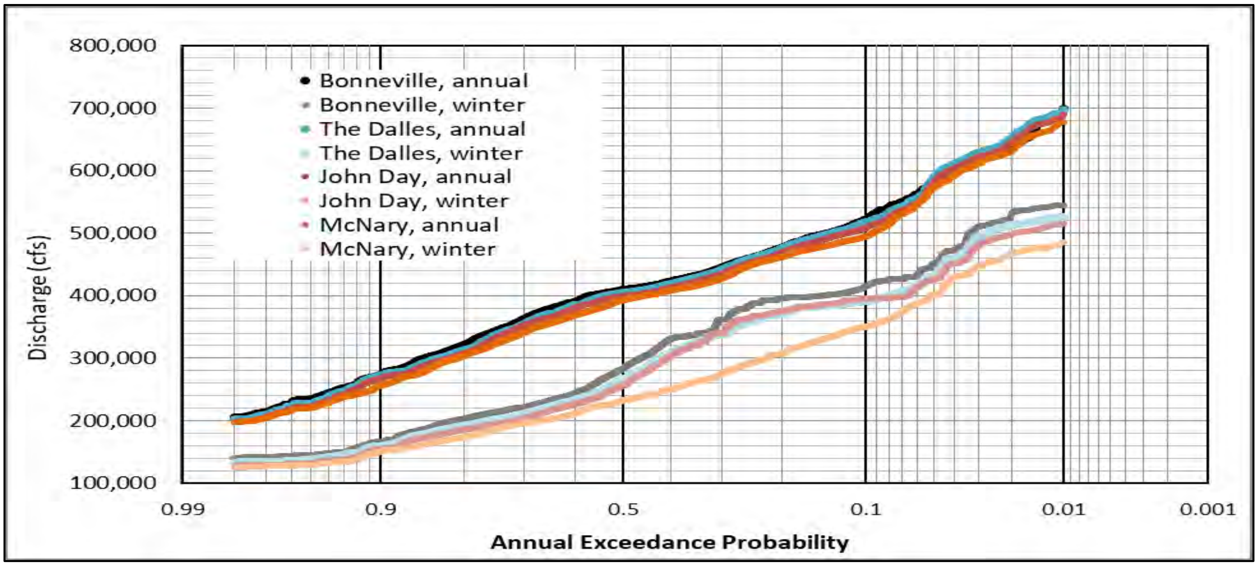

Figure 4-57. Peak Discharge-Frequency Data for McNary, John Day, The Dalles, and Bonneville Dams Outflow

Note: The winter period is defined as November through March.

Bonneville and The Dalles Dams are considered run-of-river projects and are modeled in ResSim typically holding a constant pool throughout the year. Both of the projects will occasionally draft in ResSim to a low pool and fill to a slightly higher pool to provide some flood storage during winter flood events. John Day Dam provides up to 535 thousand acre-feet (kaf) of storage and is operated according to a rule curve. Like the two downstream projects, John Day will operate for flood control and draft deeper and fill higher to provide additional flood protection during the winter months, but historically this seldom happens. A summary table of the operating ranges for these projects is shown in Table 4-2. In real-time operations, the pools will fluctuate hourly and daily through the entire operating bands; these real-time fluctuations are not modeled in ResSim. Summary elevation hydrographs including the seasonal operating ranges for Bonneville, The Dalles, and John Day Dams are shown in Figure 4-58 through Figure 4-60.

Table 4-2. Forebay Operating Range Modeled in ResSim for Bonneville, The Dalles and John Day Dams

Range	Bonneville Dam (feet NGVD29)	The Dalles Dam (feet NGVD29)	John Day Dam (feet NGVD29)
Maximum	77.0	160.0	268.0
Normal	76.0	158.1	263.55 to 265.0
Minimum	70.0	155.0	257.0

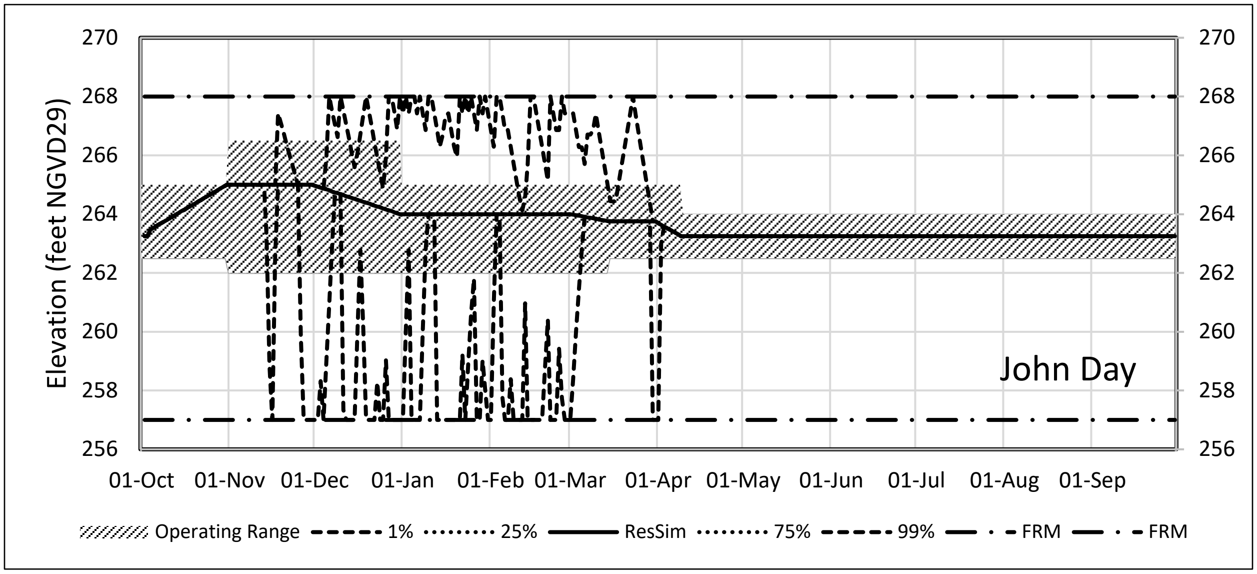

Figure 4-58. Median, 1 Percent, and 99 Percent Summary Elevation Hydrograph for John Day Dam

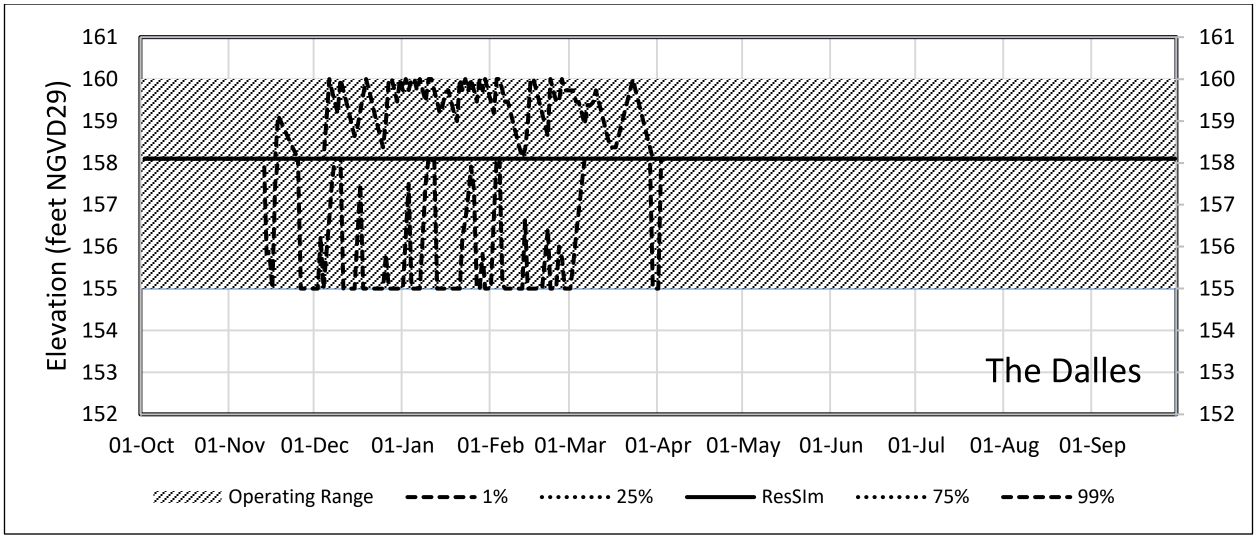

Figure 4-59. Median, 1 Percent, and 99 Percent Summary Elevation Hydrograph for The Dalles Dam

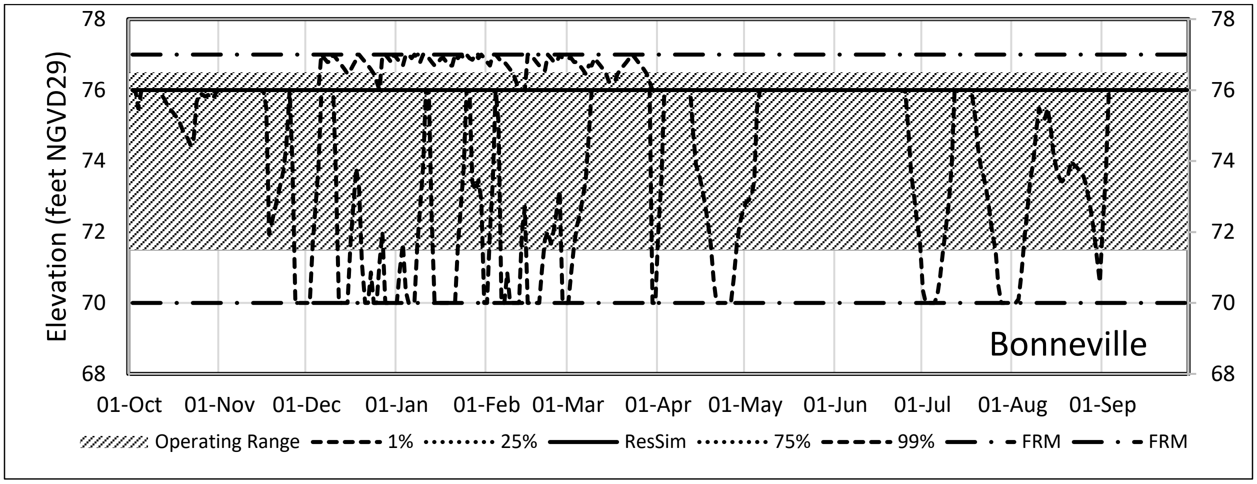

Figure 4-60. Median, 1 Percent, and 99 Percent Summary Elevation Hydrograph for Bonneville Dam

The profiles in Reaches 2, 3, and 4 are shown in Figure 4-61. Reach 2 has a major constriction a few miles above the Bonneville Dam that can cause a substantial increase in water surface elevations upstream, the effect being a relatively high sensitivity to flow changes throughout the reach. Reach 3 has a relatively flat pool for the lower 10 miles, but water levels throughout the reach can be affected by changes in upstream flow. The lower 50 miles of Lake Umatilla (Reach 4) is very flat for most of the year, but even at RM 235, a water surface rise of a few tenths of a foot is possible during the freshet that occurs during a low pool.

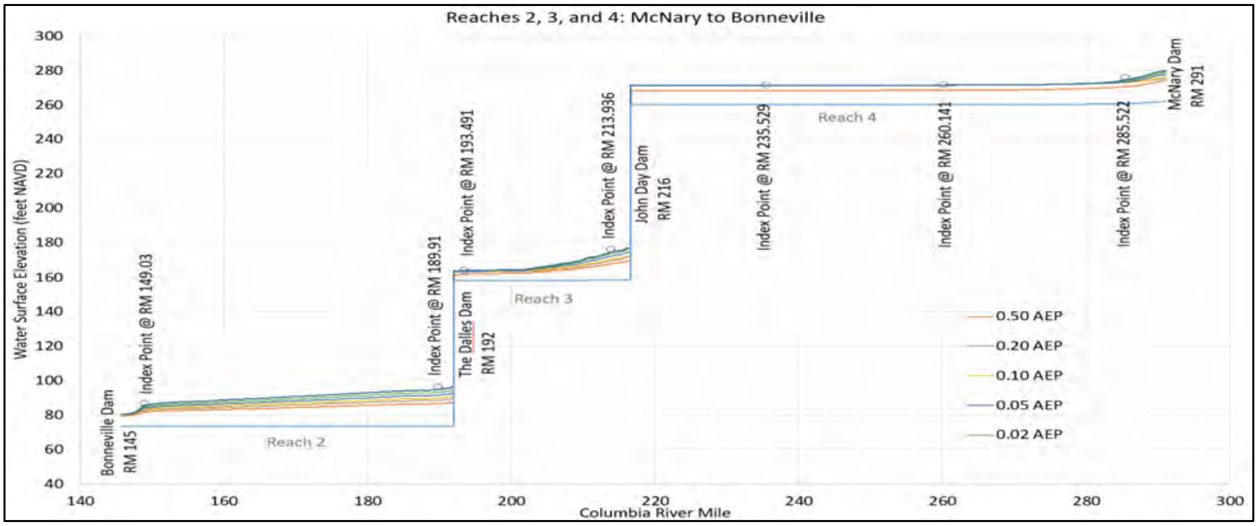

Figure 4-61. Annual Exceedance Probability Profile for Reaches 2, 3, and 4

4.3.4.3 Reach 1 – Columbia River below Bonneville Dam

Reach 1 is the lowest, western-most reach in the Columbia River Basin. It extends from Bonneville Dam (RM 146) down to the Tongue Point gage near Astoria, Oregon (RM 18.6), and includes 25 miles of the Willamette River up to the falls at Oregon City, 18 miles of the Cowlitz River up to Castle Rock, and a half-dozen smaller river reaches that are influenced by Columbia River flood stages. This reach includes the largest damage centers in the basin (e.g., Portland, Vancouver, Longview, etc.) and some of the most varied terrain, including a large estuary at the downstream boundary, many large islands and side channels, and over 40 major leveed areas.

The HEC-RAS model includes over 200 miles of river reaches and over a hundred storage areas representing leveed areas, sloughs, and backwater areas typically associated with smaller tributaries. Figure 4-62 shows a map of the HEC-RAS model geometry and index locations.

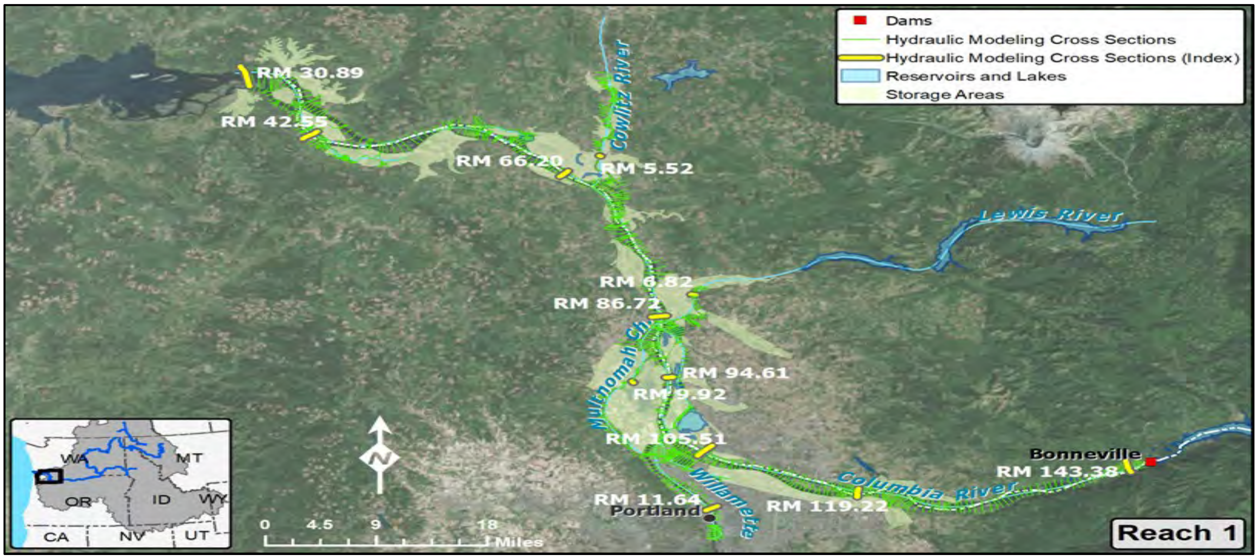

Figure 4-62. Reach 1 Location Map

The CRSO study area in Reach 1 is restricted further based on model fidelity at the lower end. Caution should generally be applied with the model results, as the hydraulic model has been thus far developed to simulate flood conditions along the mainstem Columbia River. For CRSO study purposes, it is recommended to only use data above RM 30 and to focus analysis on changes in the mainstem Columbia River and major tributaries directly influenced by the Columbia River.

Inflow to Reach 1 includes Bonneville Dam outflow and inflow from more than a dozen tributary inflow locations along the reach. There are roughly 18,100 square miles (mi^2) below Bonneville Dam. The largest tributaries are the Willamette (11,460 mi^2), the Cowlitz (2,586 mi^2), and the Lewis (1,046 mi^2). Other major tributaries include the Sandy, Washougal, and Clackamas Rivers, and there are a dozen smaller tributaries covering 1,600 square miles from RM Bonneville Dam down to RM 19.

Bonneville Dam outflow is often the largest inflow to the reach, but unlike the other reaches, local inflows during winter flood events can and often do contribute to the annual maximum water levels. The seasonal water level patterns of the lower Columbia River system are a complex interaction of heavily regulated upper Columbia River Basin flows above Bonneville Dam, tributary and local inflow, and tidal dynamics at the mouth. At the upstream end of the reach, local flows are relatively insignificant during winter storm events, and annual maximum stages generally occur with spring snowmelt from the upper basin. At the downstream end below RM 40, annual maximum stages almost always occur during high-tide events from November to February (greater than 80 percent of the years from 1965 to 2015). The middle portion of Reach 1 is influenced by both the upstream and downstream patterns, as well as the winter-dominated hydrologic patterns of the local tributaries. While many of the largest floods in the lower Columbia River are commonly associated with spring snowmelt from the upper basins, the mainstem Columbia River has more often than not (greater than 60 percent of the years from 1965 to 2015) had an annual maximum stage occurring during the winter months as high up as RM 105.

Peak annual water levels in the Portland/Vancouver area are influenced by winter flood events, which are driven by relatively short-duration storms from the Willamette River and other local tributaries. Freshet flows on the Columbia River often result in the highest water levels of the year at Portland/Vancouver, but the largest storms typically occur in the winter. This is different than almost anywhere else in the study area, where annual peak water levels almost always coincide with the spring freshet. This is evident in plots of the winter and annual peak discharge-frequency curves for the Bonneville Dam outflow and the Columbia River at the Vancouver gage. Discussed in greater detail in the FRM Appendix, some operations at the Columbia River projects aim to reduce flood peaks at Portland/Vancouver by controlling the timing of releases from Bonneville Dam such that lower Bonneville Dam outflow is coincident with peak local flows and water levels at Vancouver. Often, the highest releases from Bonneville Dam during the winter period do not coincide with peak water levels at Vancouver. See Figure 4-63 for peak discharge-frequency curves at Bonneville Dam and the Columbia-Willamette River confluence.

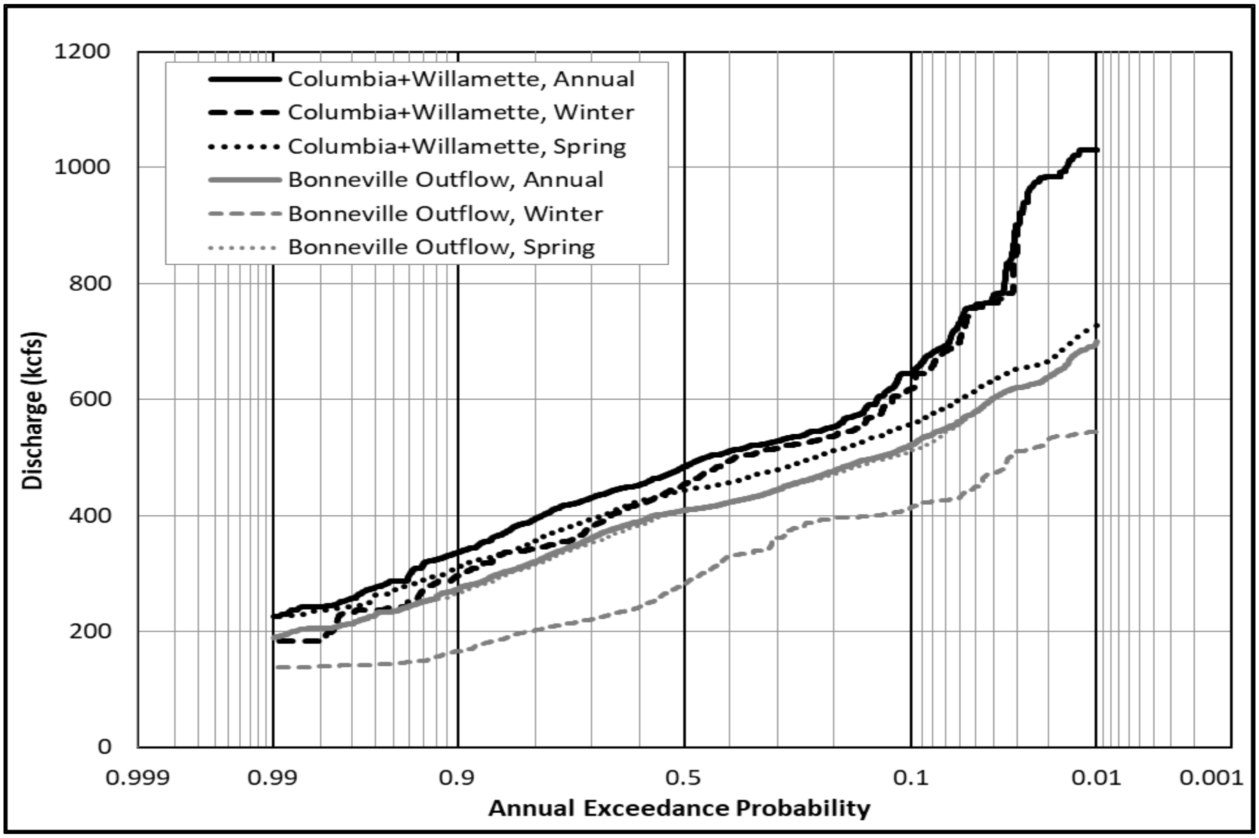

Figure 4-63. Annual Spring and Winter Peak Discharge Probability Curves for Bonneville Dam Outflow and the Columbia-Willamette River Confluence

Note: Spring is April through July, and winter is November through March.

Unlike all of the other model reaches, Reach 1 does not have a reservoir at the downstream boundary. This boundary condition does not change with any CRSO alternative, nor do the flows in any of the tributaries in this reach.

The entirety of the water surface profile for Reach 1, with the exception of the upstream portion of the Cowlitz River, is influenced by both the downstream tidal boundary and the flow in the river. Tidal influence can be seen all the way up to the Bonneville Dam on the Columbia River and the falls at Oregon City on the Willamette River during low-flow seasons in late summer and early fall. Similarly, releases from Bonneville Dam during the spring freshet can create backwater effects up the major tributaries that are typically dominated by local inflow hydrology.

The AEP and minimum profiles for the mainstem Columbia River and major tributaries are shown in Figure 4-64 and Figure 4-65. There are numerous smaller tributaries and side channels modeled as river reaches.

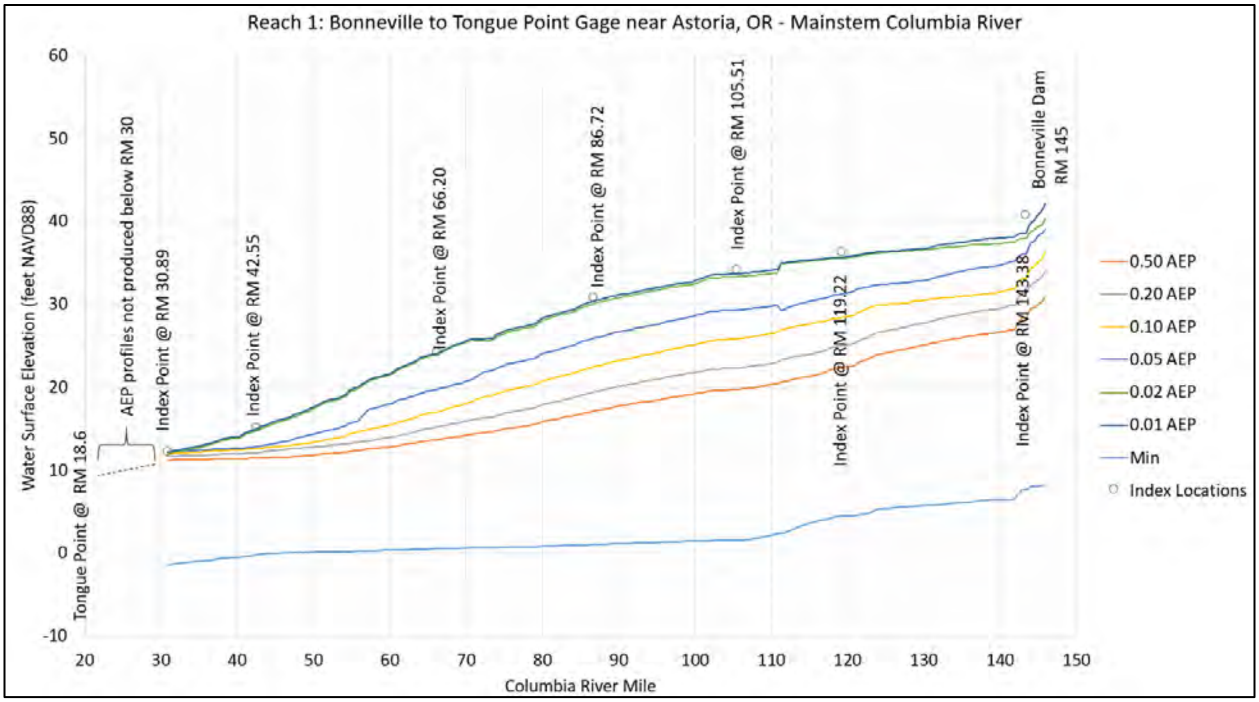

Figure 4-64. Annual Exceedance Probability Profiles for the Mainstem Columbia River Below Bonneville Dam

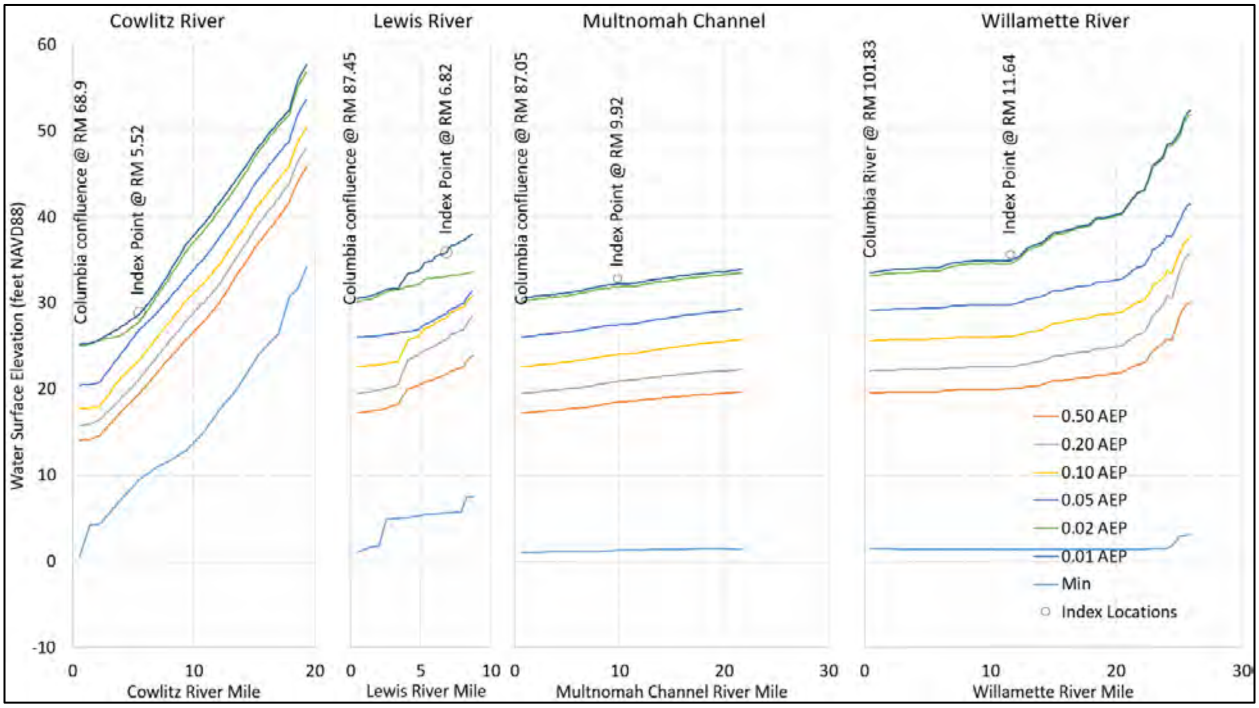

Figure 4-65. Annual Exceedance Probability Profiles for Major Tributaries and the Multnomah Channel in Reach 1.

There are also dozens of leveed areas, sloughs, and small tributaries that are modeled using storage areas connected to river reaches, and the water levels in these storage areas are determined by water level in the adjacent river reaches. Because the model was developed primarily to develop flood profiles and conditions in the mainstem Columbia River, the storage areas' primary function is to represent storage in the river system. In other words, the model is not intended to accurately capture water level dynamics within the various leveed and off-channel areas. To do this would require a much finer-scale investigation to local hydrology and hydraulics.

Summary elevation hydrographs throughout the reach align closest with the summary flow hydrographs; however, the signal is generally muted with proximity to the downstream tidal boundary. Summary hydrographs at select index locations are shown in Figure 4-66.

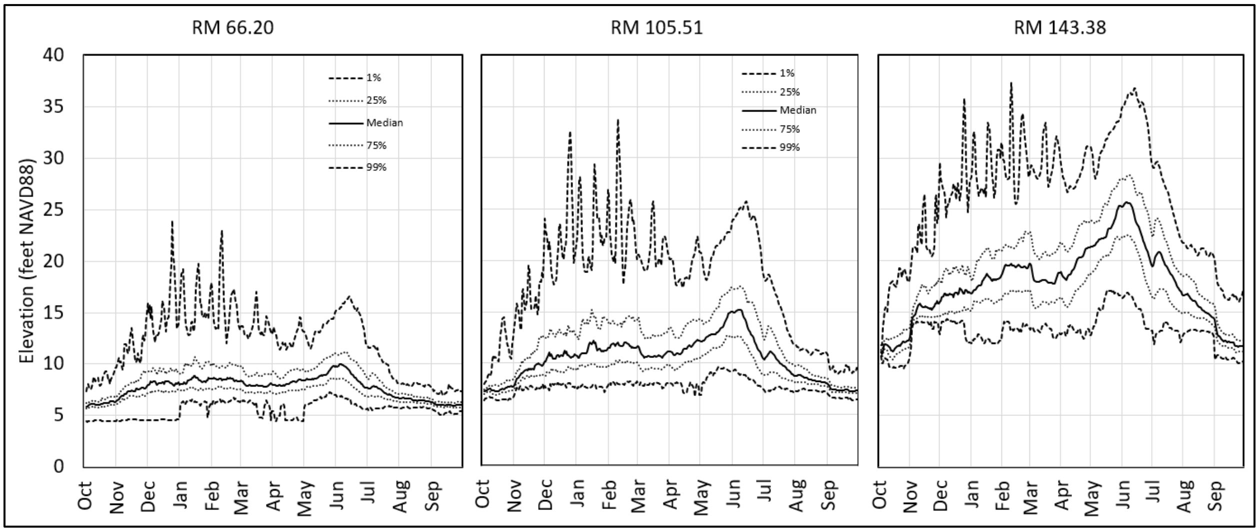

Figure 4-66. Summary Elevation Hydrographs at River Mile 66 at Longview, Washington; River Mile 105 at Vancouver, Washington; and River Mile 143 just below Bonneville Dam

CHAPTER 5 - ALTERNATIVES ANALYSIS

5.1 INTRODUCTION TO HYDROLOGY AND HYDRAULICS ALTERNATIVES ANALYSIS

The H&H Alternatives Analysis presented herein includes detailed description of the H&H changes occurring with each multi-objective alternative (MO). Because of the overlap between the four MOs and additional value of being able to compare MOs to each other (not just to the No Action Alternative condition), the MOs are discussed concurrently for each location.

The analysis is grouped by region, and then by location and/or hydrologic metric, most often reservoir elevation, dam outflow, or flow and water level conditions at key locations between projects. Within each section, discussion usually progresses chronologically from the beginning of the water year to the end. At each of the major CRSO storage projects, an overview of the operational measures simulated in the ResSim model is provided.

Effort is attempted to relate the H&H effects under a given MO to specific operational measures; however, it is often not possible to draw definitive boundaries around the influence of one measure over another, as the measures tend to interact within the model.

The analysis is presented almost entirely as a narrative within this section. Summary data plots and comparison tables are provided at the end of the narrative section. It is recommended to reference the data plots and tables while reading the narrative.

5.2 REGION A – KOOTENAI, FLATHEAD, AND PEND OREILLE BASINS

5.2.1 Libby Operational Changes

Six measures directly impact hydroregulation at Libby Dam. They are shown in Table 5-1. Three of the measures (**Modified Draft at Libby**, **December Libby Target Elevation**, and **Sliding Scale at Libby and Hungry Horse**) are included in all four of the MOs, and exactly define Multiple Objective Alternative 1 (MO1). The **Ramping Rates for Safety** and **Slightly Deeper Draft for Hydropower** measures are added to Multiple Objective Alternative 2 (MO2) and Multiple Objective Alternative 3 (MO3), and the **McNary Flow Target** and **Winter Stage for Riparian** measures are added to Multiple Objective Alternative 4 (MO4). The specific targets modeled for the **December Libby Target Elevation** measure are notably deeper for MO2 and MO3 than what was applied in MO1 and MO4.

The **Modified Draft at Libby** measure involves changes to draft and refill procedures at Libby Dam, which aims to: improve Libby Dam's management of reservoir space to balance local and system FRM needs, temperature management for sturgeon flow augmentation, refill of the reservoir, and operational flexibility for releases in the spring and summer. Changes to Libby Dam's operations including a modified Storage Reservation Diagram (SRD) to operate for local hydrologic conditions in medium- to low-water years (<6.9 Maf Libby Dam April through August forecast) and modifying refill procedures to improve chances of refill by accounting for future planned releases in the modified draft calculations.

Table 5-1. Operational Measures Impacting Libby Dam

Short Measure Description	Short Name	MO1	MO2	MO3	MO4
Modify Libby draft and refill operations when water supply forecast is 6.9 Maf or less	Modified Draft at Libby	X	X	X	X
Eliminate end-of-December variable draft at Libby and replace with single draft target	December Libby Target Elevation	X 2,420 ft	X 2,400 ft	X 2,400 ft	X 2,420 ft
Strive to hold minimum 220 kcfs spring flow/200 kcfs summer flow at McNary using upstream storage	McNary Flow Target	–	–	–	X
Ramping rate limitations at all projects will be defined only for safety or engineering	Ramping Rates for Safety	–	X	X	–
The storage projects may be drafted slightly deeper for hydropower	Slightly Deeper Draft for Hydropower	–	X	–	–
Implement sliding scale summer draft at Libby and Hungry Horse	Sliding Scale at Libby and Hungry Horse	X	X	X	X
Support establishment of vegetation by limiting Bonners Ferry stage height November through March	Winter Stage for Riparian	–	–	–	X

The **December Libby Target Elevation** measure involves changing Libby Dam's variable end-of-December draft targets to a single target of 2,420 feet NGVD29 in MO1 and MO4, which is higher than most No Action Alternative years. MO2 and MO3 have an additional 20 feet of hydropower draft below the FRM elevation. This causes Libby Dam to be 11 feet lower at end of December than the No Action Alternative. These deeper drafts are part of the **Slightly Deeper Draft for Hydropower** measure.

The **McNary Flow Target** measure aims to maintain 220 kcfs outflow from May 1 to June 15 and 200 kcfs outflow from June 16 to July 31 using up to 2.0 Maf of upstream storage for years with a below average (87.5 Maf) April-issued April through August water supply forecast at The Dalles. Libby (along with Hungry Horse and Albeni Falls Dams) provides augmentation to back fill up to half the volume provided by Grand Coulee Dam, with Libby providing 26.7 percent of the total 2 Maf.

The **Sliding Scale at Libby and Hungry Horse** measures involve changes to summer draft at Libby and Hungry Horse Dams to allow the two dams to operate more locally for resident fish and balance these needs with flow augmentation for migrating anadromous fish in the Columbia River. The end-of-September target elevation at Libby and Hungry Horse Dams have been changed from a step function to a straighter, interpolated draft function. The operations in this measure are based off local water supply forecasts instead of the May water supply forecast at The Dalles that was used in the No Action Alternative.

The **Ramping Rates for Safety** measure involves a partial relaxing of flow and pool elevation restrictions, which aims to increase hydropower generation and flexibility to integrate renewable resources. At Libby and Hungry Horse, ramping rates are increased to add operational flexibility to raise and lower flows to meet fluctuations in hydropower demand. Note the ResSim model does not do load shaping, which is where dam outflows can change hourly, daily, and weekly for hydropower needs.

The **Slightly Deeper Draft for Hydropower** measure involves drafting Libby, Hungry Horse, Grand Coulee, and Dworshak slightly deeper for hydropower generation.

The **Winter Stage for Riparian** measure aims to limit the Bonners Ferry stage in the winter to aid in the survival of the riparian vegetation downstream of Libby Dam. This is modeled by limiting Libby Dam discharge to keep the Bonners Ferry stage below 53 feet (1,753 feet NGVD29) between November and March. This rule is not in effect for the months of January through March when the water supply forecast is above 6.9 Maf. When the expected Bonners Ferry stage is greater than 53 feet, the minimum release from Libby Dam is increased from 4 to 9 kcfs.

5.2.2 Libby Reservoir Elevations (Lake Koocanusa)

There are numerous changes in Lake Koocanusa water levels under each of the MOs as compared to the No Action Alternative condition. Due to the overlapping measures across the MOs (and because there are no changes to project inflow), there are strong similarities in the resulting H&H conditions and patterns of change as compared to the No Action Alternative. For example, the changes evident in MO1 can be seen in each of the other MOs, and water levels under MO2 and MO3 are practically identical.

For all alternatives, the largest changes in Lake Koocanusa water levels occur during the drawdown period in the winter months, where water levels are lower for typical and dry forecast years during the drawdown period, but higher for wet years. Water levels are similar for the rest of the year in the majority of conditions, with some exceptions specific to individual alternatives. For example, under MO2 and MO3, water levels are lower under all water year types in the months of November and December, and MO4 has lower water levels during dry years in the fall.

Evident in the water year hydrographs, the differences in water level vary by water year type, higher or lower forecasts, and time of year. The following pages include a more detailed discussion of the changes in specific seasons and water year types.

The **December Libby Target Elevation** measure results in direct changes in the end-of-December target and impacts water levels for all MOs during the winter months through the drawdown period. Under MO1 and MO4, the **December Libby Target Elevation** measure sets a new target elevation of 2,420 feet NGVD29. The new target is achieved within a foot in 95 percent of all years. In typical and high forecast years (the lower 55 percent of years), the new target is 9 feet higher than the No Action Alternative of 2,411 feet NGVD29. In low forecast years (the highest 20 percent of years) in which the No Action Alternative targets a pool at 2,426.7 feet NGVD29, the water levels under MO1 and MO4 are typically 6.7 feet lower.

Under MO2 and MO3, the new end-of-December hydropower draft target is 2,400 feet NGVD29. To meet this target, the end-of-November target was 7 feet lower than in MO1, MO4, and the No Action Alternative. Compared to the No Action Alternative, the Lake Koocanusa water levels under MO2 and MO3 are 11 feet lower in normal to high-water years, and as much as 26 feet lower in some low forecast years. Water levels in January are starting off 10 to 25 feet lower than the No Action Alternative due to the deeper hydropower end-of-December target, but modified targets under the **Modified Draft at Libby** measure, similar those under MO1 and MO4, result in less dramatic differences in pool elevations by the end of January. The January 31 frequency plots show the water level in the lowest 20 percent of years (wet years) can be 10 to 20 feet higher, and water levels are lower compared for the highest 60 percent of years (dry years), frequently more than 20 feet lower. It should be noted that starting in January, MO2 and MO3 use the same SRD as MO1 and MO4, which was designed to accommodate the end-of-December target of 2,420 feet without requiring outflows above full powerhouse. For FRM, similar draft targets and pool elevations to the No Action Alternative would be possible in wet years in MO2 and MO3.

For MO1 and MO4, water levels are typically higher as draft continues in January and February due to being higher in the pool on December 31. During higher water supply forecasts, the draft rate is similar to the No Action Alternative, but the pool reaches a specific elevation generally a couple weeks later due to the higher pool elevation in December. During shallower draft conditions, water levels are lower due to the December change of the **December Libby Target Elevation** measure. The January 31 frequency plot shows water levels up to 5 feet lower for most years and much higher (10 to 20 feet) in the lowest 20 percent of years with the deepest drafts being leveled off at around 2,383 feet NGVD29 by the new SRD under the **Modified Draft at Libby** measure. In the highest 20 percent of years, water levels are 6 to 7 feet lower under MO1 and MO4 compared to the No Action Alternative, also due to the **Modified Draft at Libby** measure. By the end of February, the changes in water levels have diminished for typical conditions, but the same condition of higher pool levels at deeper drafts and lower pool levels at shallower drafts continues.

The effects of **the December Libby Target Elevation**, **Slightly Deeper Draft for Hydropower**, and **Modified Draft at Libby** measures, affecting all four MOs, continue to be seen throughout the draft in the spring. The **December Libby Target Elevation** measure effectively delays the draft from December into January, causing some of the driest years to not fully recover the additional space drafted in MO1 and MO4. The **Modified Draft at Libby** measure causes the deeper drafts for years with forecasts less than 6.9 Maf. This can be seen as lower water levels on April 10 in about half of the years for all of the MOs. Under MO2 and MO3, water levels during dry years are even lower (as much as 20 feet) due to the **Slightly Deeper Draft for Hydropower** measure. In wet years, the pool is drafted similarly to the No Action Alternative by April 10 under all alternatives, but it can be drafted less deep in the wettest 25 percent of years due in part to the delayed draft related to the **December Libby Target Elevation** measure and in part to the **Modified Draft at Libby** measure. There is no change in the deepest draft or the draft occurring during the deeper half of years, evident in the April 30 frequency plot.

Refill is similar under MO1, MO2, and MO3 with improvements due to the **Modified Draft at Libby** measure; the July 31 target of 2,454 NGVD29 (5 feet from full) is reached about 10 percent more often under MO1 and about 5 percent more often under MO2 and MO3. Refill during drier years when a full pool is not met has similar water levels under MO2 and MO3 and higher water levels under MO1. The **McNary Flow Target** measure (under MO4 only), which calls for up to an additional 534 kaf of draft for lower Columbia River fish flows in below-average years at The Dalles, can result in water levels as much as 7 feet lower during refill. The July 31 figure shows the median end-of-July elevation is 3.4 feet lower than the No Action Alternative, and the July 31 target is met about 10 percent less often.

As a result of the **Sliding Scale at Libby and Hungry Horse** measure, which is included in all four MOs, the elevation target at September 30 is modified to be triggered based on local forecasts and to target a higher elevation (5 feet from full rather than 10 feet from full as in the No Action Alternative) in the wettest 20 percent of years compared to the No Action Alternative. The result of the measure in combination with the **Modified Draft at Libby** measure is higher water levels (1 to 5 feet) in August and September for most conditions. The September 30 frequency plot shows an almost 5 percent increase in frequency of reaching the 2,449 feet NGVD29 target for MO1, MO2, and MO3, and the new target of 2,454 feet NGVD29 occurs in about 20 percent of years for all MOs, with water levels 5 feet higher compared to the No Action Alternative. By September 30 of most years, the pool will have drafted from the September target, but in some years, the pool will have reached the September draft target earlier in the month and will fill above its end-of-month target due to fall storms, so there is an increase in probability of an end-of-September pool above 2,454 feet NGVD29 due to the higher pool target under the **Sliding Scale at Libby and Hungry Horse** measure.

Under MO4, the **McNary Flow Target** measure counteracts the higher fall water levels related to the **Sliding Scale at Libby and Hungry Horse** measure and results in a net decrease in water levels for about half of years. In low water years at The Dalles, Lake Koocanusa water levels are already low by the end of July and continue to be lower than the No Action Alternative through September. The median end August and September elevations are 6 and 5.2 feet lower, with some years are being up to 13 feet lower. The probability of end-of-September pool levels below 2,435 feet NGVD29 increases from 2 percent of years to over 10 percent of years under MO4.

Changes in the month of October are negligible for MO1, MO2, and MO3 for most years; however, the **Sliding Scale at Libby and Hungry Horse** measure can cause the starting pool levels to be about 5 feet higher in some years (less than one-third) for all MOs. In MO4, water levels are consistently lower in October due to carry-over effects from the **McNary Flow Target** measure. The lower October water levels in MO4, often more than 10 feet lower, can carry over into November, although to a lesser degree. The **Winter Stage for Riparian** in MO4 has little impact on extra water stored in November due to the majority of years having been drafted to a lower elevation for the **McNary Flow Target** measure. The **Winter Stage for Riparian** measure in MO4 can cause the reservoir to be several feet higher by April in years around the median draft elevation. It has no impact on the deepest 20 percent of April drafts.

5.2.3 Libby Dam Outflow

Libby Dam outflow is impacted in almost every season for each MO due to the multiple measures directly affecting operations at the dam. The largest changes in flow conditions occur in November through March for all MOs as a result of the **December Libby Target Elevation**, **Slightly Deeper Draft for Hydropower**, and **Modified Draft at Libby** measures. The **Winter Stage for Riparian** measure in MO4 can cause lower releases in the winter and shift some of that water later into the year. Flows in the spring are lower due to the **Modified Draft at Libby** measure to account for planned flows such as the sturgeon volume. In MO4, flows in the drier half of the years at The Dalles are higher due to the **McNary Flow Target** measure. The **Sliding Scale at Libby and Hungry Horse** measure causes lower releases in the summer.

Evident in the water year hydrographs, the differences in water level vary by water year type, higher or lower forecasts, and time of year. The following pages include a more detailed discussion of the changes in specific seasons and water year types.

Under MO1, Libby outflow is similar to those under No Action Alternative for both October and November, but there are notable changes starting in December related to the **December Libby Target Elevation** measure. This measure results in an increase in outflow for drier years and decrease in outflow for typical and wetter years. The change in the 25 and 50 percent exceedance average monthly flow results are -4.9 and -4.4 kcfs (-26 and -25 percent), respectively, and the change in the 75 and 99 percent exceedance average monthly flow results are +2.7 kcfs and +3.5 kcfs (27 and 43 percent), respectively.

November flows are lower under MO4 as the reservoir is often lower with less water to evacuate as a result of additional releases the previous summer associated with the **McNary Flow Target** measure. The November median monthly average outflow decreases by 20 percent (2.9 kcfs) and by more than 50 percent for some drier years. Some of this change is due to the **Winter Stage for Riparian** measure, which can impact release timing in November and December, but the effect of this measure is smaller than other measures. Similar to MO1, the change in the end-of-December target under the **December Libby Target Elevation** measure in MO4 results in an increase in outflow for drier years and decrease in outflow for wetter years. Residual effects of the **McNary Flow Target** measure can result in a decrease in the driest years.

Changes in outflow start in November for MO2 and MO3, where the lower targets from the **Slightly Deeper Draft for Hydropower** and **December Libby Target Elevation** measures require the reservoir to draft faster than the No Action Alternative starting on November 1. Higher releases related to the deeper draft targets continue through December, resulting in substantially higher flows than those under the No Action Alternative. Changes in flow in November are commonly 3 to 5 kcfs higher, which translate to 33 to 55 percent increases in average monthly flow for all but the wettest years. In December, the increase in flow varies more widely, ranging from a couple kcfs to over 10 kcfs, or 10 to 130 percent.

It should be noted that real-time load shaping is not incorporated into the ResSim modeling, which can cause hourly and daily release changes. The **Winter Stage for Riparian** measure in

MO4 would limit load shaping; however, because load shaping is not modeled, this impact cannot be seen in the modeled results. The modeled December outflow from Libby is modeled as relatively constant flow set to meet the draft targets; therefore, the apparent decrease in the range of flows evident in the monthly discharge-duration results for all of the MOs should be regarded as a modeling artifact and not used directly. The average monthly discharge data is a better representation of changes to Libby outflow during the month of December.

MO1 and MO4 have similar releases in January, February, and March, both showing increases in average monthly flow from about 1 to 3 kcfs for typical to higher water years, which range from a 5 percent increase to over 50 percent increase, depending on the month and water year conditions. This reflects the pool being drafted at a more aggressive rate following the higher end-of-December target under the **December Libby Target Elevation** measure. For wet years requiring deeper drafts, more water is released later into the drawdown season due to the higher end-of-December target compared to the No Action Alternative. The **Winter Stage for Riparian** measure under MO4 can also impact release timing in January through March, but the effect of this measure is smaller compared to the other measures. Minimum flows occur about 10 to 15 percent less often under MO1 and MO4.

Discharges in January are considerably lower in MO2 and MO3, exceeding 40 percent less flow under some water years. This is due to the **Slightly Deeper Draft for Hydropower** measure and its inclusion in the MO3 **December Libby Target Elevation** measure, which forces a much more aggressive draft earlier in the year. Additionally, MO2 and MO3 use the same SRD for the **Modified Draft at Libby** measure as MO1 and MO4, which was designed to accommodate the end-of-December target of 2,420 feet NGVD29 without requiring outflows above full powerhouse. Under MO2 and MO3, outflow in February is 22 percent less for typical water years (estimated as the median average monthly flow value) and similar or the same as the No Action Alternative for higher or lower water years, where releases are either set at the minimum or are constrained by normal draft limits. Minimum flows do occur about 20 percent more frequency under MO2 and MO3 in January. Changes in outflow in March are similar to February, but an increase can be seen in some wetter years where pool levels have not completely met their draft target for the **Modified Draft at Libby** measure.

Applied in all of the MOs, the **Modified Draft at Libby** measure accounts for the future volume releases, and in years with a water supply forecast less than 6.9 Maf, Libby is at a deeper elevation prior to refill, resulting in lower releases in April, May, and into June for MO1, MO2, and MO3. The decrease in releases under MO2 and MO3 are larger due to frequently being drafted deeper following the deeper December draft.

The Sturgeon Pulse starts in mid-May for most years and continues into June. The Sturgeon Pulse volume is set off the May water supply forecast and has the same volume and release shape for all alternatives. In years with a forecast below 4.8 Maf, there is no Sturgeon Pulse release in any of the alternatives. Prior to the Sturgeon Pulse, there are lower releases as part of the **Modified Draft at Libby** measure in order to improve refill. This has the effect of damping changes shown for average May discharge in typical to wet years. For typical to wet years, average monthly outflow is 4 to 5 percent lower for MO1, 6 to 7 percent lower for MO2 and MO3, and up to 5 percent lower for MO4. During years when there is no Sturgeon Pulse, 14 percent of all years, Libby operates only to the **Modified Draft at Libby** measure during May and June. In these years, there is the largest change in project outflow where the average monthly outflow for May can be as much as 47 percent lower under MO1, 54 percent lower for MO2 and MO3, and 42 percent lower under MO4.

Releases in August and September for MO1, MO2, and MO3 are generally lower due to revised fall draft targets under the **Sliding Scale at Libby and Hungry Horse** measure that are higher than the No Action Alternative. The changes in outflow under MO1 are less due to typically being higher in the pool than MO2 and MO3 during the **Modified Draft at Libby** refill, and therefore it has more water to release prior to September 30. The month of August shows the largest decreases for MO1, MO2, and MO3, particularly in high water years, evident in the changes in the 1 percent average monthly flow. MO1 shows a 13 percent decrease (-2.3 kcfs), and MO2 and MO3 show a 19 percent decrease (-3.3 kcfs for both).

Under MO4, the **McNary Flow Target** measure results in 25 percent higher median average monthly releases in July and smaller decreases in June and August, 4 percent and 2 percent, respectively. This measure also causes an increasing July discharge shape as Libby Dam adjusts to a deeper and deeper draft target as more augmentation water is needed to backfill into Grand Coulee. If this measure were to be implemented in real-time operations, additional logic would be helpful to try and create smoother outflows in July and into August.

The **Slightly Deeper Draft for Hydropower** measure (applied under MO2 and MO3) relaxes the ramping rates at Libby throughout the year. This does not discernibly alter the monthly outflow, it but can change the outflow for a few days following a sharp rise or drop in flow. It could result in larger fluctuations of releases for load shaping. However, ResSim modeling does not incorporate either the hourly or daily load shaping at any project, which likely results in lower occurrence of high and low flows for certain months.

5.2.4 Kootenai River below Libby Dam

Effects on hydrology downstream follow a similar pattern to the changes in outflow from Libby, although the percent change decreases due to dilution from several major tributaries downstream of the project, particularly during the spring freshet. The relative influence of flow changes on stage is typically greater above Bonners Ferry, where the river is beyond the influence of the downstream reservoir at Cora Linn Dam. With increasing distance downstream from Bonners Ferry, the flow changes have smaller impacts on stage.

At Bonners Ferry, the changes in average monthly flow exceeding 30 percent are not uncommon for some seasons and conditions, and changes in water level at Bonners Ferry can exceed a foot for a few months in each of the four MOs. Detailed discussion changes in flow and water levels downstream of Libby for various seasons and water years for each of the alternatives are described below. Fewer ties are made to measures at the upstream projects because this detail was already outlined in the project outflow section preceding this.

Under MO1, the most notable change in flows and water levels downstream of Libby Dam occur from December through March. At Bonners Ferry, changes in median flow range from -4.3 kcfs in December to +3.1 kcfs in February, which translate to -23 and 36 percent changes, respectively; smaller changes in flow occur in wetter and drier years during these months. The December flow decrease translates to a decrease in water levels of about 1.5 feet at index points in the free-flowing reach below Libby Dam. Below Bonners Ferry, the stage change is smaller but is still -1.0 foot at RM 140 and -0.4 foot at RM 103 near the U.S.-Canada border. The largest discharge years do show an increase in MO1 of high flows in March (up to 25 percent). Those years requiring deeper drafts at Libby Dam have to release more water later into the drawdown season due to the higher end-of-December target than that under the No Action Alternative with a similar forecast. Other months under MO1 show smaller changes in flow, typically less than 5 percent change.

Under MO2 and MO3, the increased outflow from Libby Dam in November translates to increases in median monthly water levels of 1.4 to 1.8 feet at index points in the free-flowing reach below Libby Dam, and 1.6 feet at RM 150 at Bonners Ferry. Decreases in January outflow translate to decreases in median monthly water level of as much as 2 feet. Looking closer at flow changes at Bonners Ferry, the biggest change occurs during November and December, where lower flows during those months occur less often, evident in increases in the 75 and 99 percentile average monthly outflow data (30 to 120 percent). These changes translate to an increase in water level exceeding 3 feet. Other notable changes are a decrease in higher to typical flows in January (20 to 40 percent), which translates to stage decreases exceeding 3 feet.

Under MO4, the decrease in median monthly outflow from Libby Dam in November and December related to the **December Libby Target Elevation** measure translate to decreases in water levels over a foot at index points in the free-flowing reach below Libby Dam. At Bonners Ferry, the decreases in median average monthly outflow for November and December are 0.9 and 1.3 feet, respectively. Below Bonners Ferry, the decrease in stage is smaller but is still a few tenths of a foot at RM 103 near the U.S.-Canada border. From January through March, increases in median average discharge under MO4 translate to 0.4-foot, 1.2-foot, and 0.8-foot changes in water level at Bonners Ferry, respectively, and the increases in water level are a few tenths of a foot downstream near the U.S.-Canada border.

Resulting from changes in Libby outflow associated with the **Winter Stage for Riparian** measure under MO4, a 15 to 25 percent reduction in total number of days above 53 feet at Bonners Ferry (1,753 feet NGVD29) is typical for the 5-month period in higher (>50 percent) flow years. Looking at all years, the greatest change occurs during the month of December, where the occurrence of days above 53 feet is decreased from 12.8 to 4.4 percent (4 days to 1.4 days), according to the monthly elevation data. Table 5-2 shows the percent of days in each month when water levels are above 53 feet at the Bonners Ferry gage. Note the **Winter Stage for Riparian** measure is not in effect for forecasts above 6.9 Maf; years with higher Bonners Ferry stages in February and March are more likely to be larger water years that required deeper drafts, so increases in February and March might not be when this measure is in effect. There would be differences in release timing due to the **Winter Stage for Riparian** measure, which would push water later in the year, but that might not be reflected in the summary results. Additionally, the **Winter Stage for Riparian** measure would limit load shaping; however, because load shaping is not modeled, this impact cannot be seen in the modeled results.

Table 5-2. Percent of Time above 53 Feet (1,753 feet NGVD29) at the Bonners Ferry Gage

Alternative	November	December	January	February	March
No Action Alternative	10.0%	12.8%	20.7%	17.9%	5.4%
MO4	9.9%	4.4%	14.9%	20.5%	8.0%
Change	0.1%	8.4%	5.8%	-2.6%	-2.6%

For all four MOs, a decrease in average May flow can exceed 20 to 30 percent during lower water years when the Sturgeon Pulse does not happen. Under these conditions, water levels at Bonners Ferry can be more than a foot lower under MO1 and MO4, and as high as 2 feet lower under MO2 and MO4. Flows and stages during the Sturgeon Pulse look to be the similar to those under the No Action Alternative. The years that have the Sturgeon Pulse and the volume and pattern of the releases is the same in all alternatives.

Summer flows and water levels are slightly lower for MO1, MO2, and MO3, with water levels typically a few tenths lower at Bonners Ferry. Under MO4, water levels can be over a foot higher in the latter half of June and throughout the month of July due to the **McNary Flow Target** measure. There is a slight increase in typical August water levels (less than 0.2 foot), and September water levels are within a tenth of foot of the No Action Alternative. There is a reduction of up to a few tenths of a foot in the higher stages that occur in August. This is related to the end-of-September change in the **Sliding Scale at Libby and Hungry Horse** measure, in which the largest 15 percent of years at Libby Dam only have a 5-foot draft from full and the largest 25 percent of years have less of a draft than the No Action Alternative.

There is a reduction in the highest stages in August for MO1, MO2, and MO3. This is related to the-end-of September change under the **Sliding Scale at Libby and Hungry Horse** measure, in which the largest 25 percent of years at Libby Dam only have a 5-foot draft from full. MO4 has the same influence, although the changes in higher August flows and water levels are negated by increased outflow associated with the **McNary Flow Target** measure.

5.2.5 Kootenai River Annual and Seasonal Peaks

Peak flows on the Kootenai River are similar or lower for all of the MOs, with negligible change (<1 percent) occurring during higher flow years (<0.50 percent AEP), and decreases exceeding 20 percent for lower peak years (from 50 to 90 percent AEP). The decreases in annual peaks are related to decreases in freshet peak in all MOs and can be attributed to a variety of measures resulting in deeper drafts earlier in the spring.

Due to changes to improve refill under MO1 and MO4 **Modified Draft at Libby** measure, there is a resulting increased probability of spill. The probability of Libby Dam spill occurring in a given year is increased from less than 1 percent under the No Action Alternative to about 2 percent under MO1 and MO4. This results in a negligible (<1 percent) increase (<1 percent) in peak flows downstream at Bonners Ferry, and no change in flood risk (see the Flood Risk Management Appendix for more discussion on flood risk).

Under MO2 and MO3, there are no notable changes in the annual peak outflow from Libby Dam for all years but the driest years (>85 percent AEP). In those drier years, there are decreases in spring peaks. The probability of peak spring outflows at or less than 12.7 kcfs increases from less than 1 percent of years to about 10 percent of years, and a very low peak outflow of 6 kcfs occurs in 6 percent of years. The **Slightly Deeper Draft for Hydropower** measure, in combination with the **December Libby Target Elevation** measure, causes Libby Dam to draft deeper and thus release more water in November and December. In the driest 15 percent of years, winter outflow would be the highest annual outflow. The change can be seen as far downstream as the Columbia River flowing into Lake Roosevelt. However, ResSim modeling does not incorporate neither the hourly nor daily load shaping at any project, which can cause the real-time hourly data to be higher than the modeled daily average values.

At Bonners Ferry under MO2 and MO3, winter peak flows are increased in most years due to deeper drafts and increased outflow in November and December. Alternatively, the occurrence of low winter peaks below 20 kcfs at Bonners Ferry decreases from 30 percent of years under the No Action Alternative to <1 percent of years under MO2 and MO3. The decreases in spring outflow in drier years means the spring peak at Bonners Ferry is lower in dry years. Freshet peaks less than 25 kcfs only occurred in about 1.5 percent of years under the No Action Alternative, whereas they would occur in almost 10 percent of years under MO2 and MO3. In most of these drier years, the annual maximum would occur during the winter instead of with the freshet.

At Bonners Ferry under MO2 and MO3, increases in winter AEP elevation exceeding a couple feet can be seen for probabilities less than 0.10. The probability of winter peaks below elevation 1,755.5 feet NGVD29 decreases from about 45 percent of years to less than 1 percent. Related more to changes in spring peaks, the annual peak elevation at Bonners Ferry during lower flow years can be over 1.5 feet lower, but there are negligible changes to the 50 percent AEP stage or during larger peak years.

Under MO1 and MO4, change in winter peaks are less notable than those under MO2 and MO3. Under MO1, higher draft rates (around 11 kcfs) can result in the peak outflow from Libby in less than 10 percent of winters (i.e., in the driest winter years, but this change has little effect on winter peaks in the Kootenai River downstream). Winter peaks are similar or slightly lower under MO4 for almost all years.

5.2.6 Hungry Horse Operational Changes

Five measures directly impact hydroregulation at Hungry Horse Dam. They are shown in Table 5-3. The **Sliding Scale at Libby and Hungry Horse** measure is included in all four of the multiple objective alternatives, and the **Hungry Horse Additional Water Supply** measure is included in all but MO2. The **Ramping Rates for Safety** and **Slightly Deeper Draft for Hydropower** measures are added to MO2 and MO3, and the **McNary Flow Target** is included in MO4.

These **Sliding Scale at Libby and Hungry Horse**, **Hungry Horse Additional Water Supply**, and **McNary Flow Target** measures specifically target summer operations, resulting in changes to storage and outflows, although the impacts from these changes are not isolated to the summer period. The other two measures are directed at improving hydropower generation flexibility that could potentially impact operations any time of the year, although the **Slightly Deeper Draft for Hydropower** measure (only in MO2) targets winter elevations directly. The **Ramping Rates for Safety** (MO2 and MO3) measure would impact spring operations the most, but these changes are not evident in the modeled results as ResSim does not model hourly, daily, or weekly load shaping.

Table 5-3. Operational Measures Impacting Hungry Horse Dam

Short Measure Description	Short Name	MO1	MO2	MO3	MO4
Increase water managers' flexibility to store and release water from Hungry Horse Reservoir	Hungry Horse Additional Water Supply	X	–	X	X
Strive to hold minimum 220 kcfs spring flow/200 kcfs summer flow at McNary using upstream storage	McNary Flow Target	–	–	–	X
Ramping rate limitations at all projects will be defined only for safety or engineering	Ramping Rates for Safety	–	X	X	–
The storage projects may be drafted slightly deeper for hydropower	Slightly Deeper Draft for Hydropower	–	X	–	–
Implement sliding scale summer draft at Libby and Hungry Horse	Sliding Scale at Libby and Hungry Horse	X	X	X	X

The **Hungry Horse Additional Water Supply** measure includes Hungry Horse Dam outflow increased to release an additional 90 kaf during the summer resulting in modified elevation targets at Hungry Horse Dam. The increased outflows are arbitrarily removed ("diverted") from the Flathead River above Flathead Lake (from upstream of Flathead Lake near RM 109) to represent total consumptive use (worse case) impacts to flows so that there can be flexibility in implementation. The intent of this measure is to represent the implementation of the Confederated Salish and Kootenai Tribes—Montana Compact that may use up to 90 kaf of storage from Hungry Horse for irrigation, municipal and industrial (M&I), or in-stream purposes. Because approvals for the compact are still being implemented, it is unknown at this time how much will be used for each purpose and how much will be consumptively used. The modeled outflow increase and diversion of 90 kaf is applied as a flat flow of 493 cubic feet per second (cfs) over the months of July, August, and September. The end-of-September target is 90 kaf lower corresponding to an elevation of 3,546 feet NGVD29, 4 feet lower than the No Action Alternative, and in years where the flow augmentation draft is 20 feet, to an elevation of 3,535.8 feet NGVD29, 4.2 feet lower than the No Action Alternative. This is achieved by adjusting the downstream minimum flow at Columbia Falls to be 493 cfs higher in July, August, and September for all years.

The **McNary Flow Target** measure aims to maintain 220 kcfs outflow from May 1 to June 15 and 200 kcfs outflow from June 16 to July 31 using up to 2.0 Maf of upstream storage for years with a below average (87.5 Maf) April-issued April to August water supply forecast at The Dalles. Hungry Horse (along with Libby and Albeni Falls Dams) provides augmentation to back fill up to half the volume provided by Grand Coulee Dam, with Hungry Horse providing 11.6 percent of the total 2.0 Maf.

The **Sliding Scale at Libby and Hungry Horse** measure involves changes to summer draft at Libby and Hungry Horse Dams to allow the two dams to operate more locally for resident fish and balance those needs with flow augmentation. The end-of-September operations at Libby and Hungry Horse Dams have been changed to have an interpolated draft instead of step function draft. The operations in this measure are based off local water supply forecasts instead of the May water supply forecast at The Dalles that was used in the No Action Alternative.

The **Ramping Rate for Safety** measure involves a partial lift of flow and pool elevation restrictions, which aims to increase hydropower generation and flexibility to integrate renewable resources. At Libby and Hungry Horse, ramping rates are increased to add operational flexibility to raise and lower flows to meet fluctuations in hydropower demand.

The **Slightly Deeper Draft for Hydropower** measure involves drafting some of the storage reservoirs deeper for hydropower generation. In MO2, Libby, Hungry Horse, Grand Coulee, and Dworshak were drafted deeper for hydropower. In MO3, only Libby was drafted deeper for hydropower generation as part of the **December Libby Target Elevation** measure.

5.2.7 Hungry Horse Reservoir Elevations

The differences in reservoir elevation above Hungry Horse Dam vary seasonally and with different water year types. Reservoir elevations under MO1, MO3, and MO4 are 4 to 8 feet lower than those under the No Action Alternative for most of the year, particularly during drier years and particularly in the fall and winter months. Reservoir elevations under MO2 are similar to those under the No Action Alternative for much of the year but are commonly 3 to 8 feet lower from January through June when the reservoir is typically drawn down. The following pages include a more detailed discussion of the changes in specific seasons and water year types.

It should be noted that when MO1 and MO3 were modeled, the initial Hungry Horse Reservoir levels at the start of each water year were erroneously set lower than intended. A subsequent sensitivity analysis revealed that this initialization error primarily affected pool elevation results in the fall and winter. This initialization error causes the MO1 and MO3 results to be too low during the fall and winter. Years at the median and higher elevations should have water levels 1 to 3 feet higher in MO1 and MO3 than shown from October through May. For years with reservoir elevations lower than the median elevation, the results should be 5 to 10 feet higher from October through February, compared to the data originally reported. The Hungry Horse elevation tables for MO1 and MO3 do not have this initialization error accounted for in its values. This initialization error had little effect on flows or elevations downstream from Hungry

Horse Dam. Hungry Horse Dam's modeled releases were up to 1 kcfs lower than they should have been, but by the time flow reaches Flathead Lake, the MO1 results have little error.

The **Sliding Scale at Libby and Hungry Horse** measure in all MOs results in very similar elevation targets at the end of September and does not significantly change summer outflows. In the No Action Alternative, the summer flow augmentation releases are determined by a step function that requires a 10-foot draft in 80 percent of years or 20 feet in the driest 20 percent of years (targeting 3,550 feet or 3,540 feet NGVD29 respectively based on the May water supply forecast at The Dalles). In the **Sliding Scale at Libby and Hungry Horse** measure, the step function is replaced with an interpolated draft target between the 80th and 90th percentile, so that the draft target is linearly interpolated between 3,550 feet and 3,540 feet in those years. This results in minor changes year to year with a potential reduction on storage impacts during the drier years. In MO1, MO2, and MO4 changes from this measure are not apparent as other measures have larger summer impacts except for the 80th to 85th percentiles. In MO2, without the **Hungry Horse Additional Water Supply**, the **Sliding Scale at Libby and Hungry Horse** measure results in an end-of-September pool that is 8.3 to 3.4 feet higher than the No Action Alternative in those 80th to 90th percentiles. It also can affect percentiles beyond the 90th because the location of the forecast changes how often the rule is active. As an example, the probability of pools below 3,540 feet decreased from 21 percent in the No Action Alternative to 7 percent in MO2. The end-of-September increase in comparison with the No Action Alternative results in similar or higher winter elevations until January.

The **Hungry Horse Additional Water Supply** measure in three of the alternatives (MO1, MO3, and MO4) results in lower reservoir levels at the end of September by approximately 4 feet. In MO1 and MO3, the **Hungry Horse Additional Water Supply** measure results in approximately half of years that the September 30 elevation is at least 4 feet lower compared to the No Action Alternative. In approximately 10 percent of years, the September 30 elevation will be between 4 and 16 feet deeper due to a combination of the **Hungry Horse Additional Water Supply** measure**, Sliding Scale at Libby and Hungry Horse** measure, and meeting minimum flows (in all alternatives, consistent with the No Action Alternative). The pool can be more than 5 feet lower during the lowest 5 percent of years on September 30. In MO3, low pools are also more common, with the probability of pools below 3,535 feet NGVD29 increasing from 1 percent of years to about 4 percent of years compared to the No Action Alternative. In MO4, in wetter years, the results are the same as MO1 and MO3, but in the drier half of years, September 30 is 4.9 feet to 15.3 feet deeper than the No Action Alternative. In these years, the **Hungry Horse Additional Water Supply** measure is responsible for 90 kaf of the draft, 4.0 to 4.2 feet depending on the depth. The additional extra difference in the draft is due to **McNary Flow Target**.

For MO1 and MO3, and MO4 in the wetter years, the end-of-September elevation decrease in comparison to the No Action Alternative results in lower winter and spring reservoir elevations. Fall and winter operations typically are to meet minimum flows at a time when inflows are low, which requires drafting Hungry Horse Dam to meet these minimum flows in all alternatives. In the alternatives (MO1, MO3, and MO4), the draft is greater to meet the same minimum flows in most years. In MO1 and MO4, the median daily water levels are 4 to 8.4 feet lower than the No Action Alternative with the largest median difference in December (over 8 feet). The least difference in median daily water levels is in May through August, approximately 0 to 3 feet. There is a 10 percent chance that water levels between September and February could be lowered by as much as 10 feet, and a 2 percent chance that water levels between September and February could be lowered by as much as 15 feet. Larger changes in fall reservoir elevations are more likely to occur when dry years happen back to back, and the reservoir becomes over drafted throughout the winter and into spring because inflows are less than minimum outflow requirements. The annual frequency maximum November-through-July plot shows how the peak refill elevation is dropped in MO1, MO3, and MO4 due to the decreased carryover from previous water year.

The **McNary Flow Target** measure, only in MO4, causes the deepest draft with up to 232 kaf of volume from Hungry Horse. The **McNary Flow Target** measure only occurs in below average years; this is evident by the change in the September 30 elevation change in MO4 compared to MO1 and MO3. In above-average years, MO1, MO3 and MO4 summer drafts (and impacts through the winter and spring) are nearly identical. However, in drier years in MO4, the combination of **Sliding Scale at Libby and Hungry Horse**, **Hungry Horse Additional Water Supply**, and mostly the **McNary Flow Target** measure results in lower storage elevations. MO4 end-of-September elevations are 5 to 15 feet deeper than No Action Alternative for the 60th to 99th percentiles, and the **Sliding Scale at Libby and Hungry Horse** measure actually decreases the deeper draft as seen in the 80th to 85th percentile end-of-September elevations. For MO4, the median end-of-month water levels are 1.7 feet to 8.5 feet lower with the largest difference in median daily water levels in September through April (4.8 feet to 8.5 feet lower), and the least difference in median daily water levels in May through August (1.7 feet to 4.2 feet lower). In MO4, Hungry Horse end-of-month pool elevations were more than 10 feet deeper in the fall through the winter, 40 percent in October, 30 percent in November, 25 percent in December, and 20 percent in January. There is a reduction in the differences of more than 10 feet during the water year. However, not even the highest reservoir elevations are within a foot of the No Action Alternative elevations in the fall and winter more than 10 percent of the time. Larger changes in fall reservoir elevations are more likely to occur when dry years happen back to back, and the reservoir becomes over drafted throughout the winter and into spring because inflows are less than minimum outflow requirements. The annual frequency maximum November to July plot shows how the peak refill elevation is dropped in MO4.

The spring elevations are closer to the No Action Alternative, but they are still deeper in the majority of years. The 10 percent of deepest drafts still have the same frequency of happening; see April 30 target date frequency plots as this elevation is driven by FRM operations in all alternatives consistent with the No Action Alternative. At the end of June, only the top 20 percent of years meet an elevation of 3,559 feet NGVD29 in MO4, compared to 50 percent in the No Action Alternative. The median June 30 elevation is 1.9 feet lower as a result of the increased outflow under the **McNary Flow Target** measure. In July, that measure begins the deeper drafts for the rest of the summer. By the end of August, the median elevation is 4.2 feet lower in MO4.

The **Slightly Deeper Draft for Hydropower** measure, only in MO2, allows Hungry Horse to be drafted deeper. To provide additional generation, the reservoir is drafted to meet elevation targets lower than FRM from January through the end of May. This results in elevations that are consistently lower than the No Action Alternative until the end of June. The April 10, April 30, and May 31 target is 10 feet below the upper rule curve (URC). The January, February, and March targets seek an elevation that would achieve a 75 percent probability of filling to the April 10 target. This results in median elevations that are consistently 4 to 8 feet lower than the No Action Alternative until the end of June. Later in the summer, water levels on June 30 are typically 1.3 feet lower, and normal full pool (3,560 feet NGVD29) refill is achieved in about 30 percent of years.

The **Ramping Rate for Safety** measure, in MO2 and MO3, does not cause noticeable changes to pool elevations in the hydroregulation modeling.

5.2.8 Hungry Horse Dam Outflow

The same measures that impact pool elevations discussed above impact outflows. Generally, the measures that impact elevations in the summer increase outflows (**Hungry Horse Additional Water Supply**, **McNary Flow Target**), except for **Sliding Scale at Libby and Hungry Horse**, which slightly decreases summer outflows. The impacts to storage at the end of the summer carry over into the next water year and impact flows in the fall through spring. The **Slightly Deeper Draft for Hydropower** measure under MO2 increases January outflows, resulting in lower outflow through the rest of spring. The following description of the outflow impacts for each MO is provided below by examining each of the measures.

The **Sliding Scale at Libby and Hungry Horse** measure, in all four MOs, results in minor changes to September flows. The largest change within this measure is from a switch in forecast location and interpolating the draft point instead of a step function.

The **Hungry Horse Additional Water Supply** measure in three of the alternatives (MO1, MO3, and MO4) consistently increases Hungry Horse outflows from late July through September, simulating additional 90 kaf supplied for increased diversion downstream in the summer months. Considering the **Sliding Scale at Libby and Hungry Horse** measure may reduce flow in August and September in some years, and the **Hungry Horse Additional Water Supply** measure may increase outflow by about 500 cfs in July, August, and September of every year, the resulting net change in flow in a given year varies between 0.3 to 0.6 kcfs. For MO1 and MO3, which do not include the **McNary Flow Target** measure, the increase in flow translates to an increase in monthly average outflow of 17 to 21 percent (0.6 kcfs) in August and September for most years. Changes in July outflow vary throughout the month and under different water year conditions, but they are relatively small compared to other months.

It should be noted that under MO1 and MO3, the initial Hungry Horse Reservoir levels at the start of each water year were erroneously set lower than intended, and the effects of this initialization on Hungry Horse discharge are smaller than the effects on reservoir elevation. The posted M-C results are close to what would be expected for MO1 and MO3. Winter flows would be lower than for the No Action Alternative, with flows at the 1 percent exceedance level being the most underpredicted (the underprediction ranges from 0.2 to 0.9 kcfs at the 1 percent exceedance level). By May and June, the underprediction in flows from the initialization error is just 0.1 to 0.2 kcfs for most water year types. Moving downstream through the system, flow effects from initialization have less and less of an effect as the flows become larger and larger.

The **McNary Flow Target** measure, only in MO4, causes the deepest draft with up to 232 kaf of volume as additional flow is released in the summer months to support higher flows in the Columbia River downstream of McNary Dam in below-average water years. The **McNary Flow Target** measure only occurs in below average years, this is evident by the change in the summer outflows change in MO4 compared to MO1 and MO3. The changes in Hungry Horse outflow results under MO4 are due to a combination of the **Hungry Horse Additional Water Supply**, **Sliding Scale at Libby and Hungry Horse** and **McNary Flow Target** measures, but in below-average years (as measured at The Dalles), the impacts from the **McNary Flow Target** measure is greater than the other two.

Decreased outflows after September through the spring are a result of the change to summer operations with primarily the **Hungry Horse Additional Water Supply** and **McNary Flow Target** measures and the resulting decreased reservoir elevations at the end of September. The outflows from the fall through the spring months are either to support minimum flows (which would be the same as the lowest releases in the No Action Alternative) or smaller releases that already meet minimum flows in an attempt to fill back to normal winter elevations. The median average monthly flows in November through April may decrease by 3 to 6 percent (0.1 to 0.2 kcfs).

In terms of percentage flow changes, the higher and lower flows for November through January show larger decreases than the median values. For example, the 1 and 99 percent exceedance monthly average flow values for December are each 32 percent lower, compared to the 6 percent decrease at the median value. This is because in MO4 years, a large water supply forecast requires less draft to reach their draft targets in the No Action Alternative, and dry years are now always just supporting minimum flows at Columbia Falls as its constraint.

Under MO1, MO3, and MO4, there is a reduction in flows (2 to 8 kcfs) in most years from April through June. Of these months, the largest changes (typically less than 1 kcfs) occur in April as the snow starts to melt and inflows to the reservoir increase and the additional space in the reservoir allows for a greater portion of these flows to be stored. The **Slightly Deeper Draft for Hydropower** measure, only in MO2, allows Hungry Horse to be drafted deeper. In the winter (January and February), monthly average outflows increase by 5 and 1.9 kcfs respectively for the 50th percentile. These are 100 and 33 percent increases from the No Action Alternative. Minimum winter outflows are also increased from 300 to 900 cfs to support increased hydropower in the driest years. Throughout the spring, outflows are either set to meet targets for hydropower flexibility or to support minimum flows (which would be the same as the lowest releases in the No Action Alternative). For March and April, the monthly average outflows decrease by 0.4 and 0.8 kcfs and decrease in June by 1.8 kcfs for the 50th percentile.

5.2.9 Flathead River below Hungry Horse Dam

The changes in flow in the Flathead River below Hungry Horse Dam (upstream of the influence of the Flathead Lake) translate to changes in stage. The influence of flow changes on stage in the free-flowing portion of the Flathead River is evaluated at RM 147, located at the gage at Columbia Falls, Montana. Stage changes related to flow changes are quickly decreased below roughly RM 130 near Kalispell, Montana, where backwater effects from Flathead Lake start to influence river stages.

Under MO1 and MO3, the major changes in the Flathead River can be described as lower flows in the winter (primarily reduced frequency of higher flows), lower spring flows, and then higher summer releases. These changes are driven largely by the **Hungry Horse Additional Water Supply** measure. MO4 has the same changes but includes additional releases in the summer in some years due to the **McNary Flow Target** measure. Under MO2, the **Slightly Deeper Draft for Hydropower** measure results in increased releases in January and February and decreased flow later in the spring. Affecting all four MOs, the **Sliding Scale at Libby and Hungry Horse** measure can result in slightly lower flows in August and September during driest 10 percent of years.

During the diversion period from August through September with the **Hungry Horse Additional Water Supply** measure, increased flow through the Flathead River results in an increase in water levels at Columbia Falls of typically 0.1 to 0.2 foot. The additional water during August and September from the **McNary Flow Target** measure cause an increase of another 0.2 foot, resulting in total increases of 0.3 to 0.4 foot under MO4 at Columbia Falls. The increases in summer water levels are not seen at the upper end of Flathead Lake, as the additional diversion removes all of this additional volume at the upper end of Flathead Lake.[2] Changes in Flathead Lake levels are discussed in the following section.

For MO1, MO3, and MO4, the decreased flow in the winter months can result in lower water levels on the Flathead River between Hungry Horse and Flathead Lake. Water levels can be as much as 0.5 foot lower at Columbia Falls for MO4 under some higher flow conditions, and slightly lower under MO1 and MO3; otherwise, water levels are within a couple tenths of a foot from those under the No Action Alternative. Farther downstream near Kalispell, Montana, within the backwater influence of Flathead Lake, the changes in water levels in the winter and spring are typically 0.1 to 0.2 foot less compared than the differences at Columbia Falls farther upstream.

Under MO2, the changes in flow at Columbia Falls translates to an increase in median January water surface elevation of 1.3 feet. The next largest change in median water levels at Columbia Falls is a decrease of 0.4 foot in June. Farther downstream, within the transitional zone at the upstream end of the lake near Kalispell, the effects of these same flow changes on median water levels are typically within 0.1 foot from the No Action Alternative condition.

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[2] The specific location of the diversion is arbitrary, but it is at the lower end of the Flathead River reach to show the longest potential reach impacts from this measure. Actual water withdrawal and use of this water is unknown.

The decrease in low flows from Hungry Horse in the winter under MO1, MO3, and MO4 are minimal. This is because Hungry Horse Dam is releasing flows during winter for the Columbia Falls minimums in both the No Action Alternative and the MOs. The increase in minimum flows during the winter and spring under MO2 does not result in noticeable changes in minimum flows in the Flathead River, either.

5.2.10 Flathead Lake and Seli'š Ksanka Qlispe' Dam

There are no changes to operations at SKQ Dam, and so there are very little changes to water levels in Flathead Lake. The changes seen in outflow are effectively the same changes seen coming into the lake. Some minor changes can be seen in lake levels, particularly in higher spring flow conditions, and these are associated with flow changes through the lake (due to the constriction immediately upstream of the SKQ Dam) originating from changes in outflow from Hungry Horse Dam; however, these changes are typically less than a couple tenths of a foot. Under MO2, water levels can be 0.3 to 0.4 foot lower during refill in April and May due to the **Deeper Draft for Hydropower** measure.

Under MO1 and MO3, the results show Flathead Lake levels exceeding a foot lower from late June through September for the lowest 10 percent of years. This is due to changes modeled in Hungry Horse Dam operations for the Confederated Salish and Kootenai Tribes water rights settlement for irrigation or M&I purposes (**Hungry Horse Additional Water Supply** measure), as well as the changes in summer draft (**Sliding Scale at Libby and Hungry Horse** measure). Elevations are slightly lower in the below-average flow years due to a decrease in inflows associated with the upstream water supply measure diversion.[3]

Under MO4, the potential effects on the water supply from the **Hungry Horse Additional Water Supply** measure at Hungry Horse, which could cause Flathead Lake to draft earlier due to less inflows into the lake in the summer, are cancelled out by the extra water releases in the summer for the **McNary Flow Target** measure. In years when Flathead Lake is having trouble holding its summer elevation due to low inflows, the additional water from the **McNary Flow Target** measure can be kept in Flathead Lake instead of being passed downstream to back fill Grand Coulee Dam from its draft to support higher flows at McNary Dam.

Under MO2, the decrease from late June through September during low pool conditions that occur in the lowest 10 percent of years is similar to the changes under MO1 and MO3, although the decreases is in water levels are roughly half as large because MO2 does not apply the **Hungry Horse Additional Water Supply** measure.

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[3] In reality, the location of the diversion upstream of Flathead Lake chosen for modeling is arbitrary, and these elevation decreases in Flathead Lake are not expected. The intent was to model the additional water from Hungry Horse Dam and withdraw this water from river flows downstream to show the largest (magnitude and duration) of potential impacts to flows from this measure.

5.2.11 Flathead and Clark Fork Rivers below Seli'š Ksanka Qlispe' Dam

Flow changes downstream of Seli'š Ksanka Qlispe' Dam are largely a continuation of flow changes coming from Hungry Horse Dam. One notable exception to that is the removal of 90 kaf with a simulated diversion upstream of Flathead Lake in late July through September with the **Hungry Horse Additional Water Supply** measure. The simulated diversion effectively nullifies the flow increase seen in MO1 and MO3 in the Flathead River above Flathead Lake during that same period in most years. Under MO4, the increased flow from the **McNary Flow Target** measure continues downstream past Flathead Lake and through the Pend Oreille River, eventually to the lower Columbia River.[4]

There are no changes in operations at the projects downstream of Seli'š Ksanka Qlispe' Dam (Thompson Falls, Noxon Rapids, or Cabinet Gorge Dams), so changes in flow are only a result of dilution from tributary inflows and attenuation through reaches. Changes in water level are only a result of changes in flow and are greatest in the free-flowing reach immediately below Seli'š Ksanka Qlispe' Dam. At Flathead RM 11 in Reach 27, the changes in water levels are very similar to those at Columbia Falls in Reach 28. Winter and spring water levels under MO1, MO3, and MO4 can be as much as a half-foot lower due to the **Hungry Horse Additional Water Supply** measure at Hungry Horse, and the increase in August and September water levels resulting from the increased flow with the **McNary Flow Target** measure under MO4 is 0.3 to 0.4 foot higher for most years. The largest changes in water level in this reach occur in January under MO2 as the **Slightly Deeper Draft for Hydropower** measure results in an addition 2 to 5 kcfs (>50 percent).

5.2.12 Lake Pend Oreille and Albeni Falls Dam

Lake Pend Oreille's elevation is controlled by Albeni Falls Dam, and like Flathead Lake, water levels can respond to changes in inflow, particularly during higher flow conditions, due to the constriction between Albeni Falls Dam and the lake. There are no changes to operations at Albeni Falls Dam for the MOs except under MO4, where some of the lake storage can be called upon during the drier half of years under the **McNary Flow Target** measure. The **McNary Flow Target** measure aims to maintain 220 kcfs outflow from May 1 to June 15 and 200 kcfs outflow from June 16 to July 31 using up to 2.0 Maf of upstream storage for years with a below-average (87.5 Maf) April issued April-August water supply forecast at The Dalles. Albeni Falls (along with Libby and Hungry Horse Dams) provides augmentation to back fill up to half the volume provided by Grand Coulee Dam, with Albeni Falls Dam providing 11.7 percent of the total 2.0 Maf.

Under MO4, during drier years in which the **McNary Flow Target** measure calls upon upper basin projects for storage, Lake Pend Oreille will stay steady after the full augmentation is reached until it rejoins the typical operating pool in September, whereas in the No Action

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[4] Some of the **McNary Flow Target** measure water may stay in Flathead Lake if it is already on minimum releases to try and hold its summer elevation. The flow changes seen in October under MOs should be disregarded as they are a modeling artifact related to starting conditions.

Alternative, the pool would typically be drafting, which is why a decrease is seen in September. The lake's elevation changes in the drier half of years from May through September drafted up to 2.7 feet deeper (234 kaf) than the typical summer elevation. Lake Pend Oreille's typical summer operation range is 2,062.0 to 2,062.5 feet NGVD29; in ResSim it is modeled at a flat elevation of 2,062.25 feet NGVD29 for July through mid-September when the **McNary Flow Target** measure is not in effect. This has almost 40 percent of years at Lake Pend Oreille at 2,060.0 feet NGVD29 or lower during the summer, resulting in a new summer minimum pool of 2,059.7 feet NGVD29. There is no change in the annual minimum pool of 2,051.25 feet NGVD29, which is reached in November. The actual November and December minimum range is 2,051.0 to 2,051.5 feet NGVD29; ResSim just models the middle of it.

Under MO1, MO3, and MO4, the model results display notable changes in the highest 1 percent elevations between November and March; however, these changes are more a reflection of slight changes in the release-timing of winter high-flow events than of changes in operations at Albeni Falls or at projects upstream. Similarly, the results show a 1.0-foot increase in the 1 percent AEP winter peak stage, which is unlikely to occur as the winter FRM operation at Albeni Falls is overly simplified within the ResSim model and does not fully represent how it is operated for those events. A detailed explanation of Albeni Falls operations in ResSim is provided in Appendix B, Part 3 – ResSim/Wat Documentation.

Under MO2, there are slightly larger changes in higher winter and spring water levels in Lake Pend Oreille with increases in water levels in January and February of a few tenths of a foot, and decreases in March through May of a similar magnitude. These water level changes are related to changes in winter releases from Hungry Horse Dam, as well as changes to winter FRM at other projects, which indirectly affect Albeni Falls Dam operations and releases during winter events (e.g., **Winter System FRM Space** measure at Grand Coulee Dam).

5.2.13 Pend Oreille River below Albeni Falls

Under MO4, the **McNary Flow Target** measure includes changes to operations at Albeni Falls Dam and results in additional changes in outflow in the majority of years. The average monthly flows for June increase by up to 3.0 kcfs (18 percent) from the drafting of Lake Pend Oreille. The median average monthly flows in July and August increase by 0.8 kcfs and 0.6 kcfs (3 and 6 percent), respectively, as Hungry Horse augmentation water moves down through the system. The September flows have the largest expected decrease, up to 2.0 kcfs (26 percent). Downstream of Albeni Falls Dam, the June outflow changes can result in notable stage changes. At Pend Oreille RM 87, a few miles below Albeni Falls Dam, June water levels are about a half-foot higher under MO4 for the lowest 25 percent of years. The relatively large percent change in lower September outflow does not substantially impact water levels because the reservoir above Box Canyon and Boundary Dams are relatively flat at lower flow conditions. An increase of a couple tenths of a foot can be seen under typical conditions in late July.

At RM 87 in Reach 23 just below Albeni Falls Dam, decreases in the water level of several tenths of a foot exist for higher-flow conditions in the winter months (November through February.) Increases seen in the month of October are a modeling artifact. Other locations throughout these two reaches (22 and 23) will have the same pattern of change, but the magnitude of change will typically be less because of increased proximity to the downstream dam.

5.2.14 Flathead and Pend Oreille Rivers Annual and Seasonal Peaks

Peak flows under MO1, MO3, and MO4 are decreased in both the winter and spring due to the **Hungry Horse Additional Water Supply** measure, where an additional 90 kaf is effectively held back in the winter and spring, and then released in the summer. The decreases in spring and annual peak outflow from Hungry Horse are more than 10 percent for typical and lower flow years, but the decreases in peak flows in the Flathead River downstream at Columbia Falls are smaller, typically 2 percent or less. Decreases in winter peaks (typically much less than the annual peak) at Columbia Falls are much larger, typically 5 to 15 percent lower. Similar changes in peaks are seen downstream on the lower Flathead, Clark Fork, and Pend Oreille Rivers, although the changes are increasingly diluted downstream.

Under MO2, increased drafting under the **Slightly Deeper Draft for Hydropower** measure results in an increase in both winter and spring peak outflows during typical and lower flow years. The higher draft rate of 9 kcfs would occur in most years and cause the highest winter release in about half of years. The effect of this change downstream on the Flathead River is increased spring and annual peaks during typical and drier, non-flood years (>30 percent AEP). There would be no notable changes to higher spring and annual peak flows (<30 percent AEP).[5] At Columbia Falls, the 50 percent AEP is increased by 1.7 kcfs (4 percent). This change pattern under MO2 seen at Columbia Falls continues through the Flathead and Clark Fork system, although the changes are increasingly diluted.

Under MO4, this is an increase in peaks below Albeni Falls during the lowest 10 percent of years as a result of the **McNary Flow Target** measure. Under the No Action Alternative, peak outflow from Albeni Falls could be lower than 40 kcfs in about 10 percent of years, and lower than 35 kcfs in about 2 percent of years, whereas these same flows occur about 5 percent of years and less than 1 percent of years, respectively, under MO4.

5.3 REGION B – GRAND COULEE AND MIDDLE COLUMBIA RIVER

5.3.1 Grand Coulee Dam Operational Changes

Several measures directly impact operations at Grand Coulee Dam including **Update System FRM Calculation**, **Planned Draft Rate at Grand Coulee**, **Grand Coulee Maintenance Operations**, **Winter System FRM Space**, **Lake Roosevelt Additional Water Supply**, **McNary Flow Target**, and **Slightly Deeper Draft for Hydropower**. In addition to these, measures that have larger impacts at upstream projects (e.g., **December Libby Target Elevation, Modified Draft at Libby**, and

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[5] The model results show increases in spring and annual peak flows throughout the Flathead, Clark Fork, and Pend Oreille River basin resulting from operational changes at Hungry Horse and, to a lesser extent, Albeni Falls Dam, but these changes are a modeling artifact related to modified refill logic in the ResSim model made during the simulation of the **Slightly Deeper Draft for Hydropower** measure.

Hungry Horse Additional Water Supply) indirectly impact Grand Coulee Dam by changing inflow to Lake Roosevelt.

All of the MOs contain the **Update System FRM Calculation**, **Planned Draft Rate at Grand Coulee**, and **Grand Coulee Maintenance Operations** measures. Of all the MOs, only MO2 does not contain the water supply measures at Hungry Horse, Grand Coulee, or Chief Joseph. Similarly, only MO3 does not contain the **Winter System FRM Space** measure, and it has a different SRD shape with a flat spot like the No Action Alternative. MO4 is unique in that it is the only alternative that includes **McNary Flow Target** measure, and MO2 is the only alternative that contains the **Slightly Deeper Draft for Hydropower** measure (Table 5-4).

Table 5-4. Modeled Operational Measures at Grand Coulee Dam

Short Measure Description	Short Name	MO1	MO2	MO3	MO4
Update the upstream Storage Corrections Method as applied to the Grand Coulee SRD	Update System FRM Calculation	X	X	X	X
Decrease the Grand Coulee Dam draft rate used in planning drawdown	Planned Draft Rate at Grand Coulee	X	X	X	X
Operational constraints for ongoing Grand Coulee maintenance of power plants	Grand Coulee Maintenance Operations	X	X	X	X
Develop draft requirements/assessment approach to protect against rain-induced flooding	Winter System FRM space	X	X	–	X
Increase volume of water pumped from Lake Roosevelt during annual irrigation season	Lake Roosevelt Additional Water Supply	X	–	X	X
Increase water diversion from the Columbia River for the Chief Joseph Dam Project	Chief Joseph Dam Project Additional Water Supply	X	–	X	X
Strive to hold minimum 220 kcfs spring flow/200 kcfs summer flow at McNary using upstream storage	McNary Flow Target	–	–	–	X
The storage projects may be drafted slightly deeper for hydropower	Slightly Deeper Draft for Hydropower	–	X	–	–

The **Update System FRM Calculation** measure involves changes to the Grand Coulee Dam upstream adjustment procedure for FRM to ensure operations are adaptable to a wide range of upstream storage conditions. For all of the MOs except MO3, this involves removal of a “flat spot” in the SRD curve deeper in the pool during drawdown.

The **Planned Draft Rate at Grand Coulee** measure aims to reduce Lake Roosevelt’s risk of landslide activity due to rapid drawdowns. This has Grand Coulee Dam draft earlier in the winter so there will be a slower draft rate through the winter and spring, which will result in less erosion in and around Lake Roosevelt. This measure does not change the maximum allowable draft rate from 1.5 feet per day.

The **Grand Coulee Maintenance Operations** measure includes added operational constraints for accelerated maintenance of power plants and spillways at Grand Coulee Dam, which aim to represent Grand Coulee Dam’s hydraulic capacity limitations associated with accelerated maintenance activities at the project. This decreases the dam's hydraulic capacity to account for the additional operational constraints associated with the maintenance activities at Grand Coulee Dam. This measure does not impact total outflows but does impact spill levels in some situations.

The **Winter System FRM Space** measure requires additional space in Grand Coulee to reduce rain-induced flooding downstream at Portland/Vancouver to better manage risk associated with winter atmospheric rivers flood events. This has Grand Coulee Dam draft in December to provide a fixed 650 kaf of space for winter FRM operations. The measure does not change the winter system FRM operations, which use space at Grand Coulee, Dworshak and Albeni Falls Dams to reduce flows in the lower Columbia River; it just guarantees that Grand Coulee Dam does have space in the winter for FRM.

The **Lake Roosevelt Additional Water Supply** measure includes increased diversion of an additional 1.2 Maf pumped from Lake Roosevelt to Banks Lake for irrigation and M&I uses. The additional water for the pumping from Lake Roosevelt behind Grand Coulee Dam was added to the amount included in the No Action Alternative and then reshaped. The changes to pumping from Lake Roosevelt are discussed more in Section 5.3.3, Grand Coulee Dam Outflow.

The **Chief Joseph Dam Project Additional Water Supply** measure includes a new diversion of about 10 kaf downstream of Chief Joseph Dam for irrigation of authorized acres in the Chief Joseph Dam Project. The diversion schedule has monthly average diversion flows of about 20 to 50 cfs from May through August. In the ResSim model, the diversion was simulated with a direct withdrawal from the river at RM 514.55, about 4 miles below the dam. There were no changes made to the rules at Chief Joseph Dam.

The **McNary Flow Target** measure provides up to 2.0 Maf of augmentation for years with an April water supply forecast at The Dalles of 87.5 Maf or lower. (In ResSim, the current month's forecast was used). This measure attempts to keep flows above 220 kcfs at McNary Dam from May 1 to June 15, and above 200 kcfs from June 16 to July 31. Grand Coulee Dam provides up to 40 kcfs of augmentation water each day until the 2.0 Maf of augmentation is provided. Grand Coulee Dam provides all of the augmentation water up front as it is the only storage project that can directly regulate McNary flow on a daily basis. The upstream projects of Hungry Horse, Albeni Falls, and Libby Dams then draft their augmentation water (1.0 Maf total) to backfill into Grand Coulee Dam throughout the summer. The upstream project's refill targets are lowered daily as Grand Coulee Dam provides more augmentation water. Albeni Falls Dam provides most of its water in June and into July if augmentation is still in effect. Libby and Hungry Horse Dams' water is released more in July and August to try and provide a smoother operation as the projects are attempting to hit a value below full pool, but the peak elevations are often not reached until July or August.

The **Slightly Deeper Draft for Hydropower** measure involves drafting Libby, Hungry Horse, Grand Coulee, and Dworshak deeper for hydropower generation. This measure involves partially lifting flow and pool elevation restrictions to increase hydropower generation and flexibility to integrate renewable resources

5.3.2 Grand Coulee Reservoir (Lake Roosevelt) Elevations

All of the measures listed in the previous section directly impact operations at Grand Coulee, but the **Winter System FRM Space** and **McNary Flow Target** measures have the largest effects on reservoir levels above Grand Coulee Dam. The **Planned Draft Rate at Grand Coulee** and **Update System FRM Calculation** measures have minor effects on pool levels in spring with the former forcing earlier drafts, and the later determining the deepest draft requirement. Changes in inflow to Lake Roosevelt resulting from changes in operations at Libby and Hungry Horse can also affect pool levels. The **Grand Coulee Maintenance Operations** and **Lake Roosevelt Additional Water Supply** measures do not have an effect on elevation but do affect outflow and spill.

The **McNary Flow Target** measure in MO4 results in Lake Roosevelt starting the water years lower in October. In December, the **Winter System FRM Space** measure (MO1, MO2, and MO4), which drafts the pool 5 to 7 feet lower, affecting water levels into the drawdown period. **Planned Draft Rate at Grand Coulee** measure has the largest water years start to draft Lake Roosevelt more in February and March; all of the MOs are more than 13 feet deeper at the end of February in the deepest years. MO2 is deeper in the winter from the **Slightly Deeper Draft for Hydropower** measure. The deepest draft points remain the same for most water years and alternatives. Peak pool and summer operations are also unchanged except for MO4. MO4 has the lowest water levels compared to the No Action Alternative due to the draft for **McNary Flow Target**, which can be near 20 feet lower in the summer, including missing refill, and into the fall.

Because MO3 does not include the **Winter System FRM Space** and **McNary Flow Target** measures, the **Planned Draft Rate at Grand Coulee** and **Update System FRM Calculation** measures are primarily responsible for the changes in Lake Roosevelt water levels. The relatively large increase in November and December flows coming into the lake from changes at Libby Dam, most notably the **Slightly Deeper Draft for Hydropower** measure, is responsible for the several-foot increase in water levels during years when Grand Coulee is drafted deeper; the normal and shallower years are closer to No Action Alternative elevations in these months.

In addition to the changes seen under MO3 and the shared measures (the **Planned Draft Rate at Grand Coulee** and **Update System FRM Calculation** measures), the other three alternatives (MO1, MO2, and MO4) contain the **Winter System FRM Space** measure, which requires 650 kaf of space by the end of December and has major effects on water levels in the winter months. Under MO1 and MO2, the median monthly pool levels are around 4 to 6 feet lower than the No Action Alternative from mid-December through January due drafting earlier and deeper for the **Winter System FRM Space** measure for all water years. For dry years, water levels are more than 5 feet lower through February and continue to be slightly low through the drawdown in the spring. This change pattern is the same under MO4, but water levels can be a couple feet lower than those under MO1 and MO2 due to compound effects with the **McNary Flow Target** measure, both at Grand Coulee Dam and reduced outflows from the upstream storage projects.

Under MO2, the January 31 plots show water levels are consistently around 4 to 6 feet deeper for all water year conditions due to the **Winter System FRM Space** measure, except for the lowest 10 percent of years where water levels can be more than 15 feet lower than the No Action Alternative due to the **Slightly Deeper Draft for Hydropower** measure. In February at the higher 35 percent of years (dryer years), the pool is 5.4 to 6.7 feet deeper due to the **Winter System FRM Space** measure, and the pool is deeper by as much as 10 feet in lower 50 percent of years due to **Slightly Deeper Draft for Hydropower** and **Winter System FRM Space** measures. By March 1, the median pool levels realign with those of the No Action Alternative rule set, though there is a 30 percent probability of the pool being 4 to 1.8 feet deeper due to a combination of the **Winter System FRM Space**, **Update System FRM Calculation,** and **Planned Draft Rate at Grand Coulee** measures.

Affecting all of the MOs, the change in SRD shape from January through April needed to accommodate the lower planned draft rate of 0.8 foot per day under the **Planned Draft Rate at Grand Coulee** measure results in the flood draft starting earlier, especially in years with higher water supply conditions that require deeper drafts for FRM. The upstream adjustment with the **Update System FRM Calculation** measure may also impact elevation by changing the end of April and/or May FRM requirement, resulting in a decrease in water levels in the driest and wettest years.

Under MO1, MO2, and MO4, there is roughly a 2 percent increase in the probability of drafting Grand Coulee Dam to empty on April 30 as a result of the **Update System FRM Calculation** measure. Additionally, deeper drafts below 1,222.7 feet NGVD29are more likely in MO1, MO2, and MO4 due to the removal of the “flat spot” in the Grand Coulee Dam SRD under the **Update System FRM Calculation** measure. The flat spot in the No Action Alternative and MO3 results in a static draft to 1,222.7 feet (NGVD29) for a range of water supply conditions.

Under MO1, MO2, and MO3, refill and summer elevations are similar to the No Action Alternative as the reservoir fills in early July and drafts for summer flow augmentation by the end of August. The September water levels under MO1 are the same as the No Action Alternative, but water levels can be several feet lower during drier years under MO2. This is due to the **Deeper Draft for Hydropower** measure, which lowers the end-of-September target in drier years and results in water levels below 1,283 feet NGVD29 in 40 percent of years.

Under MO4, water levels are lower (4 to 10 feet, typically) during refill in May and early June in most years due to the **McNary Flow Target** measure.[6] By the end of May the median elevation is 7 feet lower due to the effects of the **McNary Flow Target** measure, and all water year types are lower. By the end of June, 40 percent of years are within 1 foot of the No Action Alternative reservoir elevation, but more than 20 percent of years are more than 20 feet deeper due to **McNary Flow Target**. The maximum refill difference can be as large as 23 feet; see maximum

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[6] Note that even though the **McNary Flow Target** measure is implemented in about half the years, the median trace is not a single water year but the median of all water years on that day. Due to operations such as the Drum Gate Maintenance, the drier half of years can be in the deeper half of years due to that constraint or something else. This causes years through the spectrum to feel the effects of the **McNary Flow Target** measure**.**

frequency April through July. In July, more than 30 percent of years are 16 feet deeper or more. In August, 30 percent of years are 14 to 15 feet deeper. By the end of September, 15 percent of years remain more than 10 feet deeper than the No Action Alternative due to the **McNary Flow Target** measure. There are only negligible changes in the wetter 50 percent of years after July through August. Lake Roosevelt starts October several feet lower in MO4 due to the carryover effects of the **McNary Flow Target**, when implemented. By the end of October, all but the driest of years have filled to the same elevations as the No Action Alternative.

5.3.3 Grand Coulee Dam Outflow

Changes to outflow in the fall through spring are attributed to several FRM-related measures at Grand Coulee Dam. The **Winter System FRM Space** measure creates 650 kaf of additional storage space starting in December to support winter FRM in the lower Columbia River. Creating this extra space results in an additional flow being released typically during the first three weeks of December; some of this draft can be pushed into January during wet years. The **Planned Draft Rate at Grand Coulee** measure reduces the designed draft rate for the Grand Coulee Dam SRD, which aims to initiate the system FRM draft earlier in the winter, but the **Winter System FRM Space** measure has a larger effect on releases in February and March with less water being released due to draft targets already being met earlier with lower pool levels through January. The impacts from the **Planned Draft Rate at Grand Coulee** measure are most pronounced in wetter years when drafts start earlier and thus higher outflows.

Although obscured by changes in inflow to Lake Roosevelt from change in operations at Libby Dam, the impacts of storage demands created by the **Winter System FRM Space** measure on Grand Coulee outflow are evident under MO1. The median changes in average outflow under MO1 for December, January, and February are 4 percent, 1 percent, and -2 percent, respectively (3.8 kcfs, 0.6 kcfs, and -2.5 kcfs). To hold the pool in January, there is a decrease in the frequency of lower flows and an increase in the frequency of higher flows, but little change on the median monthly or average monthly outflows.

Under MO2, additional water in the river from the increased drafts from storage projects causes winter FRM at Vancouver to be in effect more often. During winter FRM events, Grand Coulee Dam fills to manage downstream peaks at Vancouver. In addition, the increased incidence of winter FRM operations can have repercussions for the spring peak. This is because when Grand Coulee Dam operates for winter FRM in this model, it fills the reservoir. A 1.5-feet-per-day draft rate limit at Grand Coulee Dam can prevent it from reaching its FRM draft in April during large water years, leaving the reservoir with less space available to manage spring floods.

Relevant to MO1, MO3, and MO4, the **Lake Roosevelt Additional Water Supply** measure directly affects Grand Coulee Dam outflows. The increase in pumping from Lake Roosevelt ranges from a couple hundred cfs in March to several kcfs in May through September, with a peak of 4 kcfs in July, and occurs consistently during both high and low water years. The change in pumping is inversely related to the change in dam outflow, but the net change in project outflow during this period is a combination of this volume and other changes related to other measures at Grand Coulee Dam and above.

Under MO1, MO3, and MO4, outflow from the spring through the summer is influenced the most by the **Lake Roosevelt Additional Water Supply** measure, but other upstream measures do affect inflows to Lake Roosevelt. The **Winter System FRM Space** measure can add to the reduction in flows in March and February during drier years in all MOs but MO3. The **Modified Draft at Libby** measure can have lower flows in the spring most years for all MOs. The **Slightly Deeper Draft for Hydropower** measure at Libby and Hungry Horse Dams can also contribute to lower flows in the spring for MO2.

Under MO4, Grand Coulee Dam operates for McNary flow targets using its own storage starting in May. The upstream storage projects, sometimes in May but more in June through August, backfill into Lake Roosevelt by releasing storage and missing refill. In these drier years, the net outflow increase from Grand Coulee is around 6 kcfs (5 percent). In above-average years, the **McNary Flow Target** measure does not come into effect, and outflows from Grand Coulee Dam are lower due to the **Lake Roosevelt Additional Water Supply** measure. To make up for more water being delivered for the **McNary Flow Target** measure in May to July, less water is released in September and October, and potentially later into the fall during very low water years, which require Lake Roosevelt to draft deeper. These decreases in September and October outflow during low water years are some of the biggest changes shown at Grand Coulee, evident in the 17 percent and 15 percent reductions in average monthly flow for the 99th percentile, and 15 percent and 11 percent for the 75th percentile.

To help illuminate the fraction of flows associated with the measure, the changes in average monthly Grand Coulee outflows are compared with the changes in inflows to Lake Roosevelt (which represents the sum of changes from Libby, Hungry Horse, and Albeni Falls Dams), and the change in Banks Lake pumping from Lake Roosevelt with the **Lake Roosevelt Additional Water Supply** measure (Table 5-5).

Table 5-5. Change in Lake Roosevelt Inflow, Increased Pumping Under the Lake Roosevelt Additional Water Supply Measure, and Change in Grand Coulee Dam Outflow (kcfs) for each of the Multiple Objective Alternatives

	Location	APR	MAY	JUN	JUL	AUG	SEP
MO1	Lake Roosevelt Inflow	-0.6	-2.7	-0.4	-0.8	-0.3	-0.1
	Pumping from Lake Roosevelt	-3.2	-3.2	-3.0	-4.2	-2.6	-2.5
	Grand Coulee	-4.6	-6.1	-4.5	-4.7	-3.4	-2.9
MO2	Lake Roosevelt Inflow	-1.4	-3.3	-1.4	-0.8	-0.4	-0.4
	Pumping from Lake Roosevelt	0.0	0.0	0.0	0.0	0.0	0.0
	Grand Coulee	-2.5	-4.1	-2.0	-0.8	-1.0	2.6
MO3	Lake Roosevelt Inflow	-1.2	-3.3	-0.8	-0.7	-0.4	-0.3
	Pumping from Lake Roosevelt	-3.2	-3.2	-3.0	-4.2	-2.6	-2.5
	Grand Coulee	-4.8	-6.7	-4.8	-4.6	-3.9	-3.2

	Location	APR	MAY	JUN	JUL	AUG	SEP
MO4	Lake Roosevelt Inflow	-0.9	-2.8	0.4	1.0	1.1	-0.5
	Pumping from Lake Roosevelt	-3.2	-3.2	-3.0	-4.2	-2.6	-2.5
	Grand Coulee	-5.2	-2.7	-0.5	-0.6	-2.6	-6.3

5.3.4 Columbia River from Grand Coulee to the Snake Confluence

The changes in Grand Coulee Dam outflow can be seen all the way through the Columbia River downstream to the Snake River confluence and beyond. Other than the **Chief Joseph Dam Project Additional Water Supply** measure under MO1, MO3, and MO4, (which does not produce any noticeable changes in the results due to the small volume of water being removed under the measure), there are no operational changes in the projects below Grand Coulee through Priest Rapids Dam.

Changes in water levels throughout the middle Columbia River mirror the flow change, but the magnitude depends on the location. Generally, the greatest changes occur in free-flowing reaches and immediately downstream of projects. The index point below Priest Rapids Dam (Columbia River Reach 14 387.7) represents the upper range of changes expected in the middle Columbia River below Grand Coulee.

Looking at RM 387.7, the monthly elevation-duration data under MO1 is typically within a half-foot of the No Action Alternative results. There is a 0.4-foot increase in median December water levels, and a decrease of 0.5 foot in May.

At the same location, the pattern change under MO2 can be described as higher flows in November and December, lower January flows, and lower flows in March through September. Under MO2, water levels are consistently over a foot higher in December, and decreases in March flows can result in typical decreases in water levels of 0.5 to 0.7 foot.

The pattern change under MO3 can be described as higher flows in November and December, lower January flows, and lower flows in March through September. Water levels are typically less than a half-foot higher in November and December and can be as much as 0.6 foot higher under higher flow conditions in January and February. Water level variability is decreased in the month of January, when there is a decrease in occurrence of higher and lower stages. Decreases in the spring and summer months is typically around a half-foot but can be as much as 1 foot during lower outflow conditions.

The pattern change under MO4 can be described as higher winter flows and lower spring freshet flows, and river flows are slightly lower in the late summer months (August through October). Under MO4, December water levels are frequently as much as a half-foot higher and can be as much as 0.6 foot higher under higher flow conditions in January and February. Decreases in September flow can be 10 to 20 percent lower in the drier 50 percent of years, and water levels can be as much as 1.3 feet lower below Priest Rapids Dam.

5.3.5 Columbia River below Grand Coulee Dam Annual and Seasonal Peaks

There are no changes in peak flows into Lake Roosevelt during wetter years (<50 percent AEP) and slight decreases (1 to 4 percent) in drier years (>50 percent AEP) for all MOs except MO4. Under MO4, peaks are the same or as much as 2 percent greater than the No Action Alternative for the driest 5 percent of years (>95 percent AEP).

With the exception of MO4 in the driest 5 percent of years, there are no changes in AEP with any of the MOs exceeding 10 percent, and most changes are within 2 percent, particularly in higher flow years (<50 percent AEP). The **Winter System FRM Space**, **Slightly Deeper Draft for Hydropower**, **Lake Roosevelt Additional Water Supply**, and **McNary Flow Target** measures all contribute to the changes in AEP.

The **Winter System FRM Space** measure under MO1, MO2, and MO4 results in increases in winter peaks of about 2 to 5 percent for typical and wetter years (<50 percent) below Grand Coulee Dam and varied smaller changes (within ± 2 percent) in annual peaks in larger years (<5 percent AEP). The increase in winter peaks is a result of the additional space required in Grand Coulee (650 kaf) starting in December for the **Winter System FRM Space** measure. These increases in winter peaks are seen through the Columbia River until about 20 miles downstream of Bonneville Dam in Reach 1. The increases are not seen in the Vancouver/Portland area because the Grand Coulee space for the **Winter System FRM Space** measure is used to decrease outflows coincident with higher flows in the lower system, where the large tributary inflows from the Willamette River and other smaller rivers during winter storms can combine with Bonneville Dam outflows to produce the annual peak water levels in the Vancouver-Portland area. The effects on water levels in Reach 1 are described in greater detail under the Section 5.5 of this document.

The **Slightly Deeper Draft for Hydropower** measure under MO2 results in consistent increases in AEP of several kcfs (1 to 2 percent) for the largest 10 percent of years (<10 percent AEP).[7] This translates to as much as a few tenths of a foot increases in water level in the upper portions of the reaches below Grand Coulee Dam.

Decreased April and May inflows to Lake Roosevelt (due to operational changes at Libby and Hungry Horse), combined with additional water removed with the **Lake Roosevelt Additional Water Supply** measure under MO1, MO3, and MO4, result in 5 to 10 kcfs lower spring peaks in most years through the Columbia River downstream of Grand Coulee. This change in peak flows

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[7] Additional water in the river from the increased drafts from storage projects causes winter FRM at Vancouver to be in effect more often. During winter FRM events, Grand Coulee Dam fills to manage downstream peaks at Vancouver. In addition, the increased incidence of winter FRM operations can have repercussions for the spring peak. This is because when Grand Coulee Dam operates for winter FRM in this model, it fills the reservoir. A 1.5 feet/day draft rate limit at Grand Coulee Dam can prevent it from reaching its FRM draft in April during large water years, leaving the reservoir with less space available to manage spring floods. Also, in rare events, a winter FRM event that fills Grand Coulee Dam means that a year that would have been a drum gate maintenance year in the No Action Alternative and a deeply drafted Grand Coulee Dam is no longer able to perform this maintenance, leaving less space in the dam to later manage high spring flows.

translates to about a 2 percent decrease at the 50 percent AEP and a 7 percent decrease at the 90 percent AEP. The effect of this measure on larger peaks (<50 percent AEP) is negligible.

The **McNary Flow Target** measure can offset the reduction in spring and early summer flows caused by other operational measures at Grand Coulee, Libby, and Hungry Horse, and result in a net increase in annual peaks below Grand Coulee Dam in the driest 10 percent of years of about 10 to 20 kcfs (roughly 7 to 15 percent). This change continues downstream through the middle and lower Columbia River reaches, although the change is increasingly diluted downstream. Winter peaks from Grand Coulee Dam may be lower in years following drier spring/summers, which call for the McNary flow augmentation.

All of the changes in AEP seen in Grand Coulee outflow generally continue downstream through the middle and lower Columbia River reaches, although the change is increasingly diluted downstream. An exception to this rule occurs with the **Winter System FRM Space** measure where the effect downstream at Vancouver and Portland, where the measure is aiming to provide increased flood risk benefits, is a decrease in winter (and therefore annual) peaks. This change is described in greater detail in Section 5.5.4 of this document. The changes in peak water levels downstream are typically within a few tenths of a foot and/or are influenced by changes in reservoir operations.

5.4 REGION C – DWORSHAK AND LOWER SNAKE RIVER BASIN

5.4.1 Dworshak and Lower Snake Project Operational Changes

There are only two measures that directly affect operations at Dworshak Dam. These include the **Modified Dworshak Summer Draft** measure with MO1 and the **Slightly Deeper Draft for Hydropower** measure for MO2.

The **Modified Dworshak Summer Draft** measure aims to provide earlier and later cold water releases for adult sockeye salmon, summer Chinook salmon, fall Chinook salmon, and steelhead that use the cool water corridor provided by Dworshak Dam through the lower Snake River. The measure includes several operational changes to control temperatures for critical adult fish in the lower Snake River. Refill to 1,600 feet NGVD29 is still targeted, but drafting to provide cool water downstream can start 11 days earlier under MO1 (June 20 instead of July 1). Also, drafting must start by 6 days earlier on July 5, instead of July 10, in the cases where the draft is delayed to give more time to refill. In real-time, the No Action Alternative could be drafted earlier if the region decided to do so to help with downstream temperature control. The August 31 draft target is also changed under the **Modified Dworshak Summer Draft** measure to be 5 feet or 10 feet higher, depending on the water supply forecast, to conserve water for September. The end-of-September target remains unchanged.

The **Slightly Deeper Draft for Hydropower** measure involves drafting Dworshak (and most other storage projects) slightly deeper for hydropower generation. This measure aims to increase hydropower generation and hydropower flexibility. To provide additional generation, the reservoir is drafted to meet elevation targets lower than FRM from January through the end of May. The April 10, April 30, and May 31 targets are 10 feet below the URC. The January, February, and March targets use an elevation that would achieve a 90 percent probability of filling to the April 10 target.

The **Increased Forebay Range Flexibility**, **Drawdown to MOP,** and **Full Range Reservoir Operations** measures relate to operational changes at the Lower Snake River projects. Of these, only the **Drawdown to MOP** measure was incorporated into the ResSim model for the assigned MO (MO4). The measure aims to operate the four Lower Snake River dams within the full reservoir operating range year-round, which would allow more operating flexibility for hourly and daily shaping of hydropower generation.

The **Breach Snake Embankments** measure is not strictly an operational change but dramatically alters the hydrologic and hydraulic regime through the lower Snake River by removing the earthen embankments and adjacent structures as required at each of the lower Snake River dams.

Summer draft is delayed if Dworshak is more than 6 inches from full as late as the following dates:

- No Action Alternative – July 7
- MO1 – July 5
- MO2 – no delay
- MO3 – July 7
- MO4 – July 7

Summer draft will start before these dates if the project is within 6 inches of full. The documentation on this draft had incorrectly marked July 10 as the latest date it would start in the No Action Alternative, MO3, and MO4.

5.4.2 Dworshak Reservoir Elevation

Under MO1, the **Modified Dworshak Summer Draft** measure results in changes to Dworshak reservoir elevation from June through September. Water levels in the reservoir are consistently lower starting June 20 through August 1, typically between 3 and 8 feet. From August 1 to August 31, draft slows dramatically and the deeper pool transitions to being about 10 feet higher than most No Action Alternative years by August 31. From September 1 to September 15, water levels are then about 10 feet higher compared to the No Action Alternative, but both are modeled to finish September 30 at 1,520 feet NGVD29.

The MO1 results show a slight decrease (1 to 3 percent) in the probability of achieving normal full pool (1,600 feet NGVD29) refill. Under the No Action Alternative, full pool is achieved about 80 percent of years, compared to about 78 percent of years under MO1. This is due to forcing the initiation of draft several days earlier in the model. In real-time, this forcing could be delayed if desired by the region. Typical water levels on June 30 are 3 to 8 feet lower due to draft initiating earlier, but in those years, refill would be achieved in June.

Under MO2, the **Slightly Deeper Draft for Hydropower** measure results in elevations that are consistently lower than the No Action Alternative from January into July. Under the No Action Alternative, normal full pool (1,600 feet NGVD29) refill is achieved in about 80 percent of years. In MO2, is it about half of the time. The goal of this measure is to move water from the spring into the winter without an effect on refill. However, in ResSim, the refill logic was not as smart as the No Action Alternative, so refill was impacted in part due to the coding of the measures. There could also be issues related to missing refill due to forecast error, causing the project to be drafted deeper than it could reliably refill. In the No Action Alternative, if refill is not achieved, the summer draft can be delayed until July 7 to reach full. However, in MO2, there is no delay for the summer draft.

There are no operational changes that would directly impact Dworshak Reservoir elevations or outflow under MO3 and MO4. The results for these two MOs do show a slight change (0.4 foot) in reservoir elevations for much of the year; however, this is a modeling artifact related to starting conditions and should be disregarded. Other sporadic changes in elevation data later in the winter and spring are most likely the result of other system changes altering the release timing and system refill start date. There are no notable changes in Dworshak Dam outflow.

5.4.3 Dworshak Dam Outflow

Under MO1, Dworshak Dam's summer outflow is different due to the change in the shape of the summer draft by the **Modified Dworshak Summer Draft** measure. Dworshak Dam, if full, starts to draft on June 20 instead of July 1. This draft can be delayed until July 5 if refill has not been achieved. Through most of July, Dworshak Dam will try to draft as much as possible; this is done by using full powerhouse plus as much spill that will keep it below the state of Idaho's 110 percent gas cap, 13 to 14 kcfs total release. In years with low summer inflows, the discharge may be lower. The **Modified Dworshak Summer Draft** measure discharges are higher than the No Action Alternative from late June through July. Discharges are then lower during the month of August. The outflow pattern in September is closer to the No Action Alternative, but higher outflows are held later before ramping down toward minimums. Outside of the summer, there is minimal change in discharge. The changes in average monthly flow are typically less than 5 kcfs; however, since the basin is smaller, the percent change is high. The changes are also greater in magnitude and percent change for lower water years. Note that the change in June occurs during the last third of the month when typical outflow is increased from around 5 kcfs to up near the gas cap value below the dam of around 13 kcfs. As long as there are enough summer inflows to support the draft from full pool to the higher end of August targets, Dworshak Dam's releases are at the gas cap capacity in July. The gas cap release is achieved in over half of the days in July, a 30 percent increase over the No Action Alternative. This is done to provide as much possible cooling water in the lower Snake River in late June and July. The June and July median average monthly outflows increased 33 percent and 15 percent (1.6 kcfs and 1.6 kcfs) to support this measure. To provide the additional water in June and July, August flows are reduced by a median average monthly outflow of 48 percent (4.9 kcfs). Some of this reduction also comes from Dworshak Dam having a higher end-of-month target at the end of August. That additional water from August is then released in September, with the median average monthly outflows increasing by 37 percent (1.8 kcfs).

Under MO2, Dworshak Dam outflow is different for most of the year due to the **Slightly Deeper Draft for Hydropower** measure, which drafts the reservoir deeper than the No Action Alternative starting in January for increases in generation. This causes increased flows (6.6 kcfs, a 311 percent median increase in January) at a time when the reservoir would typically output minimum flow. February typically shows another increase in median outflow (2.0 kcfs and 39 percent increase) as the reservoir aims to reach a deeper elevation by moving water to the winter that would be released in the spring in the No Action Alternative. By March, the reservoir has usually reached its target, so outflows are lower than the No Action Alternative (1.5 kcfs and a 24 percent decrease). During these winter months, there is an increase in occurrence of flows at 10 kcfs, as well as a reduction in flows exceeding 10 kcfs as shown in the monthly duration plots. As an example, in January, No Action Alternative outflow is 10 kcfs 10 percent of the time, and 50 percent of the time in MO2. Similar changes occur in February, when the increase in 10 kcfs occurs 40 percent of the time under MO2, compared to about 20 percent of the time under the No Action Alternative.

Under MO2, April median flows are closer to the No Action Alternative, with wetter years having a slightly higher average monthly flow and drier years are lower. The results of the May average flows are greater than the No Action Alternative, but they would likely be the same or lower than No Action Alternative due to the potential lower April 30 elevation from the **Slightly Deeper Draft for Hydropower** measure. Unfortunately, the ResSim model results do not accurately reflect changes expected from the measure. The intent of the measures is to move some water from the spring to the winter. This issue is caused by the MO2 ResSim refill logic not having been as refined as the No Action Alternative logic, so the operation is not as smooth and causes higher one-day releases in May that artificially cause higher downstream peaks and higher monthly average releases. Given that MO2 should have more space in the spring, peaks and monthly flows should actually be lower.

5.4.4 Lower Snake Dams

There are no changes to the modeled operations of the lower Snake River Dam operations under MO1 and MO2. The **Increased Forebay Range Flexibility** measure under MO1 would increase forebay operating range flexibility at the lower Snake River and John Day Projects. Change the operating elevation range restriction at the lower Snake River projects to MOP-plus 1.4 feet and at the John Day project to minimum irrigation pool (MIP)-plus 1.9 feet. This was not included in the ResSim model but would likely affect water levels in the reservoirs by allowing the reservoirs to have slightly more operating room during drawdown operations. The 1-foot operating band in the No Action Alternative can be difficult to achieve in real-time due to wind and weather events. Changes to project outflow resulting from this measure would be minimal and likely hard to detect.

The **Full Range Reservoir Operations** measure, which is assigned to MO2 only, would increase the operating range of the lower Snake River projects to their full range, but like the **Increased Forebay Range Flexibility** measure under MO1, this is not full capture in ResSim modeling. Fluctuation of the run-of-the river dams is primarily affected by hydropower loads, which are not incorporated into ResSim. In reality, the project can be anywhere in its allowable band. The change in operating range at the lower Snake River projects would not change the average monthly flows. There might be a slight decrease in flows in March if the lower Snake River projects are not drafted to a deeper operating range as they are in the No Action Alternative, but this is a very small fraction of the March flows. Conversely, there would be a slight increase in flows in September when the reservoirs do not refill as they do in the No Action Alternative.

Under MO4, the **Drawdown to MOP** measure changes the MOP on the lower Snake River dams to an earlier start date of March 15 (modeled at March 25 in ResSim) and ends August 15. During this time, Lower Granite, Little Goose, and Lower Monumental Dams are all modeled 0.25 feet higher (and operate an average of 0.25 feet higher) than the No Action Alternative, otherwise they are modeled the same as the No Action Alternative. Ice Harbor Dam has the same March 25 draft starts, but it reverts to the No Action Alternative pool in July. In reality, these projects are not held at a flat elevation and vary throughout their operating pool. They should be assumed to be at any elevation in their operating pool at any time.

5.4.5 Clearwater River and Lower Snake River Rivers

The changes in flow out of Dworshak Dam under MO1 and MO2 continue downstream to the Columbia River confluence above McNary Dam and on through the lower Columbia River past Bonneville Dam. The relatively large percent change in flow is diluted as the North Fork Clearwater River merges with the Clearwater River, and then again to a greater degree as the Clearwater River merges with the Snake River near Lewiston, Idaho. Because the lower Snake River projects are run-of-river projects and there are no major tributary inflows, the pattern change in flow is generally unaltered from Lower Granite through Ice Harbor.

Under MO2, the peak annual releases of 25 kcfs from Dworshak occurs in 40 percent of years, as opposed to 30 percent under the No Action Alternative. This release occurs more frequently in the spring and contributes to higher freshet peaks downstream on the Clearwater and Snake Rivers, evident in the 4.5 kcfs increase (7 percent) in the 50 percent annual peak discharge at Spalding. Larger increases, 7 to 12 kcfs (11 to 14 percent), occur for annual peaks between AEP 50 and 3 percent. Larger peaks (<2 percent AEP) show a negligible increase (<1 percent). Any increase shown for very large peaks (<1 percent AEP) should be disregarded as the model does not adequately capture local flood protection operations under the revised MO2 operation set.

On the Clearwater River below Dworshak Dam, at RM 38 near the Peck gauge, water level increases in June and July under MO1 are about a quarter of a foot at the median value. Decreases in August are 1.3 feet at the median value. Only the top third of August stages do not show a decrease of more than a foot in a stage. September stages have a median increase of 0.8 foot. Because there are no operational changes at Dworshak under MO3 or MO4, there are no notable changes in flow that would affect Clearwater River flows and stages.

Under MO4, the lower Snake River dams would have a 1.5-foot operating range instead of a 1-foot operating range. The projects are just as likely to be at any elevation in that operating range.

There would be major changes to the hydraulics of the lower Snake River under the **Breach Snake Embankments** measure applied in MO3. The following pages summarize the wide range of changes to hydrology and hydraulics. Changes to channel morphology and sediment dynamics are described in greater detail in Appendix C, River Mechanics.

The breaching of the four lower Snake River dams results in a dramatic change in water levels throughout the reach and minor changes in flow. A detailed description of the changes in river hydraulics, including sediment transport and channel morphology, is provided in Appendix C, River Mechanics. That report describes the channel conditions several years following dam breach and after fluvial processes have had time to move accumulated sediment and allowed for the river channel to reach a relatively stable, equilibrium state. The post-dam breach channel conditions are described as being relatively constant slope but influenced by a number of natural rapids, and with floodplains in many stretches of the river containing several inches to several feet of deposited alluvium in what would be the future floodplain areas along the river.

Using an estimate of the future channel geometry, simulations were run to determine water surface profiles over a range of conditions. The level of analysis is limited and the model output is different than the standard datasets created in the ResSim M-C modeling; however, the differences in water levels and hydraulics are so dramatically different that a description of a range of hydraulic profiles and conditions should suffice for the CRSO analyses assessing the impacts of this **Breach Snake Embankments** measure. Simulations of water year 1974, which had a peak discharge at the Snake-Clearwater confluence similar to the 1 percent AEP discharge, are used to approximate very high river flow conditions. The 50 percent AEP for MO3 is estimated as the median annual peak water surface for the deterministic model year, not the M-C compute used for No Action Alternative results. A separate geometry based on the 1934 survey results of the pre-dam channel was used for simulated low-flow conditions under MO3. Flow for these simulations are based on modeled minimum of 12.4 kcfs in the Snake River below the Clearwater River confluence. The width and depth difference plots are based on comparison of single profile comparisons of the 1974 event.

Under MO3, the water surface profile through the lower Snake River has a relatively constant slope roughly following the grade of the bed. This is a dramatic difference from the stair-step profile defined by the four dams and reservoirs from the downstream dam at Ice Harbor to the head of the upstream Lower Granite Reservoir. Water levels are as much as 100 feet lower compared to the No Action Alternative at locations immediately upstream of the dams. Moving upstream through the individual reservoirs, the changes in water levels steadily decrease until the change in water levels are as small as being within a foot of the No Action Alternative immediately below the individual projects. Figure 5-1 shows a comparison of water surface profiles for the lower Snake River reaches (from McNary to beyond Lewiston, Idaho).

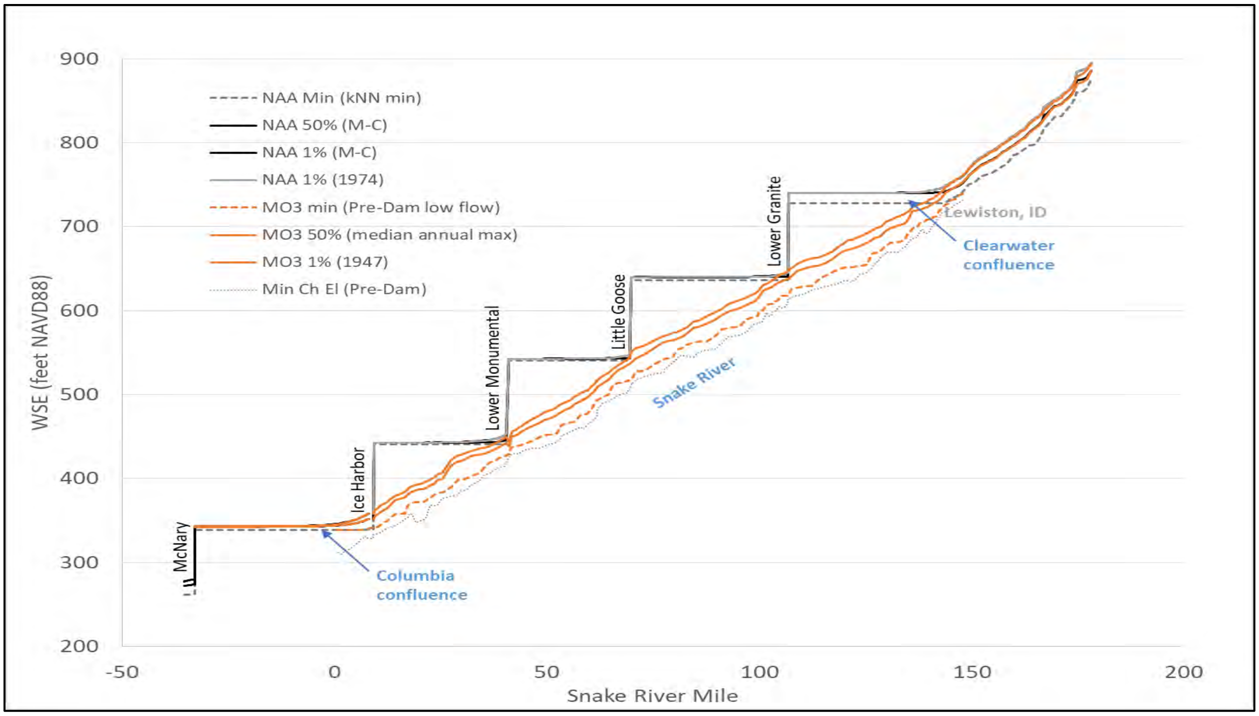

Figure 5-1. Water Surface Profiles Comparing the No Action Alternative and Multiple Objective Alternative 3

The change in depth for a large flood flow (estimated by the 1974 peak discharges, approximately equivalent to the 1 percent discharge at Clearwater-Snake confluence) ranges from about 20 feet to over 80 feet. The change in depth is sensitive to the minimum bed elevation, which generally reflects a riffle-pool system and regularly fluctuates between deep and shallow. Disregarding the fluctuations in depth from riffle to pool, the range of depth overall is relatively constant under MO3, typically between 15 feet and 30 feet, compared to the No Action Alternative, which has water depths fluctuating from about 25 feet to over 100 feet deep (Figure 5-2).

Changes in width vary more than the changes in depth. The average decrease in width is about 500 feet, but the change can be as much as a half-mile in some places. The change in width is generally greatest in the pool closest to the dams, although this is not the case with Little Goose Reservoir, which has the widest section a few miles upstream from the dam, near RM 75 (Figure 5-3).

With the exception of immediately below the existing projects, the changes in width and depth between MO3 and the No Action Alternative would be greater for lower flow conditions (e.g., 50 percent AEP, seasonal low flow, etc.).

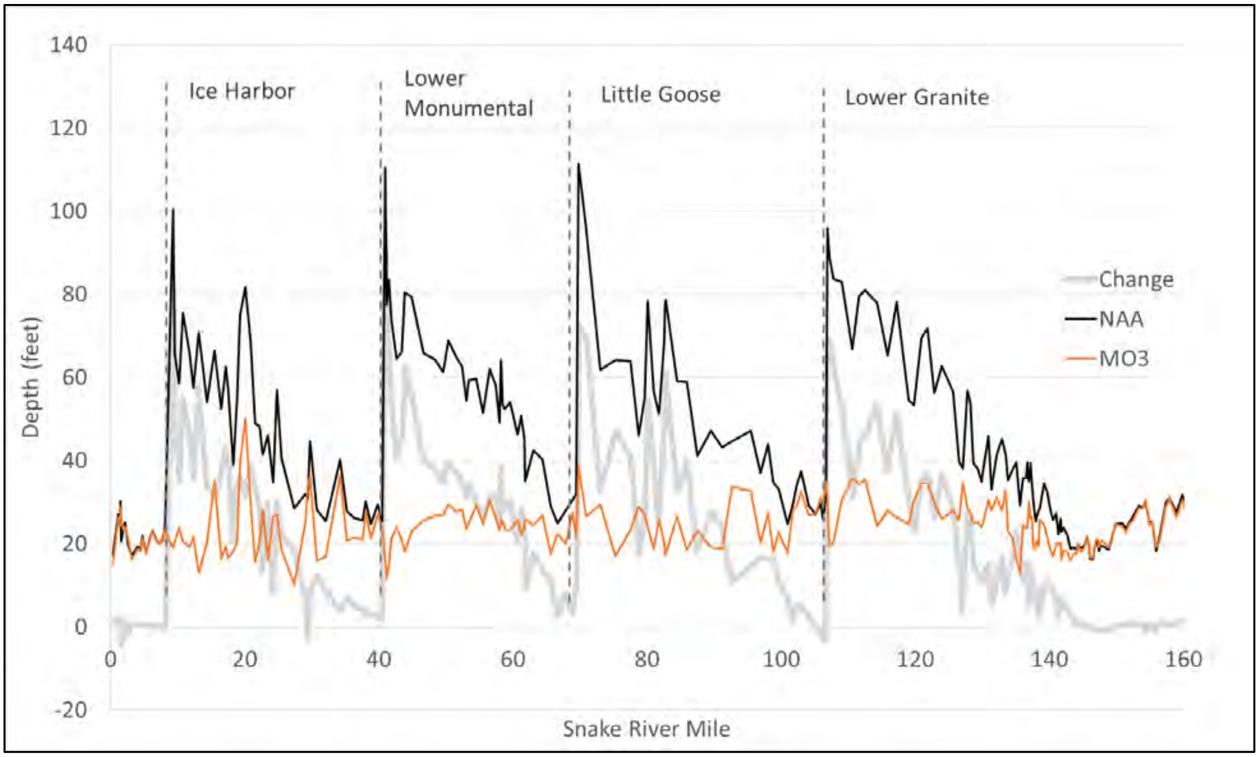

Figure 5-2. Changes in Maximum Depth during the Simulated 1974 Peak Flow Event, Similar to the 1 Percent Annual Exceedance Probability Discharge

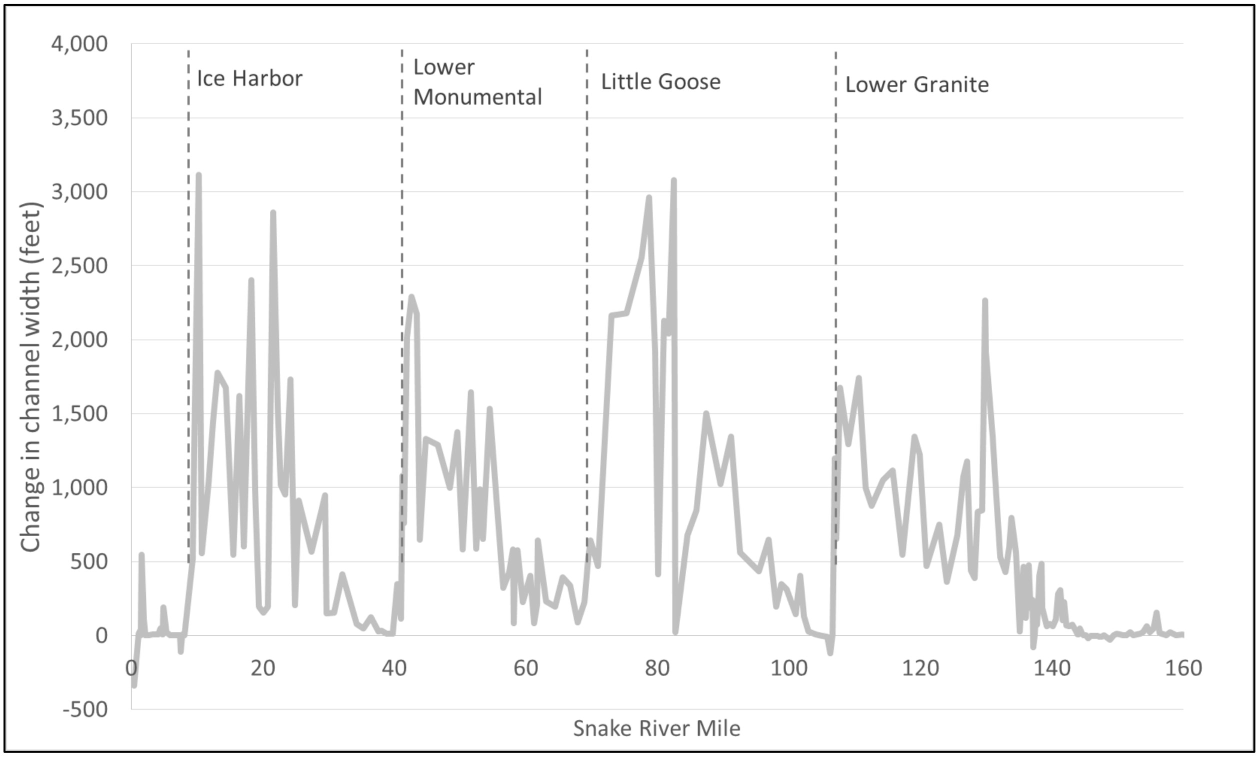

Figure 5-3. Changes in Channel Width during the Simulated 1974 Peak Flow Event, Similar to the 1 Percent Annual Exceedance Probability Discharge

Seasonal fluctuations in water level throughout the reach will be characteristic of the free-flowing reaches on the Snake and Clearwater Rivers above the zone of reservoir influence. This means typical seasonal elevation and depth range varies roughly by 10 to 15 feet, exceeding 20 feet during very large freshet peaks. (Note some locations may have larger or smaller fluctuations in water level, depending on local hydraulics.) This is in contrast to reservoir operations that typically vary less than 5 feet and have annual maximums at full pool during the winter and early spring months. Figure 5-4 shows the contrast in typical seasonal water levels from MO3 to the No Action Alternative at a non-specific location within the Lower Granite Reservoir. It also shows how the change in depth from MO3 to the No Action Alternative would vary considerably with changes in seasons and flows.

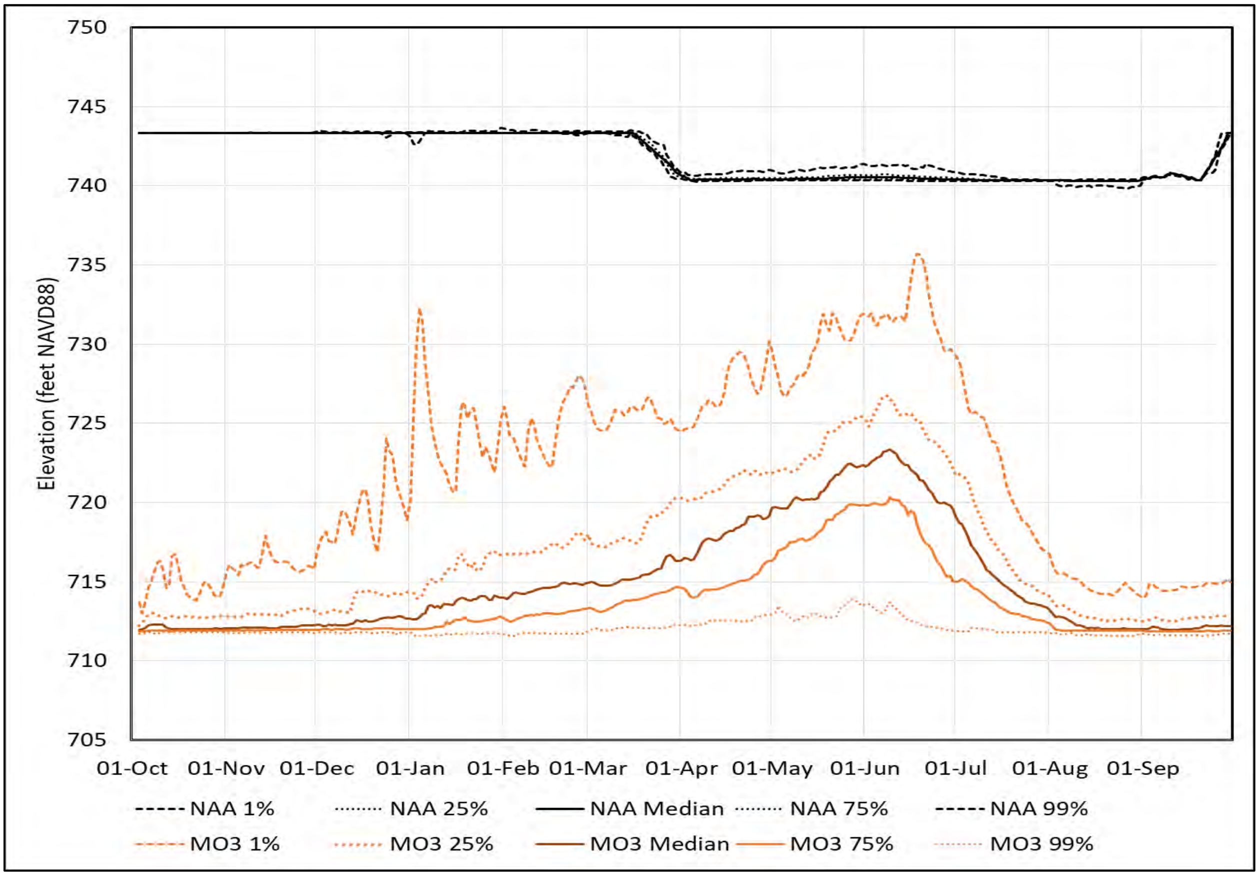

Figure 5-4. Comparison of Typical Water Level Fluctuations at a Non-Specific Location Within the Lower Granite Reservoir

Major changes in energy slope and velocity would also occur (Figure 5-5 and Figure 5-6). The slope of the energy grade for the No Action Alternative system is less than 0.00001 between each of the dams, with the exception of the upper end of each reach under higher flow conditions where the slope of the energy grade line can approach 0.0001. The velocity profile under the No Action Alternative follows a similar pattern to the energy grade, with velocities increasing with distance upstream from a project, and increasing with flow. The typical channel velocity under MO1 is less than 1 feet per second (ft/sec) for an average flow of 35 kcfs, but it can exceed 3 ft/sec at 100 kcfs at the upstream ends of a given reach between projects.

Under MO3, the slope of the energy grade line fluctuates but stays relatively constant over the length of the whole reach. Fluctuations from location to location are greater at lower flows, but the overall slope of the reach is 0.00054, which is roughly equivalent to the reach bed slope. The velocity also fluctuates between locations, typical of a riffle-pool river system, but stays relatively constant across the reach. The reach average velocity for 35 kcfs and 100 kcfs under MO3 is 5.1 ft/sec and 7.2 ft/sec, respectively, compared to 0.5 ft/sec and 1.5 ft/sec under the No Action Alternative.

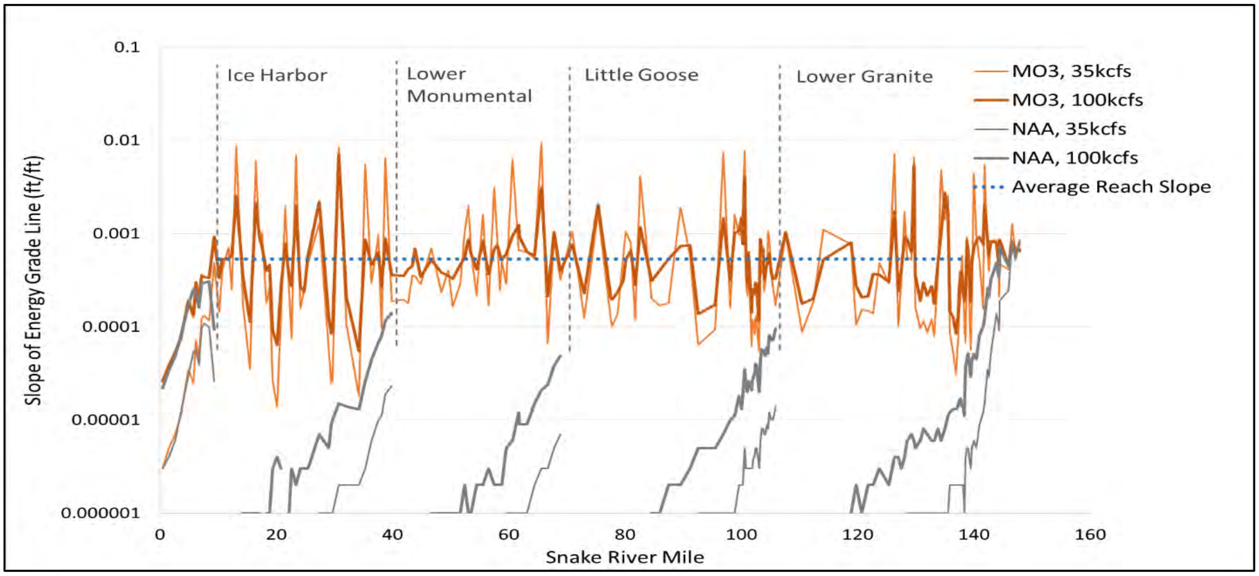

Figure 5-5. Comparison of Energy Grade Line Between Multiple Objective Alternative 3 and the No Action Alternative

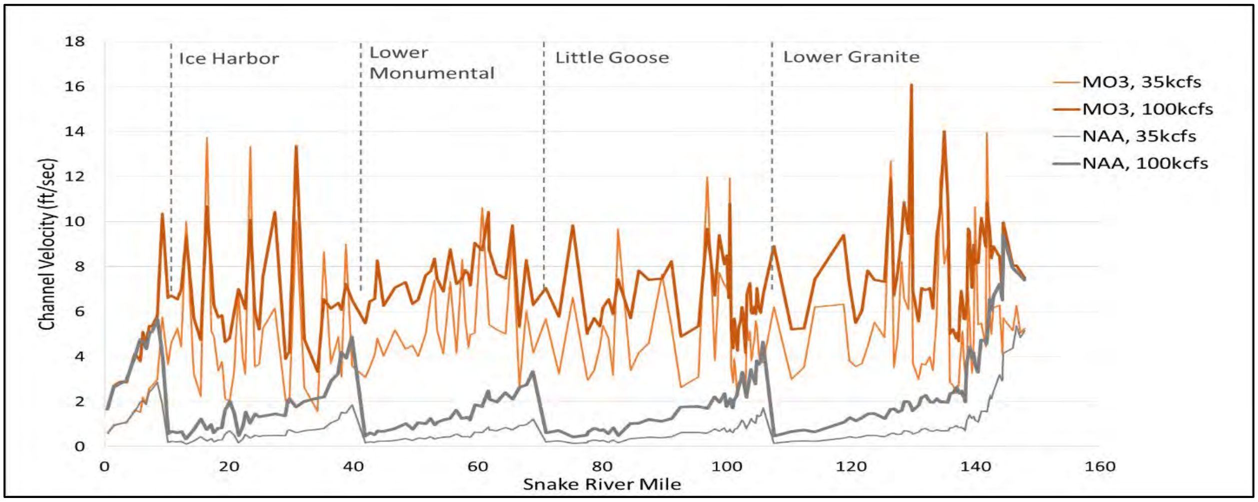

Figure 5-6. Comparison of Channel Velocity Under Multiple Objective Alternative 3 and the No Action Alternative

The upstream and downstream extents where these changes would occur are approximated using profile plots. Figure 5-7 and Figure 5-8 show the water surface profiles on the Snake and Clearwater Rivers from the Lower Granite Dam to the free-flowing portions of both rivers, showing where water surface profiles diverge from the No Action Alternative to MO3 upstream of the Snake-Clearwater River confluence, and Figure 5-9 shows the water surface profiles at the lower end of the lower Snake River reach.

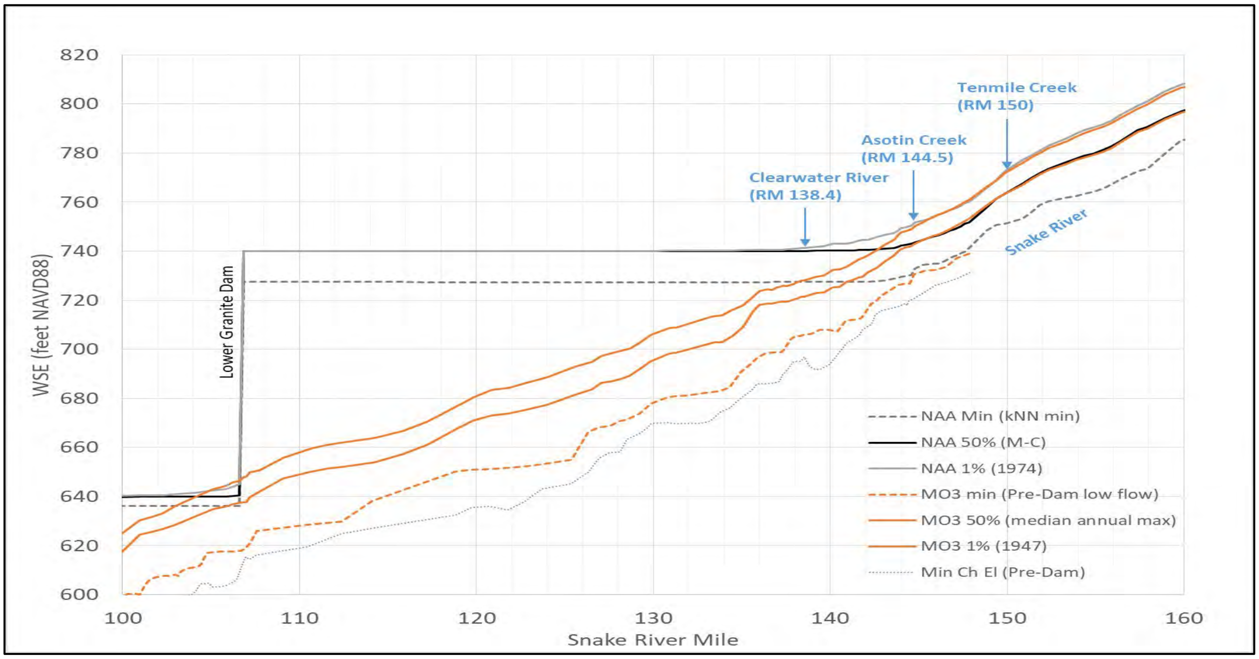

Figure 5-7. Water Surface Profiles at the Upper End of the Lower Granite Reservoir, near Lewiston, Idaho

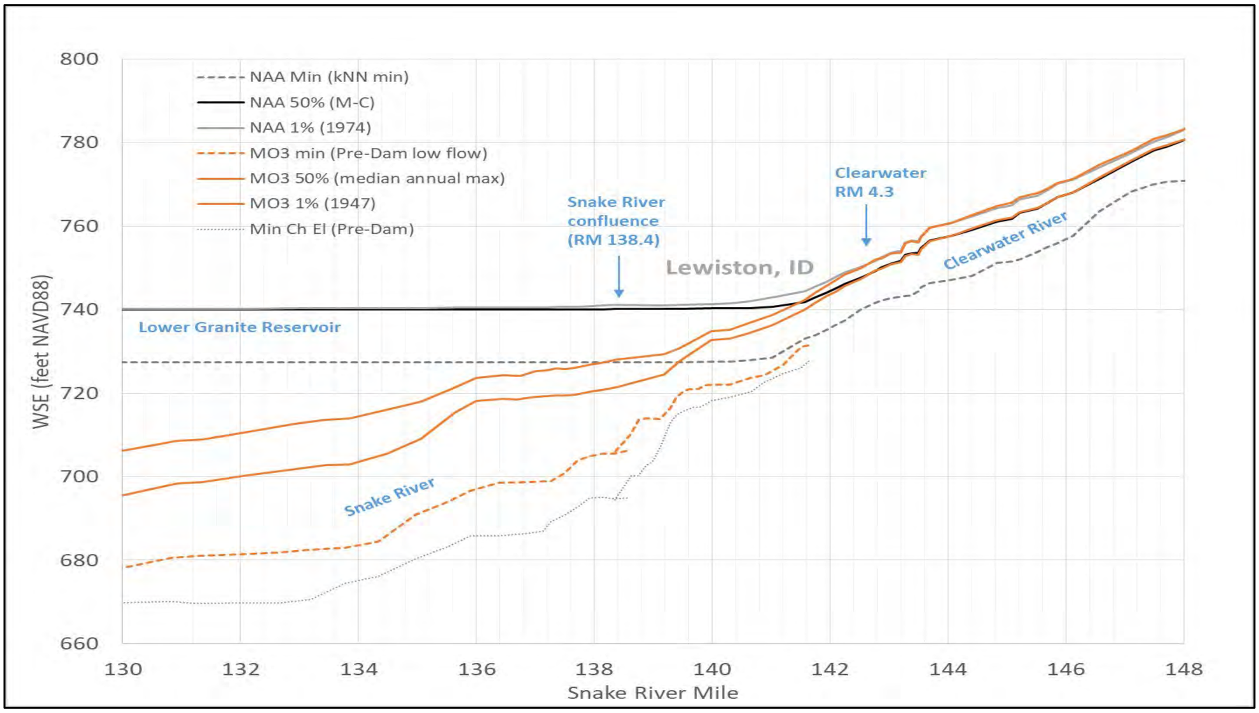

Figure 5-8. Water Surface Profiles at the Upper End of the Lower Granite Reservoir, near Lewiston, Idaho, Showing the Clearwater River Above the Snake-Clearwater Confluence

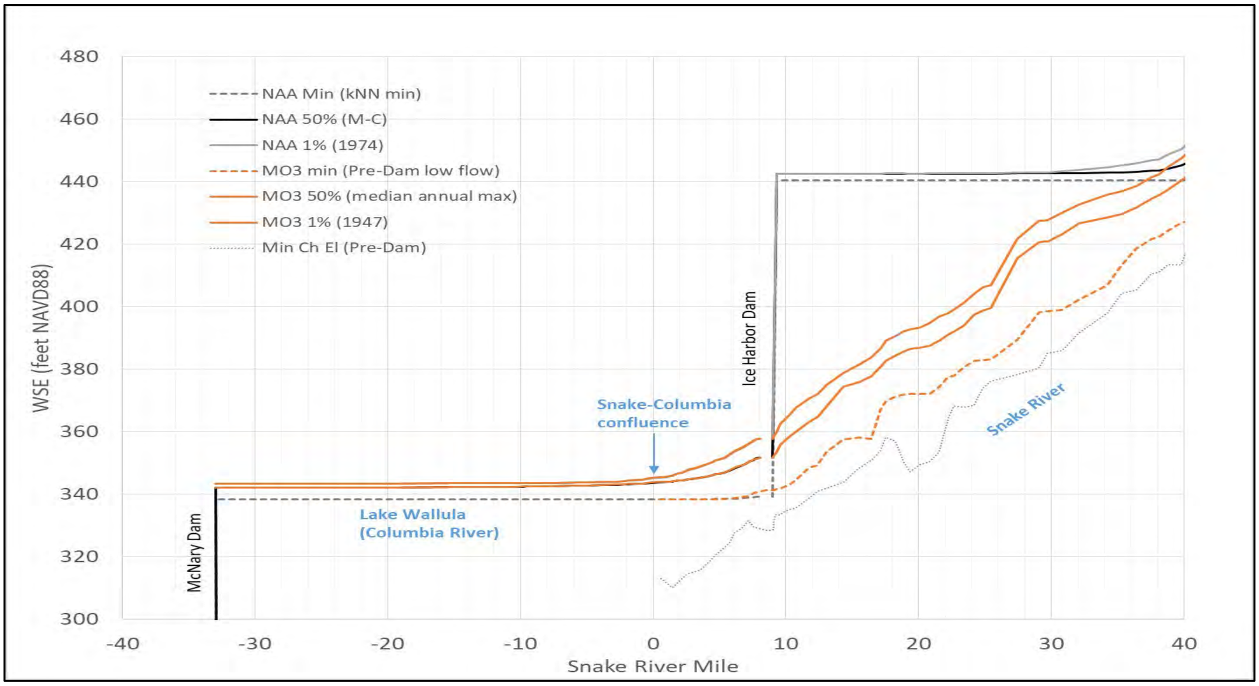

Figure 5-9. Water Surface Profiles at the Lower End of the Snake River, Including the Existing Ice Harbor Reservoir to McNary Dam

Where the Snake River enters Lake Wallula (the reservoir above McNary Dam) near the confluence with the Columbia River, a new head-of-reservoir area would develop at the location of what is currently the Ice Harbor Dam, at RM 9. Water levels on the Snake River immediately below the Ice Harbor Dam would still be influenced by operations at McNary Dam and would have similar water levels as those under the No Action Alternative for similar hydrologic conditions. The exact changes in water level in the vicinity of Ice Harbor, particularly during low-flow conditions, are uncertain due to uncertainties related to sediment deposition and hydraulics at the breach site at Ice Harbor.

Under the No Action Alternative, the Lower Granite Reservoir can affect water levels upstream on the Snake River more than 10 miles past the Clearwater River confluence and more than 4 miles up the Clearwater River. Changes in water level could be expected that far upstream. Lewiston, Idaho, is located in the vicinity of the confluence and is adjacent to the Snake and Clearwater reaches where changes in water levels are expected under the **Breach Snake Embankments** measure (Figure 5-10).

Due to the minor changes in pool operations under the No Action Alternative for each of the dams for MOP and the slight changes in flows that accompany drafting and filling periods, the model results show a 2 percent decrease in March flows and a 6 percent increase in September flows passing through the Lower Snake River under MO3. The larger impact to flows in September is related to the lower flows typical in this period. Considering that September often is the month of the year with the lowest flows, increases in low flows can be as much as 30 percent during some years.

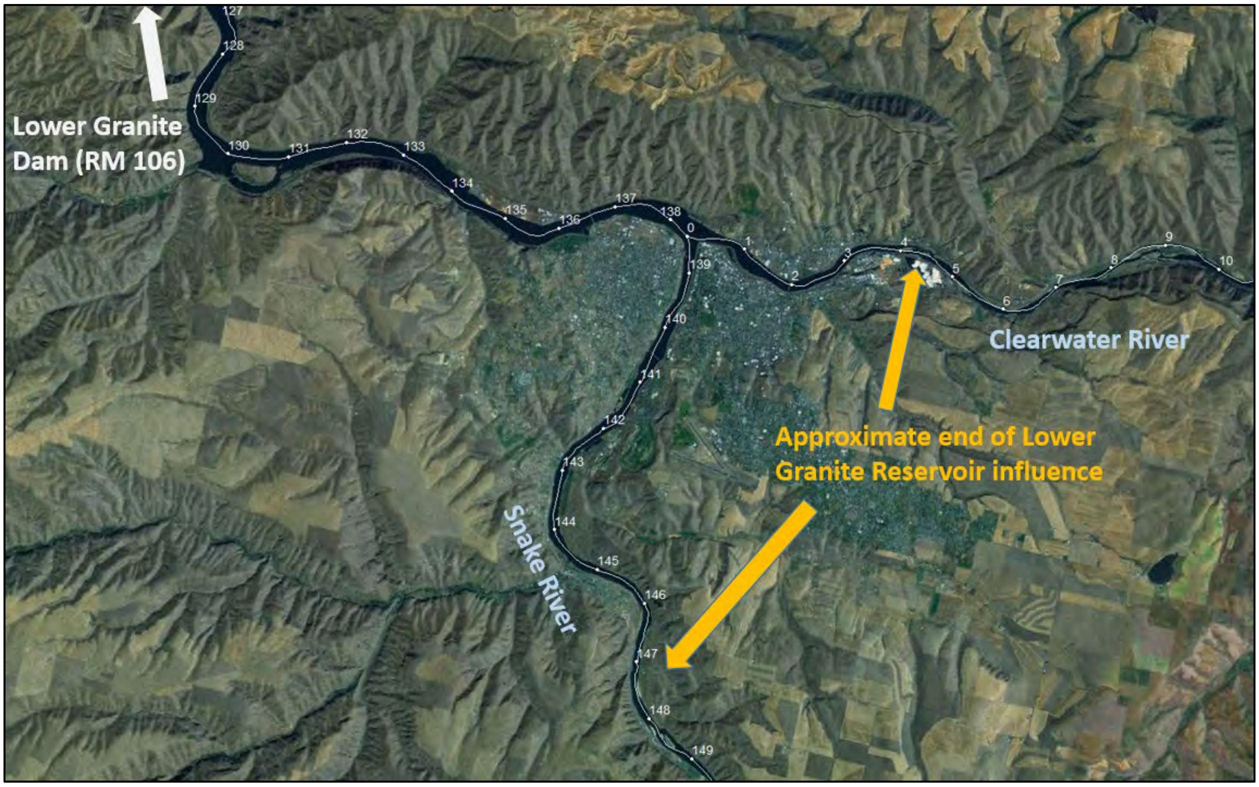

Figure 5-10. Approximate Upper Extents of Lower Granite Reservoir Influence Under No Action Alternative and Area of Hydraulic Changes Under Multiple Objective Alternative 3

It is also noteworthy that there would be additional changes in hydrology not simulated in the ResSim model. These are related to hydrologic routing through the reach, which can be thought of as travel time and attenuation of a hydrograph through the basin.

5.4.6 Clearwater and Lower Snake River Annual and Seasonal Peaks

Of all four alternatives, only MO2 results in changes to annual peak conditions on the Clearwater and lower Snake Rivers. Under MO2, the peak annual releases from Dworshak Dam of 25 kcfs occurs in 40 percent of years, as opposed to 30 percent under the No Action Alternative. This release occurs more frequently in the spring and contributes to higher freshet peaks downstream on the Clearwater and Snake Rivers, evident in the 4.5-kcfs increase (7 percent) in the 50 percent annual peak discharge at Spalding. Larger increases, 7 to 12 kcfs (11 to 14 percent), occur for annual peaks between AEP 50 and 3 percent. Changes for larger peaks (<2 percent AEP) show negligible increase (<1 percent). Any increase shown for very large peaks (<1 percent AEP) should be disregarded as the model does not adequately capture local flood protection operations under the revised MO2 operation set.[8]

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[8] It should be noted that the higher discharges from Dworshak in wetter years for spring months shown in the ResSim model results do not accurately reflect changes expected from the measure. The intent of the measures is

5.5 REGION D – LOWER COLUMBIA RIVER

5.5.1 Lower Columbia Projects Operational Changes

The **Predator Disruption Operations** measure includes modified pool elevations in April and May to disrupt avian predation upstream of the John Day Dam. This measure is only applied in MO1.

The **John Day Full Pool** measure allows the John Day Project to operate within the full reservoir operating range above MIP year-round except as needed for FRM. The measure aims to increase flexibility to shape flows and power generation within-day. The measures allow operating flexibility between elevations 262.5 feet to 266.5 feet NGVD29. Because ResSim does not model day-to-day operations in response to power market needs, the measure is represented as slightly higher pool levels from late March through early June. The No Action Alternative is operating between 262.5 and 264 feet NGVD29 from April 10 through the end of September (MIP plus 1.5 feet). This measure is added to the ResSim model only in MO3. As run-of-the river projects operate within their entire seasonal operating band, their elevation should always be considered to have an equal likelihood of being anywhere in that operating band outside of FRM operations.

The **Drawdown to MOP** measure was incorporated into the ResSim model for the assigned MO (MO4). The measure aims to operate the four lower Columbia River dams (McNary, John Day, The Dalles, and Bonneville) within a more restrictive 1.5-feet operating band above their MOP for all the projects from March 25 to August 15. This is to reduce particle travel time through these reservoirs. This operation would take the John Day Reservoir below its MIP. As run-of-river projects operate within their entire seasonal operating band, their elevation should always be considered to have an equal likelihood of being anywhere in that operating band outside of FRM operations.

The **Winter System FRM Space** and **Lake Roosevelt Additional Water Supply** measures do not include operational changes at the lower Columbia River projects; however, their effects on Grand Coulee outflow carry through the lower Columbia River. Similarly, the **McNary Flow Target** does not actually impact operations at McNary Dam, but uses up to 2.0 Maf of upstream storage to maintain 200 to 220 kcfs outflow from McNary Dam from May through July in years with a below average (87.5 Maf) April-issued April–August water supply forecast at The Dalles.

The measures that directly and indirectly affect the lower Columbia River are listed in Table 5-6, showing which of the multiple objective alternatives they are included in. Note, most of the other operational measures have some effects at downstream locations; however, they are relatively minor compared to those listed in Table 9.

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to move some water from the spring to the winter, and this could be accomplished without increasing local flood risk. It likely would decrease local flood risk as more space could potentially be available in the spring.

Table 5-6. Operational Measures Directly and Indirectly Affecting Lower Columbia River Dams

Short Measure Description	Short Name	MO1	MO2	MO3	MO4
Increase forebay operating range flexibility at the lower Snake River and John Day projects for hydropower generation flexibility	Increased Forebay Range Flexibility	X	–	–	–
Manipulate lower Columbia River reservoir elevations to disrupt juvenile salmonid predator reproduction	Predator Disruption Operations	X	–	–	–
At John Day, allow project to operate up to full pool except as needed for flood risk management	John Day Full Pool	–	X	X	–
Reservoir drawdown to minimum operating pool to reduce outmigration travel time	Drawdown to MOP	–	–	–	X
Develop draft requirements/assessment approach to protect against rain-induced flooding	Winter System FRM Space	X	X	–	X
Increase volume of water pumped from Lake Roosevelt during annual irrigation season	Lake Roosevelt Additional Water Supply	X	–	X	X
Strive to hold minimum 220 kcfs spring flow/200 kcfs summer flow at McNary using upstream storage	McNary Flow Target	–	–	–	X

5.5.2 Lower Columbia Projects Elevations

The **Drawdown to MOP** measure under MO4 would result in lower water levels at all four of the lower Columbia River projects from late March through mid-August. The decrease would depend on how large the normal full operating pool is at each particular project.

There are no other changes to operations at McNary with any other alternative. At McNary Dam, there is a modeling artifact of modeling the **McNary Flow Target** measure that can sometimes draft the pool deeper, but this would not happen under this measure if implemented.

Under MO1, there are two measures that directly target John Day Dam. The **Predator Disruption Operations** measure results in pool elevation targets 1 foot higher from April 1 to May 31, resulting in higher pool levels from late March through early June. The **Increased Forebay Range Flexibility** measure is not modeled in ResSim. This measure aims to increase forebay operating range for John Day Dam during the period where the project is operating to minimum irrigation and operating pools (MIP and MOP) at those projects. The expected actual changes from this measure would be smaller operating range during the spring and summer.

There are no rule changes at John Day Dam shown in the ResSim results under MO2. The **John Day Full Pool** measure was designed to allow the project to operate within its full range; however, this flexibility for hydropower was not able to be represented properly by the ResSim model and so operations were left similar to the No Action Alternative. The expected actual changes from this measure would be a wider range of elevation throughout the year. As run-of-river projects operate within their entire seasonal operating band, their elevation should always be considered to have an equal likelihood of being anywhere in that operating band outside of FRM operations. MO3 also includes the **John Day Full Pool** measure.

There are no rule changes at The Dalles or Bonneville Dams under MO1, MO2, and MO3. The results do show sporadic changes in the elevation-frequency on given dates and the annualized frequency in which the Bonneville Dam forebay is called to dip beneath the standard pool of 76 feet NGVD29. The winter fluctuations represent changes that could happen during winter FRM; however, the spring and summer drafts are due to ResSim trying to meet the minimum flow rule for juvenile fish (this rule is present in the No Action Alternative and was not changed for the MOs) that likely could not have been achieved with water passing through the project. These drafts can be ignored. The operating range for the Bonneville Dam No Action Alternative and MO1, MO2, and MO3 is the same, and there are no measures under these MOs that are expected to change that operating range on an hourly, daily, monthly, or annual basis. It should also be noted that ResSim does not model within the daily elevation changes that do happen in real-time operations. As run-of-river projects operate within their entire seasonal operating band, their elevation should always be considered to have an equal likelihood of being anywhere in that operating band outside of FRM operations.

5.5.3 Lower Columbia River Flow and Water Levels

In the Bonneville, The Dalles, John Day and McNary Reservoirs, water level changes are largely influenced by changes in operations at the dams. Some changes in water levels can be related to changes in flow, but these are typically small in comparison and only evident in the upstream ends of the reaches. Changes in the timing of flows through the lower Columbia River can also result in water level differences; however, most of these sporadic changes in water levels are not indicative of an expected change occurring under a certain MO but rather are anomalies of the modeling process, particularly the modeling of FRM in these lower Columbia River projects. It should also be noted that the ResSim model does not model the within-daily elevation changes that happen in real-time operations, so extremes of pool levels cannot be simulated with this model. As run-of-river projects operate within their entire seasonal operating band, their elevation should always be considered to have an equal likelihood of being anywhere in that operating band outside of FRM operations. In general, the exact change that is indicated in some extreme high- or low-flow conditions should not be focused upon, as these extremes are strongly influenced by specific events within the M-C simulations and are not representative of the general trends of change expected for a given measure.

The flow-change patterns seen coming into lower Columbia River dams can be traced through the lower Columbia River due to the minimum operational changes in the lower Columbia River projects. Below Bonneville Dam, changes in flow are the only cause for changes in water levels. Below Bonneville Dam, changes in water levels are influenced solely by changes in outflows from Bonneville. Changes in Bonneville outflows are an amalgamation of all of the changes from upstream projects throughout the Columbia River Basin.

Some general conclusions can be made about all of the MOs. Changes are typically within a couple percent of those under the No Action Alternative condition; however, some larger changes can occur during certain seasons and/or flow conditions with each of the specific alternatives. Maximum changes in water levels are less than 1.0 foot at RM 143 and lower than 0.5 foot at/below RM 105 near Portland/Vancouver. Typical changes in monthly water levels are less than a couple tenths of a foot, and none of the MOs result in changes in water levels exceeding 0.1 foot at/below RM 42.

While several of the previously described basins and reaches have several changes in common, the pattern of flow changes seen the lower Columbia River below Bonneville Dam is fairly unique for each of the MOs. For this reason, the changes in flow and water levels for each MO are described separately. One exception is the general summary in the following paragraph, and the description of changes to AEP conditions at the end of this section. Discussion with each MO is focused on Reach 1 flow changes and water levels, with emphasis on changes greater than 5 percent.

5.5.3.1 Multiple Objective Alternative 1

Under MO1, changes in flow can be summarized as increases in typical winter discharge and decreases in the spring through fall discharge. MO1 does not result in less than or equal to 0.1 foot at and below RM 66.

The percent increase in December discharge is greatest under typical to lower water year conditions, and the increase in January is greatest in very low water years. Water levels in December can be as much as 0.5 foot higher at RM 143 but are within 1 foot at and below RM 105. Increases in December flow are largely attributed to the **Winter System FRM Space** measure at Grand Coulee.

Average discharge during April and May are consistently 2 to 3 percent lower and can be as much as 5 percent lower in May during very low water years. Water levels at RM 143 are typically 0.1 to 0.3 foot lower and can be a half-foot lower during low water years in May. At RM 105, these changes in water levels are 0.1 to 0.2 foot. The largest average monthly decrease of any of the MOs occurs during very high water years in April (-12 kcfs). Lower flows in the spring through summer are largely attributed to the **Lake Roosevelt Additional Water Supply** measure at Grand Coulee.

The largest percent reduction in flow of MO1 is in August where the average monthly flow is consistently 5 to 6 percent lower (7 to 8 kcfs). This can result in water level decreases of 0.4 to

0.7 foot at RM 143, 0.2 to 0.3 foot at RM 105, and within 0.1 foot at and below RM 60. These decreases result from both the **Lake Roosevelt Additional Water Supply** measure and the **Modified Dworshak Summer Draft** measure.

5.5.3.2 Multiple Objective Alternative 2

Under MO2, there are consistent increases in November through January and September, and decreases in all other months.

The largest changes occur in December when typical and higher years have an average monthly inflow increase of about 7 percent (11 kcfs) and lower years have an increase of 13 percent (16.4 kcfs). Increases in December water levels range from 0.5 to 0.9 foot at RM 143, 0.3 to 0.5 foot at RM 105, and 0.2 foot or less at and below RM 66.

November and January increases in flow are generally much smaller than December; however, changes in average monthly flow in lower to very low water years in January can exceed 5 percent. This can result in water levels 0.5 foot higher at lower flow conditions at RM 143. Increases in flow from November through January are largely attributed to the **Slightly Deeper Draft for Hydropower** and **Winter System FRM Space** measures.

Decrease flow in March through August is generally associated with the **Slightly Deeper Draft for Hydropower** measure. The **Winter System FRM Space** in combination with the **Planned Draft Rate at Grand Coulee** (reduces flows by 0.6 kcfs) measures are also partially responsible for the larger decreases in March (6 to 7 kcfs, 3 to 4 percent). These lower flows in March result water level 0.3 to 0.4 foot lower at RM 143.

Average September flow is a couple kcfs higher under typical conditions, but it can exceed 4 percent (3 kcfs) in very low water years. This increase in flow can translate to increase in lower water levels of 0.2 to 0.3 foot at RM 143, and negligible change at/below RM 105. This change is also attributed largely to the **Slightly Deeper Draft for Hydropower** measure.

5.5.3.3 Multiple Objective Alternative 3

Under MO3, there are increases in November and December, decreases in January outflow in most years, and consistent decreases March through September. Increases in flow in November and December are typically less than 3 percent but can be as high as 7 percent in December in lower water years. This translates to water level increases up to 0.4 foot at RM 143, and less than 0.2 foot at and below RM 105. These increases in flow can be attributed to the **Slightly Deeper Draft for Hydropower** measure on top of the **December Libby Target Elevation** measure at Libby Dam.

Average monthly flows are generally lower in January and as much as 5 percent in higher flow years. This can translate to water levels about 0.4 foot lower under higher normal water conditions at RM 143, and less than 0.2 foot lower at and below RM 105. These changes in

January flows are also largely related to the same measures at Libby affecting November and December.

Decreases in flow related to the **Lake Roosevelt Additional Water Supply** measure at Grand Coulee can be seen from March through September. These changes in flow are generally within 1 to 3 percent of No Action Alternative conditions but can be up to 5 percent lower in low-flow years,[9] which can translate to water levels as much as a half-foot lower at RM 143 under low-flow conditions. Otherwise, decreases from April through August are 0.2 to 0.4 foot lower at RM 143, and decreases in March and September water levels are less than 0.2 feet. Farther downriver at RM 105, May water levels are typically 0.2 to 0.3 foot lower, and typically less than a tenth of a foot lower in other months.

5.5.3.4 Multiple Objective Alternative 4

Changes to lower Columbia River flow under MO4 include variable changes in winter and early spring and decreased flows under most conditions from April through November, but with higher flow during lower flow years in May through June. The largest changes in flow generally occur during lower to very low flow years, and during the low-flow months of August through October.

March flow is increased slightly due to the drafting to slightly lower pools at the four lower Columbia River and four lower Snake River dams under the **Drawdown to MOP** measure. The March increase in flows shows up as a short spike in outflow in the summary hydrographs in these projects. Such a spike would likely not occur in real operations, but more water being released slightly earlier would be an effect of this operational change. A similar dip in the summary outflow hydrographs can be seen in August.

With the exception of the slight increase in March, flow through the lower Columbia River is typically lower from February through November as a result of the **Winter System FRM Space** measure, **Update System FRM Calculation** Measure (which determines the deepest draft point at Grand Coulee), and the **Lake Roosevelt Additional Water Supply** measure. The **McNary Flow Target** measure also contributes to lower flow in August, September and October in lower flow years as the upstream projects released their water early in the season. As they return to normal operating elevations, the effects of the **McNary Flow Target** measure can continue into the next water year, sometimes even lowering the peak discharges in the spring of the following year as projects try and recover the lost storage. The largest percent change in flows occurs in typical to very low water years in September where decreases in average monthly flow are 7 to 13 percent. That decrease in September can translate to decreases in water levels from 0.5 to 0.9 foot at lower water conditions at RM 143, 0.1 to 0.3 foot at RM 105, and 0.1 foot or less at RM 66. Decreases in water levels throughout the spring and summer in typical to

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[9] The decrease in flow in the Columbia River later in the year (e.g., April through July, particularly in lower flow years) can also be partially attributed to measures farther upstream at Libby.

higher-flow years are typically within 0.3 foot at RM 143, 0.2 foot at RM 105, and 0.1 foot at RM 66.

In the drier half of forecasted years at The Dalles, the **McNary Flow Target** measure is in effect which calls for additional upstream water to supplement flows in the lower Columbia River in May through July. The median of the drier half of years, the 75th percentile exceedance, has the average monthly outflows for May, June, and July increase by 2.6, 7.7, and 6.4 kcfs respectively (1 percent, 3 percent, and 4 percent). The driest years in May have a 21.4 kcfs increase (11 percent). According to the monthly flow-duration curves, this increase in flow occurs at release below 240 kcfs in May and below about 210 kcfs in June. These translate to increases in water levels from about 0.4 to over 1 foot at RM 143 and increases exceeding 0.5 foot at RM 105.

5.5.4 Lower Columbia River Annual and Seasonal Peaks

In the lower Columbia River, there are only a few notable changes in AEP. The **Winter System FRM Space** (not in MO3), **Update System FRM Calculation**, and **Lake Roosevelt Additional Water Supply** measures at Grand Coulee Dam (MO1, MO3, and MO4), combined with measures affecting Libby and Hungry Horse, result in decreases in spring and annual peak outflows at all four of the lower Columbia River projects, with decreases less than 2 percent for larger peak years and up to 7 percent lower for some lower peak years. These changes translate to a decrease of up to a couple tenths of a foot in spring/peak annual water levels through the lower Columbia River reaches down as far as Vancouver. Decreases in spring peak water levels farther downstream in are negligible.

The **McNary Flow Target** measure (MO4) results in increases of 20 to 30 kcfs (10 to 14 percent) in spring peaks in the lowest 4 percent of years (>96 percent AEP). In these very low freshet years, the peak spring water levels could be more than a foot higher in the Columbia River below Bonneville Dam.

The **Slightly Deeper Draft for Hydropower** measure (MO2) as simulated at Grand Coulee and Dworshak results in a slight increase (1 to 2 percent) in spring and annual peak outflows from each of the projects for larger flow years (<5 percent).[10]

Under MO4, the **Drawdown to MOP** measure would affect annual peaks in the lower Columbia River reaches above Bonneville Dam where annual peaks typically occur during the spring freshet during higher flow conditions coincident with the upper range of the operating pool. These reaches would likely show spring peaks lowered by the decreases in the operating range for most years. This measure would likely not have an effect on the larger freshet years that may result in flooding damage.

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[10] As noted previously, this increase is exaggerated and would likely be smaller, if present at all.

MO4 results show increases in winter peak outflows during lower flow years (>50 percent AEP) from John Day, The Dalles, and Bonneville Dams. This is due to draft of Grand Coulee Dam's **Winter System FRM Space** measure.

The **Winter System FRM Space** measure aims to increase FRM resiliency during certain winter storm events by creating more storage space upstream, allowing for lower Bonneville Dam releases during some locally driven winter storms in Reach 1.[11] Under the alternatives that include the measure (MO1, MO2, and MO4), winter and annual peaks in most of Reach 1 are typically 1 to 4 percent lower for larger years (<15 percent AEP). Winter peak releases through the lower Columbia River projects including Bonneville Dam are actually slightly higher due to more aggressive drafting upstream, but those higher releases are not coincident with the winter peaks in Reach 1; and because winter peaks are typically smaller than freshet peaks in the mainstem Columbia River as far down as Bonneville Dam outflow, increases in winter AEP do not necessarily translate to increases in annual AEP. Under these alternatives, annual AEP along the mainstem Columbia River is slightly lower due to decreases in releases in April through July originating from Grand Coulee Dam. Under MO3, which does not include the **Winter System FRM Space** measure, there are no changes to winter and annual peak discharges for larger flow years.

The reduction in winter AEP flows under MO1, MO2, and MO4 translates to decreases in AEP water levels as large as 0.6 and 0.7 foot in the Portland/Vancouver vicinity (Vancouver gage at RM 105.5) for the 2 and 5 percent AEP elevations, respectively. Similar decreases can be seen from about RM 120 down to RM 80, after which the changes are smaller. There are smaller changes for other AEPs and at other locations throughout the reach. Changes in peak water levels on tributaries of the Columbia (e.g., Cowlitz and Lewis Rivers) should change very little, if at all. See Table 5-7 for changes in AEP elevations along the mainstem Columbia River for each of the MOs at AEPs 50 through 1 percent.

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[11] Discussed in greater detail in the FRM Appendix, peak annual water levels in the Portland/Vancouver area are influenced by winter rain events, which are driven by relatively short-duration storms from the Willamette River and other local tributaries. This is different than almost anywhere else in the study area, where annual peak water levels almost always occur with the spring freshet. This is evident in plots of the winter and annual peak frequency curves for The Dalles Dam outflow (similar to Bonneville Dam) and the Columbia River at the Vancouver gage.

Table 5-7. Change in Annual Exceedance Probability Stages at Various Locations Along the Mainstem Columbia River below Bonneville

	AEP	50%	40%	30%	20%	15%	10%	5%	2%	1%
MO1	RM 143.38	-0.1	-0.1	-0.1	-0.2	-0.2	0.0	-0.2	-0.1	0.2
	RM 119	-0.1	-0.3	-0.4	-0.1	-0.1	-0.1	-0.8	0.0	0.1
	RM 105 (Vancouver, WA)	0.0	-0.1	-0.1	-0.2	-0.6	-0.3	-0.7	-0.6	-0.3
	RM 94	0.0	-0.2	-0.1	-0.3	-0.5	-0.2	-0.7	-0.7	-0.3
	RM 86 (St. Helens, OR)	-0.1	-0.1	-0.2	-0.3	-0.3	-0.1	-0.6	-0.7	-0.3
	RM 66 (Longview, WA)	-0.1	0.0	-0.1	-0.1	-0.1	-0.3	-0.6	0.0	-0.1
	RM 42 (Puget Island, WA)	0.0	-0.1	0.0	-0.1	-0.1	0.0	-0.1	0.0	0.0
	RM 30	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO2	RM 143.38	-0.1	0.0	-0.1	-0.1	-0.2	0.1	0.4	-0.1	0.6
	RM 119	-0.1	-0.2	-0.3	0.0	-0.2	0.0	-1.0	0.0	0.1
	RM 105 (Vancouver, WA)	0.0	-0.2	-0.1	-0.3	-0.5	-0.3	-0.6	-0.6	-0.3
	RM 94	0.0	-0.1	-0.1	-0.4	-0.3	-0.3	-0.7	-0.7	-0.3
	RM 86 (St. Helens, OR)	-0.1	-0.1	-0.2	-0.3	-0.1	-0.2	-0.7	-0.7	-0.3
	RM 66 (Longview, WA)	-0.1	0.0	-0.1	-0.1	0.0	-0.2	-0.5	0.0	-0.1
	RM 42 (Puget Island, WA)	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	-0.1
	RM 30	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO3	RM 143.38	-0.1	-0.1	-0.1	-0.2	-0.1	0.0	0.0	0.0	0.1
	RM 119	-0.2	-0.2	-0.2	-0.1	0.0	0.0	-0.1	0.0	-0.1
	RM 105 (Vancouver, WA)	-0.1	-0.2	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
	RM 94	-0.1	-0.1	-0.1	-0.2	0.0	0.0	0.0	0.0	0.1
	RM 86 (St. Helens, OR)	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.1
	RM 66 (Longview, WA)	0.0	0.0	-0.1	0.0	0.1	0.1	0.0	0.0	0.0
	RM 42 (Puget Island, WA)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RM 30	-0.1	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0
MO4	RM 143.38	-0.1	-0.1	-0.2	-0.4	-0.3	-0.1	-0.1	-0.1	0.1
	RM 119	0.0	-0.3	-0.4	-0.1	-0.2	-0.3	-0.5	0.0	0.1
	RM 105 (Vancouver, WA)	0.0	-0.2	-0.2	-0.2	-0.5	-0.3	-0.7	-0.3	-0.3
	RM 94	-0.1	-0.2	-0.2	-0.3	-0.7	-0.2	-0.7	-0.3	-0.3
	RM 86 (St. Helens, OR)	-0.1	-0.2	-0.2	-0.3	-0.5	-0.1	-0.7	-0.3	-0.3
	RM 66 (Longview, WA)	-0.1	-0.1	-0.2	0.0	0.0	-0.3	-0.5	0.0	-0.1
	RM 42 (Puget Island, WA)	-0.1	-0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
	RM 30	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5.6 SUMMARY PLOTS AND TABLES

5.6.1 Region A – Kootenai, Flathead, and Pend Oreille Basins

5.6.1.1 Water Year Plots, Elevation

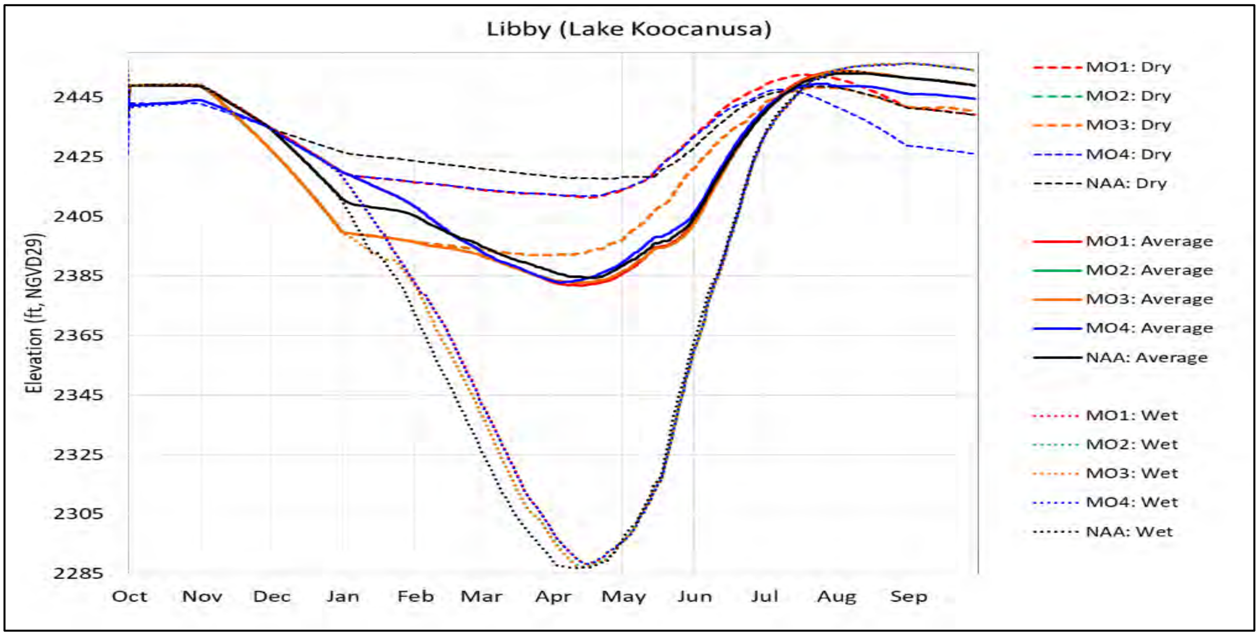


Figure 5-11. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Libby Reservoir (Lake Koocanusa)

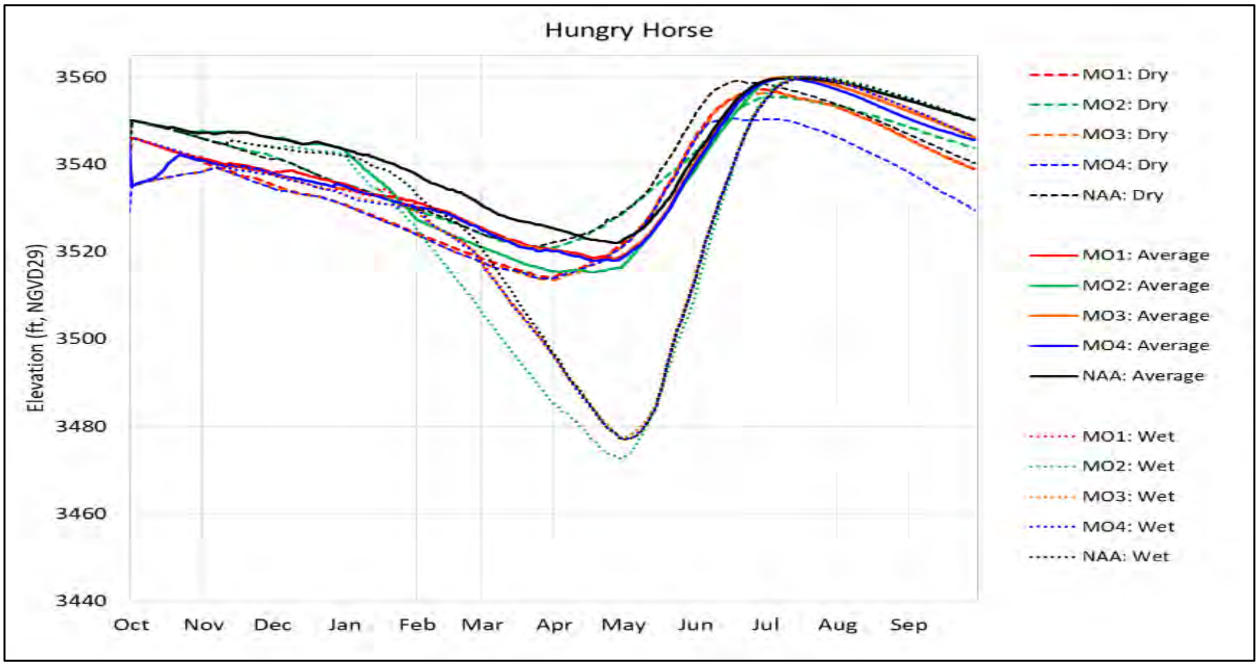


Figure 5-12. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Hungry Horse Reservoir

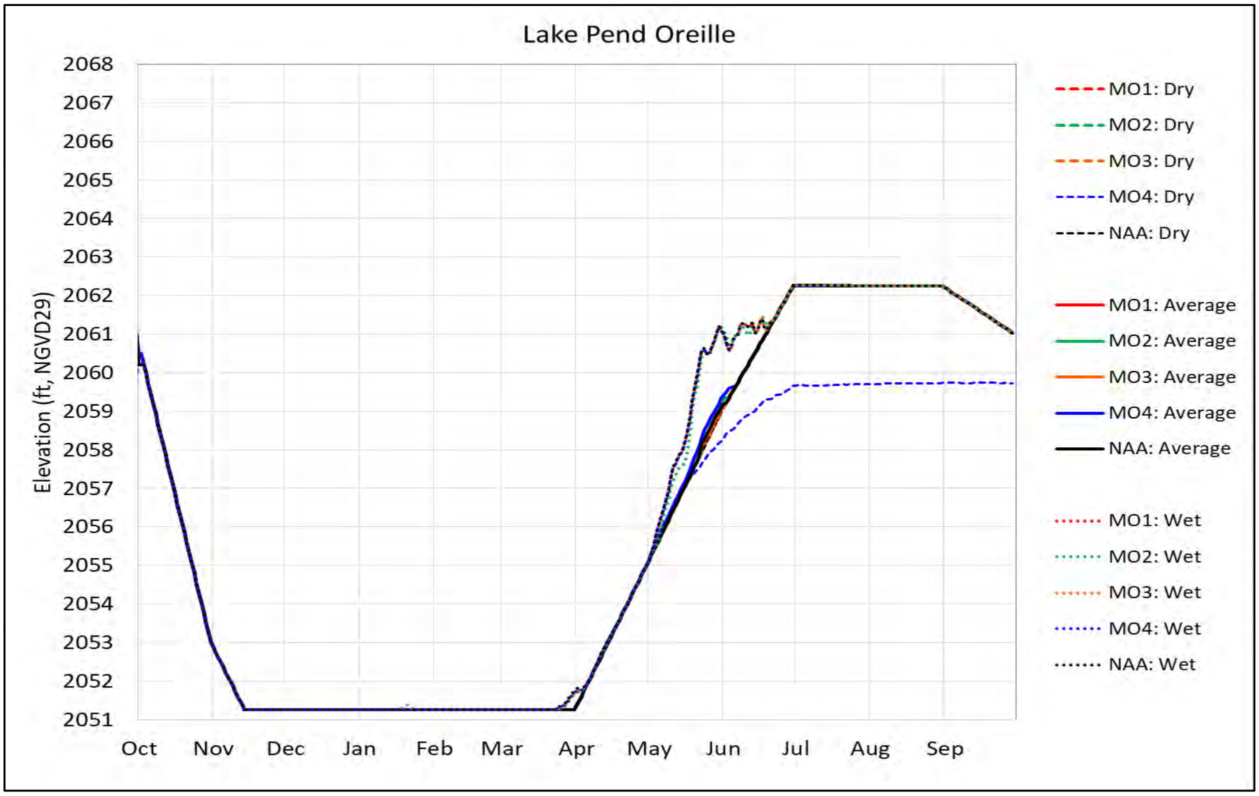
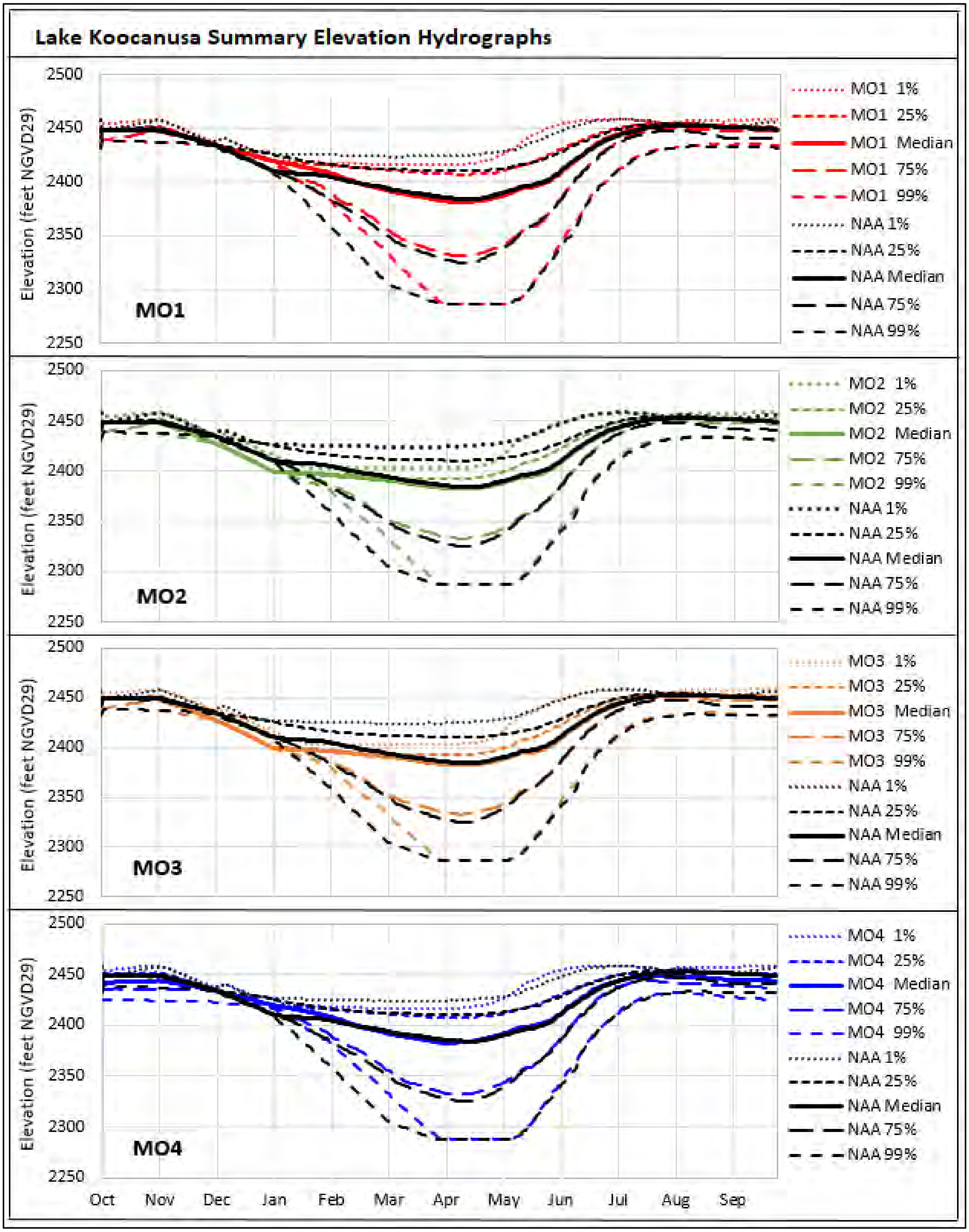


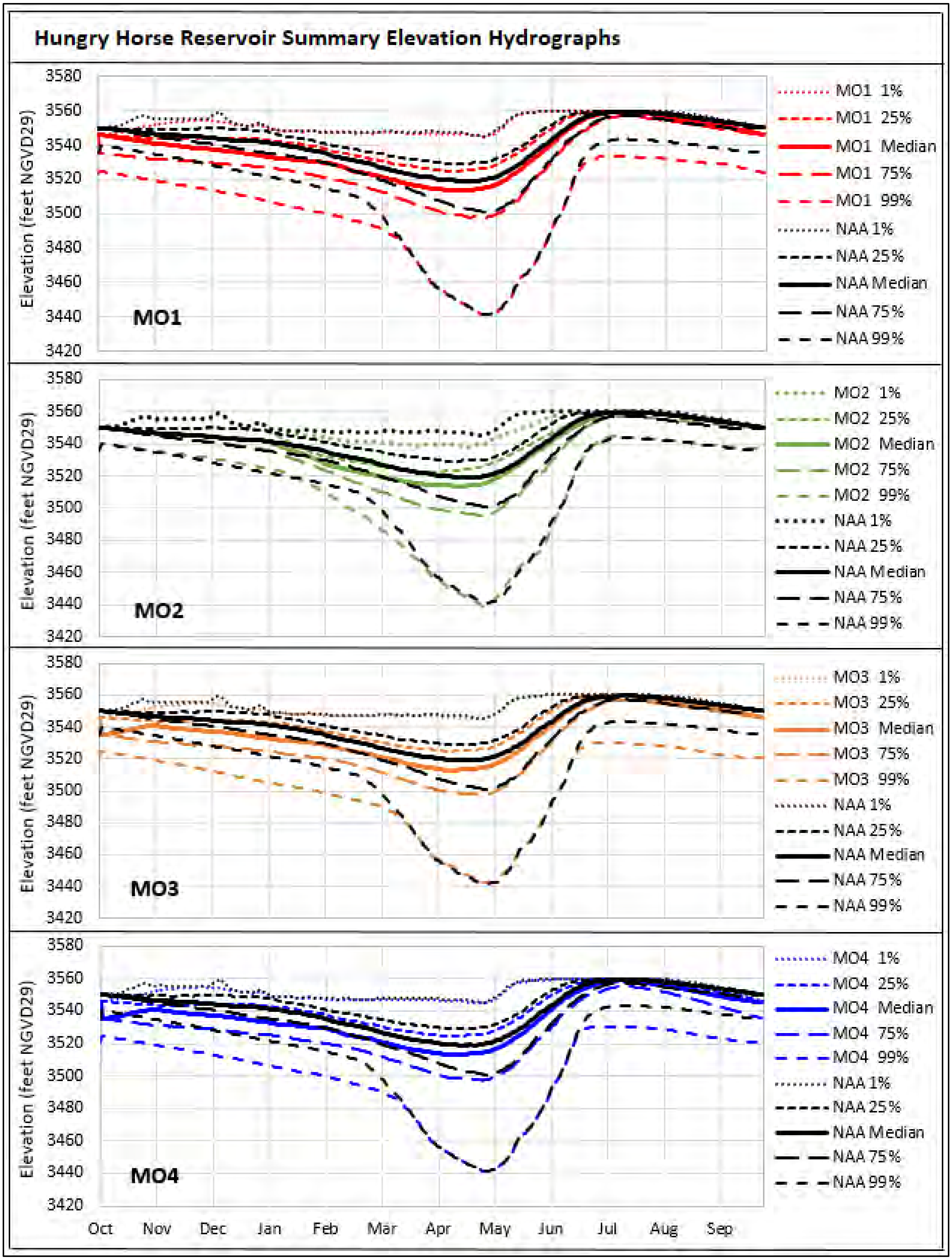
Figure 5-13. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Lake Pend Oreille

3285 *5.6.1.2 Summary Elevation Hydrographs*



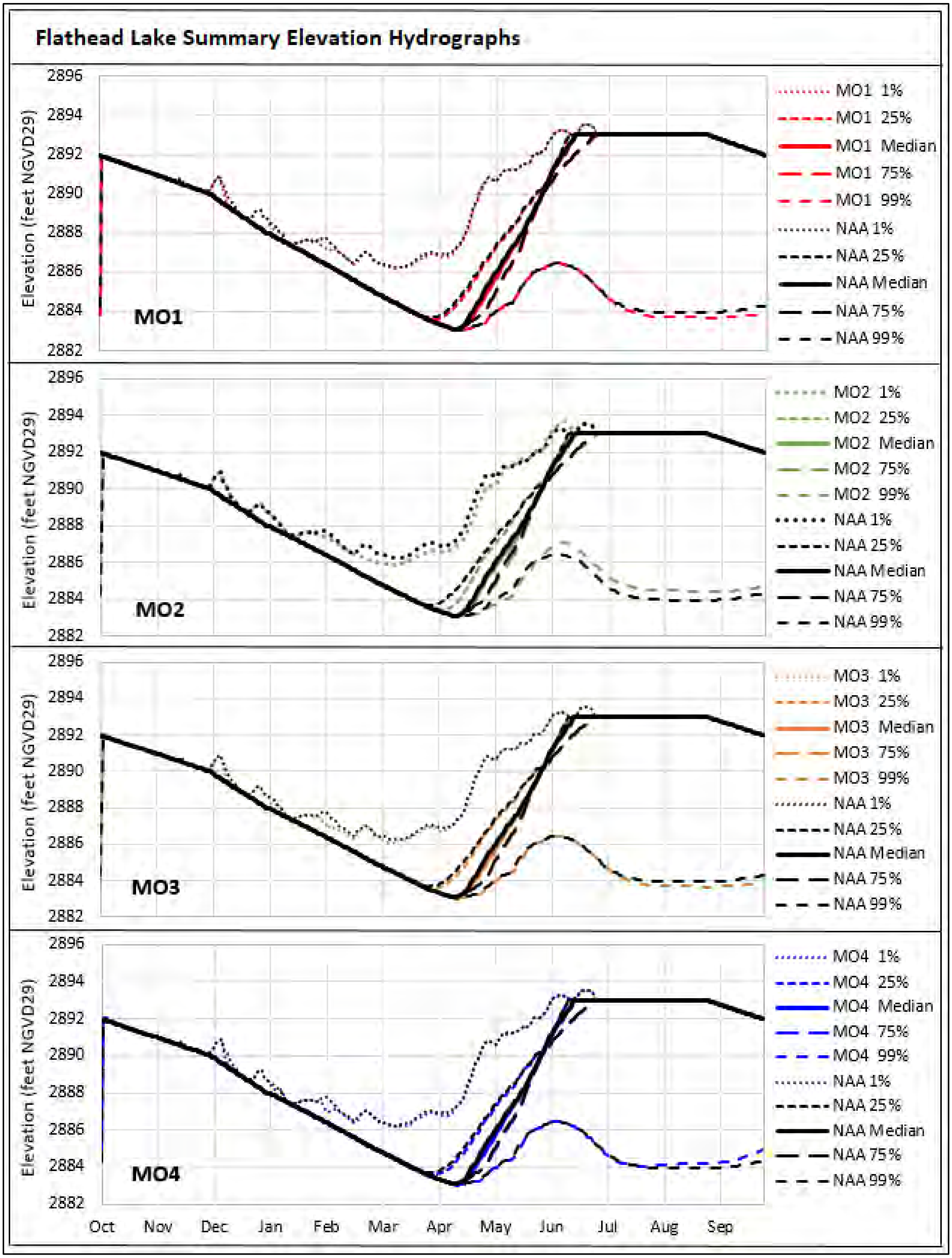
3286

3287 **Figure 5-14. Summary Elevation Hydrographs at Libby Reservoir (Lake Koocanusa)**



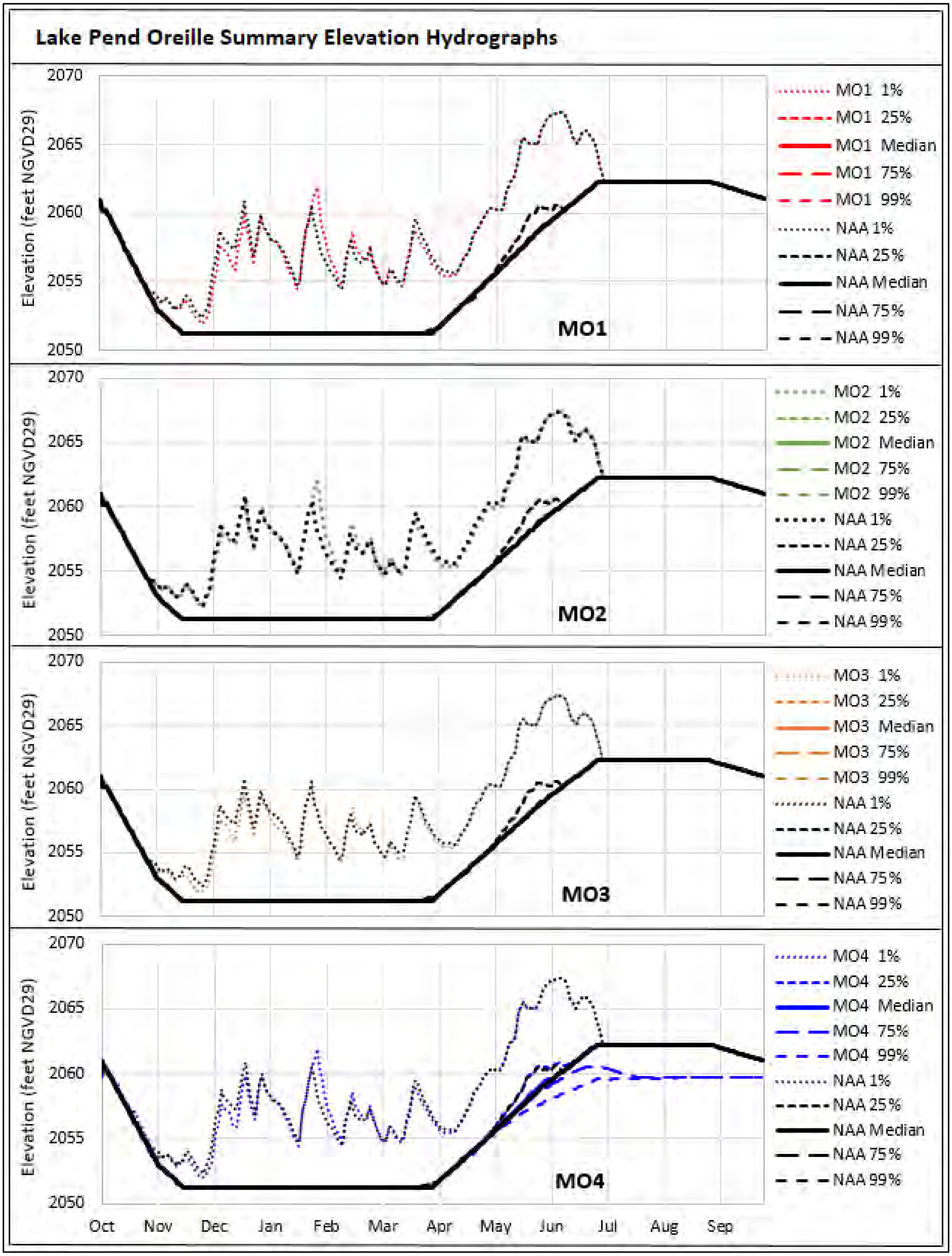
3288

3289 **Figure 5-15. Summary Elevation Hydrographs at Hungry Horse Reservoir**



3290

3291 **Figure 5-16. Summary Elevation Hydrographs at Flathead Lake**



3292

3293 Figure 5-17. Summary Elevation Hydrographs at Lake Pend Oreille

5.6.1.3 Reservoir Target Date Elevation-Frequency Plots

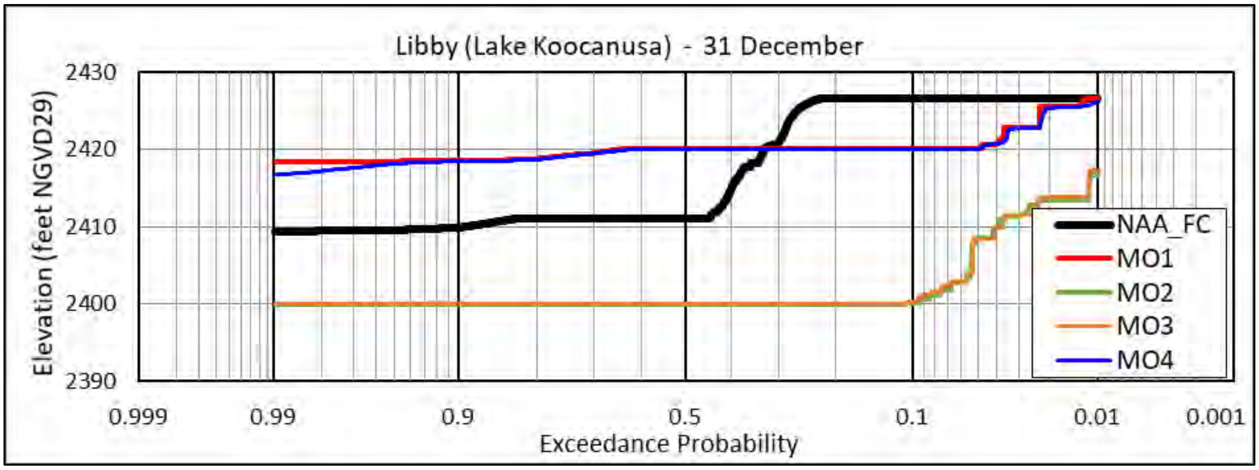


Figure 5-18. Elevation-Frequency Curves for December 31 at Libby Reservoir (Lake Koocanusa)

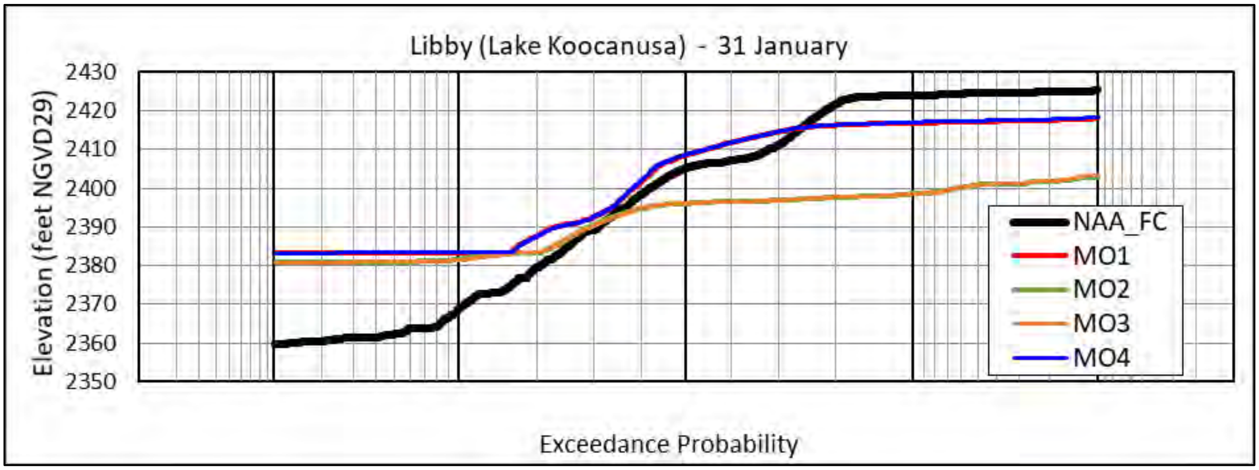


Figure 5-19. Elevation-Frequency Curves for January 31 at Libby Reservoir (Lake Koocanusa)

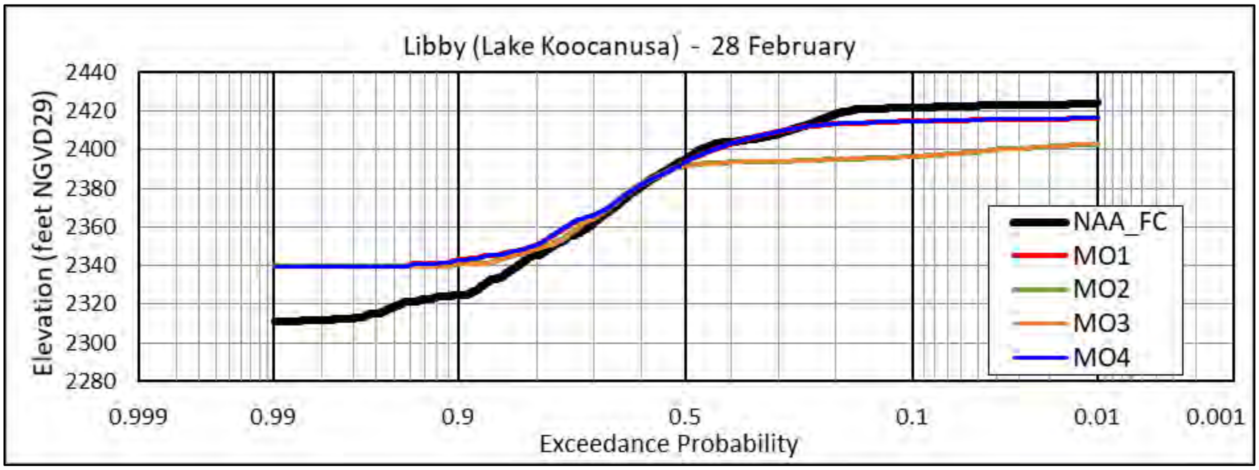
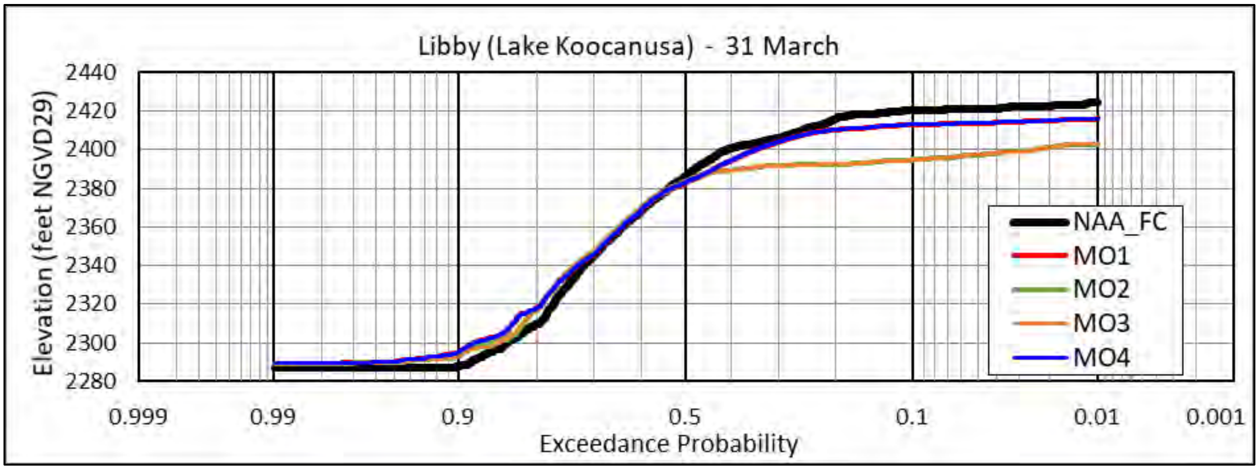
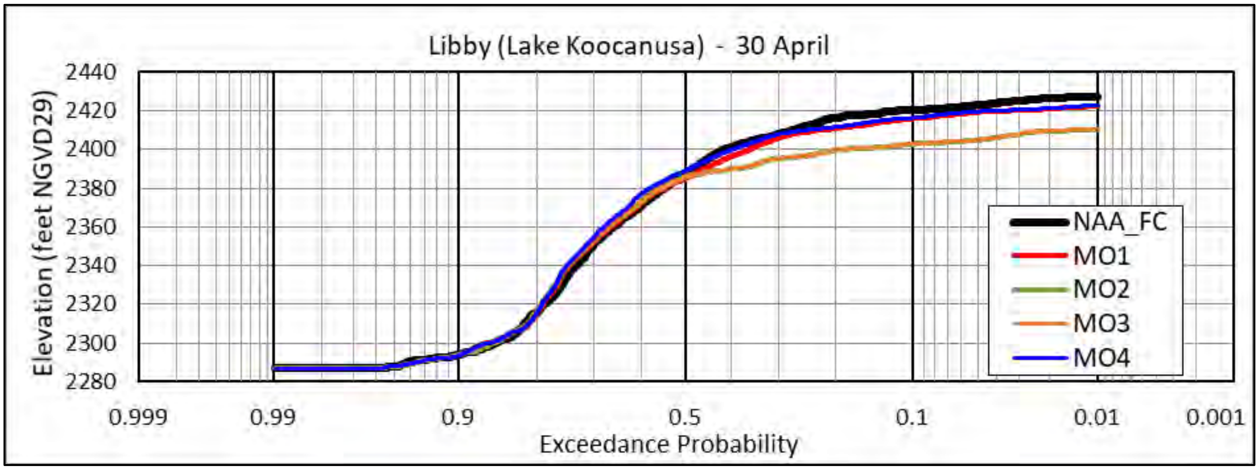


Figure 5-20. Elevation-Frequency Curves for February 28 at Libby Reservoir (Lake Koocanusa)



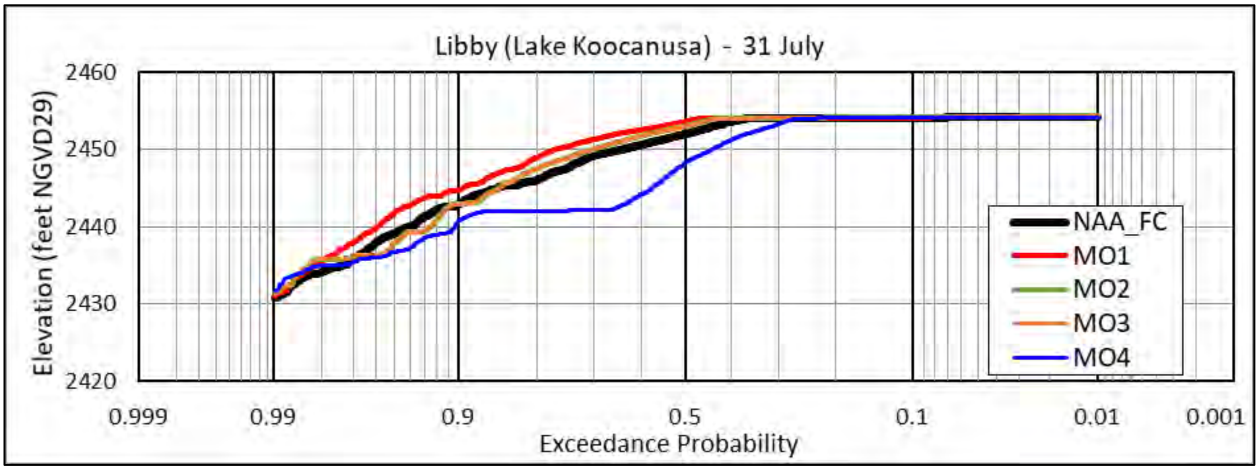
3301

3302 **Figure 5-21. Elevation-Frequency Curves for March 31 at Libby Reservoir (Lake Koocanusa)**



3303

3304 **Figure 5-22. Elevation-Frequency Curves for April 30 at Libby Reservoir (Lake Koocanusa)**



3305

3306 **Figure 5-23. Elevation-Frequency Curves for July 31 at Libby Reservoir (Lake Koocanusa)**

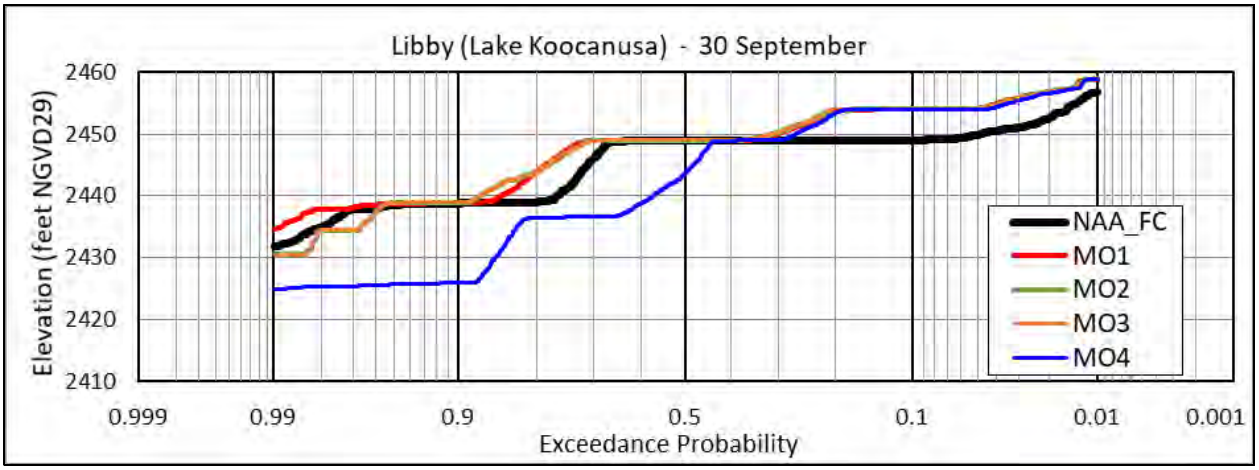


Figure 5-24. Elevation-Frequency Curves for September 30 at Libby Reservoir (Lake Koocanusa)

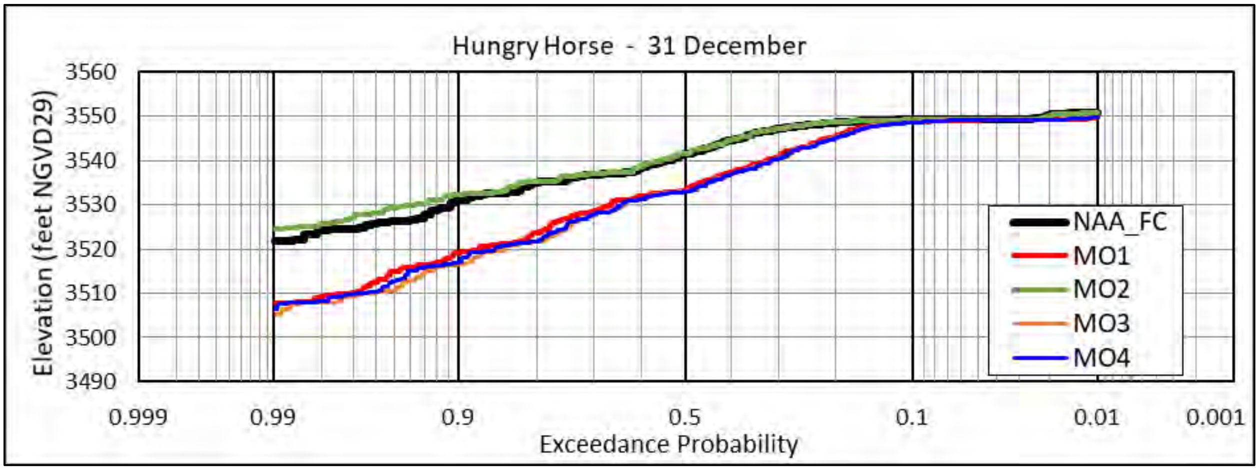


Figure 5-25. Elevation-Frequency Curves for December 31 at Hungry Horse Reservoir

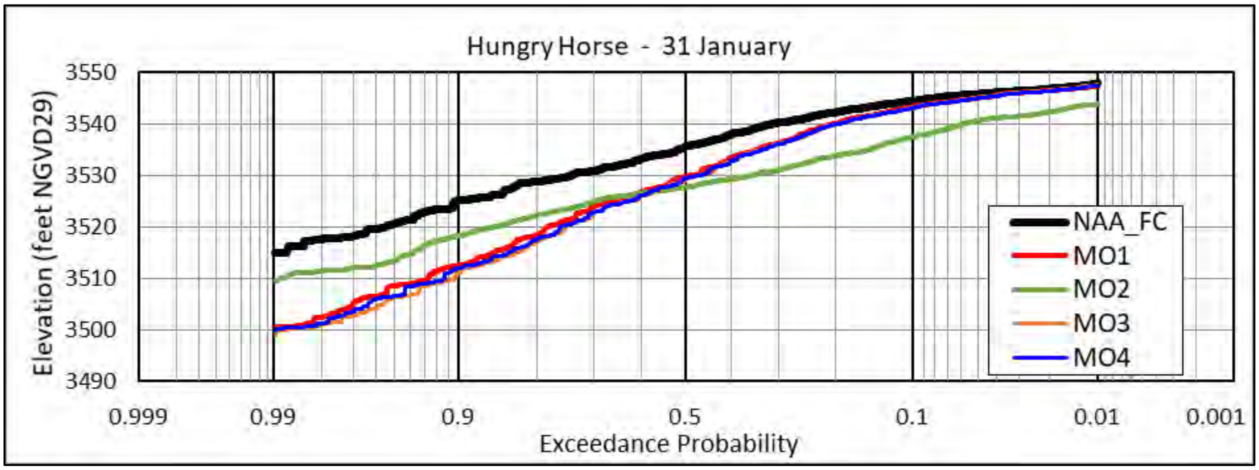


Figure 5-26. Elevation-Frequency Curves for January 31 at Hungry Horse Reservoir

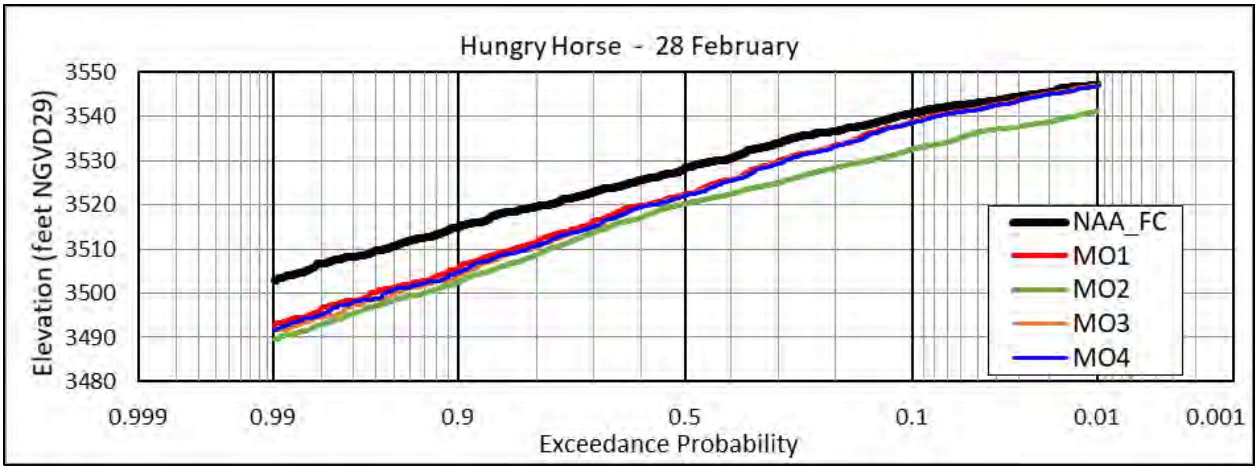


Figure 5-27. Elevation-Frequency Curves for February 28 at Hungry Horse Reservoir

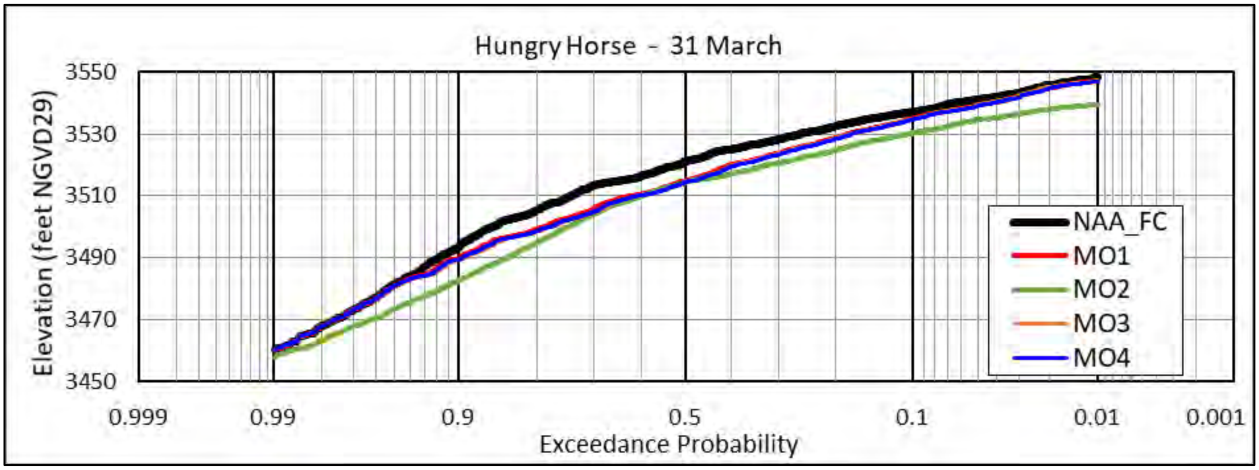


Figure 5-28. Elevation-Frequency Curves for March 31 at Hungry Horse Reservoir

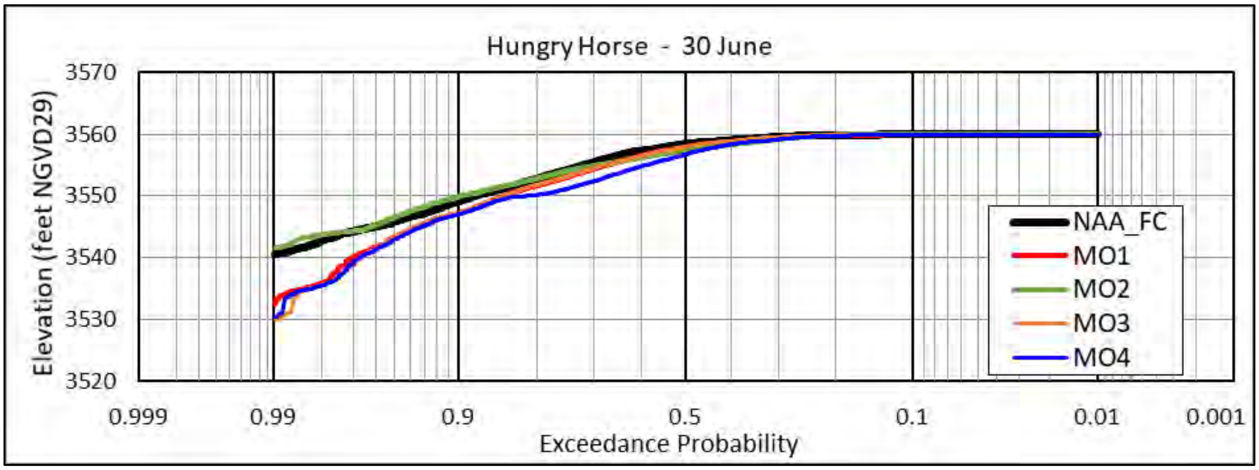


Figure 5-29. Elevation-Frequency Curves for June 30 at Hungry Horse Reservoir

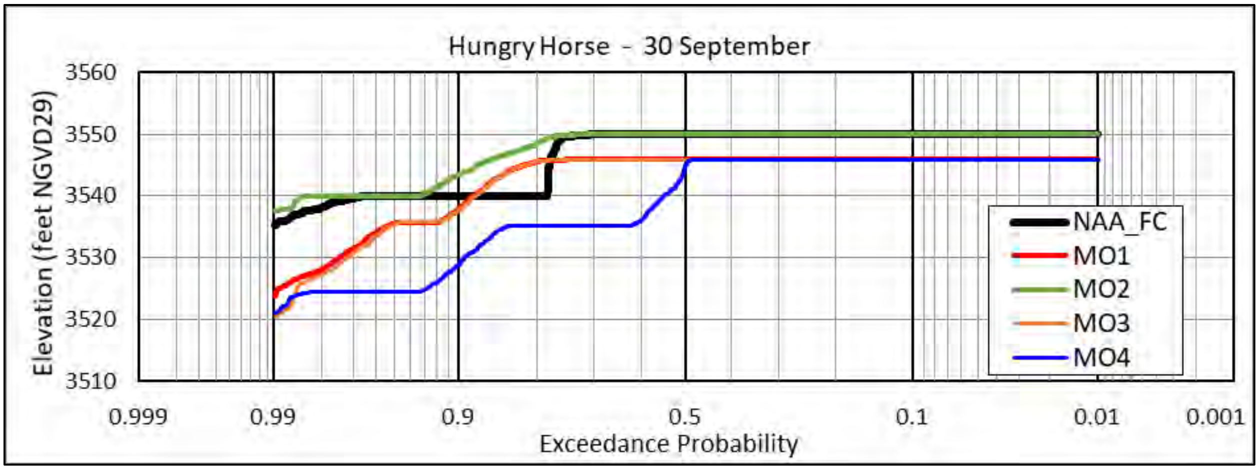


Figure 5-30. Elevation-Frequency Curves for September 30 at Hungry Horse Reservoir

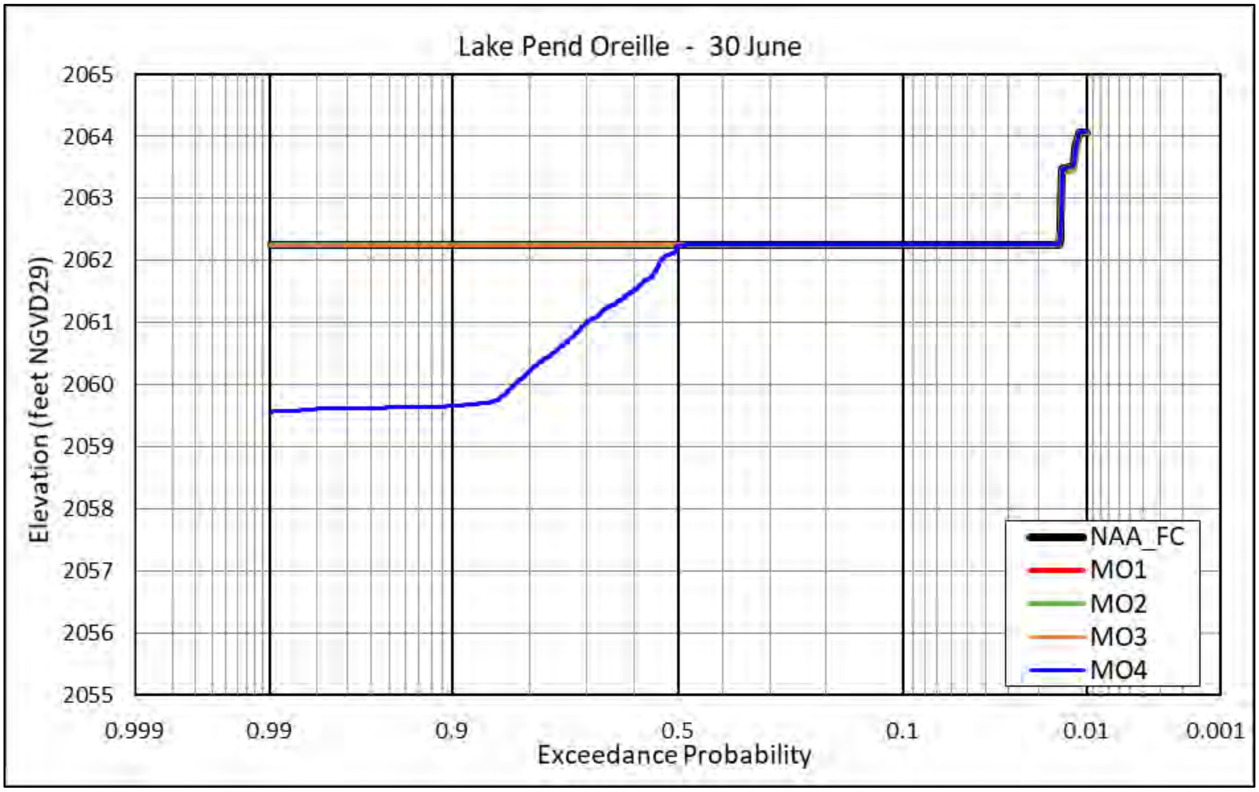
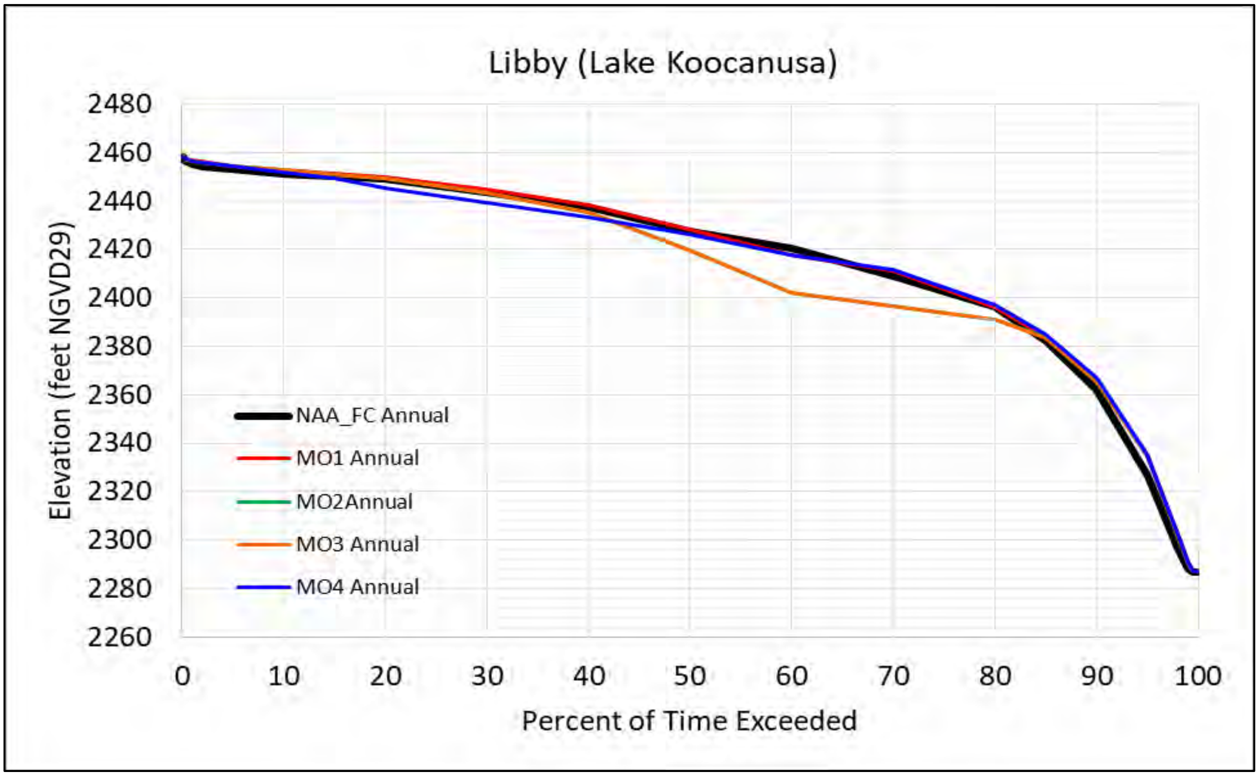
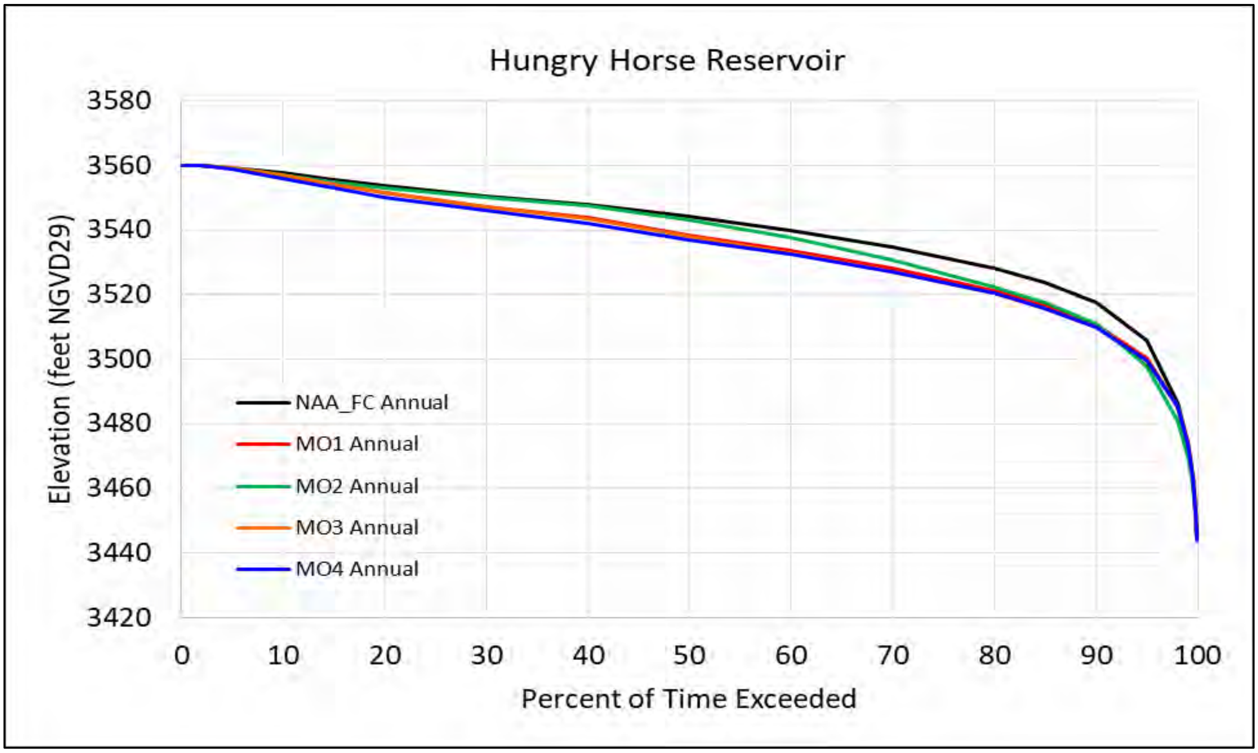


Figure 5-31. Elevation-Frequency Curves for June 30 at Lake Pend Oreille

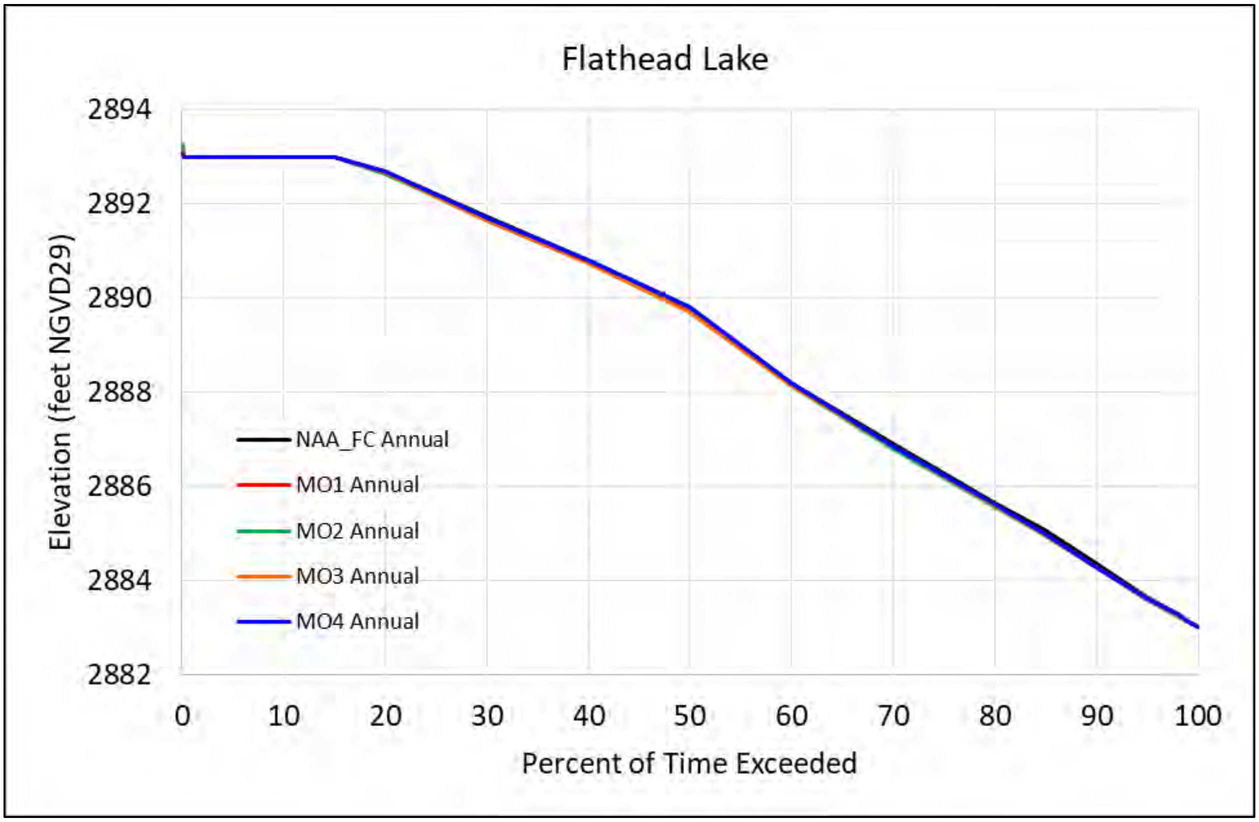
3324
5.6.1.4 Annual Elevation-Duration Plots



3325
3326 **Figure 5-32. Annual Elevation-Duration Curves at Libby Reservoir (Lake Koocanusa)**

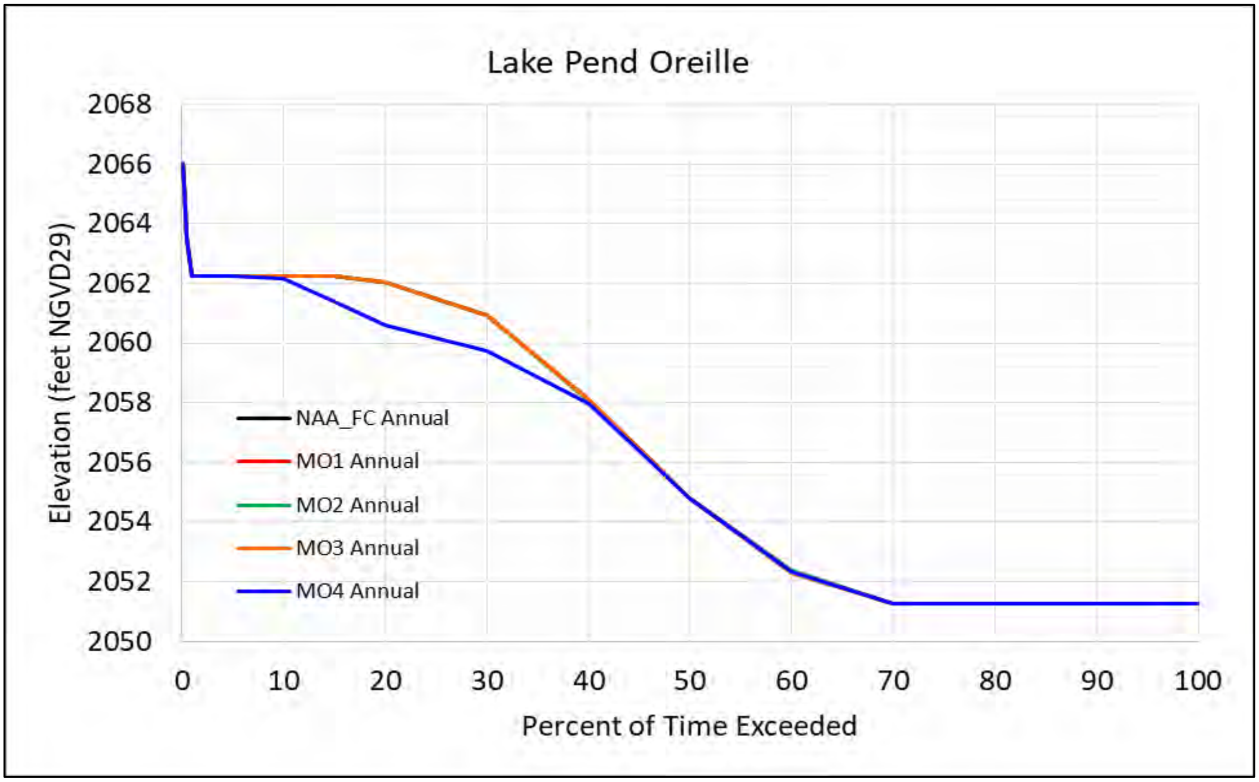


3327
3328 **Figure 5-33. Annual Elevation-Duration Curves at Hungry Horse Reservoir**



3329

3330 **Figure 5-34. Annual Elevation-Duration Curves at Flathead Lake**



3331

3332 **Figure 5-35. Annual Elevation-Duration Curves at Lake Pend Oreille**

5.6.1.5 Water Year Plots, Flow

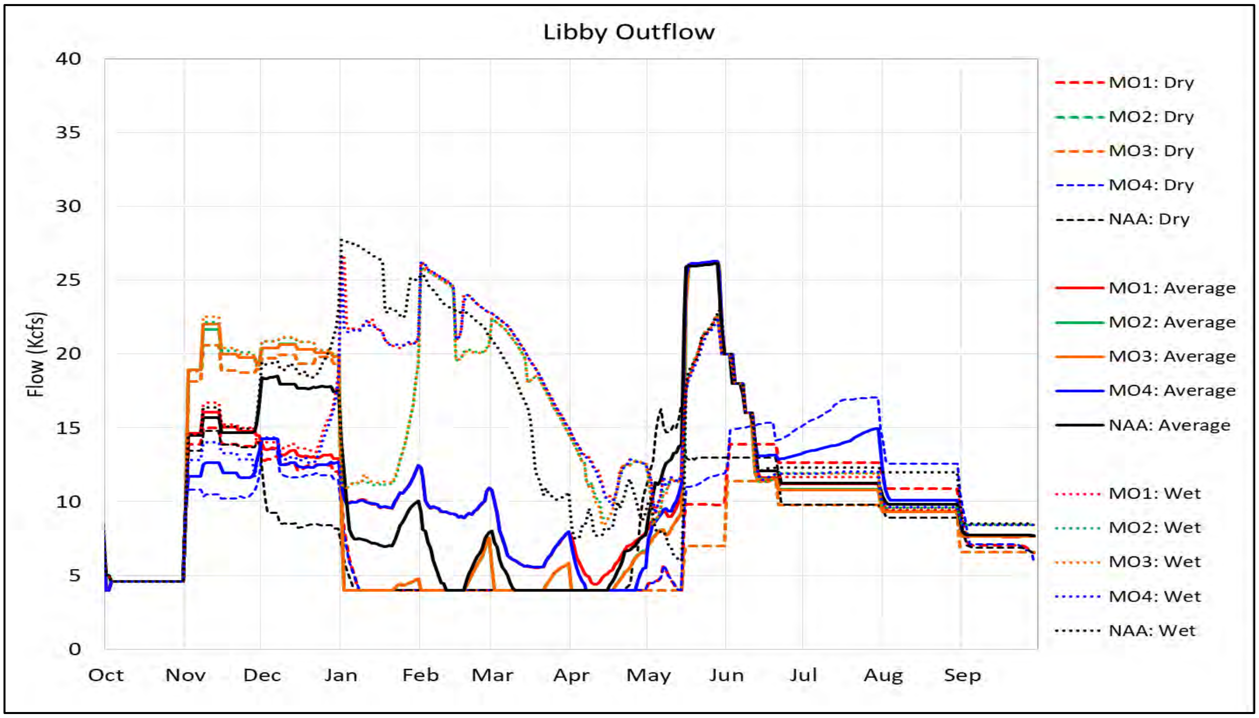


Figure 5-36. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at Libby Dam

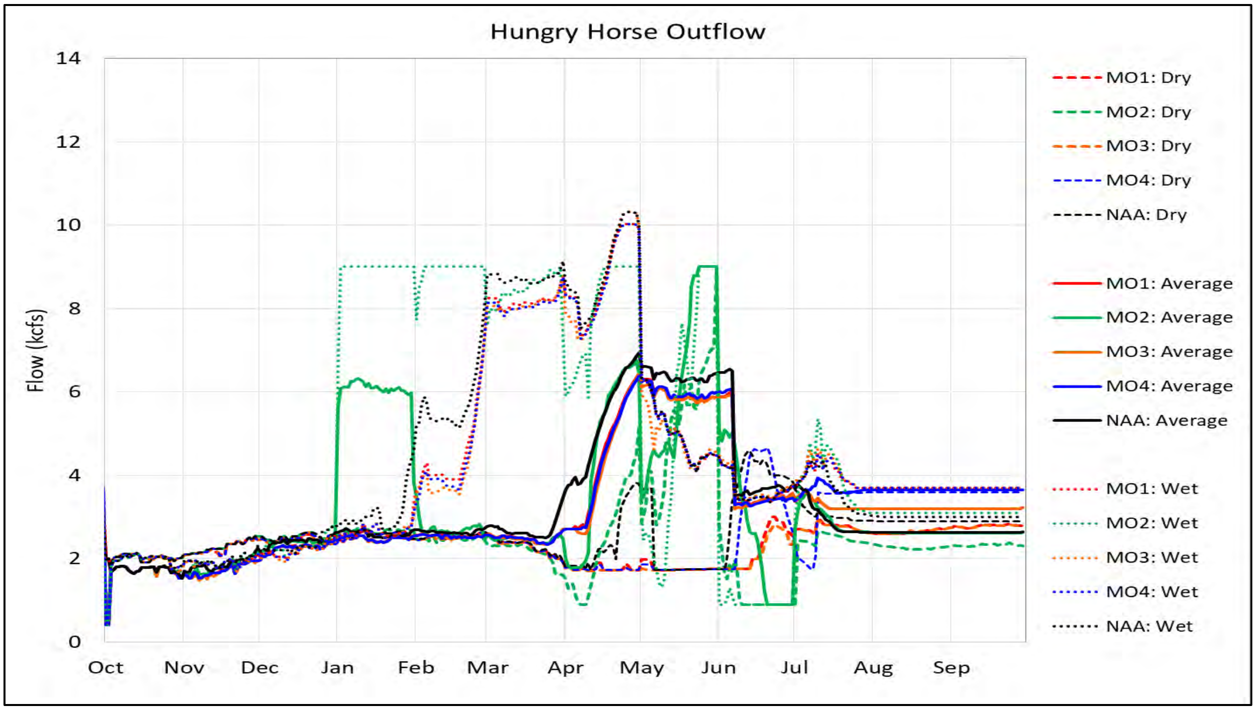


Figure 5-37. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at Hungry Horse Dam

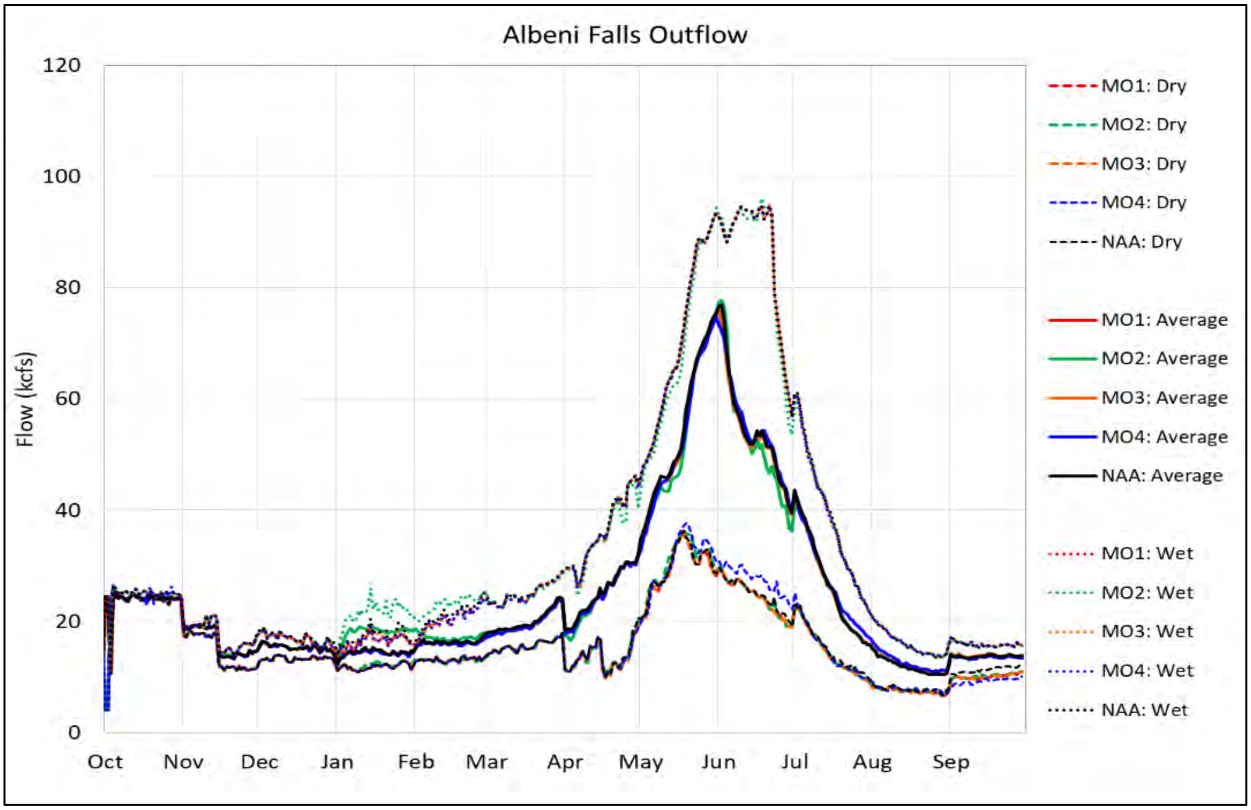
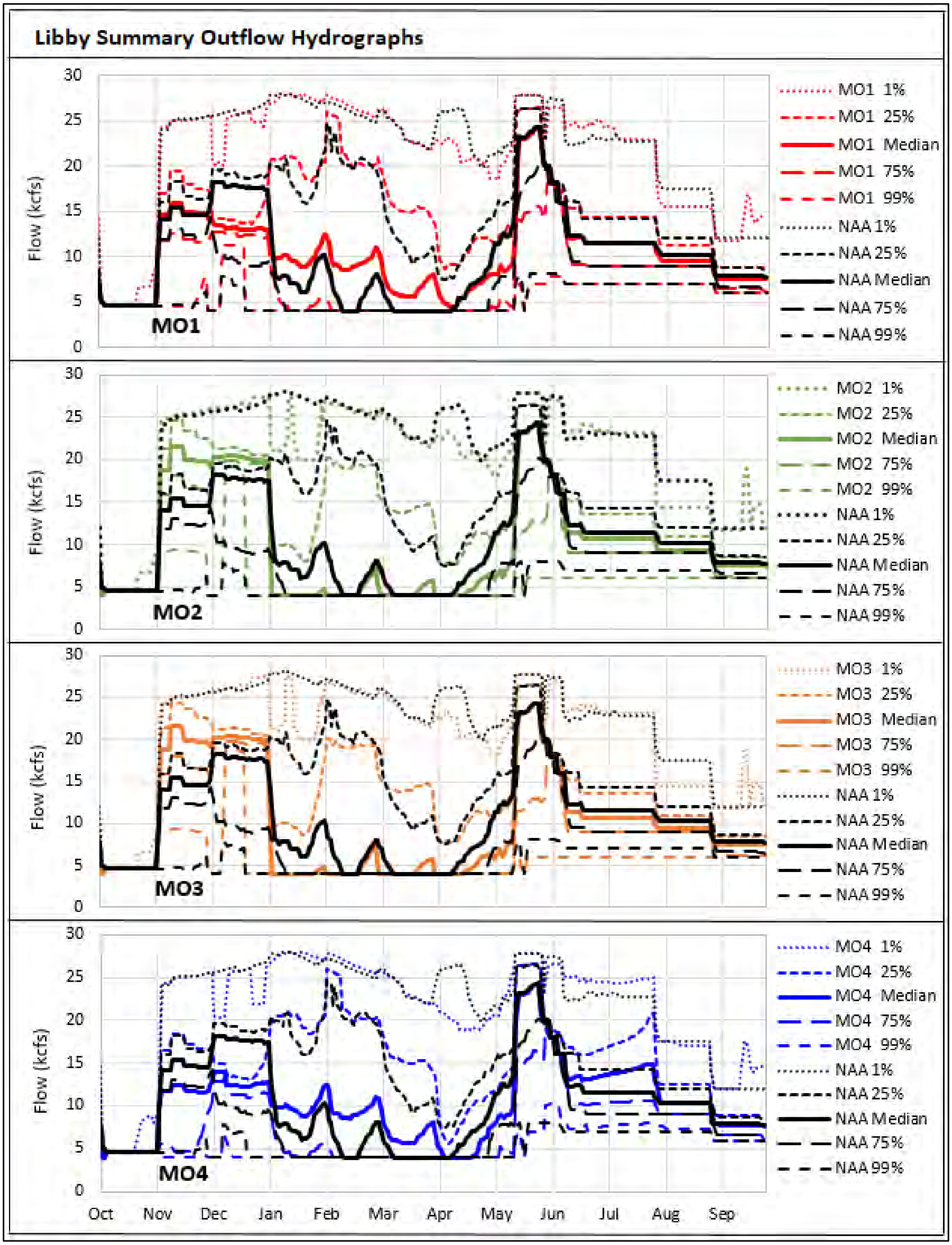


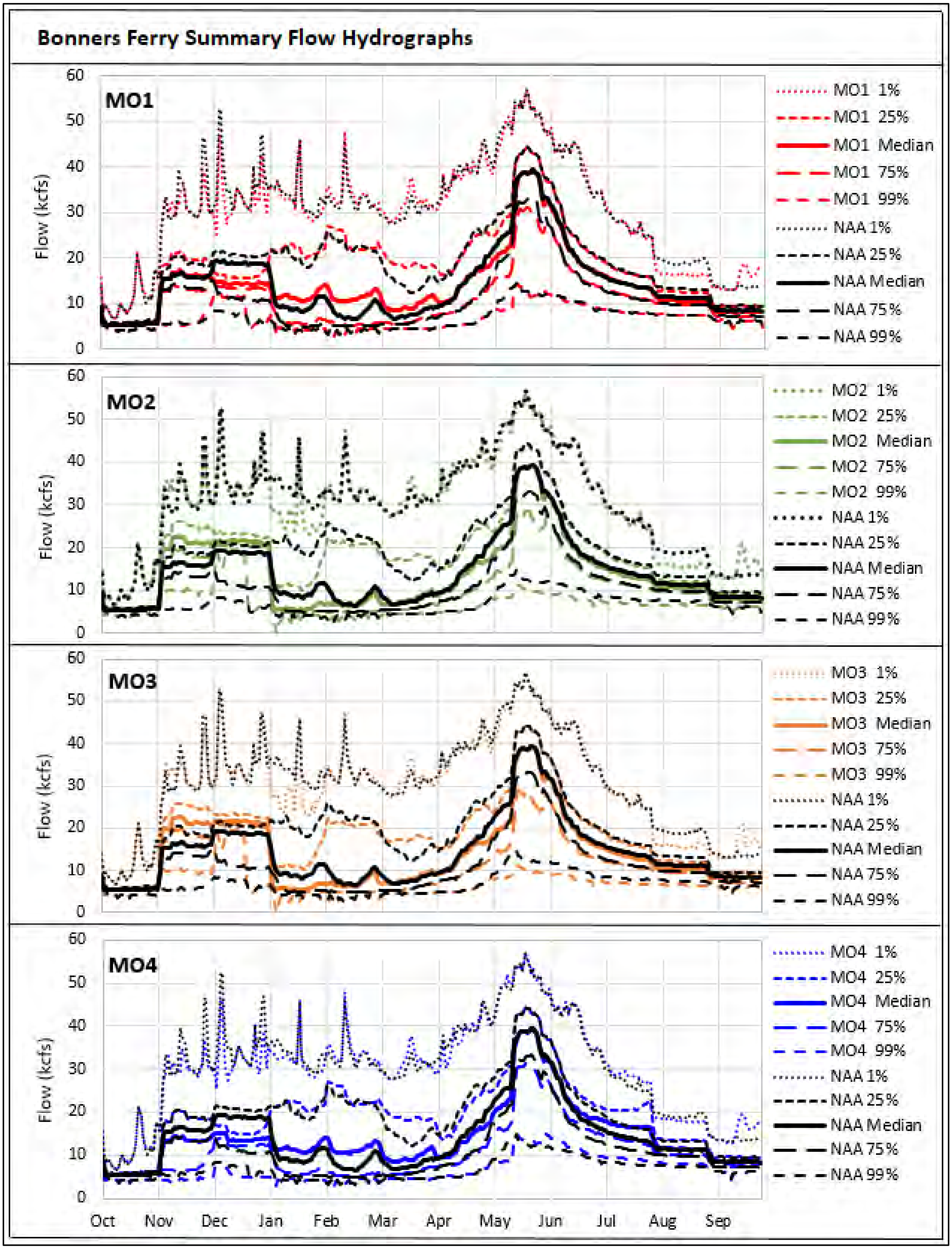
Figure 5-38. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at Albeni Falls Dam

3343 ### *5.6.1.6 Summary Flow Hydrographs*



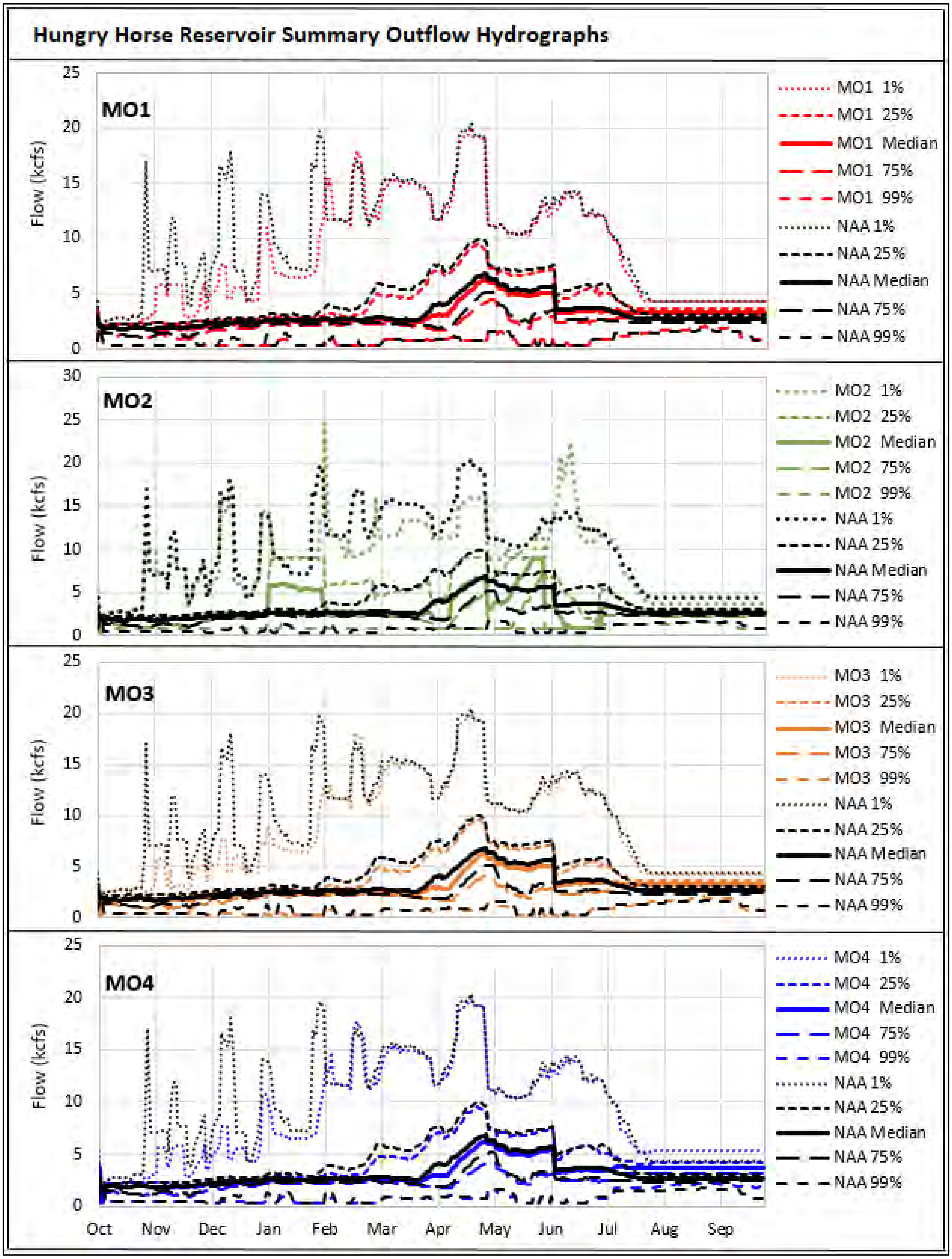
3344

3345 **Figure 5-39. Summary Outflow Hydrographs at Libby Dam**



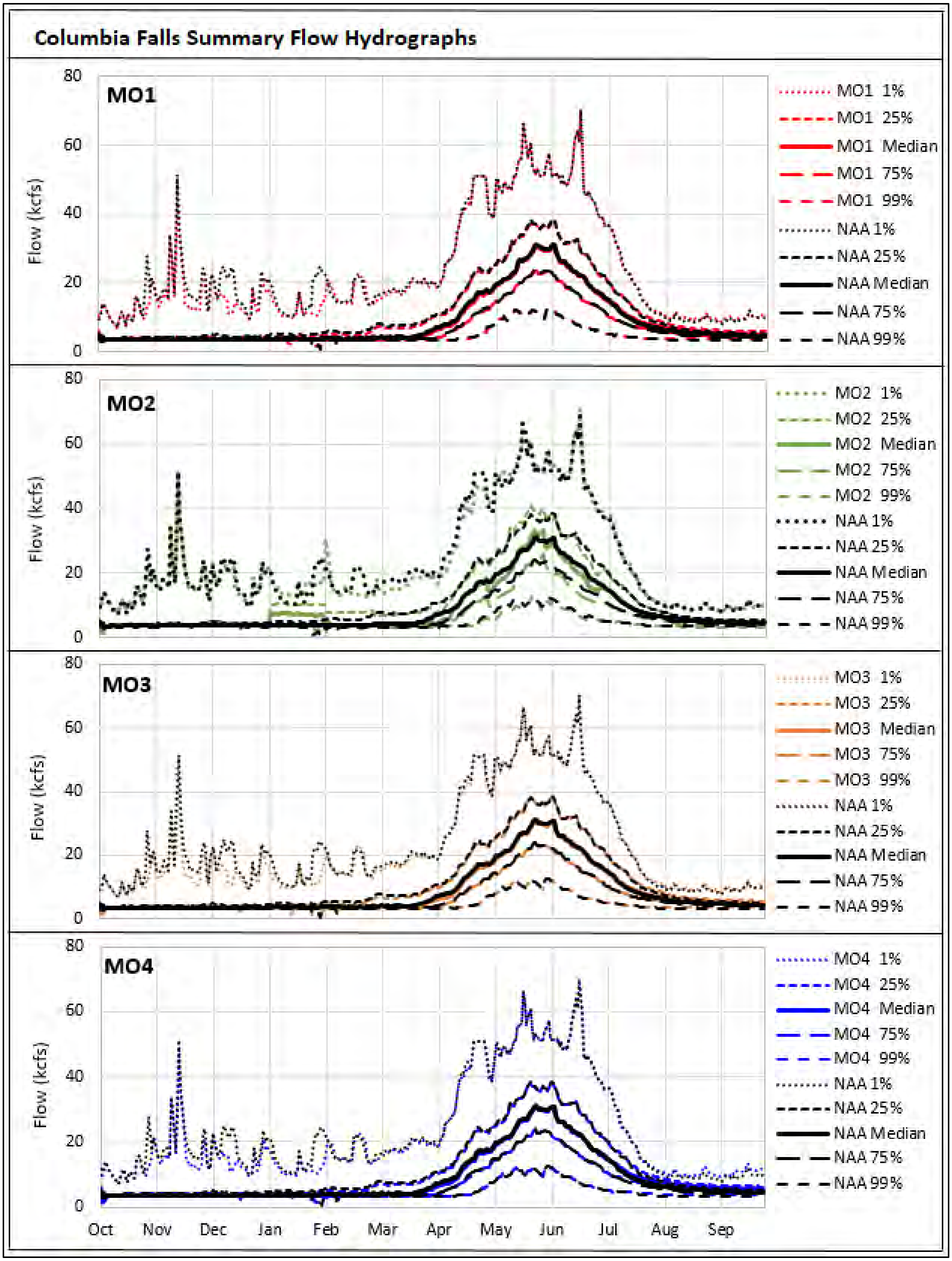
3346

3347 **Figure 5-40. Summary Flow Hydrographs at Bonners Ferry, Idaho**



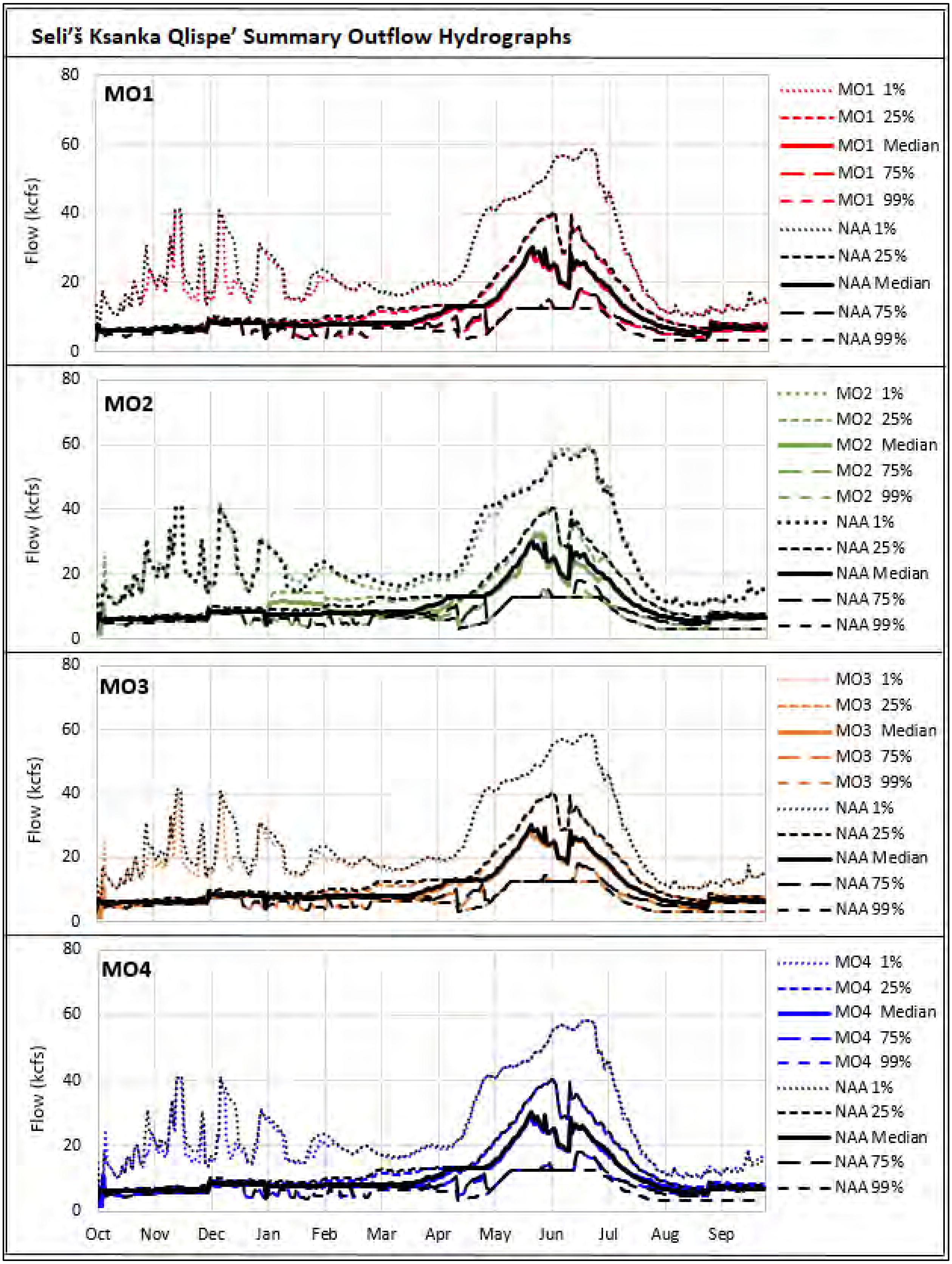
3348

3349 **Figure 5-41. Summary Outflow Hydrographs at Hungry Horse Dam**



3350

3351 **Figure 5-42. Summary Flow Hydrographs at Columbia Falls, Montana**



3352

3353 **Figure 5-43. Summary Outflow Hydrographs at Seli'š Ksanka Qlispe' Dam**

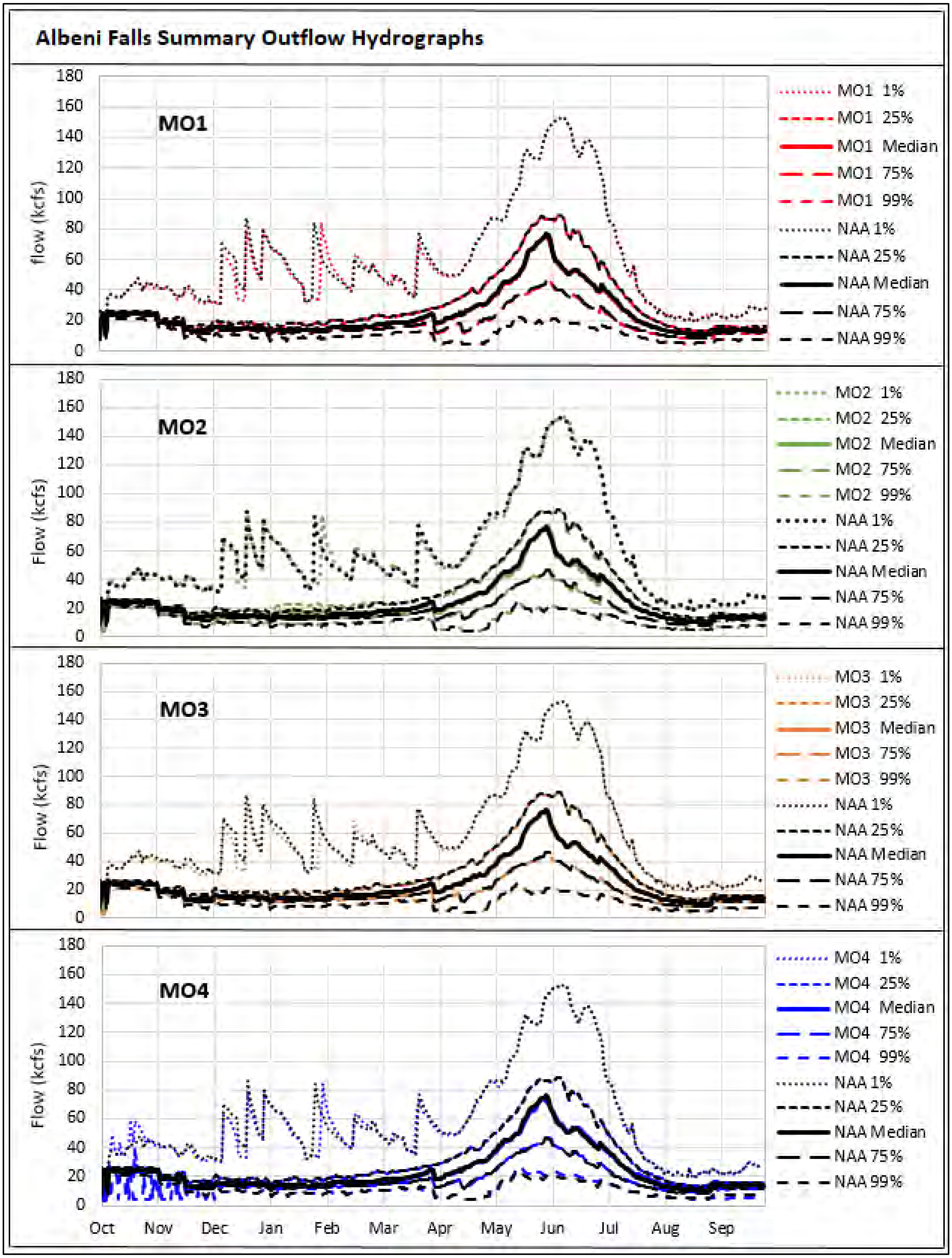


Figure 5-44. Summary Outflow Hydrographs at Albeni Falls Dam

5.6.1.7 Average Monthly Flow Summaries Tables

Table 5-8. Average Monthly Outflow Summary for Libby Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	4.9	23.5	22.0	27.1	25.8	23.0	20.8	22.7	22.6	22.9	17.8	12.0
		25%	4.7	16.2	18.9	18.3	20.0	12.2	9.9	19.2	17.1	14.3	12.1	8.8
		50%	4.7	14.3	17.7	8.8	6.3	5.5	7.0	16.4	14.2	11.5	10.3	7.9
		75%	4.7	12.0	9.9	5.6	4.0	4.0	4.4	14.0	12.9	9.0	9.0	6.8
		99%	4.7	7.0	8.2	4.3	4.0	4.0	4.0	11.6	8.8	7.1	7.1	6.0
MO1	Change (kcfs)	1%	0.6	0.4	-1.8	-1.4	0.8	0.2	-1.1	-1.0	0.9	0.3	-2.3	0.5
		25%	0.0	1.2	-4.9	1.1	1.5	3.2	0.4	-0.9	-0.6	0.0	-0.8	-0.1
		50%	0.0	0.2	-4.4	1.7	3.3	1.6	-0.6	-0.7	-0.3	0.0	-0.7	-0.2
		75%	0.0	-0.4	2.7	0.2	0.5	0.2	0.1	-2.2	-0.2	0.0	0.0	-0.2
		99%	0.0	-0.4	3.5	0.5	0.0	0.0	0.0	-5.5	0.9	0.7	0.7	0.1
	Percent change	1%	12%	2%	-8%	-5%	3%	1%	-5%	-4%	4%	1%	-13%	4%
		25%	0%	7%	-26%	6%	7%	26%	4%	-5%	-3%	0%	-7%	-1%
		50%	0%	2%	-25%	19%	52%	29%	-8%	-4%	-2%	0%	-7%	-3%
		75%	0%	-4%	27%	3%	12%	4%	1%	-16%	-1%	0%	0%	-2%
		99%	0%	-5%	43%	12%	0%	0%	0%	-47%	10%	10%	9%	1%
MO2	Change (kcfs)	1%	0.5	0.4	4.4	-5.7	-0.1	0.0	-1.1	-1.3	0.4	0.3	-3.3	0.1
		25%	-0.1	5.6	1.8	-7.7	-0.7	2.0	-0.2	-1.4	-0.9	-0.7	-1.1	-0.3
		50%	-0.1	4.9	2.4	-3.7	-1.4	-0.6	-1.8	-1.1	-0.7	-0.8	-0.9	-0.4
		75%	-0.1	4.2	9.6	-0.9	0.0	0.0	-0.4	-5.2	-0.6	0.0	0.0	-0.6
		99%	-0.1	3.7	10.7	0.3	0.0	0.0	0.0	-6.3	-2.2	-0.5	-0.5	0.0
	Percent change	1%	10%	2%	20%	-21%	0%	0%	-5%	-6%	2%	1%	-19%	1%
		25%	-1%	35%	10%	-42%	-4%	17%	-2%	-7%	-5%	-5%	-9%	-3%
		50%	-1%	34%	14%	-42%	-22%	-11%	-26%	-7%	-5%	-7%	-9%	-5%
		75%	-1%	35%	97%	-16%	0%	0%	-9%	-37%	-4%	0%	0%	-8%
		99%	-1%	53%	130%	8%	0%	0%	0%	-54%	-25%	-7%	-7%	0%
MO3	Change (kcfs)	1%	0.5	0.1	4.4	-5.4	-0.2	0.1	-1.0	-1.3	0.4	0.3	-3.3	0.1
		25%	-0.1	5.6	1.9	-7.6	-0.8	2.0	-0.2	-1.4	-0.9	-0.7	-1.1	-0.3
		50%	-0.1	4.9	2.4	-3.7	-1.4	-0.6	-1.8	-1.1	-0.7	-0.8	-0.9	-0.4
		75%	-0.1	4.2	9.6	-0.9	0.0	0.0	-0.4	-5.2	-0.6	0.0	0.0	-0.6
		99%	-0.1	3.7	10.7	0.3	0.0	0.0	0.0	-6.3	-2.2	-0.5	-0.5	0.0
	Percent change	1%	10%	0%	20%	-20%	-1%	0%	-5%	-6%	2%	1%	-19%	1%
		25%	-1%	35%	10%	-42%	-4%	17%	-2%	-7%	-5%	-5%	-9%	-3%
		50%	-1%	34%	14%	-42%	-22%	-11%	-26%	-7%	-5%	-7%	-9%	-5%
		75%	-1%	35%	97%	-16%	0%	0%	-9%	-37%	-4%	0%	0%	-8%
		99%	-1%	53%	131%	8%	0%	0%	0%	-54%	-25%	-7%	-7%	0%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO4	Change (kcfs)	1%	1.4	0.4	-2.4	-1.5	0.8	0.2	-2.2	0.1	1.6	1.5	-0.4	0.9
		25%	-0.1	0.4	-5.1	0.9	1.5	3.2	-1.4	-0.9	0.4	3.8	0.4	0.0
		50%	-0.1	-2.9	-4.7	1.6	3.3	1.6	-1.4	-0.8	0.6	2.9	0.2	-0.1
		75%	-0.1	-6.3	1.9	0.1	0.5	0.2	-0.1	-2.0	0.0	1.5	0.1	0.0
		99%	-0.1	-2.6	-1.1	0.3	0.0	0.0	0.0	-4.9	2.8	1.9	1.2	0.2
	Percent change	1%	28%	2%	-11%	-6%	3%	1%	-11%	0%	7%	7%	-2%	8%
		25%	-1%	3%	-27%	5%	7%	26%	-14%	-5%	2%	27%	4%	0%
		50%	-1%	-20%	-27%	18%	52%	29%	-21%	-5%	4%	25%	2%	-1%
		75%	-1%	-52%	19%	2%	12%	4%	-3%	-15%	0%	17%	1%	0%
		99%	-1%	-38%	-14%	7%	0%	0%	0%	-42%	32%	27%	17%	3%

3358 **Table 5-9. Average Monthly Flow Summary for Kootenai River at Bonners Ferry, Idaho**

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	9.0	26.6	29.2	31.3	29.7	27.5	30.4	40.8	40.7	27.2	19.0	13.3
		25%	6.1	18.1	20.7	21.0	23.2	15.3	19.4	34.3	27.8	17.3	13.3	9.7
		50%	5.6	15.4	18.9	10.4	8.5	8.4	14.6	31.1	23.8	14.6	11.4	8.6
		75%	5.4	13.0	11.4	6.5	5.1	5.9	10.2	27.6	20.3	11.8	9.9	7.4
		99%	5.1	7.7	9.0	5.1	4.5	4.9	7.0	18.3	12.6	9.0	8.1	6.7
MO1	Change (kcfs)	1%	0.5	0.4	-1.5	-2.6	1.3	2.7	0.4	0.5	1.0	-0.2	-2.6	1.0
		25%	0.0	1.1	-4.9	0.3	0.4	3.8	0.0	-0.4	-0.5	-0.2	-0.7	0.0
		50%	0.0	0.3	-4.3	1.7	3.1	1.5	-0.1	-0.9	-0.2	0.0	-0.7	-0.3
		75%	0.0	-0.2	2.2	0.4	0.6	0.5	0.1	-3.7	0.1	0.3	0.0	-0.1
		99%	0.0	-0.4	3.4	0.5	0.1	0.0	0.0	-4.8	0.3	0.1	0.4	0.0
	Percent change	1%	6%	1%	-5%	-8%	4%	10%	1%	1%	2%	-1%	-14%	8%
		25%	0%	6%	-23%	1%	2%	25%	0%	-1%	-2%	-1%	-5%	0%
		50%	0%	2%	-23%	17%	36%	18%	-1%	-3%	-1%	0%	-6%	-3%
		75%	0%	-2%	19%	6%	12%	9%	1%	-13%	0%	2%	0%	-1%
		99%	0%	-5%	38%	10%	2%	0%	0%	-26%	2%	1%	4%	-1%
MO2	Change (kcfs)	1%	0.3	1.6	1.7	-5.4	0.9	1.8	0.2	0.2	1.2	0.0	-3.5	0.7
		25%	-0.1	5.7	2.0	-8.6	-1.2	2.5	-0.6	-0.8	-0.7	-0.6	-1.1	-0.2
		50%	-0.1	4.8	2.6	-3.5	-1.3	-0.2	-1.1	-1.2	-0.7	-0.7	-0.8	-0.4
		75%	-0.1	4.4	9.0	-0.8	-0.1	-0.1	-0.5	-6.5	-0.7	-0.2	-0.3	-0.3
		99%	-0.1	3.8	10.7	0.3	0.0	0.0	0.0	-6.2	-2.9	-1.4	-0.9	-0.1
	Percent change	1%	4%	6%	6%	-17%	3%	7%	1%	0%	3%	0%	-18%	6%
		25%	-2%	32%	10%	-41%	-5%	17%	-3%	-2%	-2%	-4%	-8%	-2%
		50%	-1%	31%	14%	-34%	-16%	-2%	-7%	-4%	-3%	-5%	-7%	-5%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
		75%	-1%	34%	79%	-12%	-2%	-2%	-5%	-24%	-3%	-2%	-3%	-4%
		99%	-1%	49%	119%	5%	0%	0%	0%	-34%	-23%	-15%	-11%	-2%
MO3	Change (kcfs)	1%	0.6	1.3	1.7	-7.0	0.9	1.8	0.2	0.2	1.2	0.0	-3.5	0.8
		25%	-0.1	5.5	1.9	-8.6	-1.3	2.6	-0.6	-0.8	-0.7	-0.6	-1.1	-0.2
		50%	-0.1	4.9	2.6	-3.5	-1.3	-0.2	-1.0	-1.2	-0.7	-0.7	-0.8	-0.4
		75%	-0.1	4.5	9.0	-0.8	-0.1	-0.1	-0.5	-6.5	-0.7	-0.2	-0.3	-0.3
		99%	-0.1	3.8	10.7	0.3	0.0	0.0	0.0	-6.2	-2.9	-1.4	-0.9	-0.1
	Percent change	1%	7%	5%	6%	-22%	3%	7%	1%	0%	3%	0%	-18%	6%
		25%	-2%	31%	9%	-41%	-6%	17%	-3%	-2%	-2%	-4%	-8%	-2%
		50%	-1%	32%	14%	-34%	-16%	-2%	-7%	-4%	-3%	-5%	-7%	-5%
		75%	-1%	34%	79%	-12%	-2%	-2%	-5%	-24%	-3%	-2%	-3%	-4%
		99%	-1%	49%	119%	5%	0%	0%	0%	-34%	-23%	-15%	-11%	-2%
M04	Change (kcfs)	1%	0.1	0.6	-2.3	-2.1	1.2	2.6	0.0	0.8	1.0	1.2	-0.8	1.6
		25%	-0.1	0.0	-5.1	0.1	0.4	3.8	-1.6	-0.3	0.2	3.6	0.4	0.0
		50%	-0.1	-2.2	-4.8	1.6	3.1	1.5	-0.9	-0.9	0.9	2.7	0.2	-0.1
		75%	-0.1	-5.7	1.3	0.3	0.6	0.5	-0.3	-3.6	0.8	2.0	0.4	0.1
		99%	-0.1	-2.6	-0.9	0.3	0.1	0.0	0.0	-4.4	2.7	2.4	0.9	0.1
	Percent change	1%	1%	2%	-8%	-7%	4%	10%	0%	2%	2%	4%	-4%	12%
		25%	-1%	0%	-25%	1%	2%	25%	-8%	-1%	1%	21%	3%	0%
		50%	-1%	-14%	-25%	16%	36%	18%	-6%	-3%	4%	19%	1%	-1%
		75%	-1%	-44%	12%	5%	12%	9%	-3%	-13%	4%	17%	4%	1%
		99%	-2%	-34%	-10%	5%	2%	0%	0%	-24%	21%	26%	11%	1%

Table 5-10. Average Monthly Outflow Summary for Hungry Horse Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	2.5	4.7	6.9	7.1	11.5	14.5	15.6	9.6	10.7	6.9	4.4	4.4
		25%	2.2	2.4	2.7	3.1	4.0	5.7	8.1	7.0	6.1	4.2	3.1	3.1
		50%	1.9	2.0	2.4	2.6	2.7	2.7	5.4	5.7	4.3	3.4	2.7	2.7
		75%	1.4	1.4	2.1	2.3	2.4	2.2	3.1	4.1	3.2	2.6	2.4	2.4
		99%	0.8	0.8	1.6	2.0	1.7	1.5	1.7	1.7	1.7	1.8	1.9	2.0

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO1	Change (kcfs)	1%	0.0	-0.5	-2.2	-0.8	-0.1	-0.2	-0.2	-0.1	-0.3	0.0	-0.1	-0.1
		25%	0.0	0.0	-0.1	-0.4	-0.8	-0.7	-0.4	-0.3	-0.4	0.0	0.5	0.5
		50%	0.0	-0.1	-0.1	-0.1	-0.1	-0.2	-0.7	-0.4	-0.3	0.0	0.6	0.6
		75%	0.0	-0.2	-0.2	-0.2	-0.1	-0.1	-0.5	-0.4	-0.3	0.2	0.4	0.5
		99%	0.0	-0.2	-0.5	-0.3	-0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.3
	Percent change	1%	0%	-12%	-32%	-11%	-1%	-2%	-1%	-1%	-3%	0%	-2%	-2%
		25%	0%	-1%	-4%	-12%	-21%	-12%	-5%	-4%	-7%	1%	17%	17%
		50%	0%	-6%	-6%	-3%	-4%	-6%	-13%	-6%	-8%	1%	21%	21%
		75%	-1%	-14%	-10%	-7%	-5%	-3%	-17%	-9%	-11%	9%	18%	19%
		99%	-2%	-29%	-29%	-14%	-5%	-2%	-2%	-1%	-3%	-2%	12%	17%
MO2	Change (kcfs)	1%	0.1	-0.8	-0.5	2.1	-0.3	-1.8	-2.7	0.3	0.1	0.0	-0.7	-0.7
		25%	-0.1	0.0	0.0	5.6	2.0	-0.5	-1.4	0.0	-1.5	-0.1	-0.1	-0.1
		50%	-0.1	0.0	0.0	2.8	0.1	-0.2	-0.9	-0.1	-1.6	-0.3	0.0	0.0
		75%	-0.1	0.0	0.0	0.4	0.0	-0.2	-0.4	0.1	-1.6	-0.3	-0.1	-0.1
		99%	0.1	0.2	0.0	0.1	0.1	-0.2	-0.5	0.4	-0.6	-0.1	-0.2	-0.2
	Percent change	1%	3%	-17%	-7%	29%	-2%	-13%	-17%	3%	1%	-1%	-15%	-15%
		25%	-5%	-1%	0%	179%	50%	-8%	-17%	-1%	-25%	-3%	-4%	-4%
		50%	-6%	-2%	-1%	108%	2%	-8%	-17%	-2%	-37%	-10%	-1%	-1%
		75%	-10%	0%	-1%	15%	-1%	-8%	-12%	3%	-50%	-10%	-5%	-4%
		99%	9%	27%	0%	6%	8%	-14%	-32%	22%	-33%	-5%	-8%	-11%
MO3	Change (kcfs)	1%	-0.1	-0.8	-2.3	-0.7	-0.3	-0.3	-0.2	-0.1	-0.4	0.0	-0.1	-0.1
		25%	-0.1	-0.1	-0.2	-0.4	-0.9	-0.9	-0.4	-0.3	-0.4	0.1	0.5	0.5
		50%	-0.1	-0.1	-0.2	-0.1	-0.1	-0.2	-1.0	-0.4	-0.3	0.0	0.6	0.6
		75%	-0.2	-0.2	-0.3	-0.2	-0.1	-0.1	-0.6	-0.5	-0.4	0.2	0.4	0.5
		99%	-0.3	-0.2	-0.5	-0.4	-0.2	-0.1	-0.1	0.0	0.0	0.0	0.2	0.3
	Percent change	1%	-4%	-18%	-33%	-10%	-2%	-2%	-1%	-1%	-4%	0%	-2%	-2%
		25%	-5%	-2%	-6%	-12%	-23%	-15%	-4%	-4%	-7%	2%	17%	17%
		50%	-7%	-6%	-6%	-3%	-5%	-7%	-19%	-8%	-8%	1%	21%	21%
		75%	-12%	-16%	-16%	-8%	-6%	-5%	-20%	-12%	-11%	9%	18%	19%
		99%	-39%	-29%	-32%	-17%	-12%	-7%	-3%	-1%	-3%	-3%	12%	17%
M04	Change (kcfs)	1%	-0.1	-0.7	-2.3	-0.8	-0.2	-0.3	-0.2	-0.1	-0.3	0.0	1.0	1.0
		25%	-0.1	0.0	-0.1	-0.4	-0.9	-0.8	-0.4	-0.3	-0.2	0.3	1.1	1.1
		50%	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.8	-0.3	-0.2	0.4	1.0	1.0
		75%	-0.1	-0.2	-0.3	-0.2	-0.1	-0.1	-0.6	-0.3	-0.2	0.4	0.8	0.8
		99%	-0.3	-0.2	-0.5	-0.4	-0.1	0.0	0.0	0.0	0.0	0.4	0.5	0.6
	Percent change	1%	-2%	-16%	-34%	-11%	-2%	-2%	-2%	-1%	-3%	0%	23%	23%
		25%	-4%	-1%	-5%	-12%	-22%	-14%	-5%	-4%	-3%	8%	36%	36%
		50%	-6%	-6%	-6%	-3%	-4%	-7%	-15%	-6%	-5%	11%	37%	37%
		75%	-10%	-14%	-12%	-7%	-5%	-4%	-18%	-8%	-6%	17%	35%	35%
		99%	-37%	-29%	-32%	-18%	-5%	-3%	-3%	-1%	-2%	23%	28%	28%

Table 5-11. Average Monthly Flow Summary for Flathead River at Columbia Falls, Montana

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
NAA	Outflow (kcfs)	1%	8.9	14.4	14.8	11.0	14.2	17.4	30.5	38.0	43.2	23.9	8.8	8.7
		25%	4.0	4.2	4.5	5.0	5.8	7.9	15.9	29.7	31.5	15.1	6.9	5.4
		50%	3.8	3.7	3.7	3.8	3.8	4.5	12.3	25.5	24.8	11.5	5.8	4.7
		75%	3.6	3.6	3.6	3.6	3.6	3.7	8.5	21.4	20.0	8.4	4.9	4.2
		99%	3.5	3.5	3.5	3.5	3.5	3.5	5.4	15.7	12.4	5.5	3.9	3.6
MO1	Change (kcfs)	1%	-1.5	-2.3	-3.4	-1.3	-0.2	-0.4	-0.4	-0.2	-0.2	-0.1	0.7	-0.1
		25%	0.0	0.0	-0.6	-0.8	-0.9	-0.6	-0.6	-0.3	-0.2	0.2	0.5	0.6
		50%	0.0	0.0	0.0	-0.1	-0.1	-0.4	-0.7	-0.3	-0.2	0.2	0.4	0.5
		75%	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	-0.5	-0.5	0.0	0.3	0.3
		99%	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.3	0.1	0.3
	Percent change	1%	-17%	-16%	-23%	-12%	-1%	-3%	-1%	-1%	0%	0%	8%	-1%
		25%	0%	-1%	-14%	-15%	-15%	-7%	-3%	-1%	-1%	1%	8%	11%
		50%	0%	-1%	0%	-2%	-2%	-9%	-6%	-1%	-1%	2%	7%	11%
		75%	1%	0%	0%	0%	0%	-1%	-6%	-2%	-3%	0%	6%	8%
		99%	0%	0%	0%	-1%	0%	0%	-7%	-2%	-3%	-5%	2%	10%
MO2	Change (kcfs)	1%	0.1	-0.9	-0.5	2.4	0.0	-1.8	-3.6	0.6	-0.9	0.6	0.0	-0.6
		25%	-0.1	0.1	0.0	5.0	1.9	-0.5	-1.1	-0.8	-1.4	0.0	0.0	0.0
		50%	-0.1	0.0	0.0	3.4	0.4	-0.4	-0.8	0.2	-1.8	-0.3	-0.2	-0.1
		75%	-0.1	0.0	0.0	0.0	-0.1	-0.2	-0.6	-0.1	-1.5	-0.3	-0.3	-0.3
		99%	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.6	-0.1	-1.9	-0.1	-0.2	-0.1
	Percent change	1%	1%	-6%	-3%	22%	0%	-11%	-12%	2%	-2%	2%	0%	-7%
		25%	-3%	1%	-1%	100%	33%	-6%	-7%	-3%	-4%	0%	-1%	-1%
		50%	-4%	0%	0%	90%	11%	-9%	-6%	1%	-7%	-3%	-3%	-2%
		75%	-3%	0%	0%	0%	-2%	-6%	-7%	-1%	-7%	-3%	-6%	-6%
		99%	-4%	0%	0%	-1%	-2%	-3%	-11%	-1%	-15%	-2%	-5%	-3%
MO3	Change (kcfs)	1%	-1.7	-3.9	-3.5	-1.2	-0.5	-0.4	-0.3	-0.2	-0.1	0.0	0.7	-0.1
		25%	-0.2	-0.1	-0.7	-0.7	-1.0	-0.7	-0.5	-0.4	-0.1	0.3	0.5	0.6
		50%	-0.1	0.0	0.0	-0.1	-0.1	-0.5	-0.8	-0.3	-0.2	0.2	0.4	0.5
		75%	-0.1	0.0	0.0	0.0	0.0	-0.1	-0.7	-0.6	-0.5	0.0	0.3	0.4
		99%	-0.1	0.0	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.5	-0.3	0.1	0.3
	Percent change	1%	-19%	-27%	-23%	-11%	-3%	-3%	-1%	-1%	0%	0%	8%	-1%
		25%	-4%	-3%	-14%	-15%	-17%	-9%	-3%	-1%	0%	2%	8%	11%
		50%	-4%	-1%	-1%	-2%	-3%	-10%	-6%	-1%	-1%	2%	7%	11%
		75%	-2%	0%	0%	0%	0%	-2%	-8%	-3%	-3%	0%	6%	8%
		99%	-3%	0%	0%	0%	0%	0%	-8%	-3%	-4%	-5%	1%	9%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-1.7	-2.3	-3.4	-1.2	-0.2	-0.5	-0.4	-0.2	0.0	-0.1	0.8	0.8
		25%	-0.1	0.0	-0.6	-0.8	-1.0	-0.7	-0.6	-0.4	-0.2	0.2	0.9	1.0
		50%	-0.1	0.0	0.0	-0.1	-0.1	-0.4	-0.7	-0.2	-0.1	0.5	0.9	1.0
		75%	-0.1	0.0	0.0	0.0	0.0	0.0	-0.6	-0.4	-0.1	0.5	1.0	0.8
		99%	-0.1	0.0	0.0	0.0	0.0	0.0	-0.4	-0.3	-0.1	0.4	0.5	0.5
	Percent change	1%	-19%	-16%	-23%	-11%	-2%	-3%	-1%	-1%	0%	0%	9%	9%
		25%	-3%	-1%	-14%	-16%	-17%	-8%	-4%	-1%	-1%	2%	14%	19%
		50%	-3%	-1%	0%	-2%	-2%	-9%	-6%	-1%	0%	4%	16%	22%
		75%	-2%	0%	0%	0%	0%	-1%	-7%	-2%	-1%	5%	20%	19%
		99%	-3%	0%	0%	0%	0%	0%	-8%	-2%	-1%	7%	13%	14%

Table 5-12. Average Monthly Outflow Summary for Seli'š Ksanka Qlispe' Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	13.0	17.7	21.4	17.1	18.5	17.1	21.9	42.8	48.2	30.4	10.6	12.0
		25%	6.7	7.4	9.5	9.0	10.2	12.1	14.1	27.3	32.6	18.8	8.0	8.1
		50%	6.3	6.7	8.5	7.6	8.2	8.6	11.7	21.2	24.3	13.7	6.3	7.0
		75%	6.0	6.2	8.2	7.3	7.7	7.8	9.0	14.2	18.0	9.6	4.9	6.3
		99%	5.6	5.9	7.9	6.8	7.2	7.1	5.8	10.8	12.7	7.1	3.2	3.2
MO1	Change (kcfs)	1%	-1.6	-2.3	-3.5	-0.8	-0.4	-0.2	-0.1	0.0	0.0	-0.5	0.1	0.1
		25%	0.0	0.0	-0.4	-0.7	-0.9	-0.7	-0.3	-0.5	-0.3	-0.4	0.1	0.0
		50%	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.5	-0.8	-0.3	-0.2	0.0	0.0
		75%	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.4	-0.6	-0.7	-0.7	-0.1	-0.1
		99%	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	-12%	-13%	-16%	-5%	-2%	-1%	-1%	0%	0%	-2%	1%	1%
		25%	0%	-1%	-4%	-7%	-8%	-5%	-2%	-2%	-1%	-2%	2%	0%
		50%	0%	0%	0%	-1%	-1%	-3%	-4%	-4%	-1%	-2%	1%	0%
		75%	-1%	0%	0%	0%	-1%	-1%	-5%	-4%	-4%	-8%	-3%	-2%
		99%	0%	0%	0%	0%	0%	-1%	-1%	0%	0%	0%	0%	0%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO2	Change (kcfs)	1%	0.0	-0.8	-0.4	1.9	-0.3	-1.1	-1.7	-1.0	0.7	0.4	0.0	0.0
		25%	-0.2	0.0	-0.1	4.8	1.9	-0.5	-0.9	-1.5	-1.2	-0.2	0.0	-0.1
		50%	-0.2	0.0	0.0	3.3	0.5	-0.2	-0.6	-0.9	-1.5	-0.3	-0.1	-0.1
		75%	-0.2	0.0	0.0	0.2	0.0	-0.2	-0.6	-0.2	-1.1	-0.6	-0.3	-0.3
		99%	-0.2	0.0	0.0	0.0	0.0	-0.1	-0.3	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	-5%	-2%	11%	-2%	-6%	-8%	-2%	2%	1%	0%	0%
		25%	-3%	0%	-1%	53%	19%	-5%	-6%	-5%	-4%	-1%	0%	-2%
		50%	-3%	0%	0%	43%	6%	-2%	-5%	-4%	-6%	-2%	-1%	-1%
		75%	-4%	0%	0%	3%	0%	-3%	-6%	-1%	-6%	-6%	-5%	-5%
		99%	-3%	0%	0%	0%	0%	-1%	-6%	0%	0%	0%	0%	0%
MO3	Change (kcfs)	1%	-1.9	-3.4	-3.5	-1.2	-1.3	-0.3	-0.2	-0.1	0.1	-0.3	0.1	0.2
		25%	-0.3	-0.1	-0.5	-0.6	-1.0	-0.8	-0.3	-0.6	-0.3	-0.3	0.1	0.0
		50%	-0.2	0.0	-0.1	-0.1	-0.1	-0.3	-0.6	-0.8	-0.2	-0.2	0.0	0.0
		75%	-0.2	0.0	0.0	0.0	-0.1	-0.1	-0.5	-0.7	-0.7	-0.7	-0.1	-0.1
		99%	-0.2	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	-14%	-19%	-17%	-7%	-7%	-2%	-1%	0%	0%	-1%	1%	1%
		25%	-4%	-2%	-5%	-7%	-9%	-6%	-2%	-2%	-1%	-2%	2%	0%
		50%	-3%	0%	-1%	-1%	-2%	-3%	-5%	-4%	-1%	-1%	1%	0%
		75%	-4%	0%	0%	0%	-1%	-1%	-6%	-5%	-4%	-8%	-3%	-2%
		99%	-3%	0%	0%	0%	0%	-1%	-3%	0%	0%	0%	0%	0%
M04	Change (kcfs)	1%	-1.8	-2.3	-3.5	-0.9	-0.6	-0.4	-0.2	0.0	0.0	-0.5	0.3	1.0
		25%	-0.2	0.0	-0.4	-0.7	-0.9	-0.7	-0.3	-0.6	-0.3	-0.3	0.4	0.5
		50%	-0.2	0.0	0.0	-0.1	-0.1	-0.2	-0.5	-0.7	0.0	-0.1	0.8	0.5
		75%	-0.2	0.0	0.0	0.0	-0.1	-0.1	-0.5	-0.5	-0.5	-0.1	0.5	0.4
		99%	-0.2	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	-14%	-13%	-16%	-5%	-3%	-2%	-1%	0%	0%	-2%	2%	8%
		25%	-3%	-1%	-4%	-8%	-9%	-6%	-2%	-2%	-1%	-2%	5%	6%
		50%	-3%	0%	0%	-1%	-1%	-3%	-4%	-3%	0%	-1%	12%	7%
		75%	-3%	0%	0%	0%	-1%	-1%	-5%	-4%	-3%	-1%	11%	6%
		99%	-3%	0%	0%	0%	0%	-1%	-2%	0%	0%	0%	0%	0%

Table 5-13. Average Monthly Outflow Summary for Cabinet Gorge Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	21.9	24.7	39.8	32.7	33.7	36.9	55.0	94.4	104.9	50.8	18.5	18.2
		25%	10.7	13.2	14.5	13.9	16.7	20.0	29.8	59.1	70.5	34.2	13.7	12.4
		50%	9.8	10.9	12.4	11.5	13.2	15.7	23.7	47.0	51.8	25.7	11.2	10.6
		75%	8.5	9.6	11.2	10.1	11.5	13.3	17.8	34.8	39.5	17.1	8.4	9.0
		99%	7.6	8.6	10.4	9.3	9.9	11.2	9.7	24.0	23.6	12.1	5.6	5.7
MO1	Change (kcfs)	1%	-1.4	-1.2	-3.6	-0.7	-0.2	-1.0	0.0	0.0	0.0	-0.6	0.2	0.0
		25%	0.0	-0.2	-0.5	-0.5	-0.7	-0.5	-0.2	-0.6	-0.2	-0.3	0.2	0.1
		50%	0.0	-0.1	0.0	-0.3	-0.2	-0.2	-0.4	-0.6	-0.8	-0.3	-0.1	0.1
		75%	0.0	0.0	0.0	0.0	-0.1	0.0	-0.5	-0.6	-0.2	-0.4	-0.6	-0.3
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.8	0.0	-0.1	-0.1	-0.3
	Percent change	1%	-6%	-5%	-9%	-2%	-1%	-3%	0%	0%	0%	-1%	1%	0%
		25%	0%	-2%	-4%	-4%	-4%	-2%	-1%	-1%	0%	-1%	1%	1%
		50%	0%	-1%	0%	-2%	-2%	-1%	-2%	-1%	-2%	-1%	-1%	1%
		75%	0%	0%	0%	0%	-1%	0%	-3%	-2%	-1%	-3%	-7%	-3%
		99%	0%	0%	0%	0%	0%	0%	0%	-3%	0%	0%	-2%	-5%
MO2	Change (kcfs)	1%	0.1	-0.8	-0.5	2.0	-1.1	-1.1	-1.7	-0.8	1.3	0.1	0.0	0.0
		25%	0.0	0.1	0.0	4.3	1.7	-0.4	-0.8	-0.6	-0.9	-0.3	0.1	0.1
		50%	0.0	0.0	-0.1	3.4	0.8	-0.3	-0.4	-1.4	-1.5	-0.5	-0.2	-0.1
		75%	0.0	0.0	0.0	0.6	0.3	-0.1	-0.6	-0.1	-2.0	-0.7	-0.6	-0.4
		99%	0.0	0.0	0.0	0.0	0.0	-0.1	-0.2	-0.6	0.0	-0.8	-0.1	-0.4
	Percent change	1%	0%	-3%	-1%	6%	-3%	-3%	-3%	-1%	1%	0%	0%	0%
		25%	0%	0%	0%	31%	10%	-2%	-3%	-1%	-1%	-1%	0%	1%
		50%	0%	0%	-1%	30%	6%	-2%	-2%	-3%	-3%	-2%	-2%	-1%
		75%	0%	0%	0%	6%	2%	0%	-3%	0%	-5%	-4%	-8%	-4%
		99%	-1%	0%	0%	0%	0%	-1%	-2%	-2%	0%	-6%	-2%	-7%
MO3	Change (kcfs)	1%	-1.5	-1.4	-3.6	-1.4	-0.3	-1.0	0.1	-0.2	0.1	-0.5	0.2	0.1
		25%	0.0	-0.2	-0.5	-0.5	-0.8	-0.5	-0.3	-0.5	-0.1	-0.3	0.2	0.1
		50%	0.0	-0.1	-0.1	-0.3	-0.3	-0.3	-0.4	-0.6	-0.9	-0.2	-0.1	0.1
		75%	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.5	-0.7	-0.3	-0.4	-0.6	-0.3
		99%	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.7	0.0	-0.1	-0.1	-0.3
	Percent change	1%	-7%	-6%	-9%	-4%	-1%	-3%	0%	0%	0%	-1%	1%	0%
		25%	0%	-2%	-4%	-3%	-5%	-2%	-1%	-1%	0%	-1%	1%	1%
		50%	0%	-1%	-1%	-3%	-2%	-2%	-2%	-1%	-2%	-1%	-1%	1%
		75%	0%	0%	0%	0%	-1%	-1%	-3%	-2%	-1%	-2%	-7%	-3%
		99%	-1%	0%	0%	0%	0%	0%	-1%	-3%	0%	0%	-2%	-5%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-1.5	-1.3	-3.6	-0.8	-0.2	-1.0	0.0	0.0	0.0	-0.6	0.2	0.5
		25%	0.0	-0.2	-0.5	-0.5	-0.7	-0.5	-0.2	-0.6	-0.1	-0.3	0.3	0.4
		50%	0.0	-0.1	0.0	-0.3	-0.3	-0.2	-0.4	-0.6	-0.9	-0.1	0.5	0.5
		75%	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.5	-0.5	-0.1	0.2	0.5	0.4
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	0.0	0.0	0.0	0.0
	Percent change	1%	-7%	-5%	-9%	-2%	-1%	-3%	0%	0%	0%	-1%	1%	3%
		25%	0%	-2%	-4%	-4%	-4%	-2%	-1%	-1%	0%	-1%	2%	3%
		50%	0%	-1%	0%	-3%	-2%	-1%	-2%	-1%	-2%	-1%	4%	5%
		75%	0%	0%	0%	0%	-1%	-1%	-3%	-2%	0%	1%	5%	5%
		99%	0%	0%	0%	0%	0%	0%	0%	-2%	0%	0%	0%	0%

Table 5-14. Average Monthly Outflow Summary for Albeni Falls Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	36.4	30.8	46.3	49.9	40.5	39.6	54.5	99.1	126.5	57.6	21.0	23.0
		25%	24.9	19.2	18.5	17.7	20.3	24.3	32.4	64.2	77.9	37.2	14.9	15.7
		50%	23.7	16.7	15.3	14.5	16.6	19.8	25.2	50.7	55.6	27.4	12.0	13.7
		75%	22.6	15.1	13.5	12.5	14.0	16.9	18.3	36.4	39.6	18.6	9.5	11.9
		99%	21.6	13.2	12.1	10.9	11.5	14.2	9.2	24.7	22.3	13.5	6.6	9.3
MO1	Change (kcfs)	1%	-0.3	-0.7	-5.1	-1.1	2.7	-0.5	-0.1	0.0	0.0	-0.5	0.2	-0.2
		25%	0.0	0.0	-0.2	0.0	-0.8	-0.3	-0.3	-0.7	-0.2	-0.3	0.2	0.2
		50%	0.0	0.0	0.0	-0.1	-0.4	-0.2	-0.7	-0.5	-0.3	-0.3	0.0	-0.1
		75%	0.0	0.0	0.0	0.0	0.0	-0.2	-0.5	-0.5	-0.2	-0.7	-0.6	-0.2
		99%	-0.1	0.0	0.0	0.0	0.0	0.0	-0.7	-0.8	-0.1	-0.1	-0.2	-0.9
	Percent change	1%	-1%	-2%	-11%	-2%	7%	-1%	0%	0%	0%	-1%	1%	-1%
		25%	0%	0%	-1%	0%	-4%	-1%	-1%	-1%	0%	-1%	1%	1%
		50%	0%	0%	0%	-1%	-2%	-1%	-3%	-1%	-1%	-1%	0%	-1%
		75%	0%	0%	0%	0%	0%	-1%	-2%	-1%	0%	-4%	-6%	-1%
		99%	0%	0%	0%	0%	0%	0%	-7%	-3%	0%	-1%	-3%	-10%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO2	Change (kcfs)	1%	-0.7	0.0	-1.4	1.2	2.9	-1.1	-1.2	-1.0	1.0	-0.6	0.0	-0.2
		25%	-0.9	0.0	0.0	3.8	2.0	-0.2	-0.9	-1.4	-0.9	-0.3	0.0	0.0
		50%	-0.9	-0.1	0.0	3.2	1.0	-0.3	-0.8	-1.2	-1.4	-0.3	-0.1	-0.3
		75%	-0.9	0.0	0.0	0.9	0.2	-0.3	-0.5	0.1	-0.8	-0.7	-0.6	-0.3
		99%	-1.0	0.0	0.0	0.1	0.0	-0.2	-0.7	-0.6	0.0	-0.6	-0.2	-0.9
	Percent change	1%	-2%	0%	-3%	2%	7%	-3%	-2%	-1%	1%	-1%	0%	-1%
		25%	-3%	0%	0%	22%	10%	-1%	-3%	-2%	-1%	-1%	0%	0%
		50%	-4%	-1%	0%	22%	6%	-2%	-3%	-2%	-3%	-1%	-1%	-2%
		75%	-4%	0%	0%	7%	1%	-2%	-3%	0%	-2%	-4%	-7%	-2%
		99%	-5%	0%	0%	1%	0%	-1%	-8%	-2%	0%	-5%	-3%	-10%
MO3	Change (kcfs)	1%	-1.3	-0.7	-5.1	-1.7	-1.2	-0.8	-0.1	-0.1	0.2	-0.3	0.2	-0.1
		25%	-0.9	0.0	-0.2	-0.1	-0.9	-0.3	-0.4	-0.8	-0.1	-0.3	0.2	0.2
		50%	-0.9	-0.1	0.0	-0.1	-0.4	-0.2	-0.7	-0.5	-0.3	-0.3	0.0	-0.1
		75%	-1.0	0.0	0.0	0.0	-0.1	-0.2	-0.5	-0.6	-0.1	-0.7	-0.5	-0.2
		99%	-1.0	0.0	0.0	0.0	0.0	0.0	-0.8	-0.7	-0.1	-0.1	-0.2	-0.9
	Percent change	1%	-4%	-2%	-11%	-3%	-3%	-2%	0%	0%	0%	0%	1%	0%
		25%	-4%	0%	-1%	-1%	-4%	-1%	-1%	-1%	0%	-1%	1%	1%
		50%	-4%	-1%	0%	-1%	-3%	-1%	-3%	-1%	-1%	-1%	0%	-1%
		75%	-4%	0%	0%	0%	0%	-1%	-3%	-2%	0%	-4%	-5%	-1%
		99%	-5%	0%	0%	0%	0%	0%	-9%	-3%	0%	-1%	-3%	-10%
M04	Change (kcfs)	1%	-1.4	-0.9	-5.1	-1.4	2.3	-0.7	-0.1	0.0	0.0	-0.5	0.2	-0.2
		25%	-0.9	0.0	-0.2	0.0	-0.8	-0.3	-0.4	-0.9	0.1	-0.3	0.7	0.0
		50%	-0.9	-0.1	0.0	-0.1	-0.4	-0.2	-0.7	-0.5	0.4	0.6	0.7	-0.5
		75%	-0.9	0.0	0.0	0.0	0.0	-0.2	-0.5	-0.2	2.1	0.4	0.4	-0.7
		99%	-1.0	0.0	0.0	0.0	0.0	0.0	-0.8	0.6	2.8	0.1	-0.1	-2.1
	Percent change	1%	-4%	-3%	-11%	-3%	6%	-2%	0%	0%	0%	-1%	1%	-1%
		25%	-4%	0%	-1%	0%	-4%	-1%	-1%	-1%	0%	-1%	5%	0%
		50%	-4%	-1%	0%	-1%	-3%	-1%	-3%	-1%	1%	2%	5%	-4%
		75%	-4%	0%	0%	0%	0%	-1%	-3%	-1%	5%	2%	4%	-6%
		99%	-4%	0%	0%	0%	0%	0%	-9%	2%	13%	1%	-1%	-23%

5.6.1.8 Annual Flow-Duration Plots

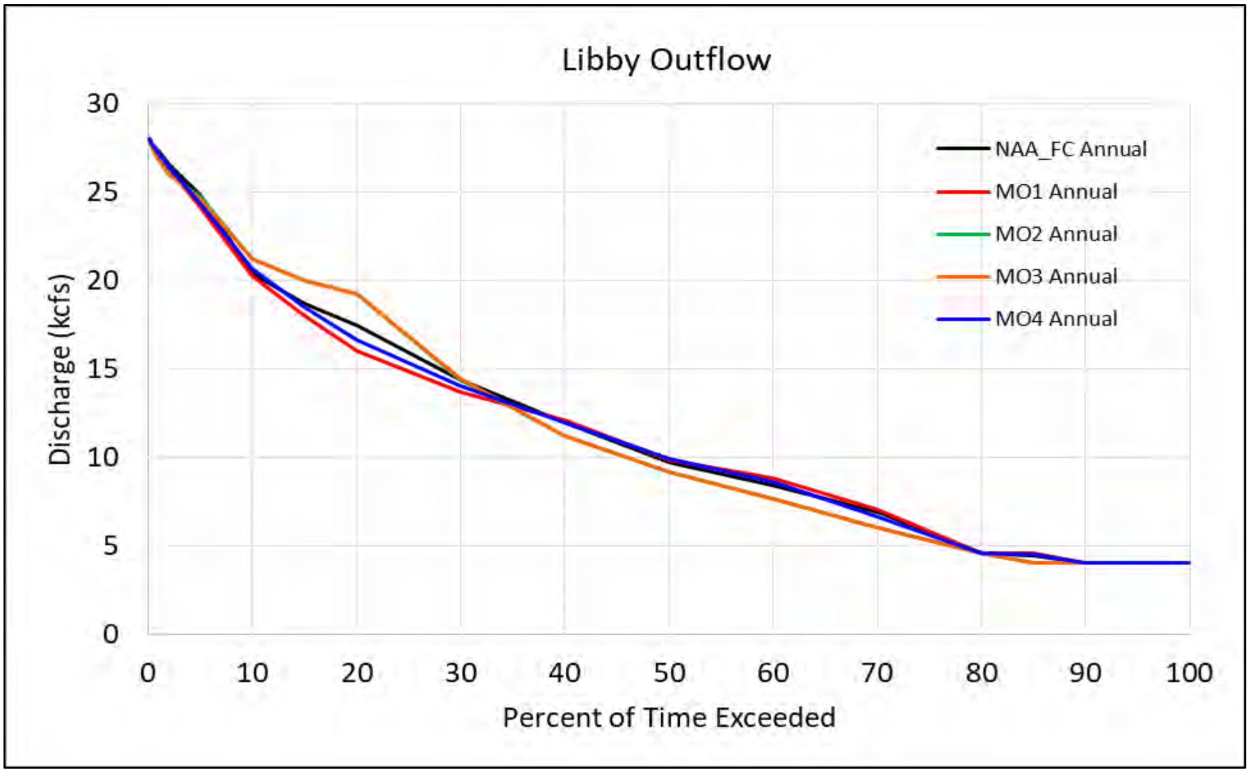


Figure 5-45. Annual Flow-Duration Curves for Libby Dam Outflow

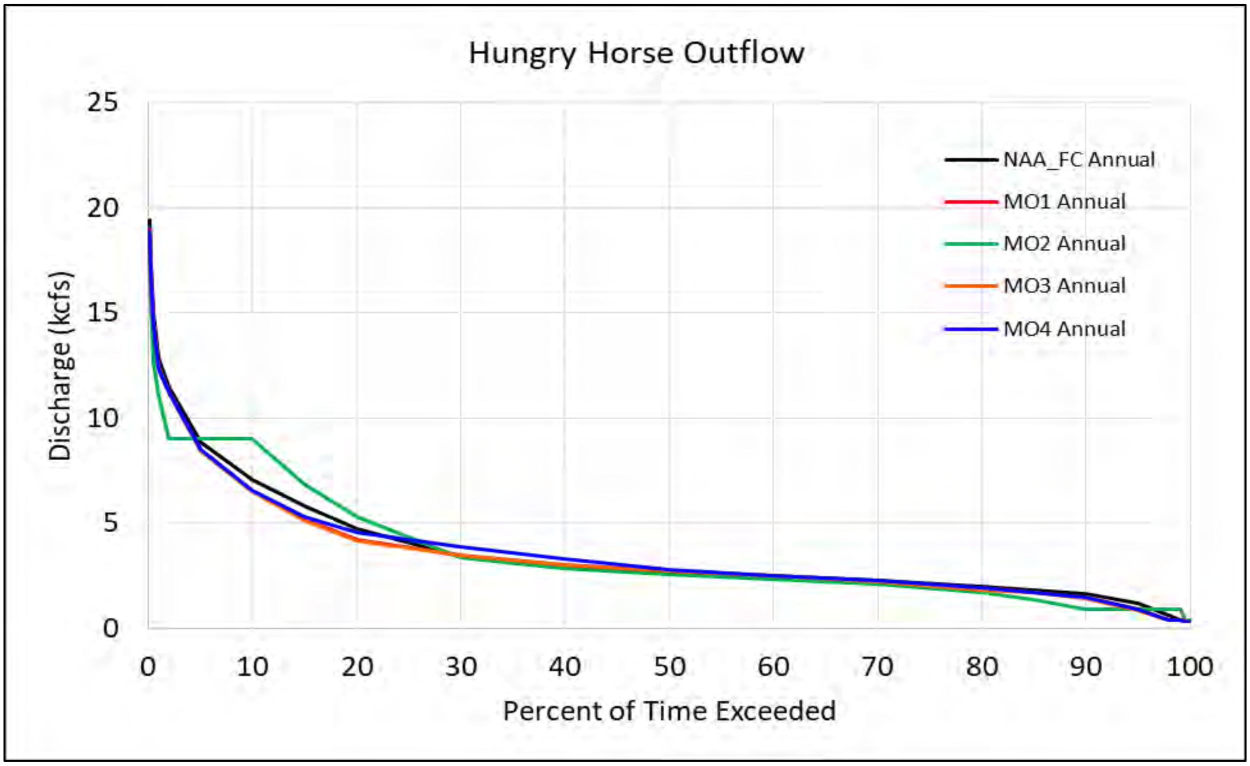
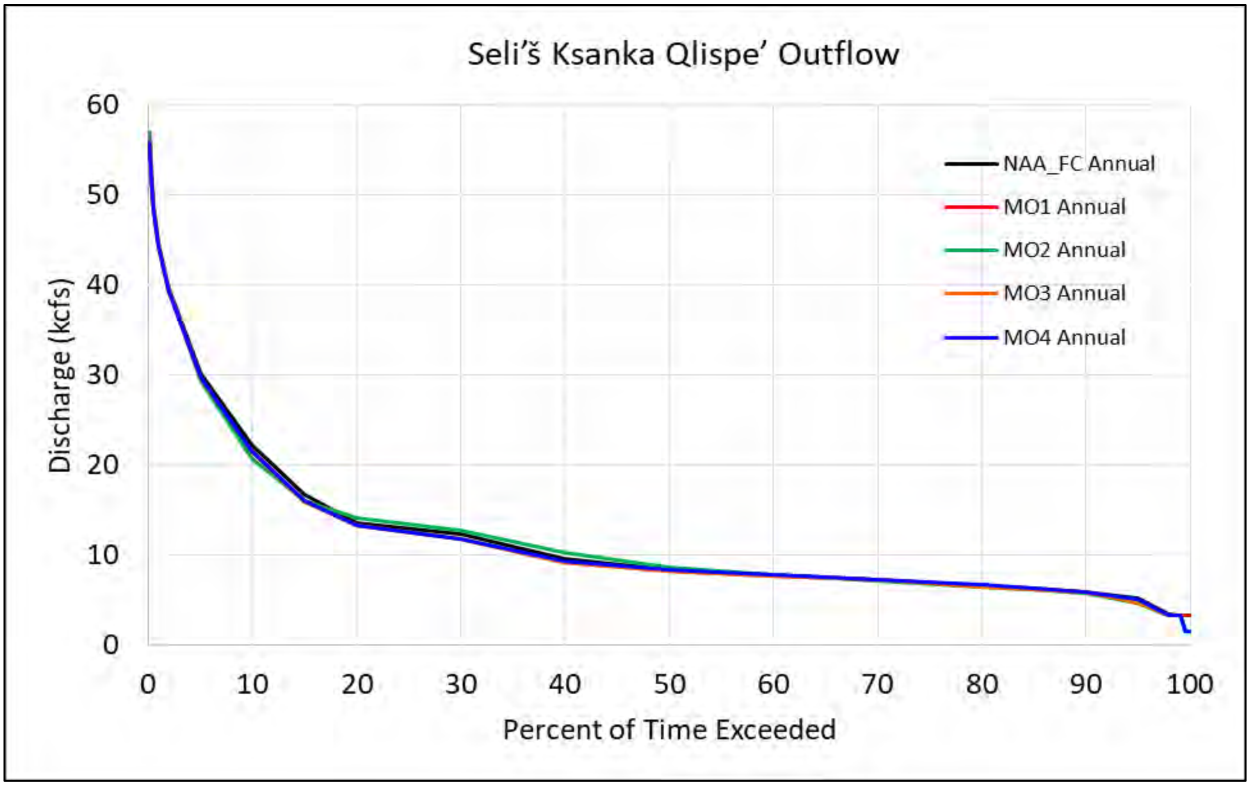
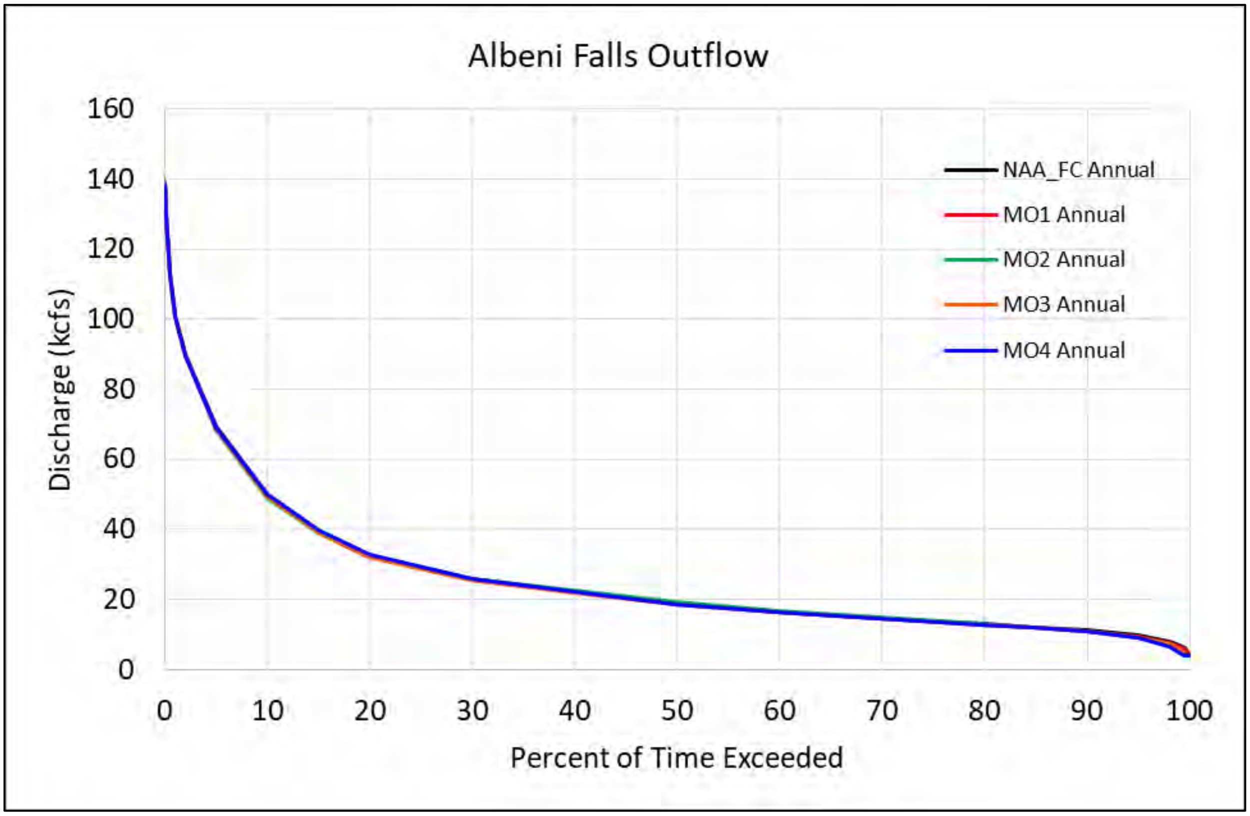


Figure 5-46. Annual Flow-Duration Curves for Hungry Horse Dam Outflow



3369

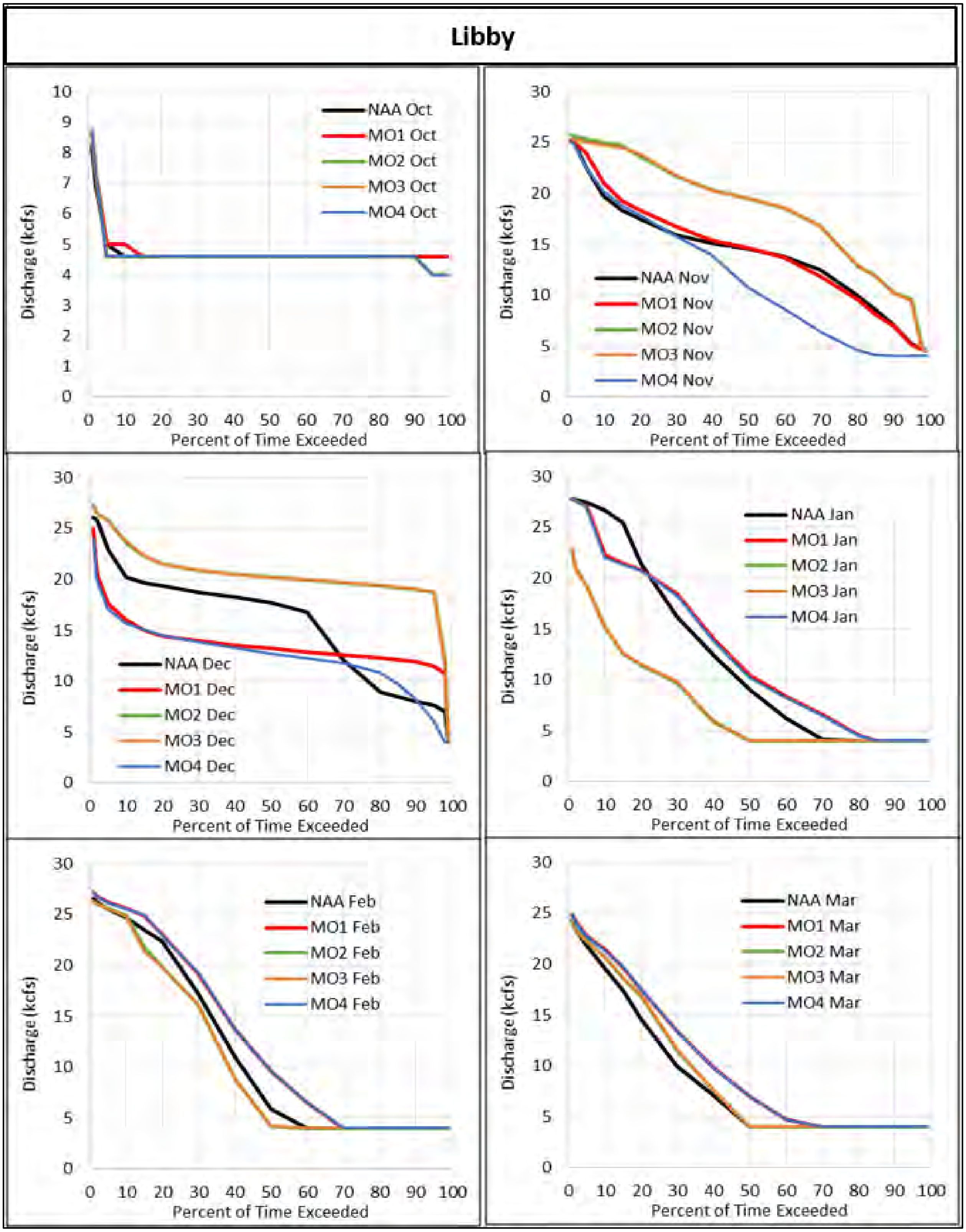
3370 **Figure 5-47. Annual Flow-Duration Curves for Seli'š Ksanka Qlispe' Dam Outflow**



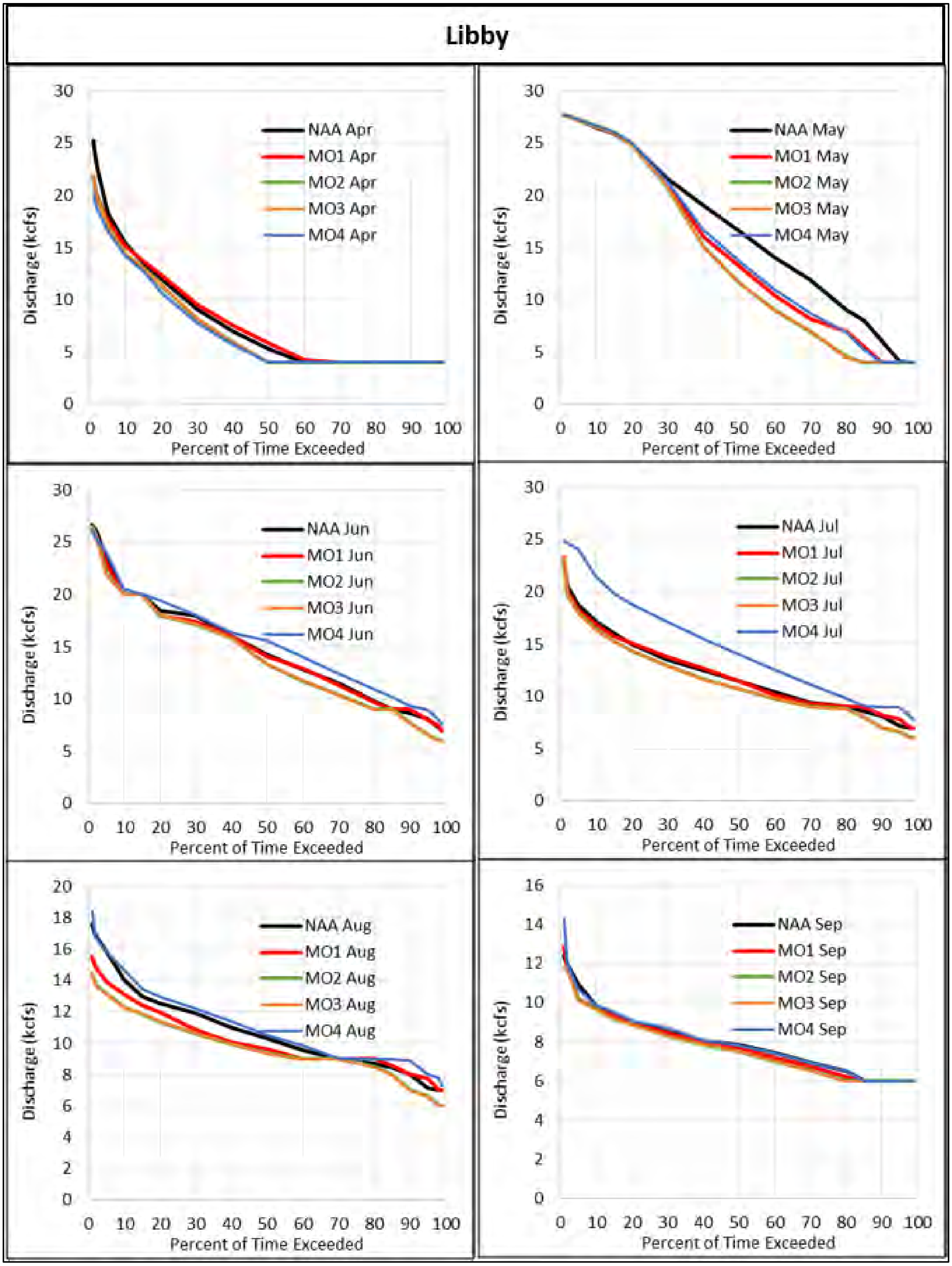
3371

3372 **Figure 5-48. Annual Flow-Duration Curves for Albeni Falls Dam Outflow**

3373
5.6.1.9 Monthly Flow-Duration Plots

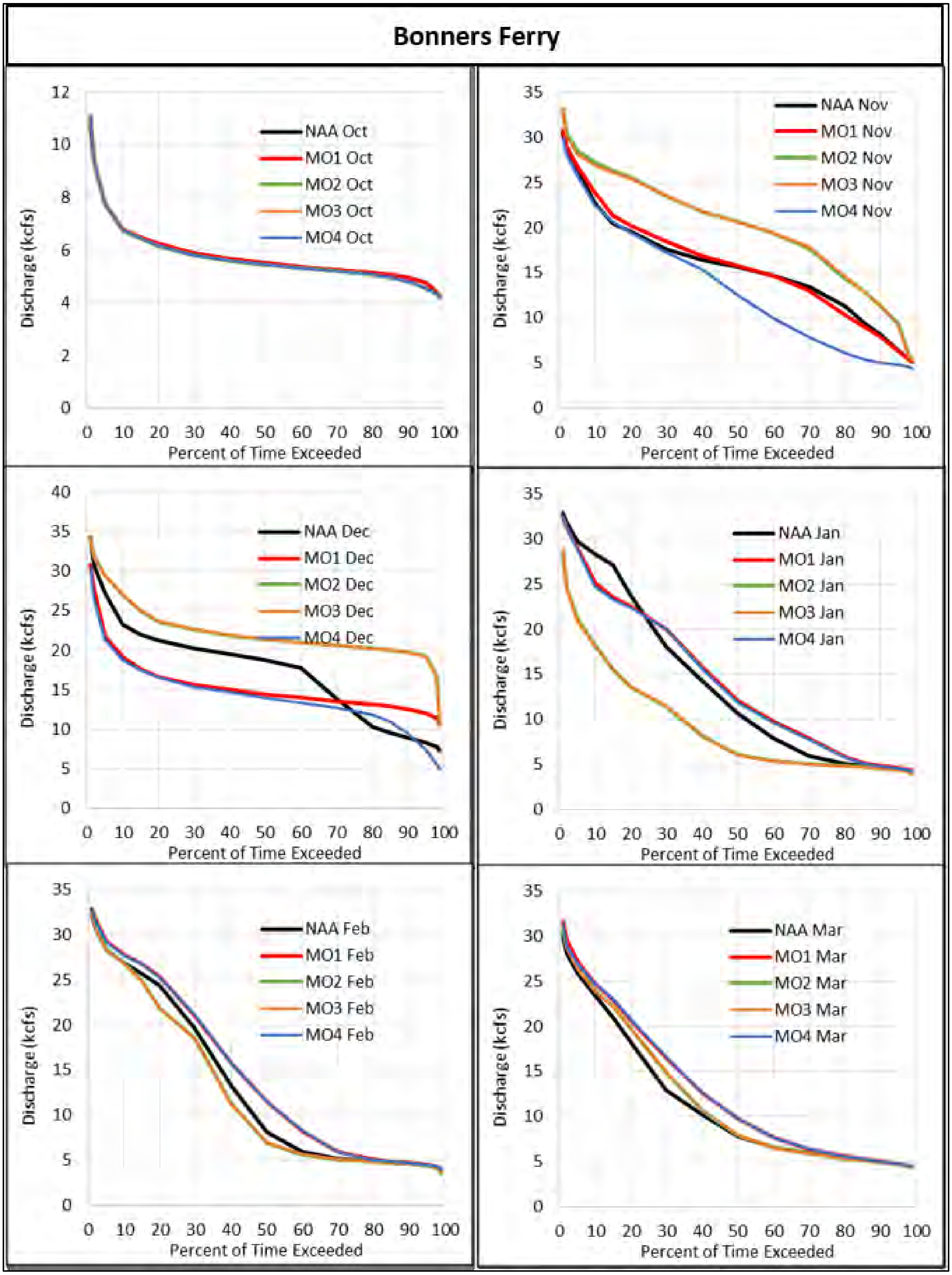


3374
3375 **Figure 5-49. Monthly Flow-Duration Curves for Libby Dam Outflow**



3376

3377 **Figure 5-50. Monthly Flow-Duration Curves for Libby Dam Outflow (continued)**



3379 **Figure 5-51. Monthly Flow-Duration Curves for Bonners Ferry, Idaho**

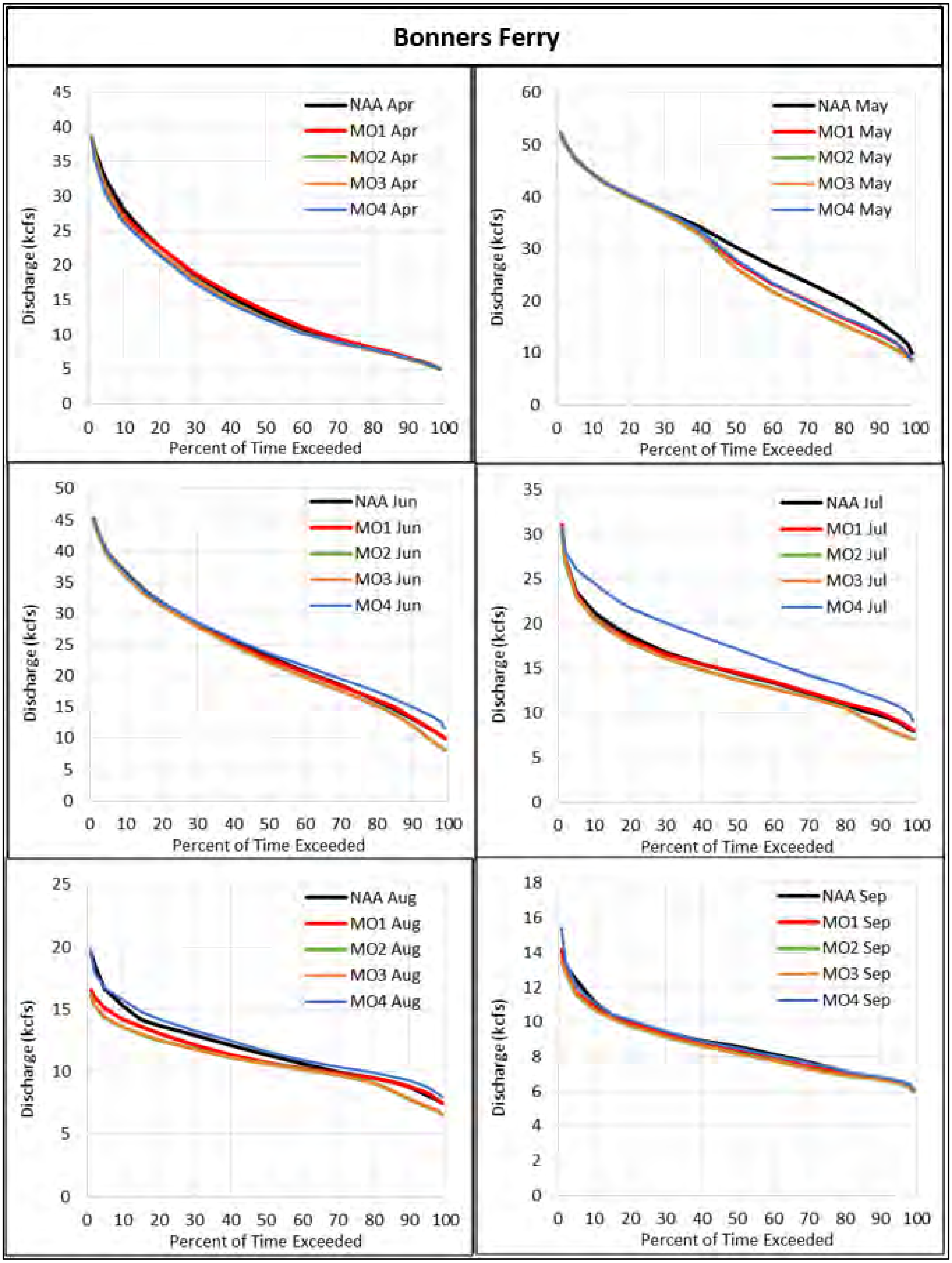


Figure 5-52. Monthly Flow-Duration Curves for Bonners Ferry, Idaho (continued)

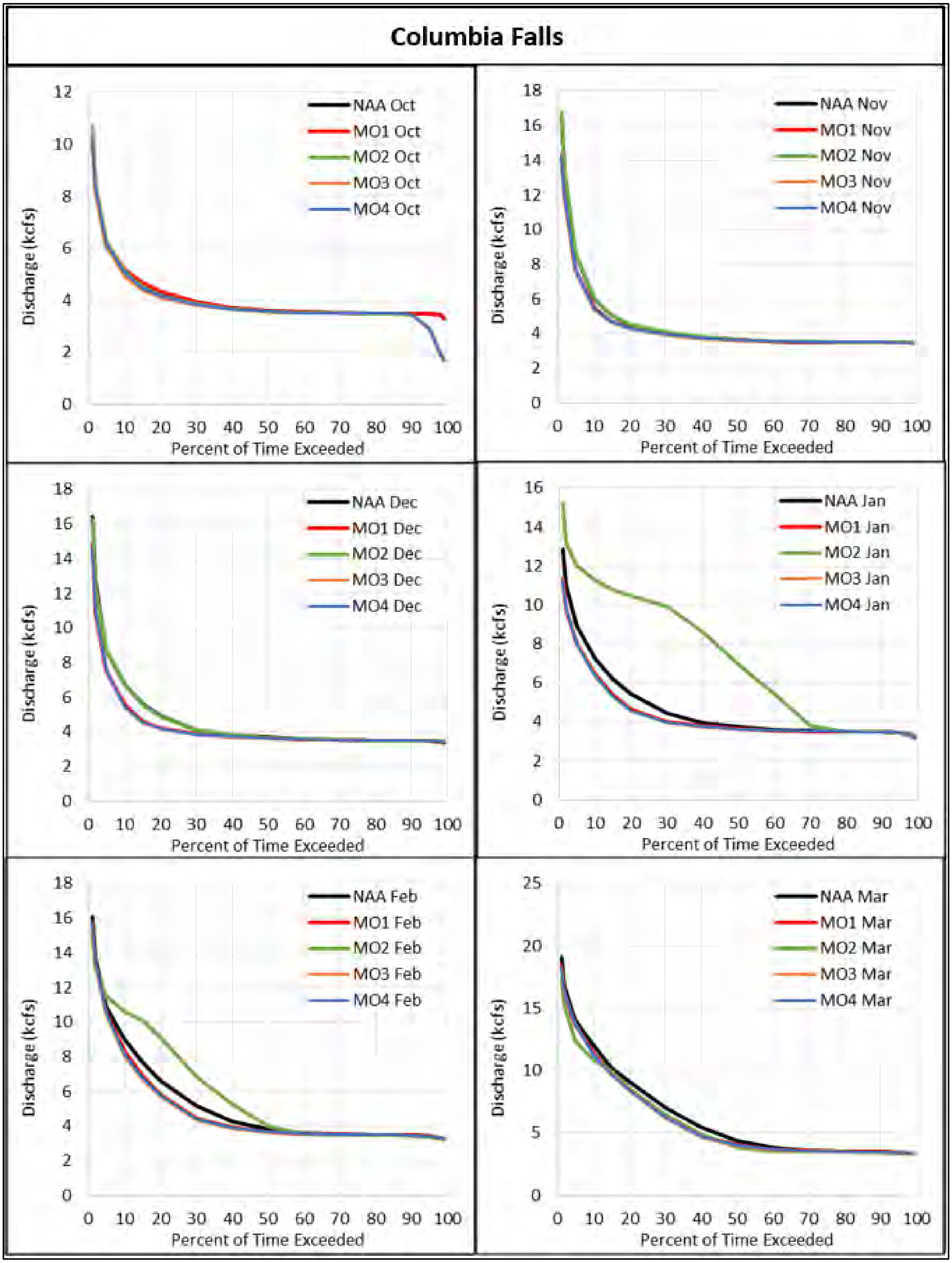


Figure 5-53. Monthly Flow-Duration Curves for Columbia Falls, Montana

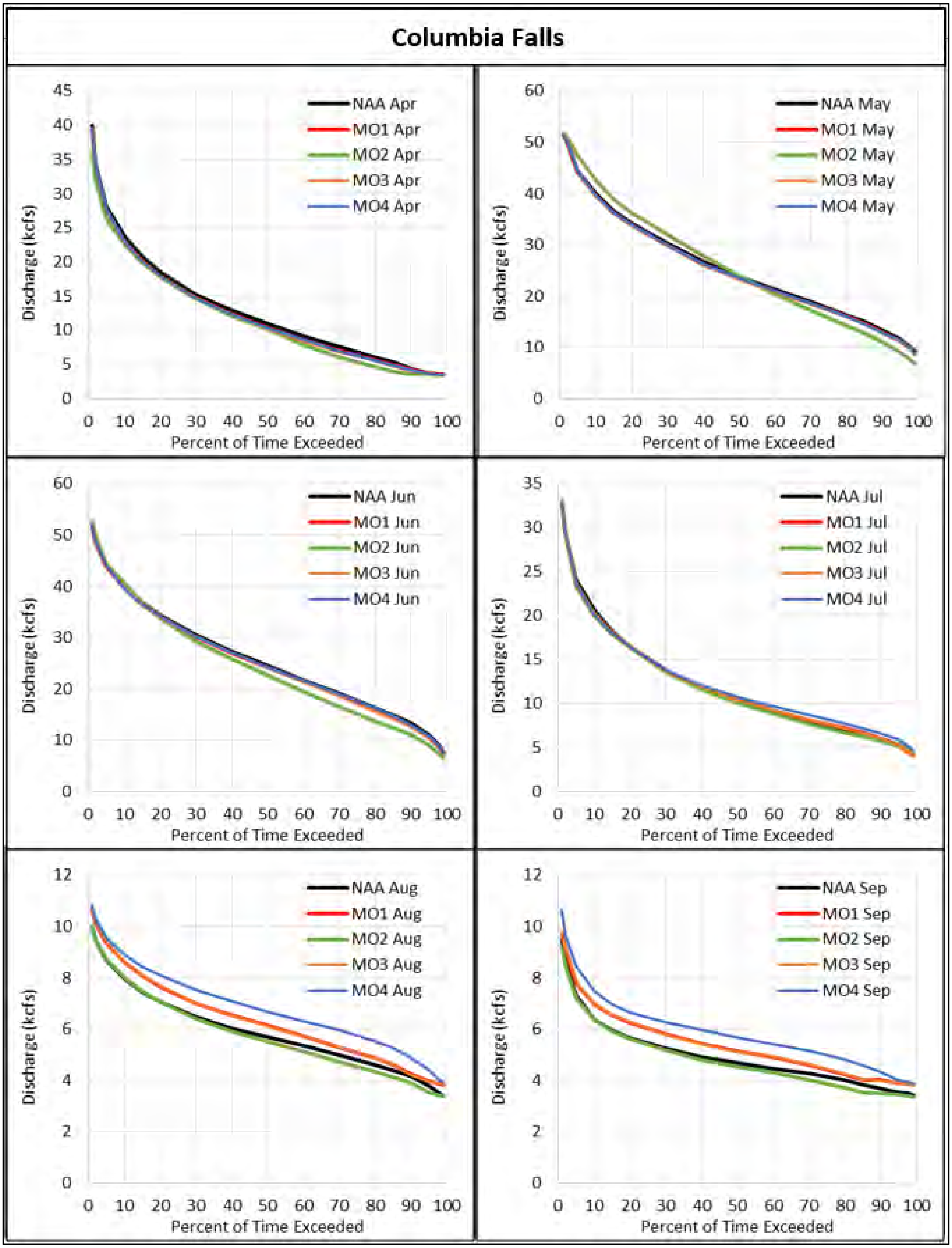


Figure 5-54. Monthly Flow-Duration Curves for Columbia Falls, Montana (continued)

5.6.1.10 Peak Flow-Frequency Plots

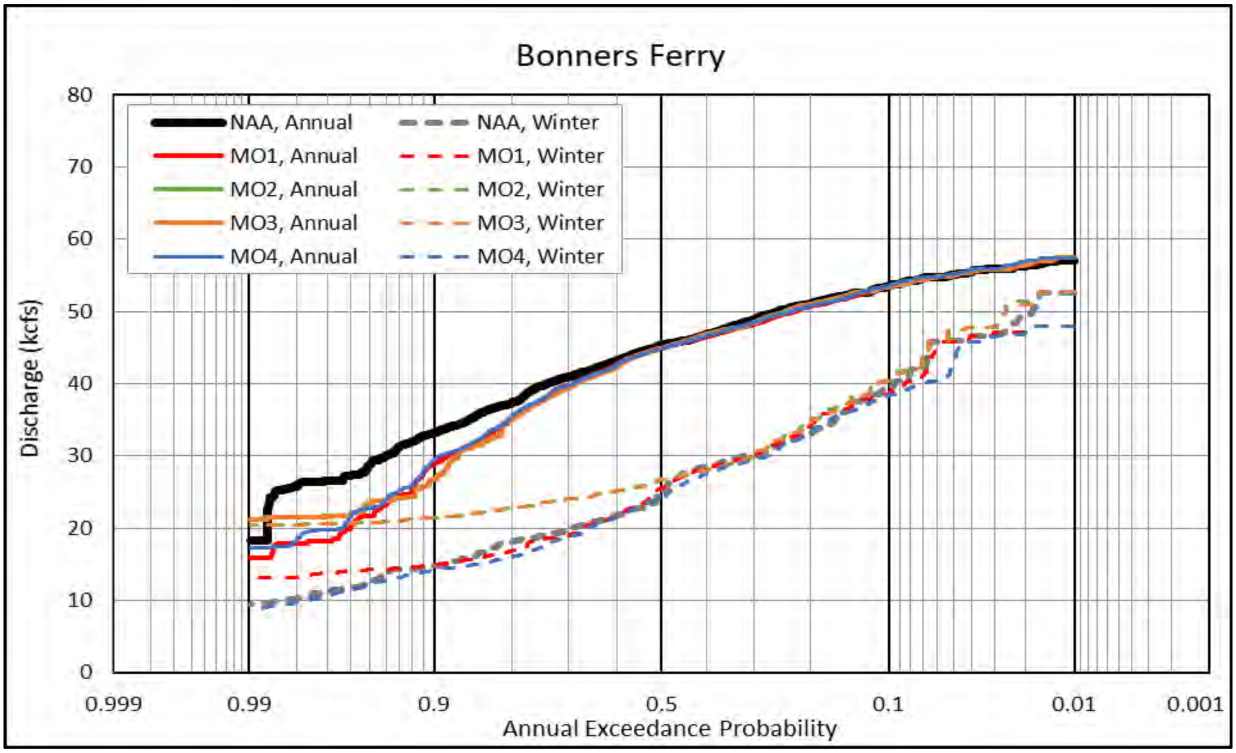


Figure 5-55. Peak Flow-Frequency Curves for Bonners Ferry, Idaho

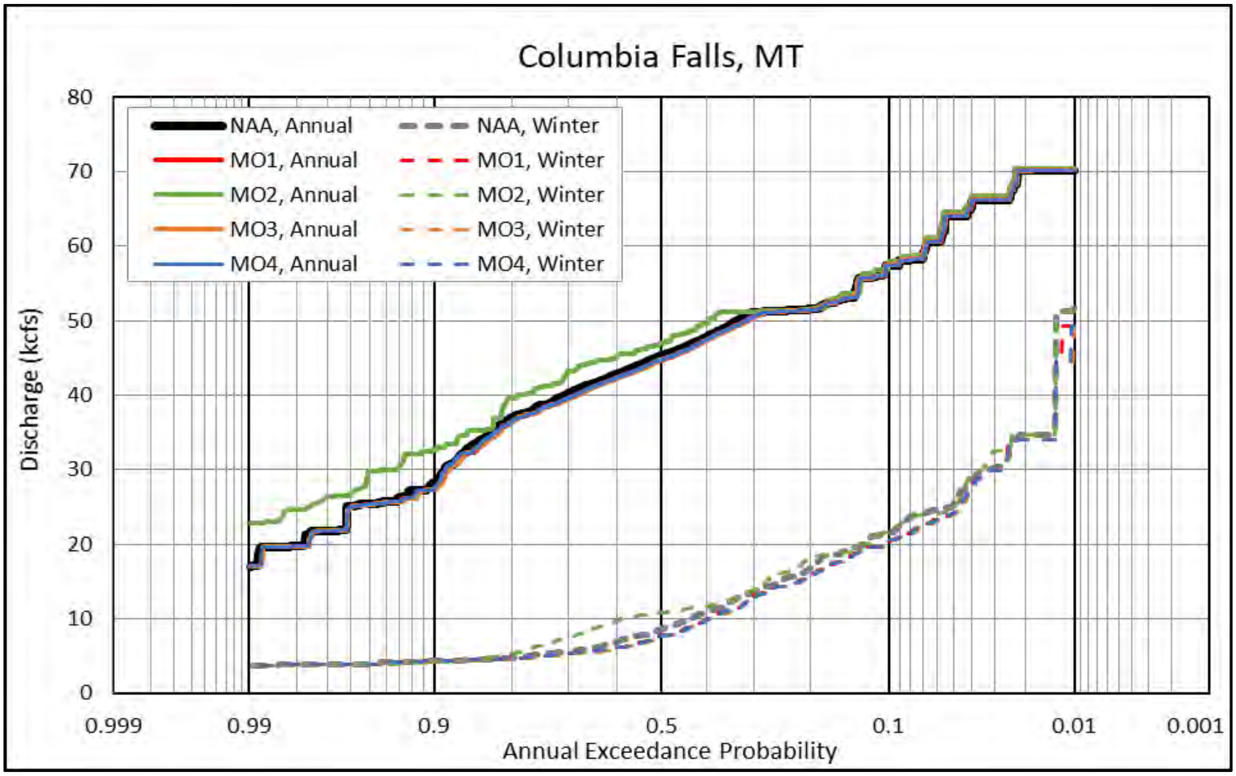
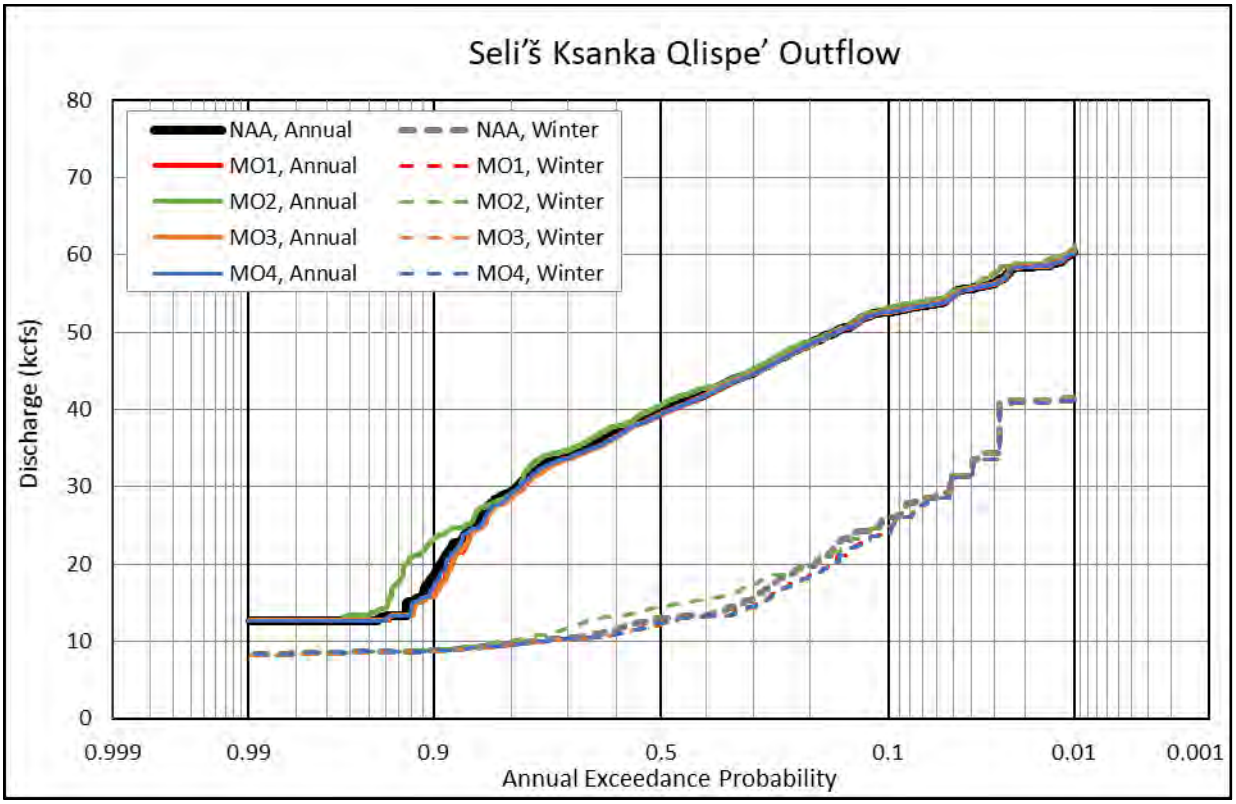
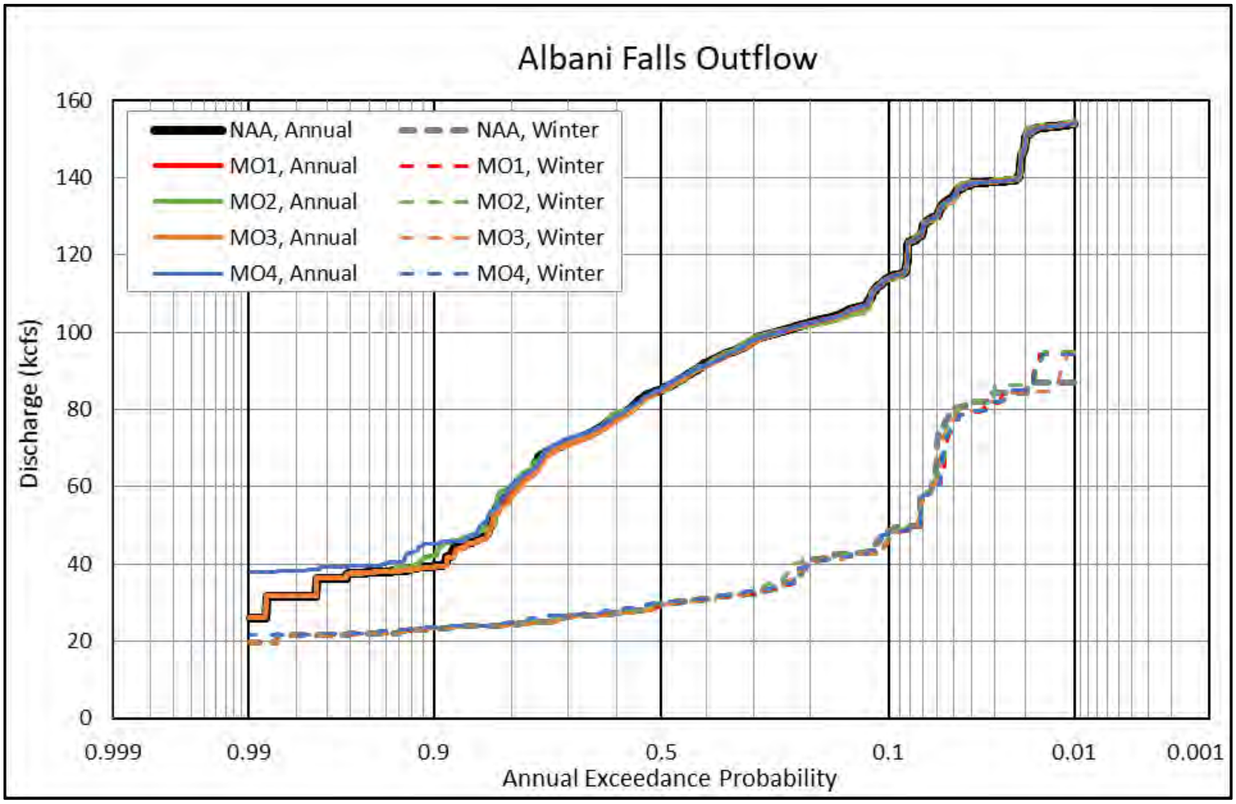


Figure 5-56. Peak Flow-Frequency Curves for Columbia Falls, Montana



3391

3392 **Figure 5-57. Peak Flow-Frequency Curves for Seli'š Ksanka Qlispe' Dam**



3393

3394 **Figure 5-58. Peak Flow-Frequency Curves for Albeni Falls Dam Outflow**

5.6.2 Region B – Middle Columbia River Basin

5.6.2.1 Water Year Plots, Elevation

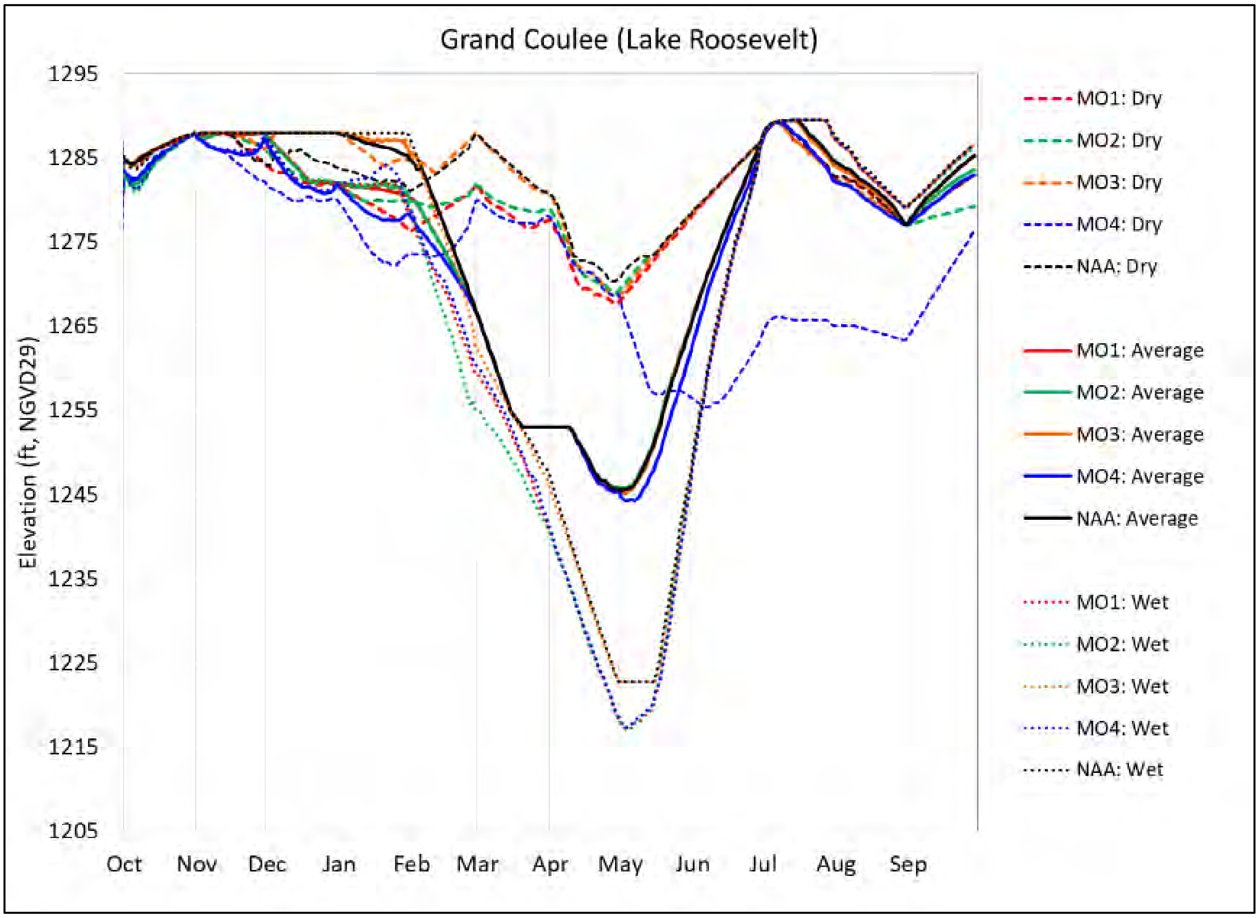
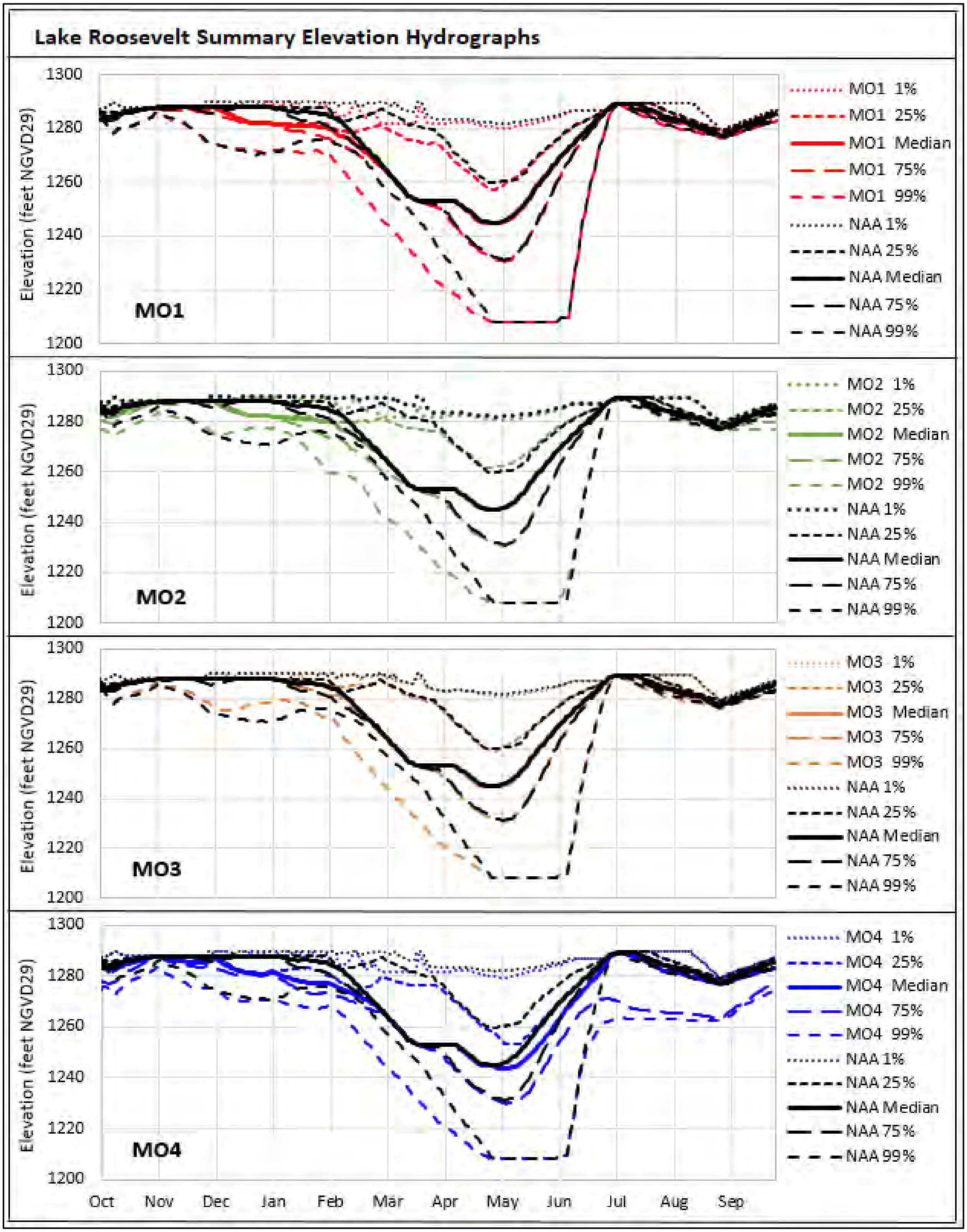


Figure 5-59. Summary Elevation Hydrographs for Dry, Average, and Wet Water Years at Grand Coulee (Lake Roosevelt)

3400 *5.6.2.2 Summary Elevation Hydrographs*



3401

3402 Figure 5-60. Summary Elevation Hydrographs at Grand Coulee (Lake Roosevelt)

5.6.2.3 Reservoir Target Date Elevation-Frequency Plots

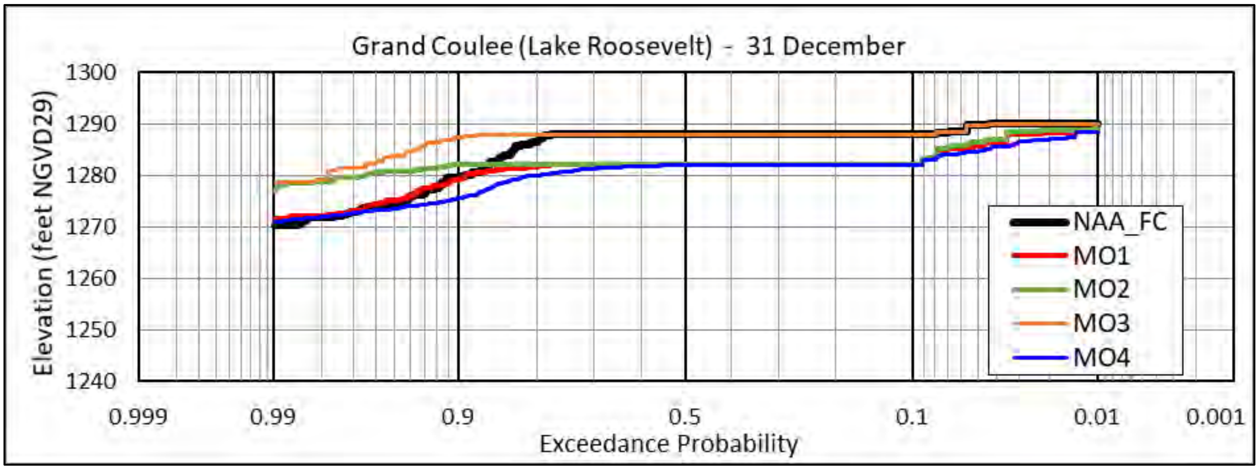


Figure 5-61. Elevation-Frequency Curves for December 31 at Grand Coulee (Lake Roosevelt)

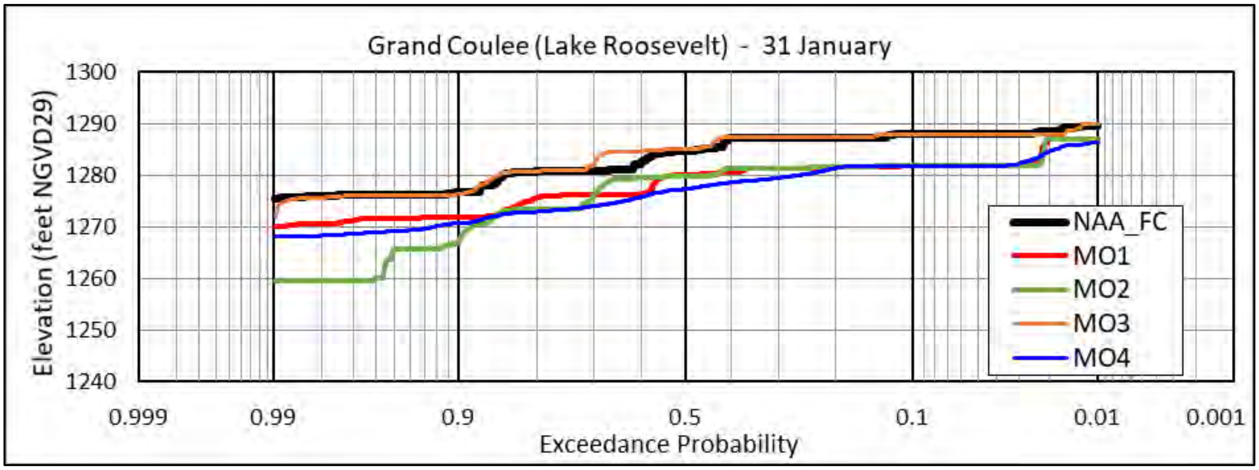


Figure 5-62. Elevation-Frequency Curves for January 31 at Grand Coulee (Lake Roosevelt)

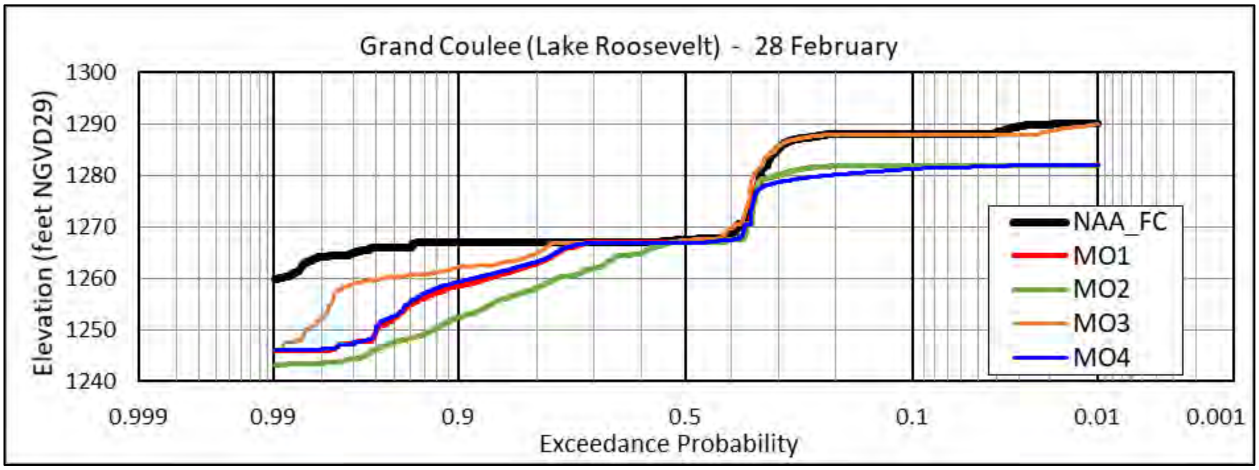
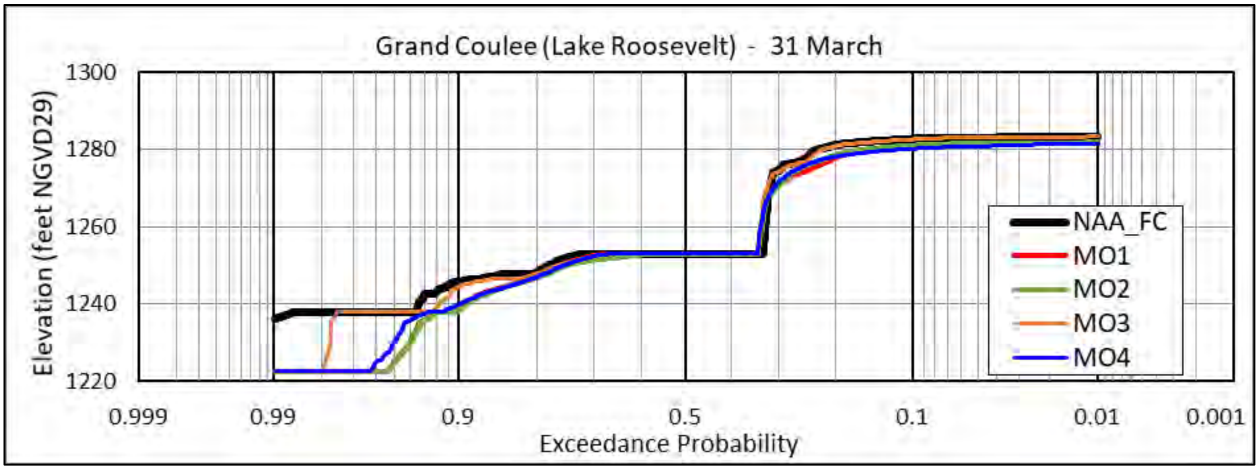
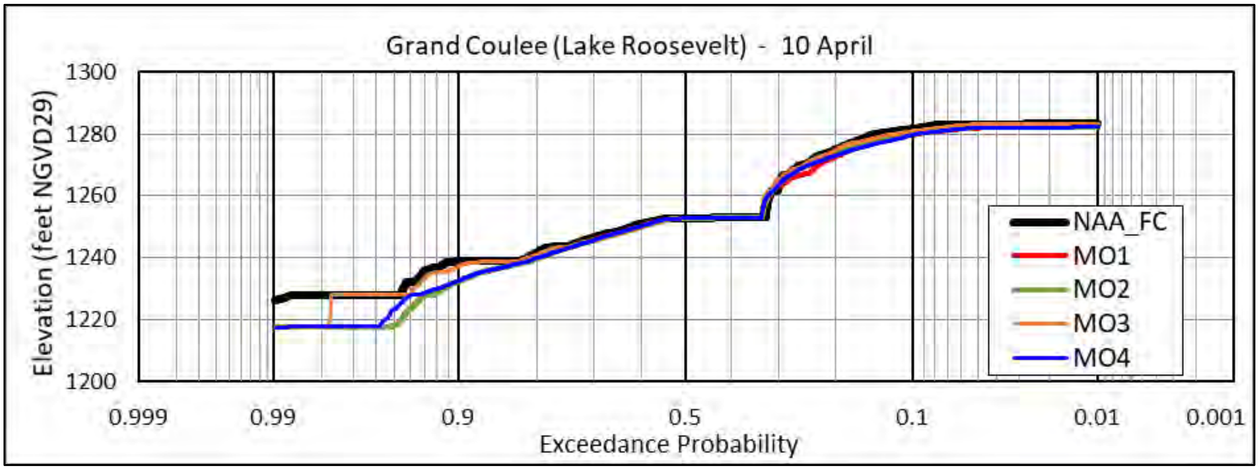


Figure 5-63. Elevation-Frequency Curves for February 28 at Grand Coulee (Lake Roosevelt)



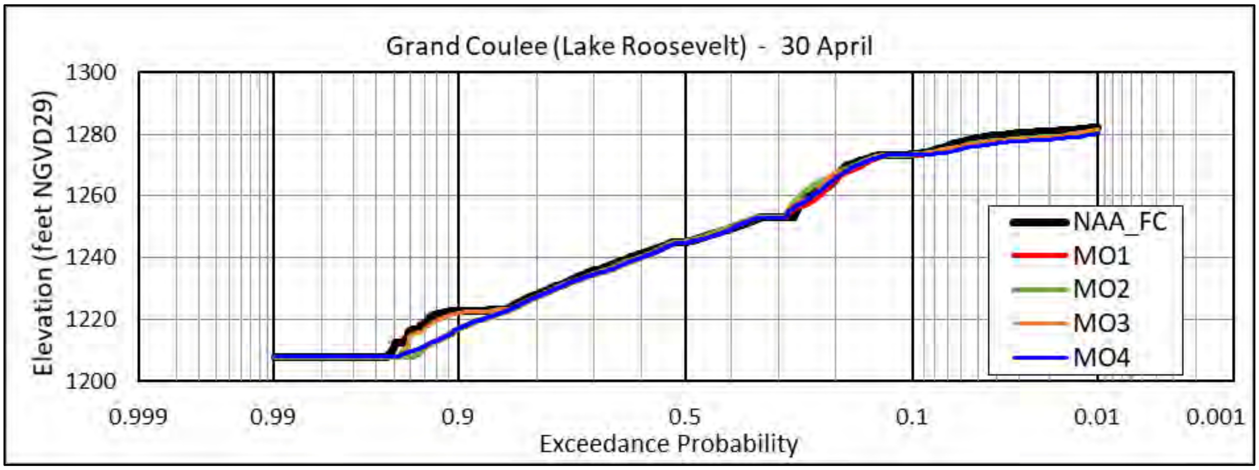
3410

3411 **Figure 5-64. Elevation-Frequency Curves for March 31 at Grand Coulee (Lake Roosevelt)**



3412

3413 **Figure 5-65. Elevation-Frequency Curves for April 10 at Grand Coulee (Lake Roosevelt)**



3414

3415 **Figure 5-66. Elevation-Frequency Curves for April 30 at Grand Coulee (Lake Roosevelt)**

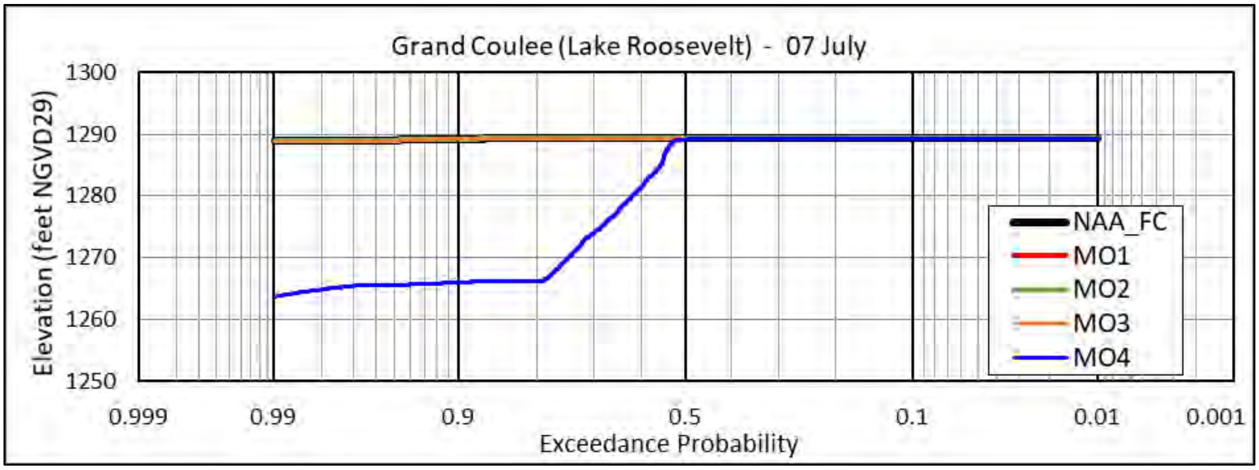


Figure 5-67. Elevation-Frequency Curves for July 7 at Grand Coulee (Lake Roosevelt)

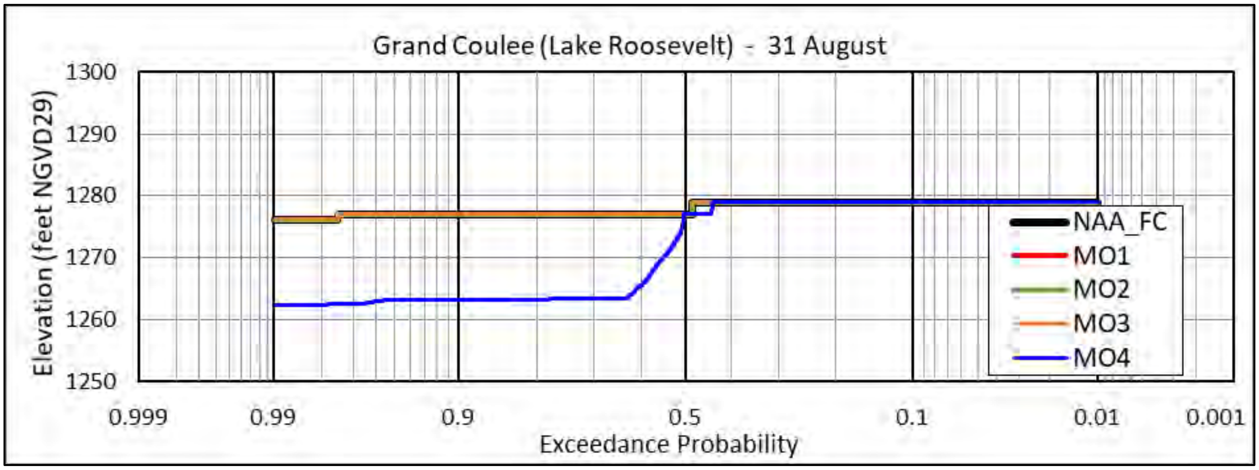


Figure 5-68. Elevation-Frequency Curves for August 31 at Grand Coulee (Lake Roosevelt)

5.6.2.4 Annual Elevation-Duration Plots

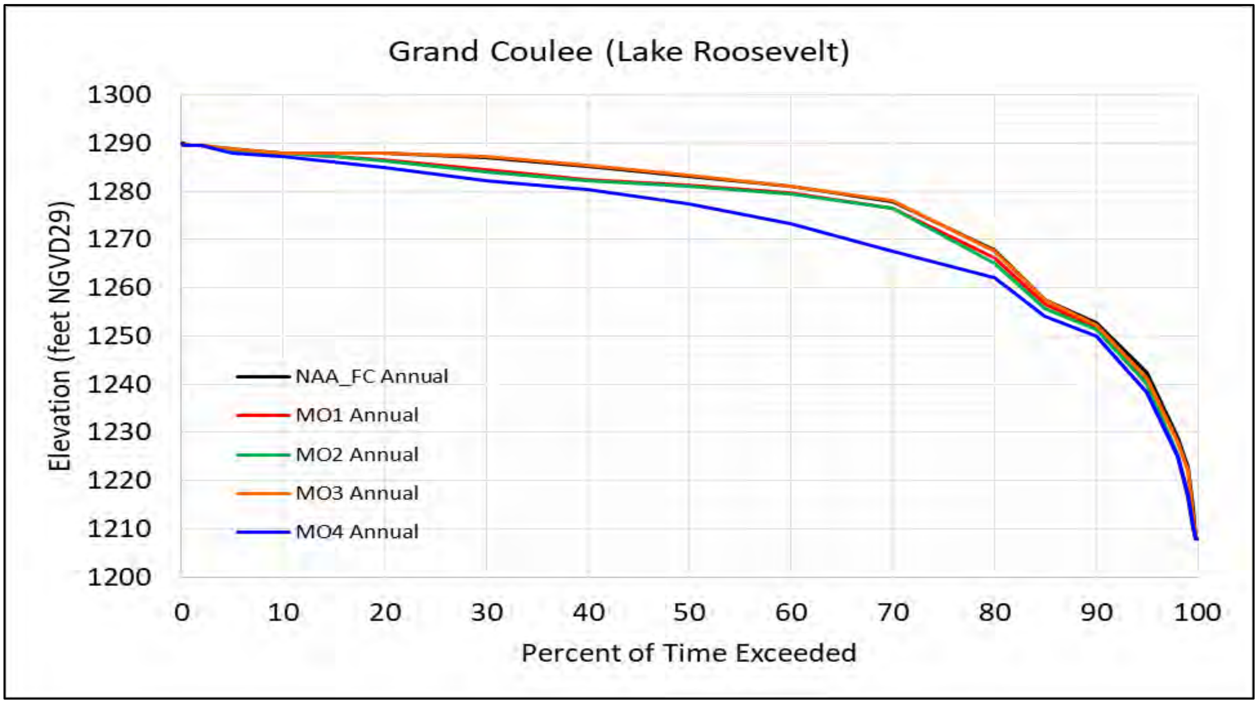


Figure 5-69. Annual Elevation-Duration Curves for Grand Coulee (Lake Roosevelt)

5.6.2.5 Water Year Plots, Flow

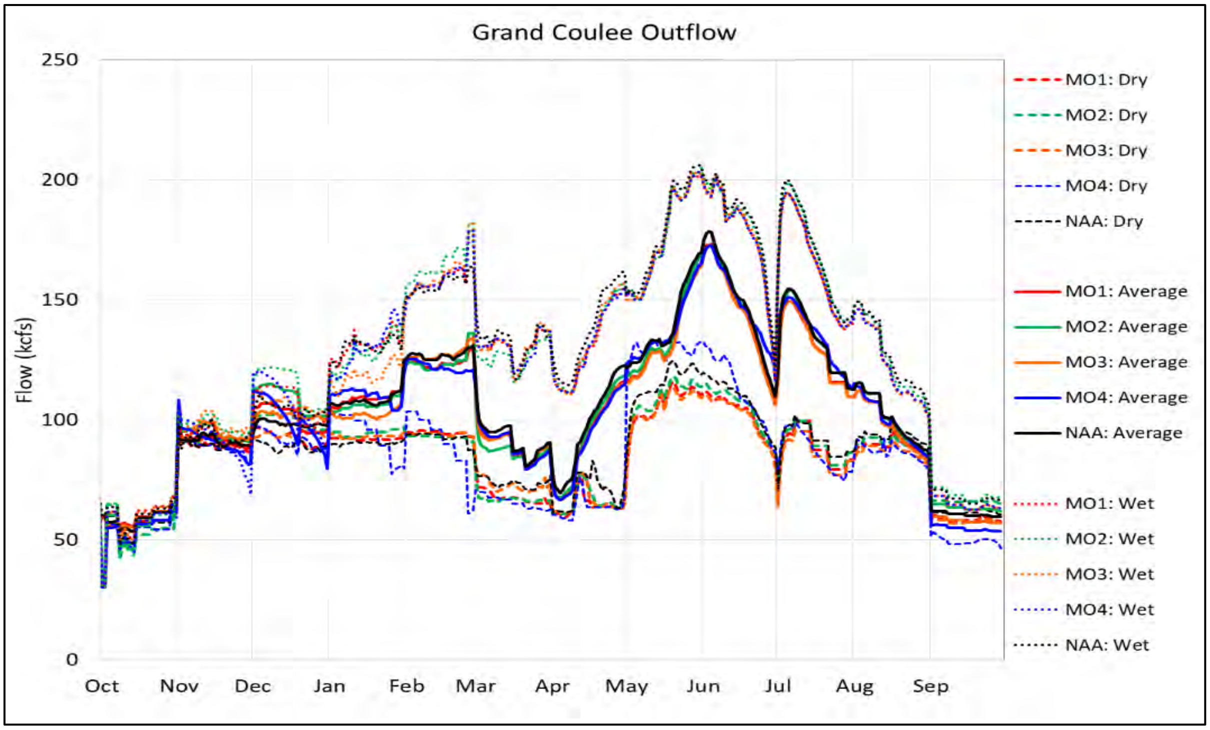


Figure 5-70. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at Grand Coulee Dam

5.6.2.6 Summary Flow Hydrographs

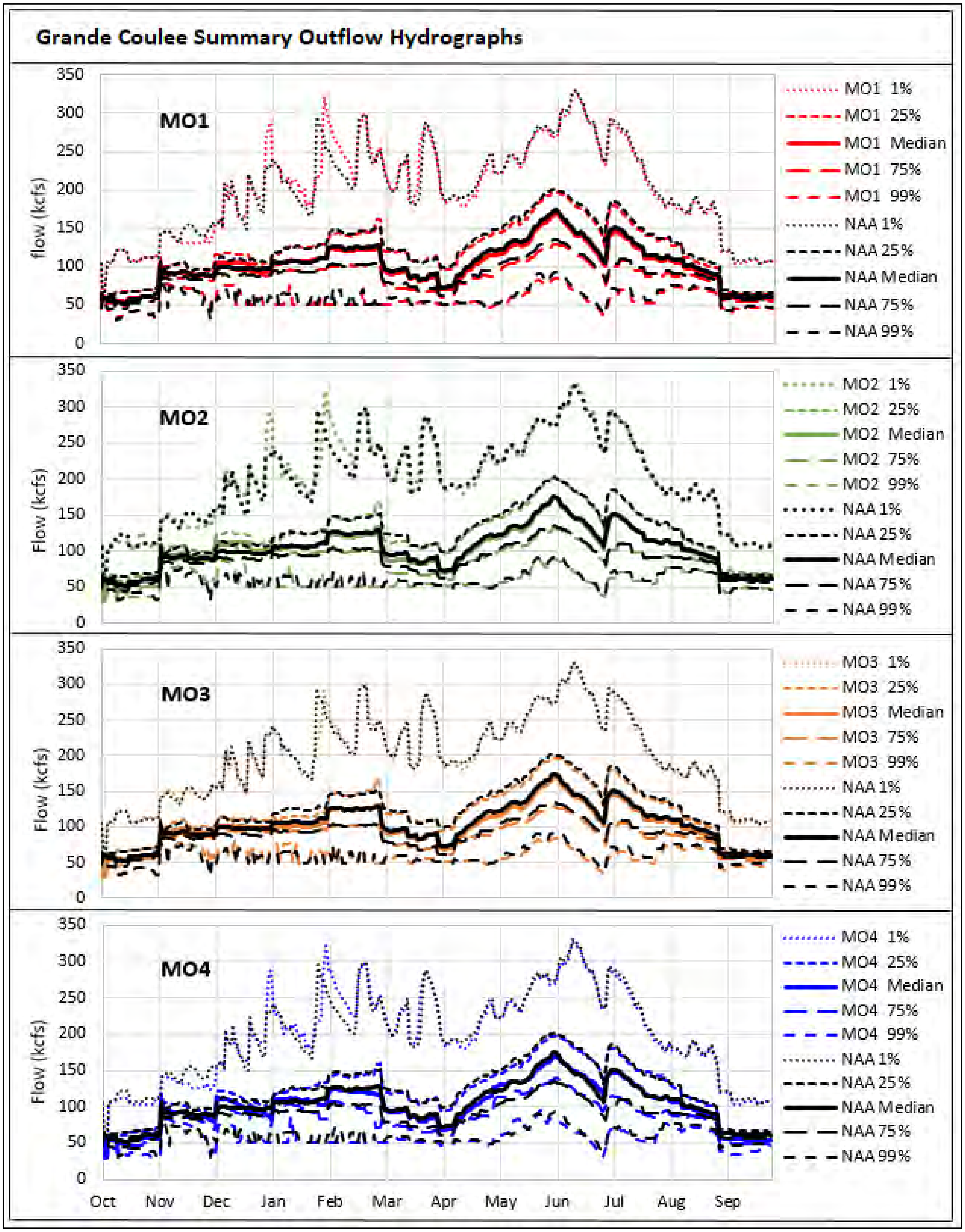


Figure 5-71. Summary Outflow Hydrographs for Grand Coulee Dam

5.6.2.7 Average Monthly Flow Summaries Tables

Table 5-15. Average Monthly Inflow Summary for Lake Roosevelt

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
NAA	Outflow (kcfs)	1%	97.7	125.3	151.2	155.4	152.7	142.4	124.6	206.5	283.7	242.9	162.7	119.2
		25%	71.3	93.0	100.3	109.7	114.8	83.7	80.6	154.2	196.8	159.9	111.5	80.0
		50%	63.7	81.7	91.7	95.2	100.0	65.5	68.9	130.8	166.2	133.3	98.0	75.2
		75%	60.0	76.5	84.1	86.7	91.6	55.4	57.5	113.4	136.5	98.6	88.0	72.3
		99%	56.4	71.1	76.8	81.1	79.8	46.5	40.2	95.5	105.6	80.9	78.1	67.0
MO1	Change (kcfs)	1%	0.0	-0.1	-5.0	1.0	2.3	1.7	2.4	1.9	0.3	-1.2	0.1	0.3
		25%	0.0	0.0	-4.8	-1.2	0.6	1.8	0.5	-2.0	-0.4	-0.9	-1.1	-0.3
		50%	0.0	0.7	-2.9	1.9	1.8	0.5	-0.6	-2.7	-0.4	-0.8	-0.3	-0.1
		75%	0.0	0.7	-0.5	0.6	1.1	0.7	0.1	-2.3	-1.8	0.7	-0.5	-0.5
		99%	0.0	-0.5	2.6	0.6	0.7	0.6	-0.2	-1.8	-0.9	-0.5	0.6	0.1
	Percent change	1%	0%	0%	-3%	1%	2%	1%	2%	1%	0%	0%	0%	0%
		25%	0%	0%	-5%	-1%	0%	2%	1%	-1%	0%	-1%	-1%	0%
		50%	0%	1%	-3%	2%	2%	1%	-1%	-2%	0%	-1%	0%	0%
		75%	0%	1%	-1%	1%	1%	1%	0%	-2%	-1%	1%	-1%	-1%
		99%	0%	-1%	3%	1%	1%	1%	0%	-2%	-1%	-1%	1%	0%
MO2	Change (kcfs)	1%	-0.2	1.2	-0.8	-2.7	2.0	0.4	0.6	1.0	1.0	-0.4	0.1	0.0
		25%	-0.2	4.5	2.4	-5.8	0.4	1.4	-0.6	-3.5	-1.7	-0.9	-1.3	-0.5
		50%	-0.2	4.8	4.3	-0.4	-0.4	-0.5	-1.4	-3.3	-1.4	-0.8	-0.4	-0.4
		75%	-0.2	5.1	6.5	0.2	0.0	-0.3	-0.6	-3.3	-3.5	-2.0	-1.2	-0.8
		99%	-0.2	3.7	9.8	-0.3	0.0	-0.3	-0.4	-2.6	-4.1	-2.9	-0.1	0.0
	Percent change	1%	0%	1%	-1%	-2%	1%	0%	1%	0%	0%	0%	0%	0%
		25%	0%	5%	2%	-5%	0%	2%	-1%	-2%	-1%	-1%	-1%	-1%
		50%	0%	6%	5%	0%	0%	-1%	-2%	-3%	-1%	-1%	0%	0%
		75%	0%	7%	8%	0%	0%	0%	-1%	-3%	-3%	-2%	-1%	-1%
		99%	0%	5%	13%	0%	0%	-1%	-1%	-3%	-4%	-4%	0%	0%
MO3	Change (kcfs)	1%	-0.3	-1.6	-4.5	-5.1	0.2	0.5	1.8	1.8	0.3	-1.1	0.3	0.2
		25%	-0.2	4.1	2.3	-9.6	-1.4	0.8	0.0	-3.0	-0.5	-0.9	-1.2	-0.4
		50%	-0.2	5.4	4.3	-3.4	-1.4	-0.5	-1.2	-3.3	-0.8	-0.7	-0.4	-0.3
		75%	-0.2	5.1	6.4	-0.9	-1.0	-0.3	-0.4	-3.5	-2.9	-1.8	-1.1	-0.7
		99%	-0.2	3.8	9.8	-0.6	-0.9	-0.3	-0.3	-2.9	-3.8	-3.3	-0.3	-0.1
	Percent change	1%	0%	-1%	-3%	-3%	0%	0%	1%	1%	0%	0%	0%	0%
		25%	0%	4%	2%	-9%	-1%	1%	0%	-2%	0%	-1%	-1%	0%
		50%	0%	7%	5%	-4%	-1%	-1%	-2%	-2%	0%	-1%	0%	0%
		75%	0%	7%	8%	-1%	-1%	0%	-1%	-3%	-2%	-2%	-1%	-1%
		99%	0%	5%	13%	-1%	-1%	-1%	-1%	-3%	-4%	-4%	0%	0%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-0.3	-2.1	-5.7	-3.0	1.9	1.5	2.4	1.8	0.3	-1.2	0.4	0.3
		25%	-0.5	-2.1	-5.5	-1.3	0.6	1.7	-0.3	-2.2	0.0	0.7	0.5	-0.6
		50%	-0.2	-1.0	-3.8	1.8	1.8	0.4	-0.9	-2.8	0.4	1.0	1.1	-0.5
		75%	-0.3	-3.0	-1.5	0.4	1.1	0.7	-0.6	-2.7	1.1	7.7	1.8	-0.8
		99%	-0.2	-3.7	-0.6	0.2	0.7	0.6	-0.2	-1.2	4.7	5.2	2.5	-0.1
	Percent change	1%	0%	-2%	-4%	-2%	1%	1%	2%	1%	0%	0%	0%	0%
		25%	-1%	-2%	-6%	-1%	1%	2%	0%	-1%	0%	0%	0%	-1%
		50%	0%	-1%	-4%	2%	2%	1%	-1%	-2%	0%	1%	1%	-1%
		75%	-1%	-4%	-2%	0%	1%	1%	-1%	-2%	1%	8%	2%	-1%
		99%	0%	-5%	-1%	0%	1%	1%	-1%	-1%	4%	6%	3%	0%

Table 5-16. Average Monthly Outflow Summary for Grand Coulee Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	94.1	129.9	174.1	189.9	212.6	185.8	190.5	230.9	275.0	246.6	175.2	110.8
		25%	66.5	98.6	109.1	124.4	147.2	117.4	119.7	165.0	181.5	157.8	117.9	68.1
		50%	59.2	90.9	96.7	108.4	126.3	93.1	97.1	138.3	149.5	133.8	102.4	62.9
		75%	54.1	84.1	88.3	95.6	105.2	77.6	79.2	118.1	121.3	98.3	91.6	58.9
		99%	49.3	77.5	79.3	75.8	81.1	66.3	60.4	96.7	91.4	80.8	81.5	52.8
MO1	Change (kcfs)	1%	0.8	-0.3	1.5	4.7	14.7	-2.7	-7.7	-4.4	-1.3	-5.4	-3.4	-2.9
		25%	0.3	-0.7	2.2	0.1	-3.3	-0.1	-4.5	-6.2	-3.8	-4.3	-4.6	-2.9
		50%	0.4	0.0	3.8	0.6	-2.5	-2.3	-4.6	-6.1	-4.5	-4.7	-3.4	-2.9
		75%	0.3	0.0	5.7	0.5	-2.1	-4.1	-3.0	-5.8	-4.2	-4.1	-3.3	-2.6
		99%	0.4	0.0	3.6	6.3	2.5	-3.1	-1.3	-8.9	-4.9	-3.6	-3.2	-2.7
	Percent change	1%	1%	0%	1%	2%	7%	-1%	-4%	-2%	0%	-2%	-2%	-3%
		25%	1%	-1%	2%	0%	-2%	0%	-4%	-4%	-2%	-3%	-4%	-4%
		50%	1%	0%	4%	1%	-2%	-3%	-5%	-4%	-3%	-3%	-3%	-5%
		75%	1%	0%	6%	1%	-2%	-5%	-4%	-5%	-3%	-4%	-4%	-4%
		99%	1%	0%	5%	8%	3%	-5%	-2%	-9%	-5%	-4%	-4%	-5%

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
MO2	Change (kcfs)	1%	-3.3	1.7	5.8	1.2	17.9	-5.6	-7.6	-3.7	3.6	-0.3	-0.8	0.0
		25%	-5.0	3.7	8.7	-2.4	0.6	-3.5	-2.8	-4.5	-1.6	-0.4	-1.9	2.7
		50%	-4.8	2.0	10.9	-1.2	-3.0	-5.2	-2.5	-4.1	-2.0	-0.8	-1.0	2.6
		75%	-5.1	4.1	13.1	1.7	-3.5	-5.5	-1.8	-3.8	-2.5	-1.7	-1.9	2.3
		99%	-5.7	3.9	10.5	9.9	0.3	-3.8	-0.7	-5.2	-2.3	-1.8	-1.3	1.4
	Percent change	1%	-4%	1%	3%	1%	8%	-3%	-4%	-2%	1%	0%	0%	0%
		25%	-8%	4%	8%	-2%	0%	-3%	-2%	-3%	-1%	0%	-2%	4%
		50%	-8%	2%	11%	-1%	-2%	-6%	-3%	-3%	-1%	-1%	-1%	4%
		75%	-9%	5%	15%	2%	-3%	-7%	-2%	-3%	-2%	-2%	-2%	4%
		99%	-12%	5%	13%	13%	0%	-6%	-1%	-5%	-2%	-2%	-2%	3%
MO3	Change (kcfs)	1%	-1.7	0.5	-4.5	-3.8	6.1	-0.6	-8.0	-5.6	-1.0	-5.2	-3.3	-2.9
		25%	-1.9	3.4	1.7	-8.7	1.5	-0.4	-3.8	-6.6	-3.6	-4.0	-4.8	-3.0
		50%	-1.8	2.2	3.7	-5.4	0.1	-2.3	-4.8	-6.7	-4.8	-4.6	-3.9	-3.2
		75%	-1.8	3.9	5.9	0.2	-1.9	-1.8	-2.6	-7.0	-5.2	-5.6	-4.7	-2.9
		99%	-1.7	3.9	4.9	9.7	0.9	-0.3	0.0	-8.0	-7.5	-5.7	-4.1	-2.9
	Percent change	1%	-2%	0%	-3%	-2%	3%	0%	-4%	-2%	0%	-2%	-2%	-3%
		25%	-3%	3%	2%	-7%	1%	0%	-3%	-4%	-2%	-3%	-4%	-4%
		50%	-3%	2%	4%	-5%	0%	-2%	-5%	-5%	-3%	-3%	-4%	-5%
		75%	-3%	5%	7%	0%	-2%	-2%	-3%	-6%	-4%	-6%	-5%	-5%
		99%	-3%	5%	6%	13%	1%	0%	0%	-8%	-8%	-7%	-5%	-6%
M04	Change (kcfs)	1%	-1.8	-0.4	-0.3	1.8	16.6	-2.3	-6.2	-4.3	-2.0	-5.4	-2.5	-2.9
		25%	-5.0	-1.9	0.8	-1.5	-3.2	0.0	-5.2	-5.7	-2.7	-1.9	-3.1	-5.1
		50%	-5.1	-1.4	2.7	1.4	-4.3	-2.5	-5.2	-2.7	-0.5	-0.6	-2.6	-6.3
		75%	-5.8	-0.1	3.6	2.3	-5.3	-4.9	-3.9	6.0	6.1	1.9	-3.7	-8.6
		99%	-7.6	-1.6	2.0	9.0	0.0	-5.6	-1.9	11.4	1.1	-5.1	-3.9	-9.2
	Percent change	1%	-2%	0%	0%	1%	8%	-1%	-3%	-2%	-1%	-2%	-1%	-3%
		25%	-8%	-2%	1%	-1%	-2%	0%	-4%	-3%	-1%	-1%	-3%	-8%
		50%	-9%	-2%	3%	1%	-3%	-3%	-5%	-2%	0%	0%	-3%	-10%
		75%	-11%	0%	4%	2%	-5%	-6%	-5%	5%	5%	2%	-4%	-15%
		99%	-15%	-2%	2%	12%	0%	-9%	-3%	12%	1%	-6%	-5%	-17%

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Table 5-17. Average Monthly Outflow Summary for Chief Joseph Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	93.8	131.6	177.0	190.0	212.2	185.2	187.7	229.7	274.6	246.3	171.3	105.0
		25%	65.7	98.4	109.4	124.9	147.8	118.2	119.9	163.5	181.8	158.4	119.0	68.6
		50%	58.5	91.1	96.3	107.9	126.7	93.6	97.6	139.2	149.7	135.0	102.6	63.1
		75%	53.7	83.8	87.9	95.9	105.9	78.4	79.8	119.1	122.0	98.7	92.4	59.3
		99%	49.6	78.6	79.6	77.2	82.6	67.1	60.8	96.9	91.2	81.8	82.6	53.3
MO1	Change (kcfs)	1%	0.7	-0.4	1.5	4.8	14.8	-2.5	-7.2	-5.9	-1.7	-5.1	-3.1	-2.6
		25%	0.3	-0.1	1.8	-0.4	-2.5	-0.3	-4.3	-6.4	-3.9	-4.5	-4.3	-3.0
		50%	0.3	-0.1	3.8	0.9	-2.4	-2.6	-4.2	-6.3	-4.4	-4.9	-3.2	-2.8
		75%	0.3	0.0	6.1	0.5	-2.3	-4.1	-2.5	-5.6	-4.2	-3.8	-3.1	-2.6
		99%	0.3	-0.2	3.1	5.7	2.4	-3.3	-0.9	-9.2	-5.4	-4.2	-3.4	-2.6
	Percent change	1%	1%	0%	1%	3%	7%	-1%	-4%	-3%	-1%	-2%	-2%	-3%
		25%	0%	0%	2%	0%	-2%	0%	-4%	-4%	-2%	-3%	-4%	-4%
		50%	1%	0%	4%	1%	-2%	-3%	-4%	-5%	-3%	-4%	-3%	-4%
		75%	1%	0%	7%	1%	-2%	-5%	-3%	-5%	-3%	-4%	-3%	-4%
		99%	1%	0%	4%	7%	3%	-5%	-2%	-9%	-6%	-5%	-4%	-5%
MO2	Change (kcfs)	1%	-2.8	1.7	5.8	1.3	18.0	-6.2	-6.4	-4.3	2.1	0.0	-0.2	-0.1
		25%	-4.3	4.4	9.3	-2.1	0.5	-3.3	-2.8	-4.6	-1.4	-0.5	-1.5	2.3
		50%	-4.1	2.2	10.8	-0.5	-2.9	-5.2	-2.5	-4.0	-2.0	-1.1	-0.9	2.6
		75%	-4.6	3.8	13.3	1.8	-4.0	-5.7	-1.2	-3.7	-2.6	-1.7	-1.4	2.3
		99%	-5.3	2.6	11.1	9.7	0.0	-4.5	-0.3	-5.4	-2.4	-1.5	-1.5	1.2
	Percent change	1%	-3%	1%	3%	1%	8%	-3%	-3%	-2%	1%	0%	0%	0%
		25%	-7%	4%	9%	-2%	0%	-3%	-2%	-3%	-1%	0%	-1%	3%
		50%	-7%	2%	11%	-1%	-2%	-6%	-3%	-3%	-1%	-1%	-1%	4%
		75%	-9%	5%	15%	2%	-4%	-7%	-1%	-3%	-2%	-2%	-2%	4%
		99%	-11%	3%	14%	13%	0%	-7%	-1%	-6%	-3%	-2%	-2%	2%
MO3	Change (kcfs)	1%	-0.9	0.3	-4.5	-3.8	6.2	-2.4	-6.1	-6.4	-1.9	-4.9	-3.0	-2.6
		25%	-1.3	4.0	1.6	-9.1	1.4	-0.1	-3.9	-6.5	-3.4	-4.5	-4.5	-3.0
		50%	-1.2	2.2	3.7	-5.2	0.0	-2.3	-4.7	-6.8	-4.6	-4.8	-3.8	-3.0
		75%	-1.2	3.6	6.3	-0.3	-1.7	-1.7	-2.4	-6.7	-5.0	-5.8	-4.2	-2.8
		99%	-1.1	2.2	5.4	9.7	0.9	-0.3	-0.3	-8.3	-7.4	-5.8	-4.3	-2.9
	Percent change	1%	-1%	0%	-3%	-2%	3%	-1%	-3%	-3%	-1%	-2%	-2%	-3%
		25%	-2%	4%	2%	-7%	1%	0%	-3%	-4%	-2%	-3%	-4%	-4%
		50%	-2%	2%	4%	-5%	0%	-2%	-5%	-5%	-3%	-4%	-4%	-5%
		75%	-2%	4%	7%	0%	-2%	-2%	-3%	-6%	-4%	-6%	-4%	-5%
		99%	-2%	3%	7%	13%	1%	-1%	-1%	-9%	-8%	-7%	-5%	-5%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-1.0	-0.6	-0.4	1.8	16.8	-1.9	-4.6	-4.3	-1.9	-5.1	-3.0	-2.6
		25%	-4.0	-1.3	0.5	-2.4	-2.4	-0.1	-4.9	-5.7	-2.8	-1.6	-3.3	-5.4
		50%	-4.6	-1.8	3.2	1.5	-4.1	-2.7	-5.3	-2.9	0.2	-1.4	-2.0	-5.9
		75%	-5.1	0.0	4.0	2.6	-5.5	-5.0	-3.5	5.7	5.7	1.8	-3.8	-8.7
		99%	-7.5	-1.9	2.1	8.3	-0.4	-6.3	-2.1	11.4	2.3	-4.6	-4.3	-9.6
	Percent change	1%	-1%	0%	0%	1%	8%	-1%	-2%	-2%	-1%	-2%	-2%	-3%
		25%	-6%	-1%	0%	-2%	-2%	0%	-4%	-4%	-2%	-1%	-3%	-8%
		50%	-8%	-2%	3%	1%	-3%	-3%	-5%	-2%	0%	-1%	-2%	-9%
		75%	-10%	0%	5%	3%	-5%	-6%	-4%	5%	5%	2%	-4%	-15%
		99%	-15%	-2%	3%	11%	0%	-9%	-3%	12%	3%	-6%	-5%	-18%

Table 5-18. Average Monthly Outflow Summary for Chief Joseph Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	101.7	145.0	197.3	200.7	219.8	196.3	202.6	276.5	352.4	273.3	185.6	113.6
		25%	67.9	107.0	117.9	132.5	154.7	127.2	132.3	189.2	218.1	175.3	127.7	73.6
		50%	60.0	96.3	102.3	115.2	133.5	100.2	107.9	161.8	177.6	146.7	107.7	68.2
		75%	55.1	89.0	93.3	102.3	111.2	83.7	89.0	140.8	142.7	105.9	95.7	63.5
		99%	50.7	83.9	85.7	82.8	86.7	70.6	65.8	110.0	106.1	89.3	86.7	57.5
MO1	Change (kcfs)	1%	0.3	-0.3	1.2	5.0	15.3	-2.9	-5.8	-2.3	-5.9	-5.4	-3.4	-2.7
		25%	0.4	-0.1	2.5	-0.6	-2.6	-0.5	-5.0	-4.4	-4.8	-4.4	-4.7	-3.0
		50%	0.3	-0.1	3.9	0.9	-2.5	-2.2	-4.2	-6.6	-3.8	-4.4	-3.2	-2.8
		75%	0.3	0.6	5.6	0.3	-2.3	-4.2	-3.2	-6.5	-5.8	-3.6	-3.0	-2.6
		99%	0.3	-0.4	4.2	5.4	2.4	-3.4	-0.8	-10.1	-5.0	-3.6	-3.1	-2.7
	Percent change	1%	0%	0%	1%	2%	7%	-1%	-3%	-1%	-2%	-2%	-2%	-2%
		25%	1%	0%	2%	0%	-2%	0%	-4%	-2%	-2%	-2%	-4%	-4%
		50%	1%	0%	4%	1%	-2%	-2%	-4%	-4%	-2%	-3%	-3%	-4%
		75%	1%	1%	6%	0%	-2%	-5%	-4%	-5%	-4%	-3%	-3%	-4%
		99%	1%	0%	5%	7%	3%	-5%	-1%	-9%	-5%	-4%	-4%	-5%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO2	Change (kcfs)	1%	-1.8	1.9	5.5	1.5	18.5	-6.6	-4.9	-1.9	-0.5	-0.1	-0.5	-0.2
		25%	-2.6	2.8	10.0	-2.5	0.2	-3.8	-3.6	-2.4	-2.5	-0.4	-1.9	2.3
		50%	-2.5	2.7	11.3	-0.5	-2.9	-5.1	-2.4	-4.5	-2.0	-0.6	-0.5	2.1
		75%	-3.3	4.1	13.5	1.6	-3.9	-5.6	-1.9	-4.2	-4.3	-1.8	-1.5	2.7
		99%	-3.9	2.6	10.3	9.1	0.3	-4.5	-0.8	-5.5	-3.6	-1.4	-1.1	1.5
	Percent change	1%	-2%	1%	3%	1%	8%	-3%	-2%	-1%	0%	0%	0%	0%
		25%	-4%	3%	8%	-2%	0%	-3%	-3%	-1%	-1%	0%	-1%	3%
		50%	-4%	3%	11%	0%	-2%	-5%	-2%	-3%	-1%	0%	-1%	3%
		75%	-6%	5%	14%	2%	-3%	-7%	-2%	-3%	-3%	-2%	-2%	4%
		99%	-8%	3%	12%	11%	0%	-6%	-1%	-5%	-3%	-2%	-1%	3%
MO3	Change (kcfs)	1%	0.0	0.3	-4.4	-3.9	6.6	-0.7	-3.9	-3.5	-1.3	-5.1	-3.1	-2.7
		25%	0.0	2.1	1.9	-9.0	1.1	-0.4	-4.7	-4.6	-4.0	-4.4	-4.7	-3.0
		50%	0.1	3.0	4.7	-5.0	-0.5	-1.9	-4.7	-7.1	-4.4	-4.3	-3.5	-3.0
		75%	0.0	4.1	6.4	-0.4	-1.5	-1.4	-2.4	-7.3	-6.7	-5.9	-4.3	-2.9
		99%	0.1	2.4	4.7	9.8	1.0	-0.1	-0.6	-9.9	-7.7	-5.6	-3.9	-3.1
	Percent change	1%	0%	0%	-2%	-2%	3%	0%	-2%	-1%	0%	-2%	-2%	-2%
		25%	0%	2%	2%	-7%	1%	0%	-4%	-2%	-2%	-3%	-4%	-4%
		50%	0%	3%	5%	-4%	0%	-2%	-4%	-4%	-2%	-3%	-3%	-4%
		75%	0%	5%	7%	0%	-1%	-2%	-3%	-5%	-5%	-6%	-4%	-5%
		99%	0%	3%	5%	12%	1%	0%	-1%	-9%	-7%	-6%	-4%	-5%
M04	Change (kcfs)	1%	-1.5	-0.3	-0.9	2.2	17.3	-2.8	-3.7	-2.1	-5.9	-5.3	-2.7	-2.7
		25%	-2.5	-1.2	0.8	-2.4	-2.9	-0.5	-5.3	-4.0	-3.9	-3.2	-3.9	-5.2
		50%	-3.0	-1.0	3.8	1.6	-4.0	-2.3	-5.3	-3.9	-2.2	-1.8	-1.7	-6.2
		75%	-3.7	-0.2	4.2	2.5	-5.8	-5.0	-4.0	3.1	6.6	2.1	-3.6	-8.4
		99%	-5.6	-1.2	1.1	8.1	0.0	-5.7	-0.9	17.4	3.4	-5.5	-4.5	-9.6
	Percent change	1%	-1%	0%	0%	1%	8%	-1%	-2%	-1%	-2%	-2%	-1%	-2%
		25%	-4%	-1%	1%	-2%	-2%	0%	-4%	-2%	-2%	-2%	-3%	-7%
		50%	-5%	-1%	4%	1%	-3%	-2%	-5%	-2%	-1%	-1%	-2%	-9%
		75%	-7%	0%	4%	2%	-5%	-6%	-5%	2%	5%	2%	-4%	-13%
		99%	-11%	-1%	1%	10%	0%	-8%	-1%	16%	3%	-6%	-5%	-17%

5.6.2.8 Annual Flow-Duration Plots

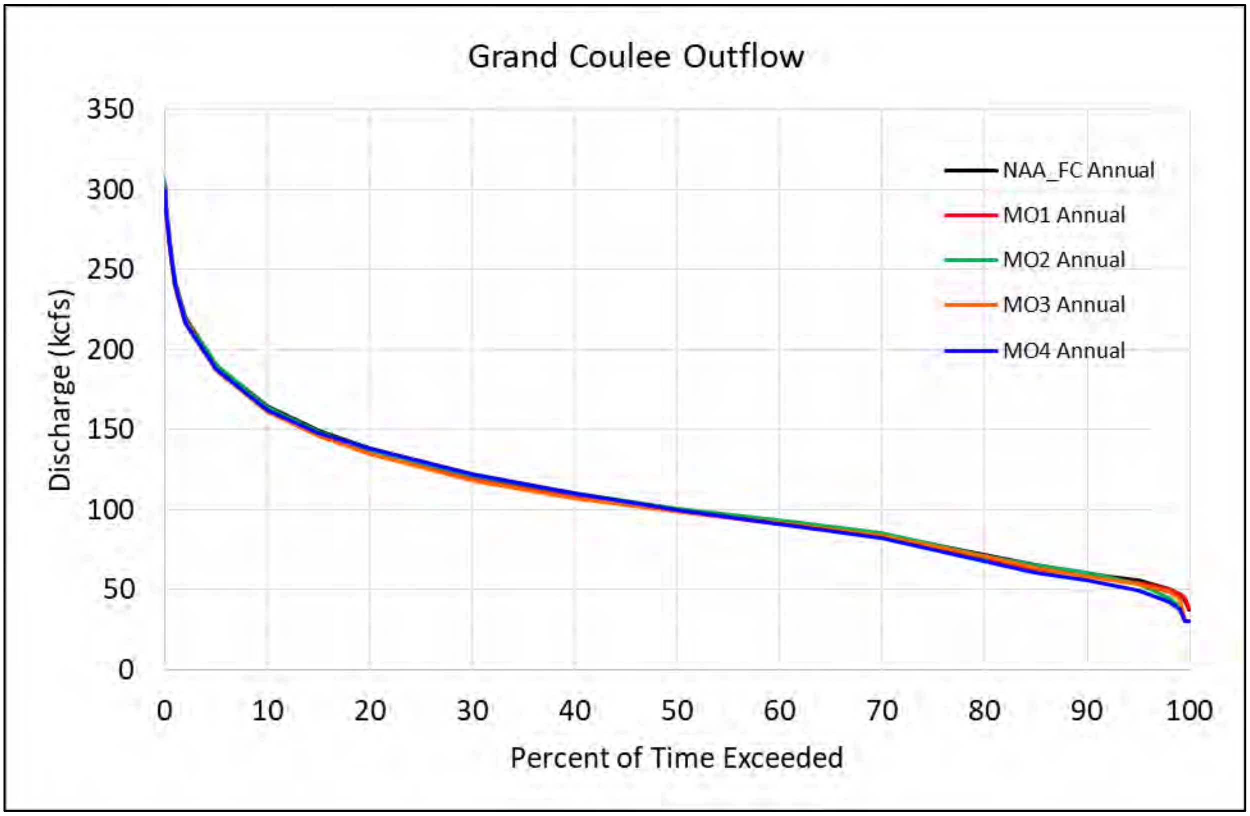


Figure 5-72. Annual Outflow-Duration Curves for Grand Coulee Dam

5.6.2.9 Monthly Flow-Duration Plots

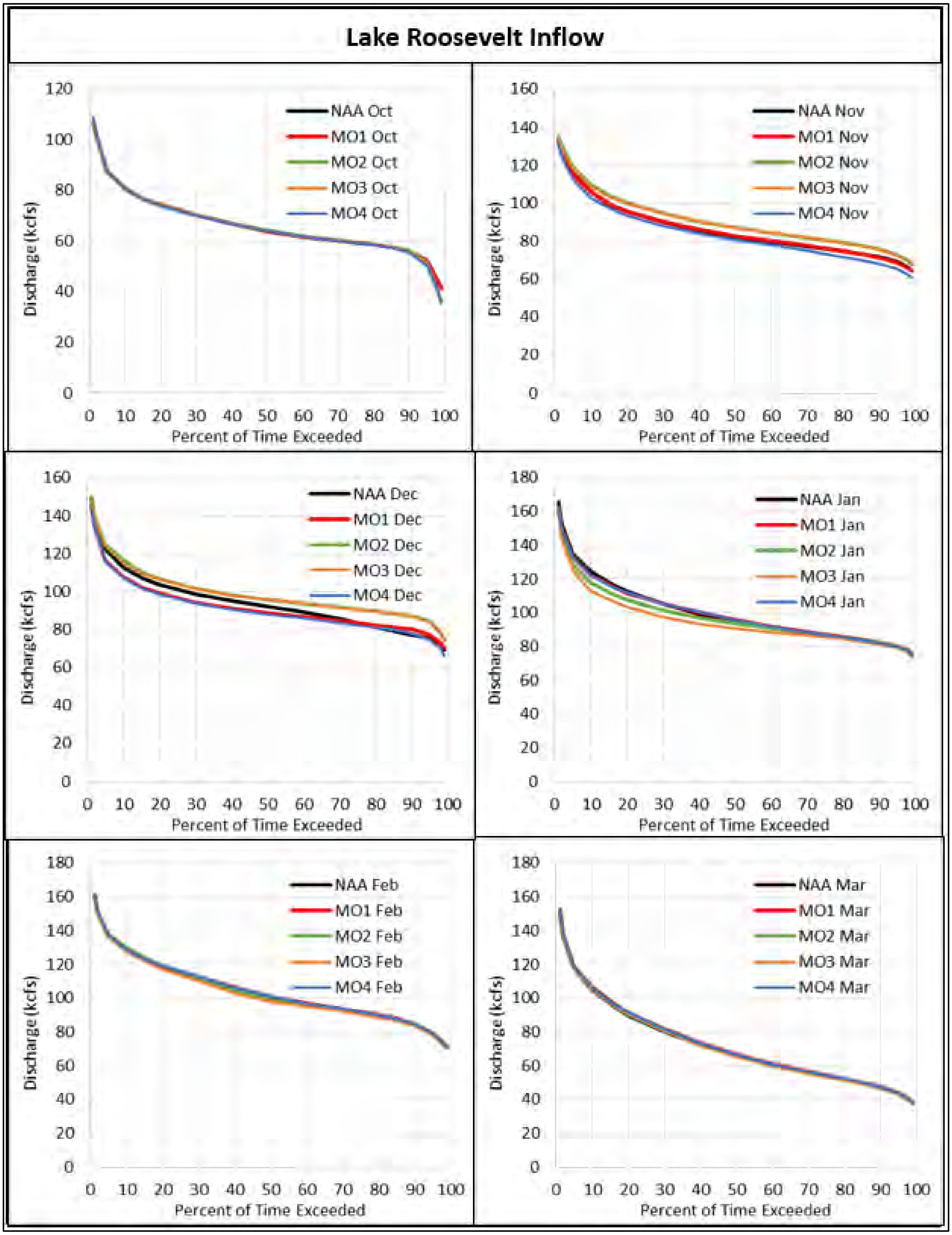
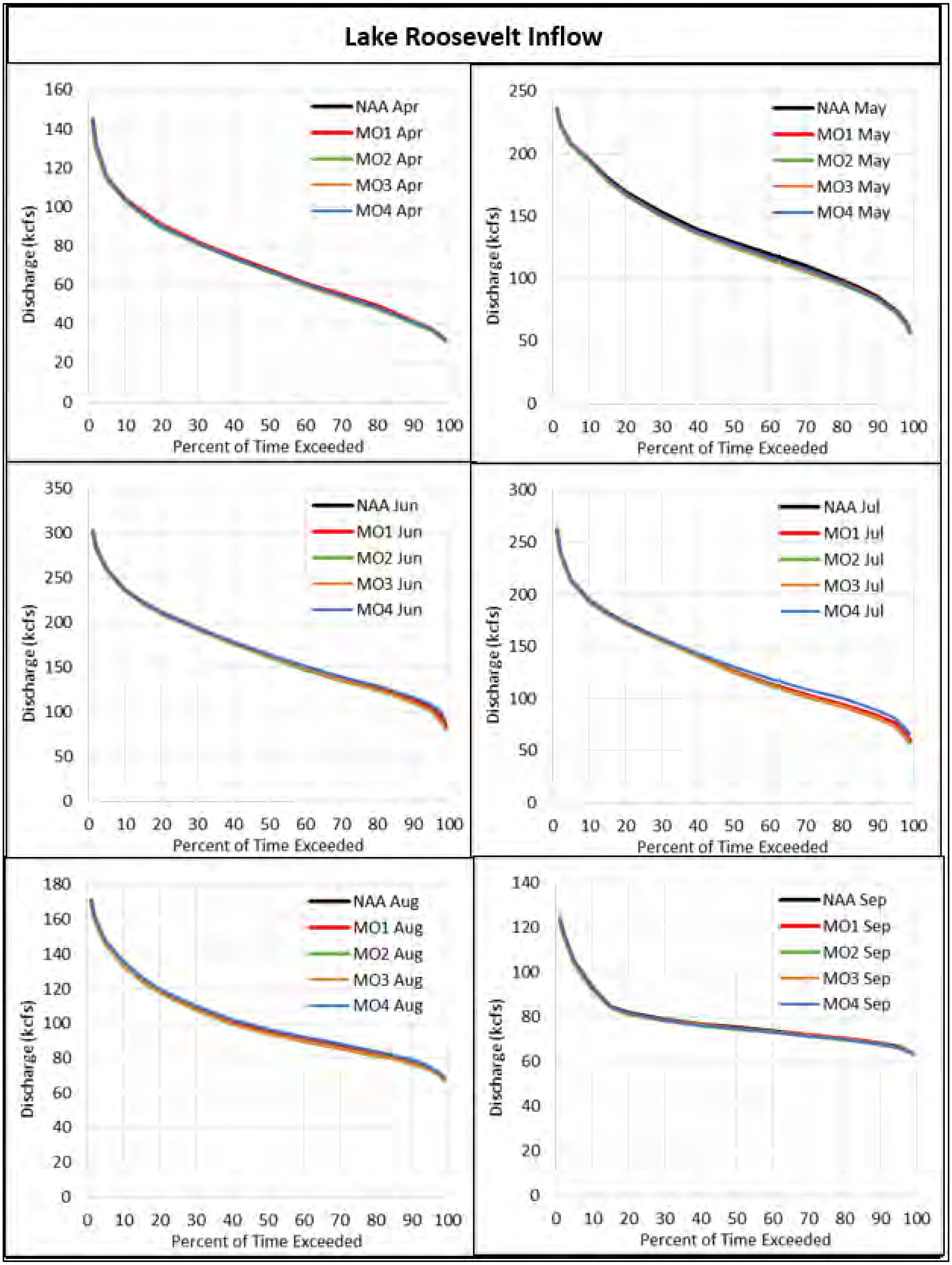


Figure 5-73. Monthly Flow-Duration Curves for Lake Roosevelt Inflow



3442

3443 **Figure 5-74. Monthly Flow-Duration Curves for Lake Roosevelt Inflow (continued)**

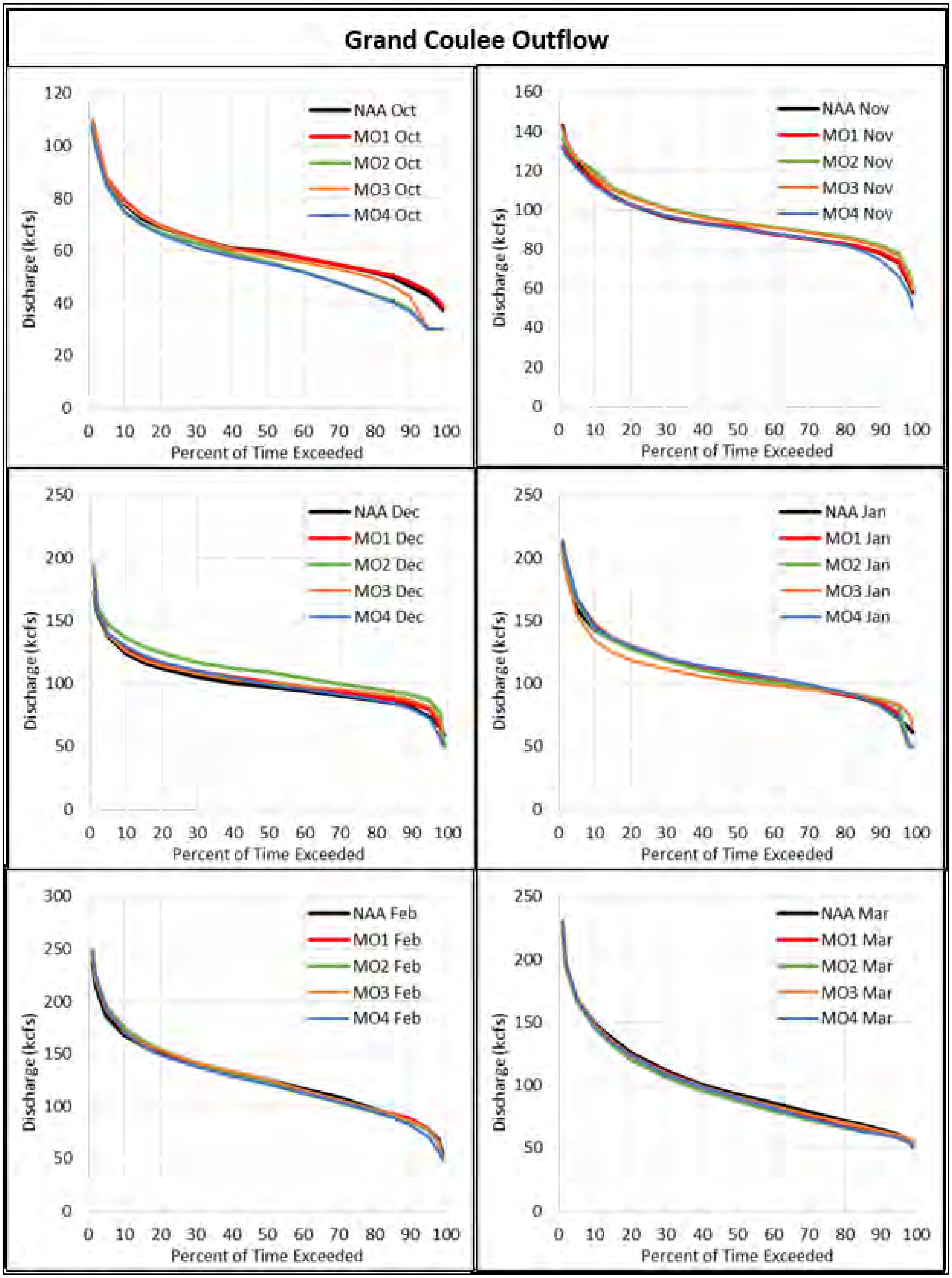
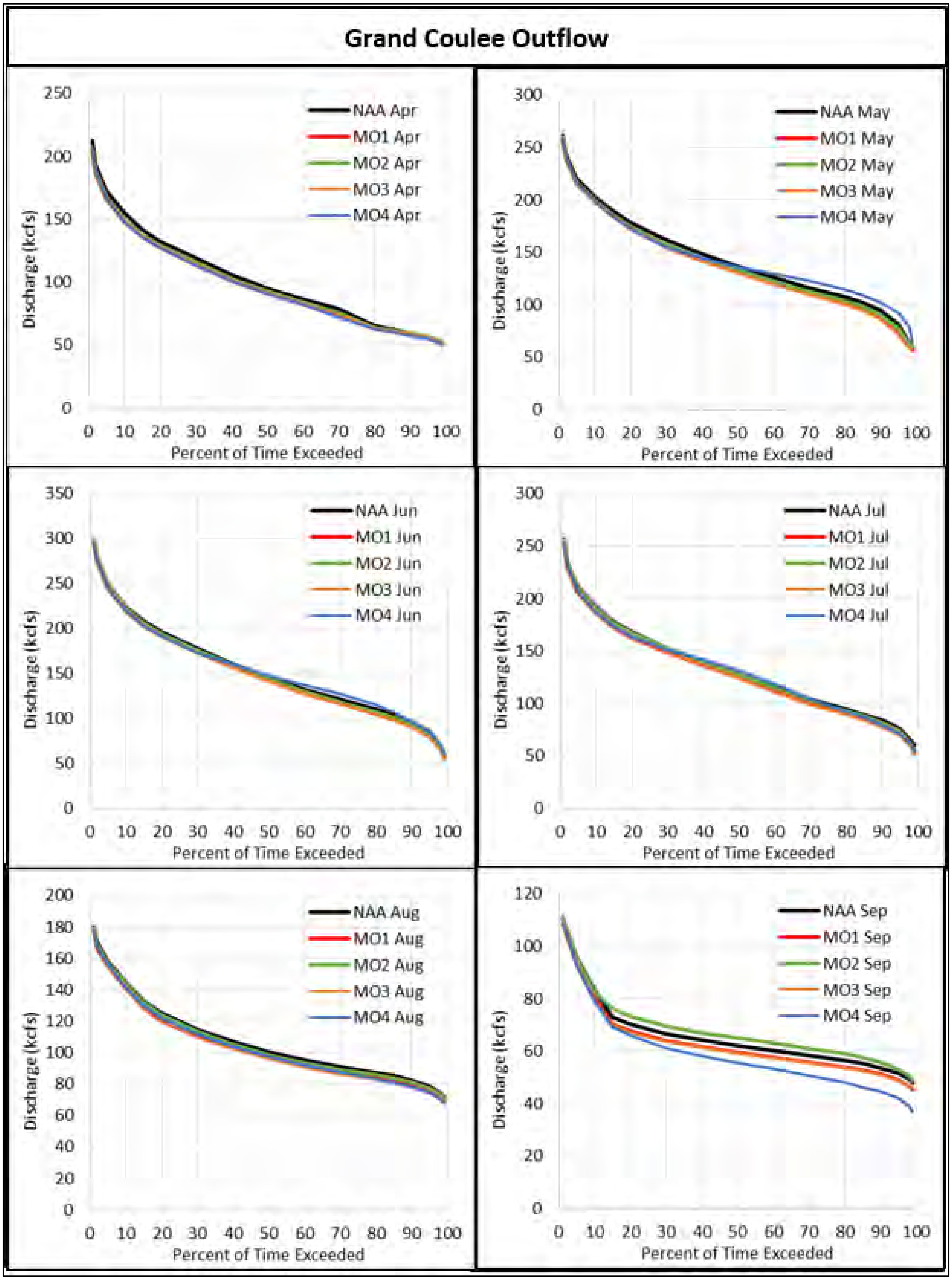
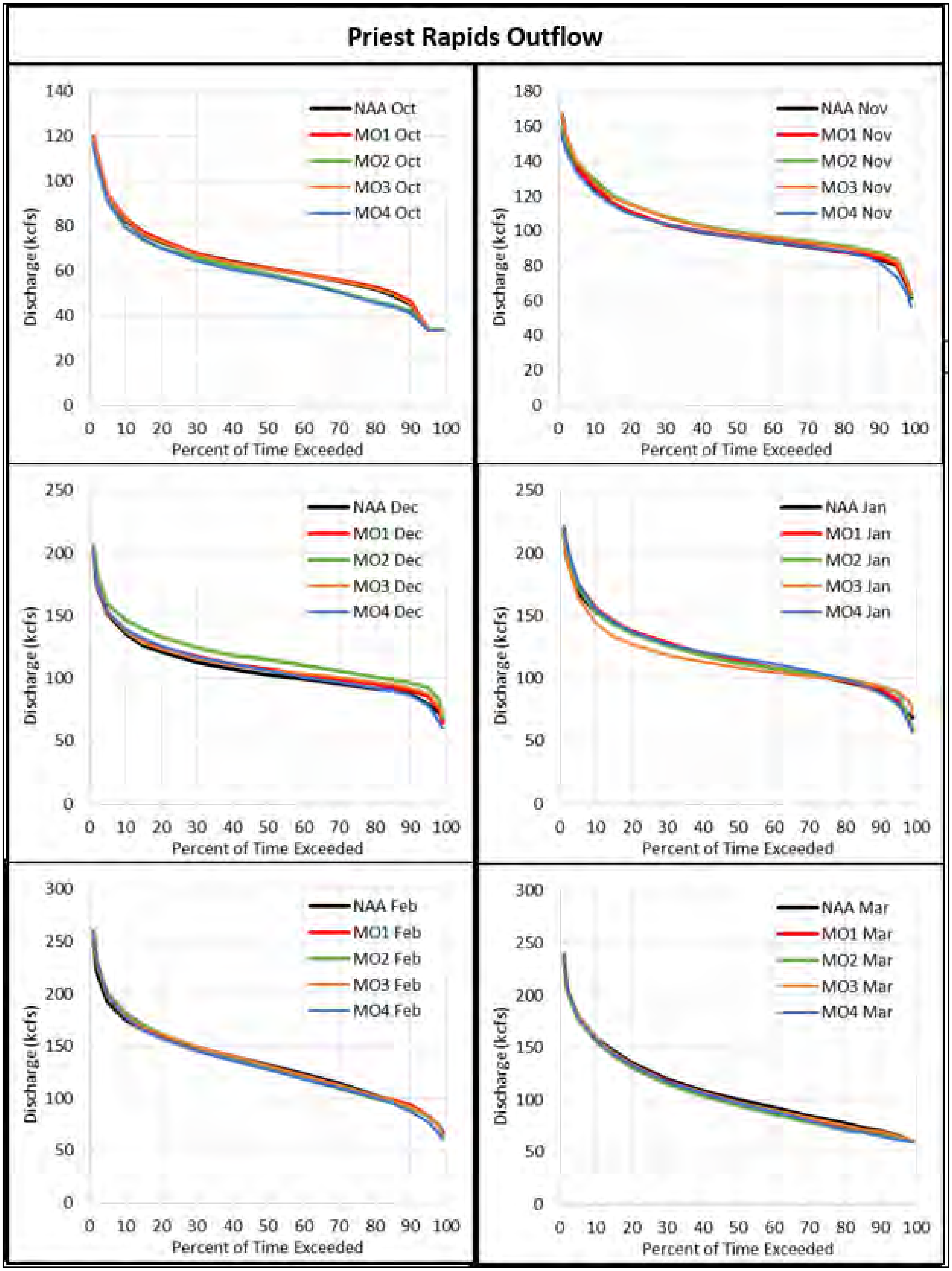


Figure 5-75. Monthly Outflow-Duration Curves for Grand Coulee Dam

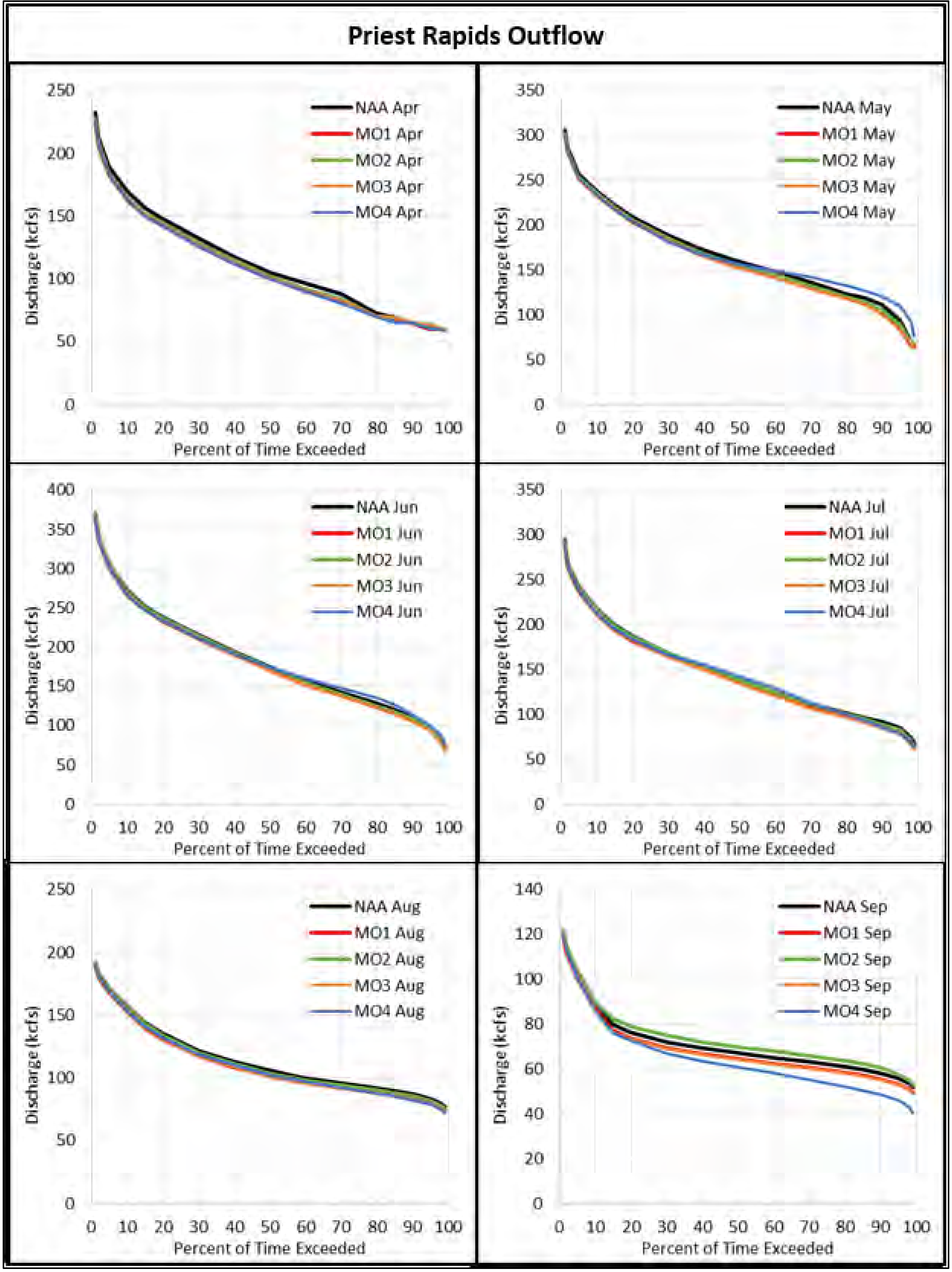
3446


3447 **Figure 5-76. Monthly Outflow-Duration Curves for Grand Coulee Dam (continued)**



3448

3449 **Figure 5-77. Monthly Outflow-Duration Curves for Priest Rapids Dam**



3450
3451 **Figure 5-78. Monthly Outflow-Duration Curves for Priest Rapids Dam (continued)**

5.6.2.10 Peak Flow-Frequency Plots

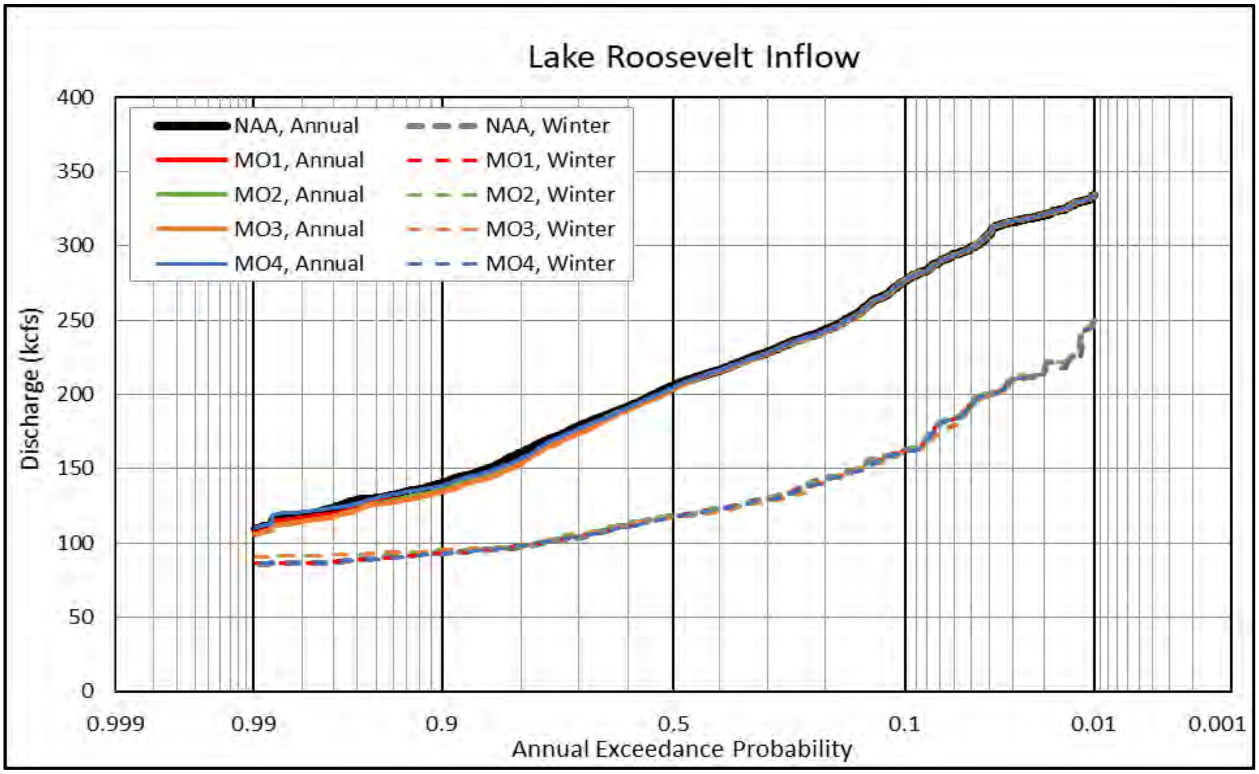


Figure 5-79. Peak Discharge-Frequency Curves for Lake Roosevelt Inflow

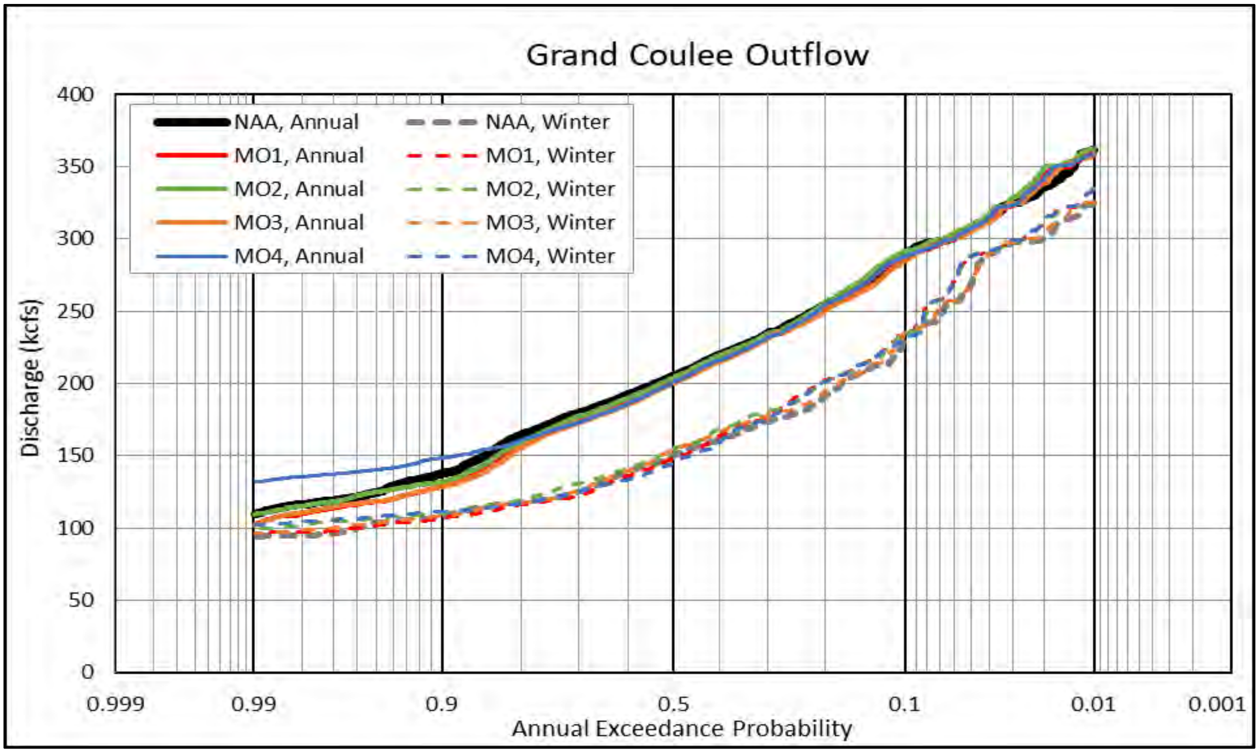


Figure 5-80. Peak Discharge-Frequency Curves for Grand Coulee Dam Outflow

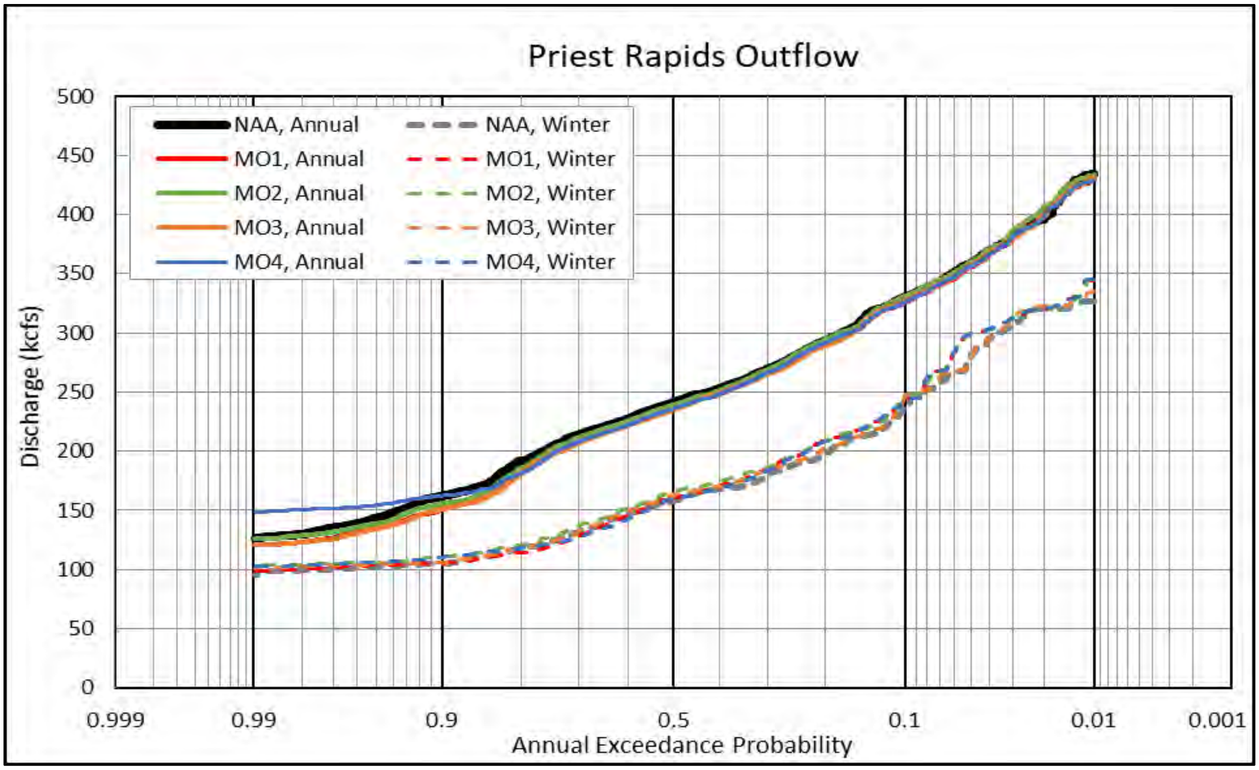


Figure 5-81. Peak Discharge-Frequency Curves for Priest Rapids Dam Outflow

5.6.3 Region C – Lower Snake River Basin

5.6.3.1 Water Year Plots, Elevation

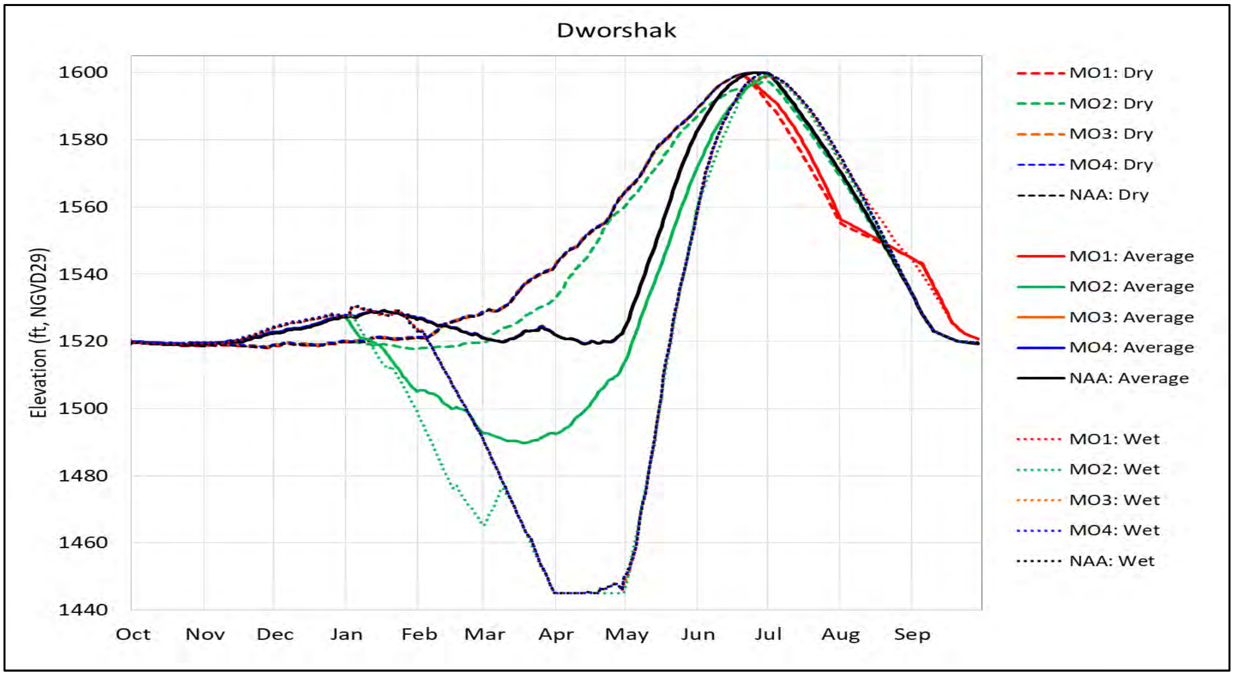


Figure 5-82. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Dworshak Reservoir

5.6.3.2 Summary Elevation Hydrographs

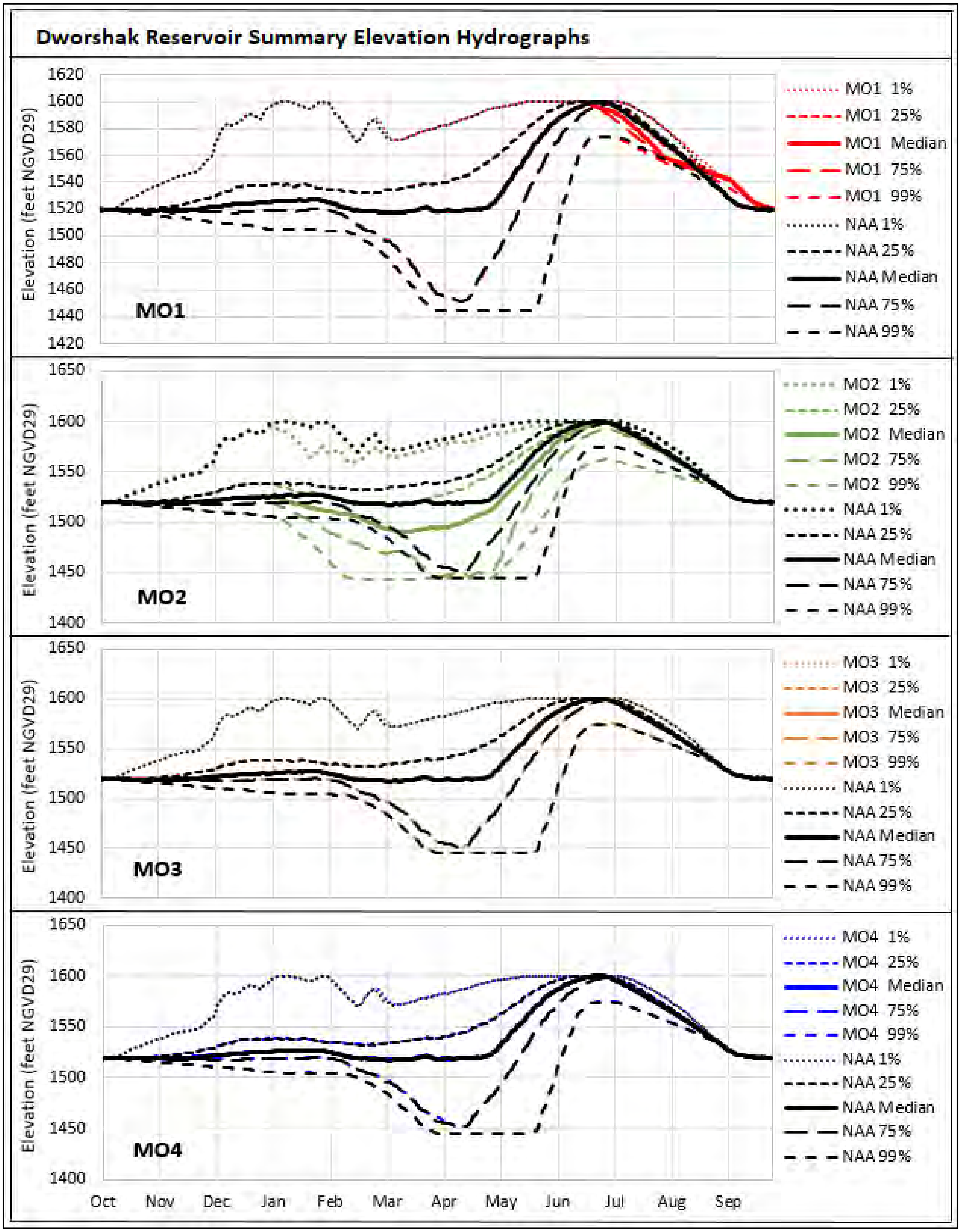


Figure 5-83. Summary Elevation Hydrographs at Dworshak Reservoir

5.6.3.3 Reservoir Target Date Elevation-Frequency Plots

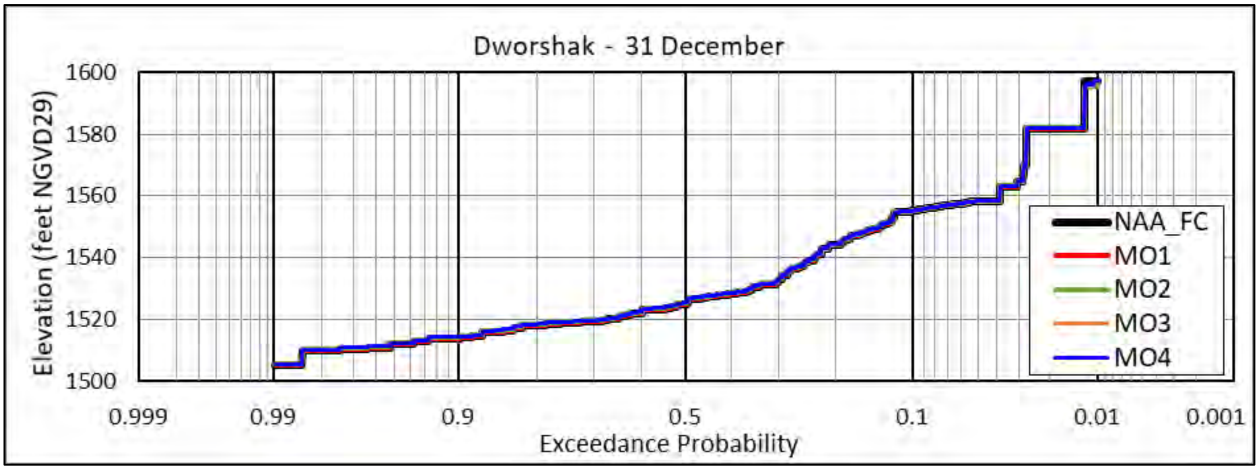


Figure 5-84. Elevation-Frequency Curves for December 31 at Dworshak Reservoir

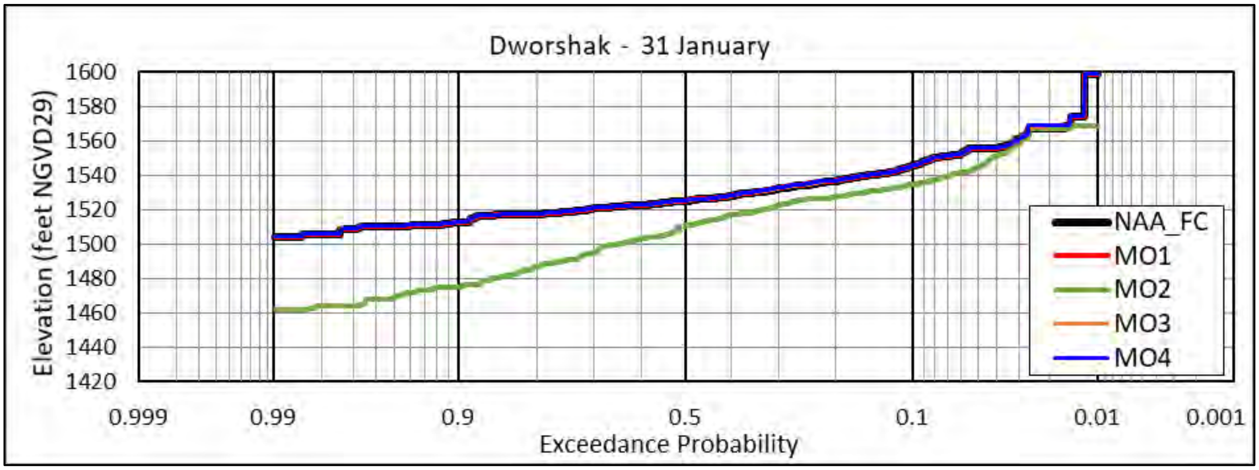


Figure 5-85. Elevation-Frequency Curves for January 31 at Dworshak Reservoir

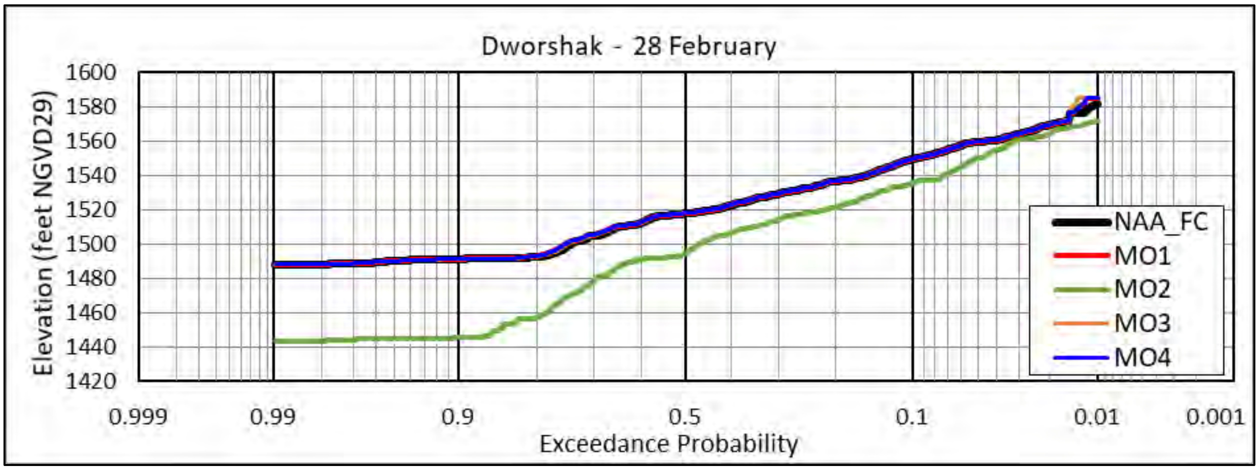


Figure 5-86. Elevation-Frequency Curves for February 28 at Dworshak Reservoir

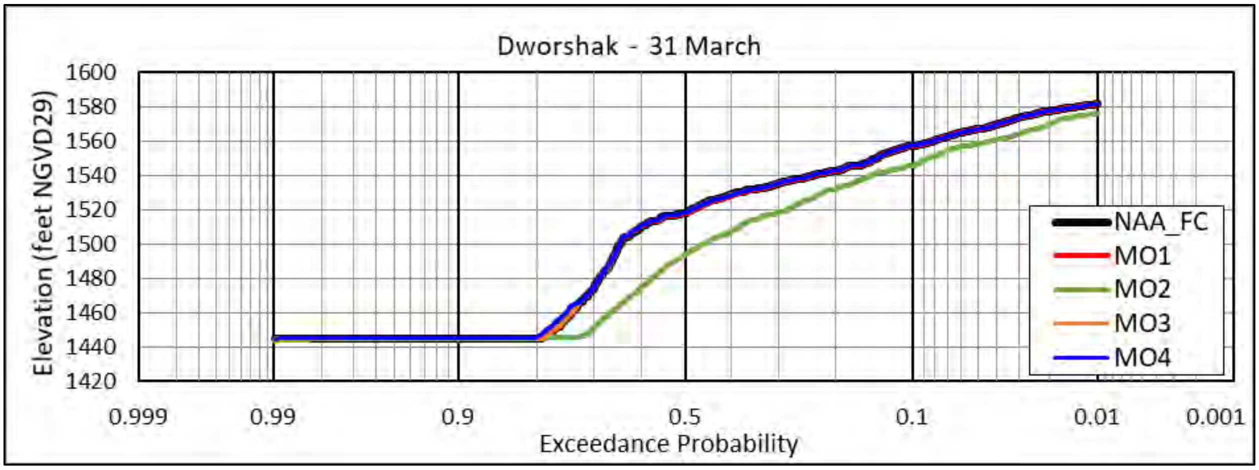


Figure 5-87. Elevation-Frequency Curves for March 31 at Dworshak Reservoir

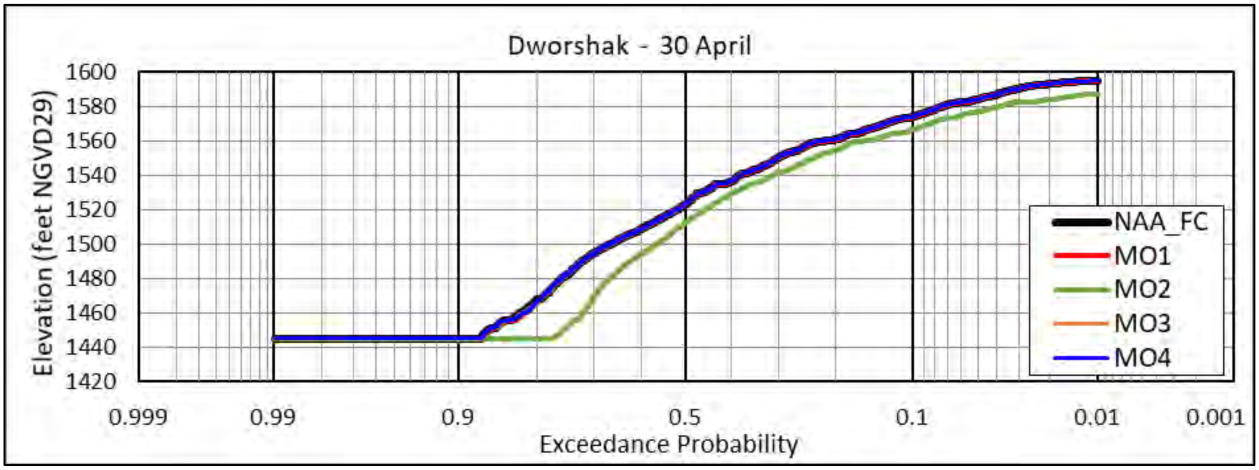


Figure 5-88. Elevation-Frequency Curves for April 30 at Dworshak Reservoir

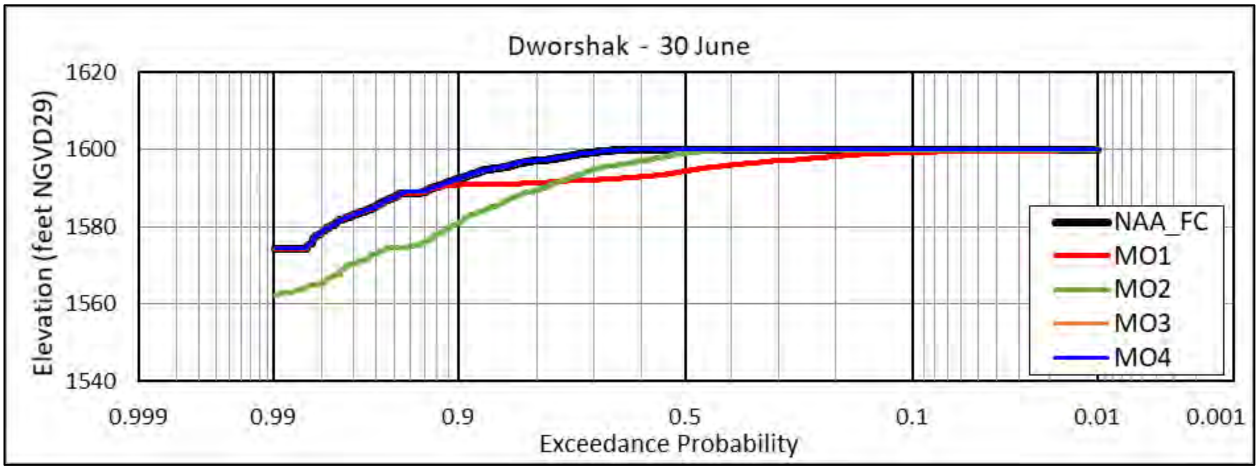


Figure 5-89. Elevation-Frequency Curves for June 30 at Dworshak Reservoir

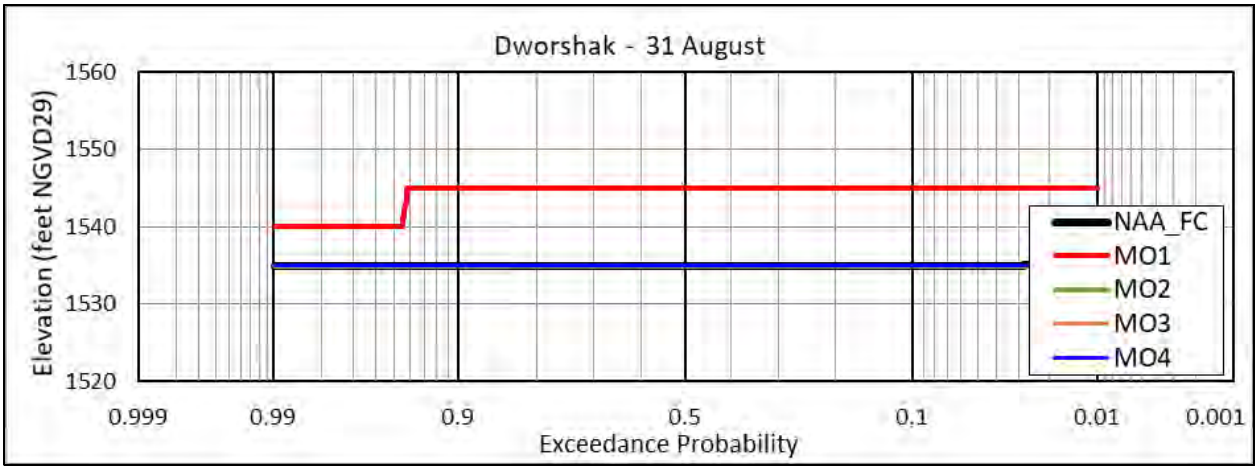


Figure 5-90. Elevation-Frequency Curves for August 31 at Dworshak Reservoir

5.6.3.4 Annual Elevation-Duration Plots

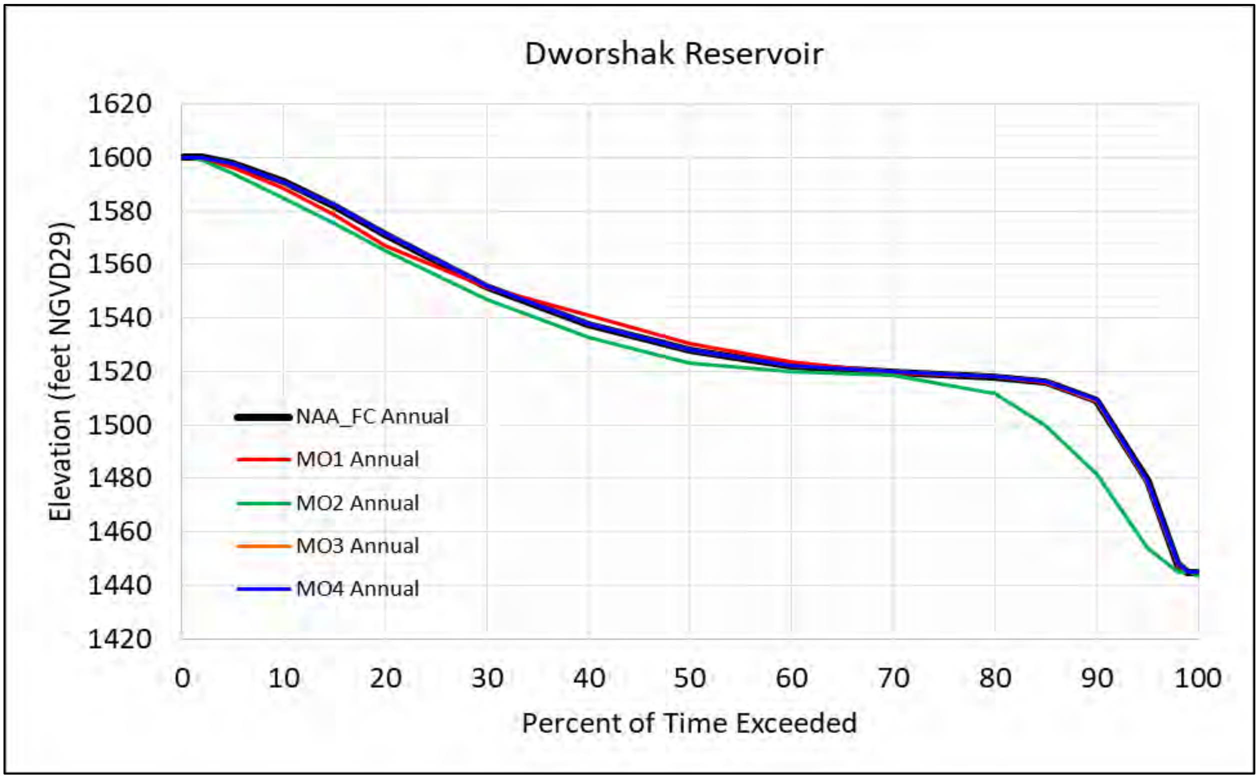


Figure 5-91. Annual Elevation-Duration Curves for Dworshak Reservoir

5.6.3.5 Water Year Plots, Flow

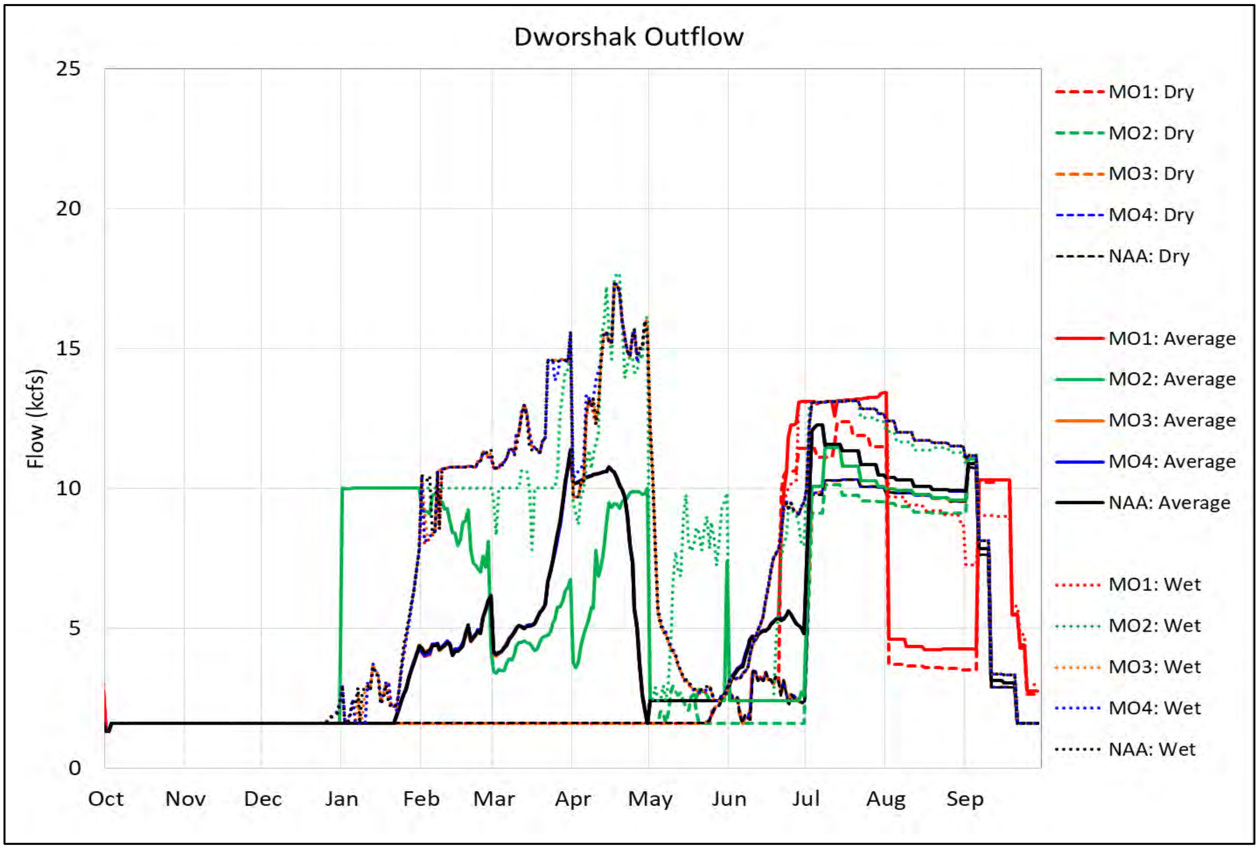
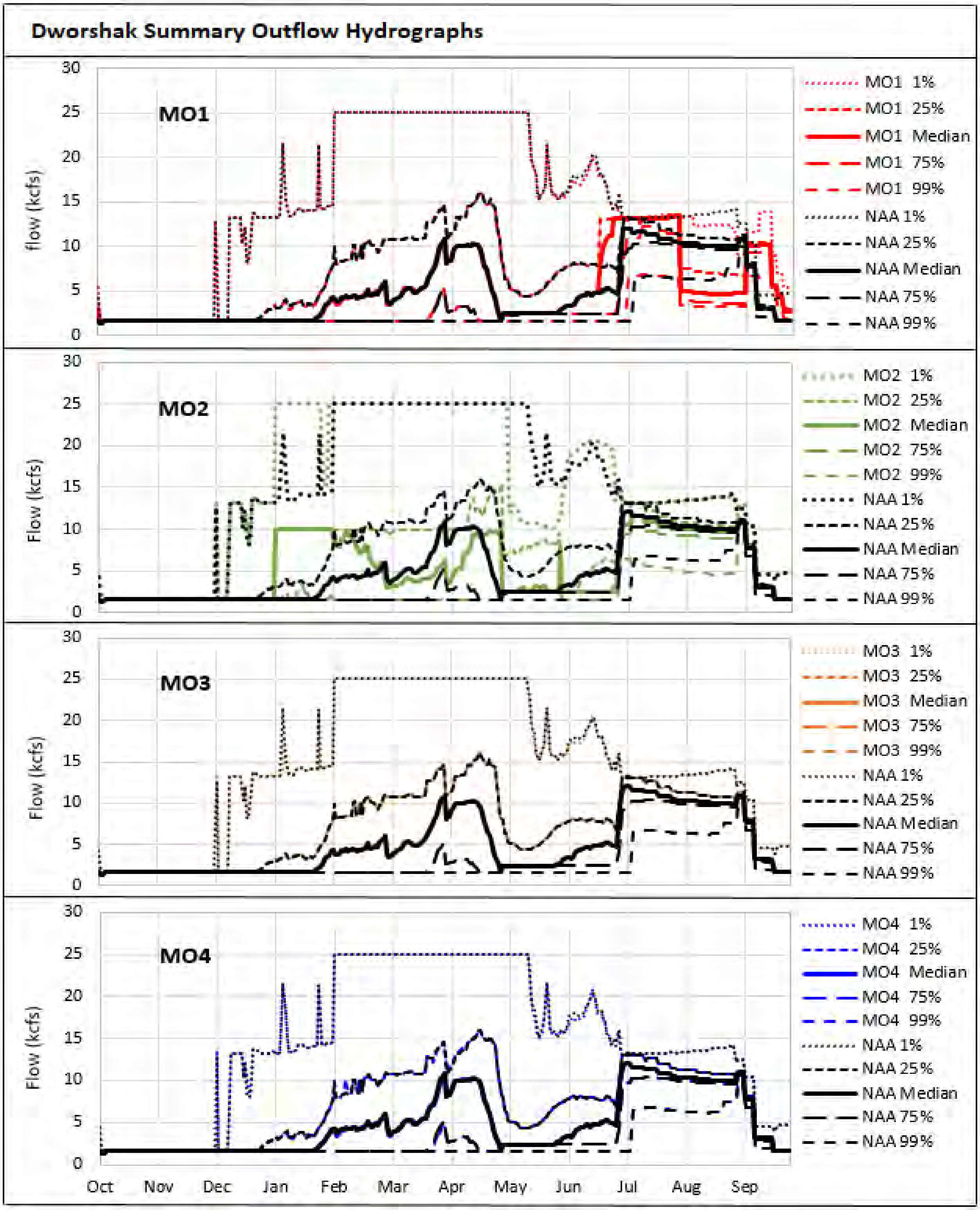


Figure 5-92. Summary Outflow Hydrograph for Dry, Average, and Wet Water Years at Dworshak Dam

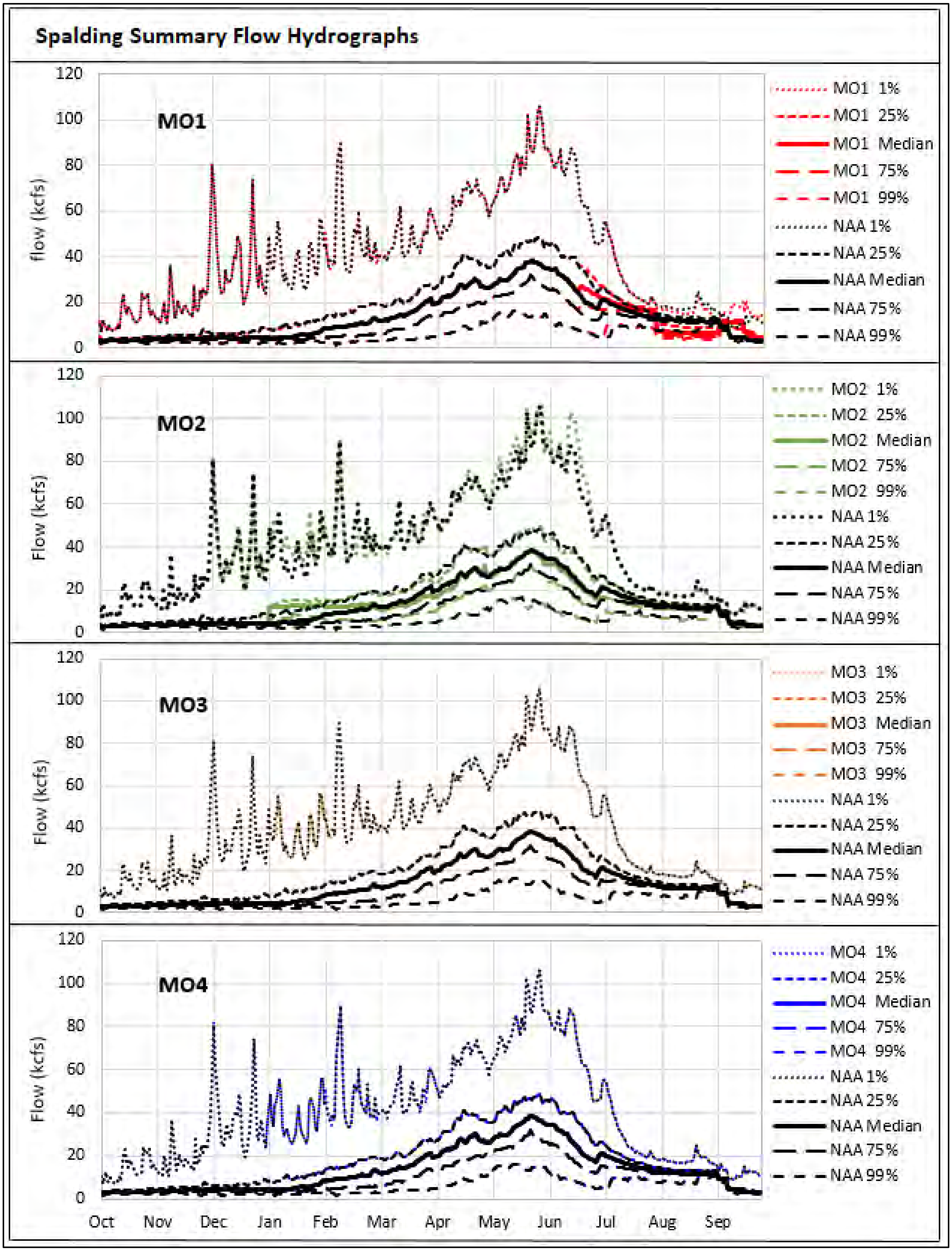
3489

5.6.3.6 Summary Flow Hydrographs



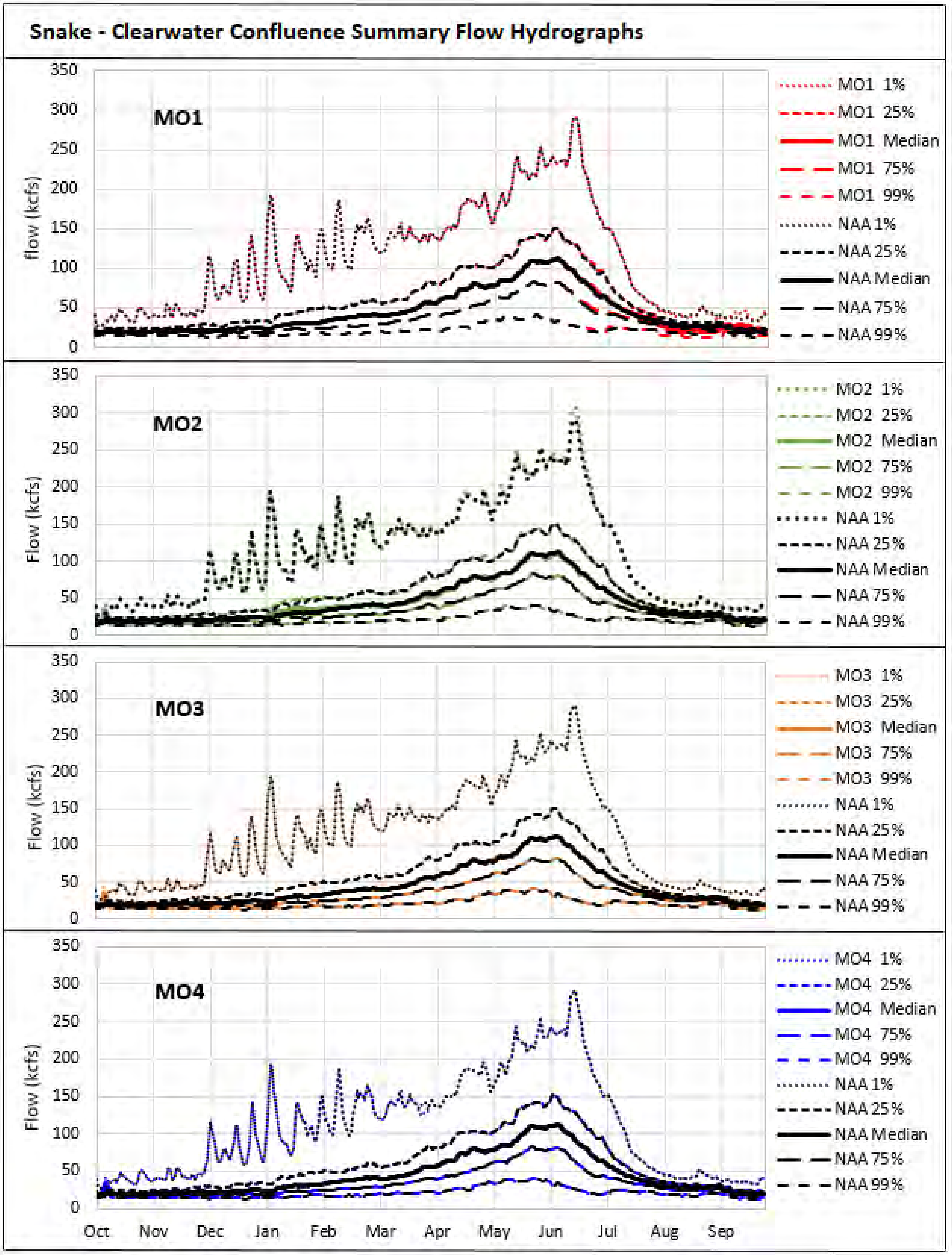
3490

3491 **Figure 5-93. Summary Outflow Hydrographs for Dworshak Dam**

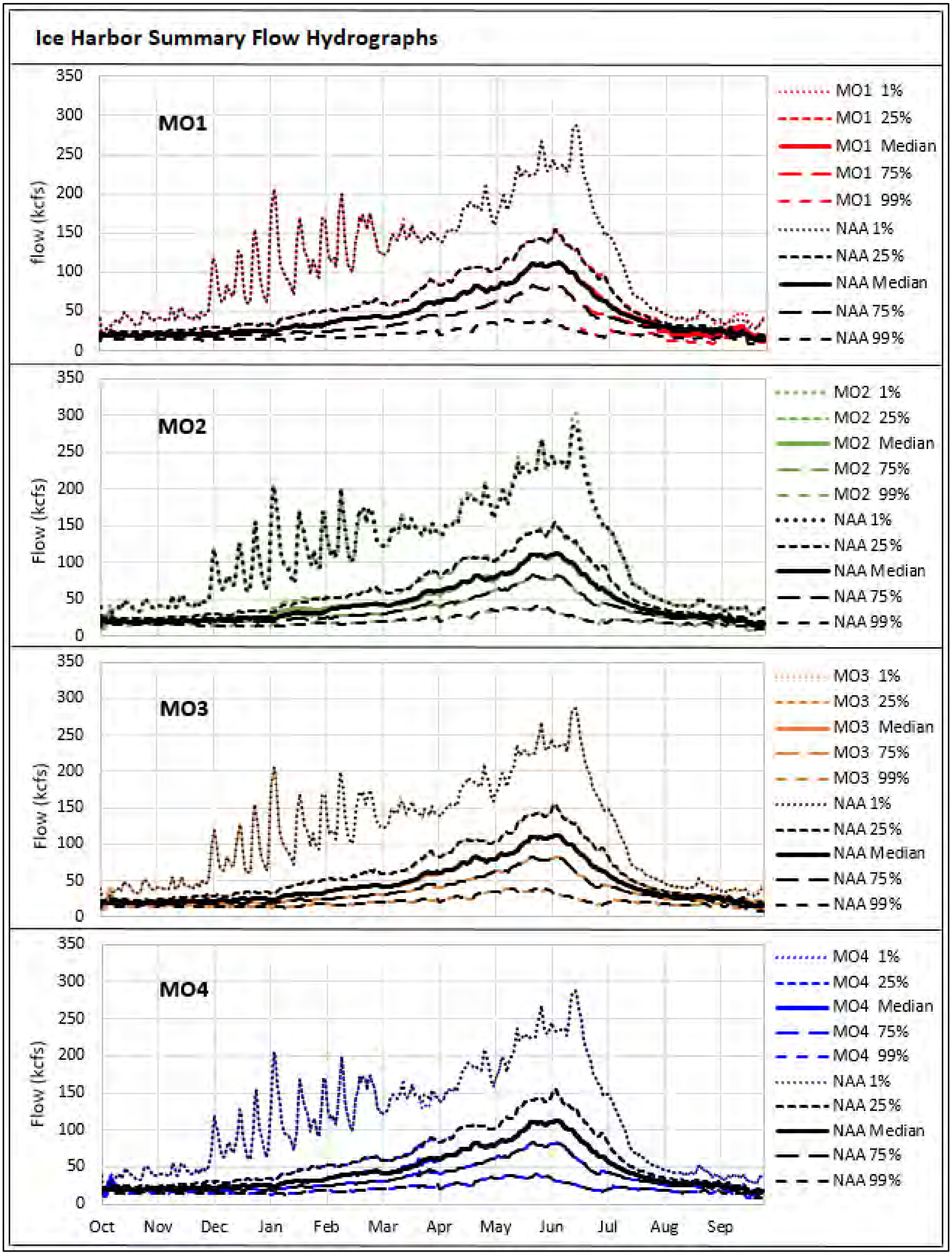


3492

3493 **Figure 5-94. Summary Discharge Hydrographs for the Clearwater River at Spalding, Idaho**



3494
3495 **Figure 5-95. Summary Discharge Hydrographs for the Snake River and Clearwater Confluence**



3496

3497 **Figure 5-96. Summary Outflow Hydrographs for Ice Harbor Dam**

5.6.3.7 Average Monthly Flow Summaries Tables

Table 5-19. Average Monthly Outflow Summary for Dworshak Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	1.7	1.6	8.7	13.5	23.3	25.0	25.0	17.3	15.6	13.2	13.6	6.4
		25%	1.6	1.6	1.9	4.2	9.3	11.8	13.2	6.2	7.5	11.9	11.0	5.2
		50%	1.6	1.6	1.6	2.1	5.1	6.2	9.6	3.5	4.8	10.7	10.2	5.0
		75%	1.6	1.6	1.6	1.6	1.6	2.3	4.6	2.4	2.4	9.6	9.8	4.8
		99%	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	7.4	9.3	4.5
MO1	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-1.9	0.0	0.0	0.0	0.1	0.1	-1.1	1.9
		25%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.3	-3.5	1.9
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	-4.9	1.8
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	-5.6	1.8
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	-5.5	1.5
	Percent change	1%	2%	0%	0%	0%	-8%	0%	0%	0%	0%	1%	-8%	29%
		25%	3%	0%	0%	0%	-1%	0%	0%	0%	23%	11%	-32%	37%
		50%	2%	0%	0%	0%	0%	1%	0%	0%	33%	15%	-48%	37%
		75%	2%	0%	0%	0%	0%	0%	0%	0%	0%	13%	-57%	37%
		99%	1%	0%	0%	0%	0%	0%	0%	0%	0%	38%	-59%	33%
MO2	Change (kcfs)	1%	0.0	0.0	0.0	7.4	-4.2	0.0	-0.6	-5.5	1.2	0.0	0.0	-0.1
		25%	0.0	0.0	0.0	5.5	0.7	-2.6	-0.3	0.5	-2.6	-0.2	-0.4	0.0
		50%	0.0	0.0	0.0	6.6	2.0	-1.5	-1.9	1.0	-2.2	-0.2	-0.4	0.0
		75%	0.0	0.0	0.0	2.3	0.3	-0.7	-2.5	0.6	-0.1	-0.3	-0.7	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-3.2	-0.1
	Percent change	1%	0%	0%	0%	55%	-18%	0%	-2%	-31%	8%	0%	0%	-1%
		25%	0%	0%	0%	129%	7%	-22%	-2%	8%	-35%	-1%	-4%	-1%
		50%	0%	0%	0%	311%	39%	-24%	-20%	27%	-45%	-2%	-4%	0%
		75%	0%	0%	0%	141%	19%	-30%	-54%	25%	-3%	-4%	-7%	-1%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-3%	-34%	-1%
MO3	Change (kcfs)	1%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		25%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
	Percent change	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		25%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-1.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		25%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
	Percent change	1%	0%	0%	0%	0%	-8%	0%	0%	0%	0%	0%	0%	0%
		25%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	0%	1%	1%	0%	0%	1%	0%	0%	0%
		75%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%

Table 5-20. Average Monthly Flow Summary for Spalding, Idaho

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	12.6	13.5	30.3	28.2	35.3	37.1	46.8	65.7	69.0	31.3	17.6	10.6
		25%	4.3	5.7	6.6	9.6	16.4	20.8	33.9	39.1	38.6	20.0	13.5	7.1
		50%	3.4	4.5	4.7	5.9	10.6	15.5	26.8	33.4	28.7	17.0	12.2	6.5
		75%	3.1	3.5	3.9	4.1	5.9	9.8	18.5	28.3	21.1	14.0	11.4	6.0
		99%	2.7	2.9	3.1	3.1	3.5	6.0	11.2	21.4	12.7	11.7	10.6	5.7
MO1	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.8	0.0	0.0	0.0	-1.8	0.0	-2.0	2.1
		25%	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.7	1.2	-3.6	1.9
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.7	-5.0	1.8
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.7	-5.4	1.8
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.6	-5.5	1.7
	Percent change	1%	0%	0%	0%	0%	-2%	0%	0%	0%	-3%	0%	-11%	19%
		25%	1%	0%	0%	0%	2%	0%	0%	0%	2%	6%	-27%	26%
		50%	1%	0%	0%	0%	0%	0%	0%	0%	6%	10%	-41%	28%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	3%	12%	-48%	29%
		99%	1%	0%	0%	0%	0%	0%	0%	0%	7%	14%	-52%	29%

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
MO2	Change (kcfs)	1%	0.0	0.0	0.0	7.6	-3.7	0.0	1.8	-4.8	-0.7	0.1	-0.5	0.0
		25%	0.0	0.0	0.0	5.0	0.6	-1.0	-0.2	0.4	-1.8	0.0	-0.6	0.0
		50%	0.0	0.0	0.0	6.3	2.6	-2.0	-1.7	0.6	-1.7	-0.2	-0.5	0.0
		75%	0.0	0.0	0.0	3.5	0.6	-0.6	-1.2	0.6	-1.0	-0.5	-0.8	0.0
		99%	0.0	0.0	0.0	0.2	0.0	-0.1	0.0	0.4	-0.7	-0.5	-2.6	-0.1
	Percent change	1%	0%	0%	0%	27%	-10%	0%	4%	-7%	-1%	0%	-3%	0%
		25%	0%	0%	0%	52%	4%	-5%	-1%	1%	-5%	0%	-4%	0%
		50%	0%	0%	0%	107%	24%	-13%	-6%	2%	-6%	-1%	-4%	0%
		75%	0%	0%	0%	86%	11%	-6%	-7%	2%	-5%	-3%	-7%	-1%
		99%	0%	0%	0%	7%	1%	-2%	0%	2%	-6%	-5%	-25%	-1%
MO3	Change (kcfs)	1%	0.0	0.0	0.0	-0.2	-0.8	0.0	0.0	0.0	-0.5	0.0	0.0	0.0
		25%	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	0%	0%	-1%	-2%	0%	0%	0%	-1%	0%	0%	0%
		25%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
MO4	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		25%	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	0%	0%	0%	-2%	0%	0%	0%	0%	0%	0%	0%
		25%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-21. Average Monthly Flow Summary for the Snake River and Clearwater River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	35.3	37.0	64.1	93.2	104.6	122.1	149.3	169.0	206.5	100.2	42.7	33.3
		25%	23.8	26.1	31.7	41.9	52.4	61.0	92.1	121.2	133.4	63.2	33.6	26.0
		50%	19.7	20.9	23.9	28.3	39.0	47.2	69.7	94.4	96.4	47.9	29.2	22.6
		75%	17.7	18.4	19.1	22.5	27.4	35.3	50.0	73.4	70.6	37.2	25.2	20.1
		99%	15.8	15.9	16.4	18.4	19.9	24.8	33.6	60.2	35.5	28.0	22.0	17.3
MO1	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.6	1.2	0.0	0.0	-0.3	0.0	-2.0	1.9
		25%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.3	0.4	-4.4	1.7
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.5	-4.9	1.8
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2.1	-5.0	1.9
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.3	-5.2	1.7
	Percent change	1%	0%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	-5%	6%
		25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	-13%	6%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	-17%	8%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	2%	6%	-20%	9%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	1%	8%	-24%	10%
MO2	Change (kcfs)	1%	1.0	0.0	0.0	1.9	-3.9	-0.2	1.8	0.5	5.4	-0.5	-0.1	-0.1
		25%	1.0	0.0	0.0	3.6	0.2	-2.4	-1.4	-1.0	-0.1	-0.3	-1.3	0.0
		50%	1.0	0.0	0.0	5.8	1.9	-1.6	-0.8	0.4	-2.3	-0.1	-1.0	-0.1
		75%	1.0	0.0	0.0	4.2	1.0	-1.1	-2.0	0.5	-1.9	-0.6	-0.5	0.0
		99%	1.0	0.0	0.0	1.9	0.0	-0.5	-0.3	0.5	0.0	-0.7	-1.5	0.0
	Percent change	1%	3%	0%	0%	2%	-4%	0%	1%	0%	3%	-1%	0%	0%
		25%	4%	0%	0%	9%	0%	-4%	-1%	-1%	0%	0%	-4%	0%
		50%	5%	0%	0%	20%	5%	-3%	-1%	0%	-2%	0%	-3%	0%
		75%	5%	0%	0%	19%	3%	-3%	-4%	1%	-3%	-2%	-2%	0%
		99%	6%	0%	0%	10%	0%	-2%	-1%	1%	0%	-3%	-7%	0%
MO3	Change (kcfs)	1%	1.0	0.0	0.0	0.0	-0.8	0.4	0.0	0.0	-0.6	0.0	0.0	0.0
		25%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
		50%	1.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
		99%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	3%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%
		25%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		99%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	1.0	0.0	0.0	0.0	-0.6	1.0	0.0	0.0	0.1	0.0	0.0	0.0
		25%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0
		50%	1.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		75%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		99%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	3%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	0%	0%
		25%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		99%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-22. Average Monthly Outflow Summary for Lower Granite Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	35.5	37.3	63.9	93.2	105.5	123.2	150.5	169.2	206.5	99.3	42.6	32.9
		25%	23.8	27.0	31.4	42.1	52.6	61.9	93.7	121.1	133.9	62.9	33.8	25.3
		50%	19.8	21.0	23.7	28.4	39.3	48.0	71.8	95.6	97.4	48.6	29.1	22.5
		75%	18.0	18.6	19.0	22.1	26.4	35.8	50.7	74.9	70.2	37.2	25.4	19.8
		99%	16.3	16.0	16.4	17.6	19.1	24.8	34.4	60.7	35.3	28.0	22.1	16.9
MO1	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.6	1.5	0.0	0.1	-0.2	0.0	-2.0	1.9
		25%	0.0	0.0	0.0	-0.1	0.0	0.0	0.1	-0.1	0.5	0.7	-4.3	1.8
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.0	-4.5	1.8
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.8	-5.2	1.9
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.4	-5.3	1.6
	Percent change	1%	0%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	-5%	6%
		25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	-13%	7%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	-16%	8%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	2%	5%	-20%	9%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	1%	9%	-24%	9%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO2	Change (kcfs)	1%	0.4	0.0	0.0	1.9	-3.9	0.2	2.2	0.4	5.8	-0.5	-0.1	-0.1
		25%	0.4	0.0	0.0	4.7	0.3	-1.7	-1.4	-1.6	-0.2	0.0	-1.1	0.0
		50%	0.4	0.0	0.0	5.4	1.7	-1.6	-1.4	0.2	-1.9	-0.7	-1.0	0.0
		75%	0.4	0.0	0.0	4.5	1.3	-1.2	-1.9	0.5	-2.0	-0.7	-0.6	0.0
		99%	0.4	0.0	0.0	2.0	0.2	-0.6	-0.2	0.5	0.0	-0.5	-1.6	-0.1
	Percent change	1%	1%	0%	0%	2%	-4%	0%	1%	0%	3%	-1%	0%	0%
		25%	2%	0%	0%	11%	1%	-3%	-1%	-1%	0%	0%	-3%	0%
		50%	2%	0%	0%	19%	4%	-3%	-2%	0%	-2%	-2%	-3%	0%
		75%	2%	0%	0%	20%	5%	-3%	-4%	1%	-3%	-2%	-3%	0%
		99%	2%	0%	0%	11%	1%	-2%	-1%	1%	0%	-2%	-7%	0%
MO3	Change (kcfs)	1%	0.4	0.0	0.0	0.0	-0.8	0.4	-0.1	0.1	-0.2	0.0	0.0	0.4
		25%	0.4	0.0	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.4
		50%	0.4	0.0	0.0	0.0	0.0	-0.3	-0.1	0.0	0.0	0.0	0.0	0.4
		75%	0.4	0.0	0.0	0.0	0.0	-0.3	-0.1	0.0	0.1	0.0	0.0	0.4
		99%	0.4	0.0	0.0	0.0	0.0	-0.3	-0.1	0.0	0.0	0.0	0.0	0.4
	Percent change	1%	1%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	1%
		25%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	2%
		50%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	2%
		75%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	2%
		99%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	2%
M04	Change (kcfs)	1%	0.4	0.0	0.0	0.0	-0.6	1.4	-0.1	0.0	0.1	0.0	0.0	0.0
		25%	0.4	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
		50%	0.4	0.0	0.0	0.0	0.1	0.1	-0.1	0.0	0.0	0.0	0.0	0.0
		75%	0.4	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
		99%	0.4	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0	0.0	0.1	0.0
	Percent change	1%	1%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	0%	0%
		25%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		99%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-23. Average Monthly Outflow Summary for Ice Harbor Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	34.9	36.5	66.2	97.1	107.3	127.5	151.0	164.5	203.4	97.2	42.4	31.3
		25%	23.6	26.5	31.6	43.7	55.5	64.7	94.7	120.8	134.6	62.8	33.0	24.0
		50%	20.2	21.4	24.5	29.4	42.0	50.7	73.0	95.4	97.2	48.4	28.1	21.2
		75%	18.3	19.2	19.5	23.1	28.3	37.9	51.6	75.4	69.9	36.5	24.7	18.7
		99%	16.3	16.3	16.9	17.9	20.7	27.1	35.9	60.2	34.8	26.6	20.3	15.3
MO1	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.6	1.5	0.0	0.0	0.1	0.0	-1.4	2.0
		25%	0.0	0.0	0.0	0.0	0.1	0.0	-0.1	-0.1	0.7	0.6	-4.0	1.9
		50%	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.1	-4.5	1.9
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2.1	-5.4	1.8
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.0	-4.7	1.6
	Percent change	1%	0%	0%	0%	0%	-1%	1%	0%	0%	0%	0%	-3%	6%
		25%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	-12%	8%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	-16%	9%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	2%	6%	-22%	10%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	3%	7%	-23%	11%
MO2	Change (kcfs)	1%	0.4	0.0	0.0	1.9	-3.9	0.2	2.2	-0.1	4.7	-0.9	0.0	0.0
		25%	0.4	0.0	0.0	4.6	0.4	-1.7	-1.0	-1.7	-1.9	-0.4	-1.1	-0.1
		50%	0.4	0.0	0.0	5.2	2.0	-1.6	-1.3	0.4	-2.0	-0.8	-0.7	-0.1
		75%	0.4	0.0	0.0	4.1	1.3	-1.0	-1.7	0.5	-1.5	-0.4	-0.5	0.0
		99%	0.4	0.0	0.0	2.2	0.1	-0.5	-0.2	0.7	-0.2	0.0	-1.1	-0.1
	Percent change	1%	1%	0%	0%	2%	-4%	0%	1%	0%	2%	-1%	0%	0%
		25%	2%	0%	0%	10%	1%	-3%	-1%	-1%	-1%	-1%	-3%	0%
		50%	2%	0%	0%	18%	5%	-3%	-2%	0%	-2%	-2%	-2%	0%
		75%	2%	0%	0%	18%	5%	-3%	-3%	1%	-2%	-1%	-2%	0%
		99%	2%	0%	0%	12%	0%	-2%	0%	1%	-1%	0%	-5%	0%
MO3	Change (kcfs)	1%	0.4	0.0	0.0	0.0	-0.8	-0.1	-0.3	0.0	-1.1	-0.1	0.0	1.3
		25%	0.4	0.0	0.0	0.0	0.1	-0.9	-0.4	0.0	0.0	-0.1	0.0	1.3
		50%	0.4	0.0	0.0	0.0	0.1	-0.9	-0.3	0.0	0.0	0.0	0.0	1.3
		75%	0.4	0.0	0.0	0.0	0.0	-0.9	-0.4	0.1	-0.1	0.0	0.0	1.3
		99%	0.4	0.0	0.0	0.0	0.0	-0.9	-0.4	0.0	0.0	0.0	0.1	1.3
	Percent change	1%	1%	0%	0%	0%	-1%	0%	0%	0%	-1%	0%	0%	4%
		25%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	5%
		50%	2%	0%	0%	0%	0%	-2%	0%	0%	0%	0%	0%	6%
		75%	2%	0%	0%	0%	0%	-2%	-1%	0%	0%	0%	0%	7%
		99%	2%	0%	0%	0%	0%	-3%	-1%	0%	0%	0%	0%	8%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	0.4	0.0	0.0	0.0	-0.6	1.5	-0.3	0.0	2.0	0.0	0.1	0.0
		25%	0.4	0.0	0.0	0.0	0.2	0.2	-0.4	-0.1	0.0	0.0	0.1	0.0
		50%	0.4	0.0	0.0	0.0	0.0	0.2	-0.3	0.0	0.0	0.1	0.1	0.0
		75%	0.4	0.0	0.0	0.0	0.0	0.2	-0.3	0.0	0.0	0.0	0.1	0.0
		99%	0.4	0.0	0.0	0.0	0.0	0.2	-0.3	0.0	0.0	0.0	0.1	0.0
	Percent change	1%	1%	0%	0%	0%	-1%	1%	0%	0%	1%	0%	0%	0%
		25%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		75%	2%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%
		99%	2%	0%	0%	0%	0%	1%	-1%	0%	0%	0%	1%	0%

5.6.3.8 Annual Flow-Duration Plots

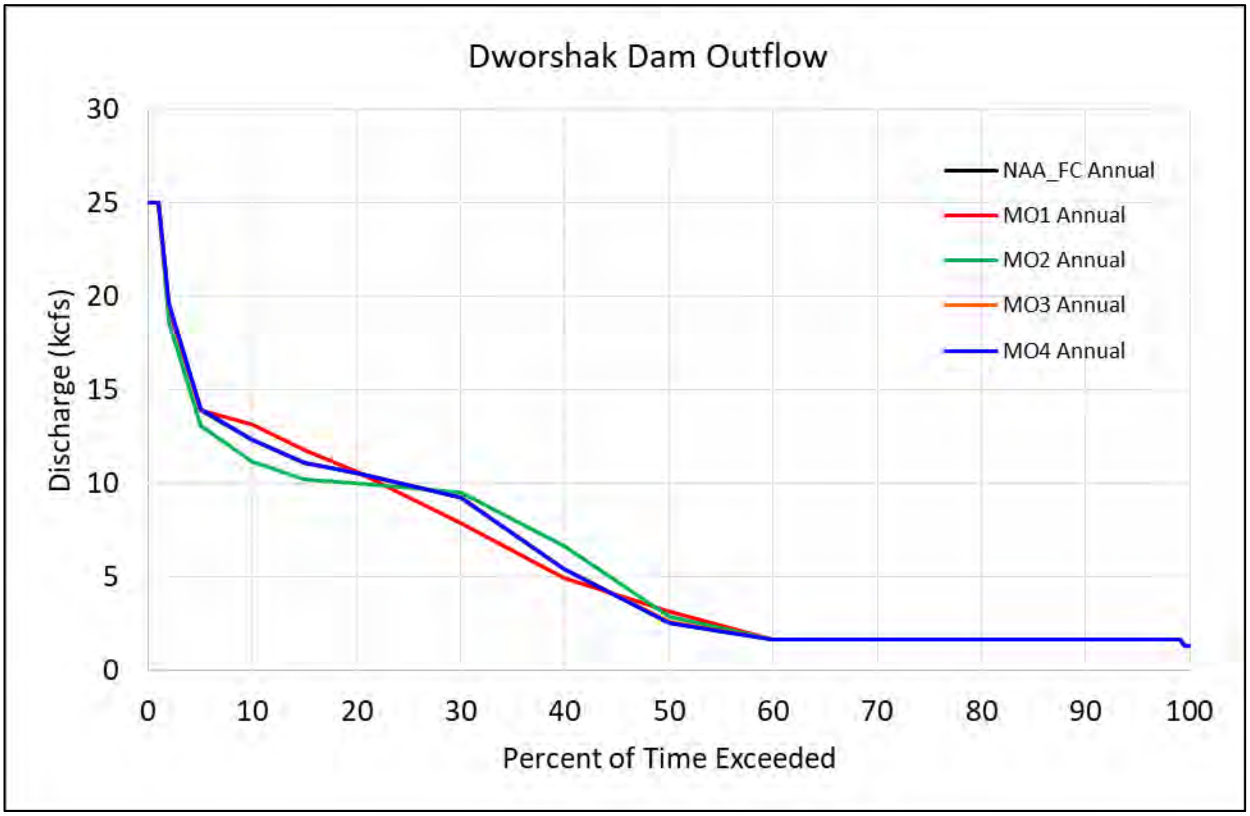
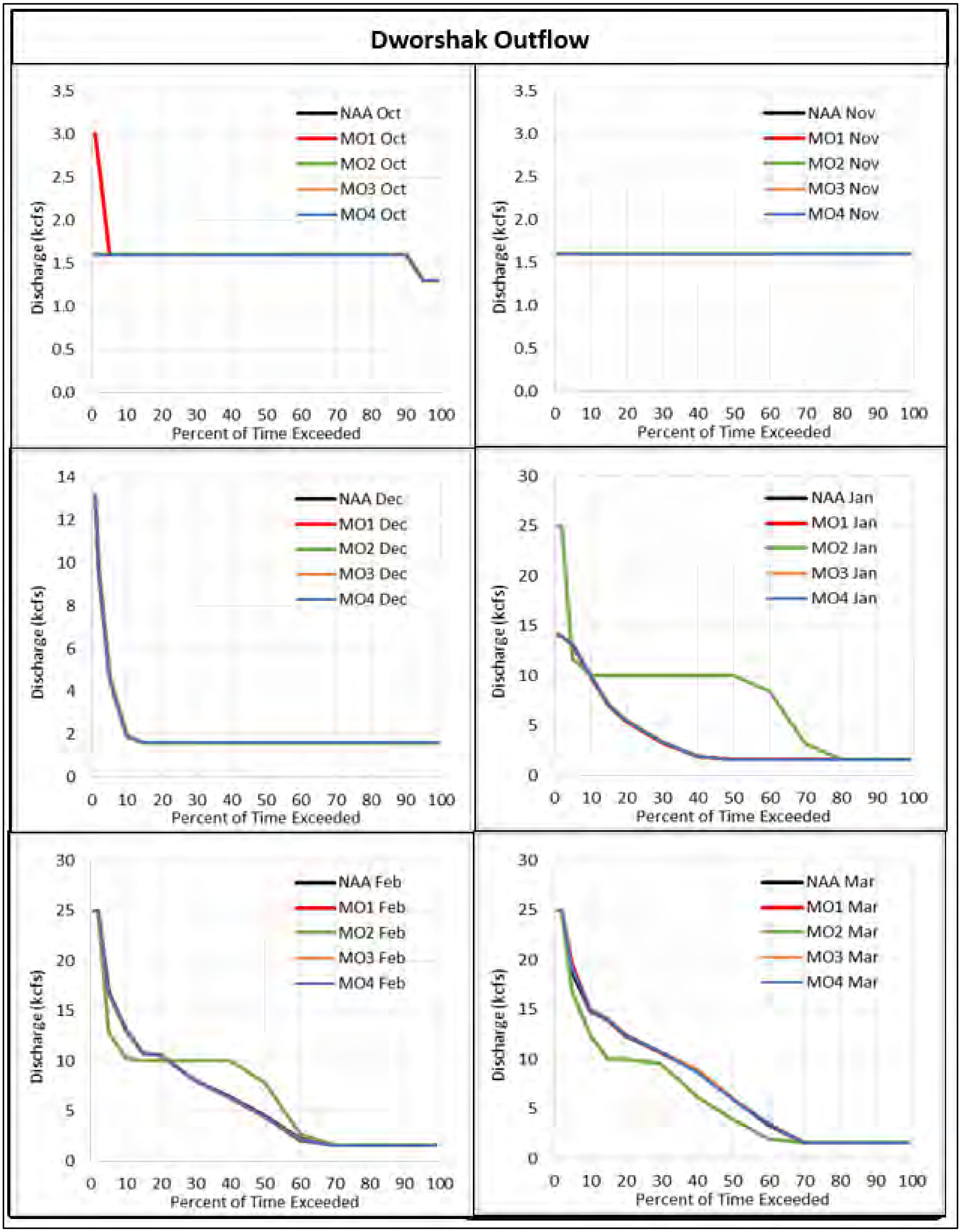


Figure 5-97. Annual Flow-Duration Curves for Dworshak Dam Outflow

3508 *5.6.3.9 Monthly Flow-Duration Plots*



3509

3510 **Figure 5-98. Monthly Flow-Duration Curves for Dworshak Dam Outflow**

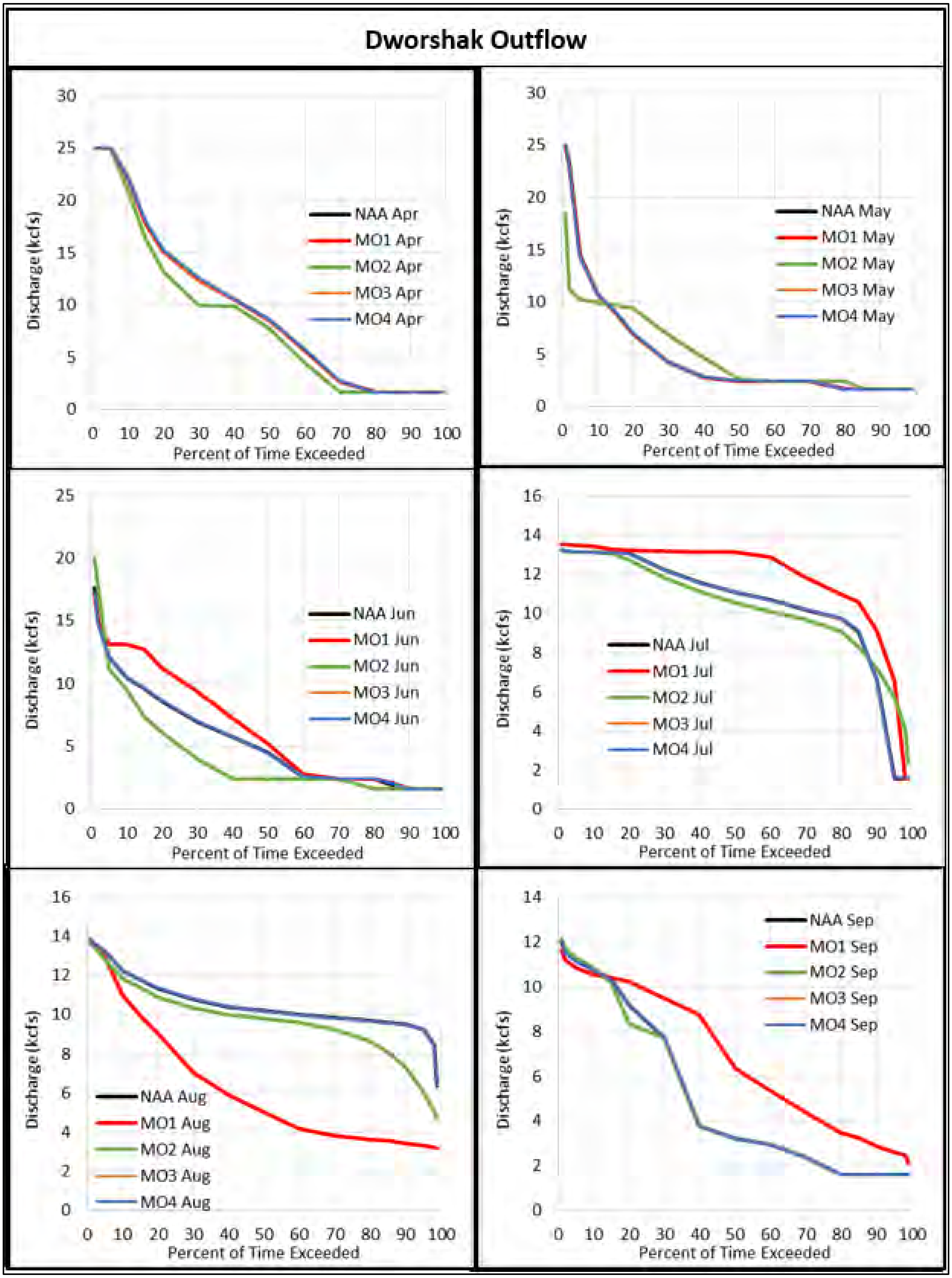
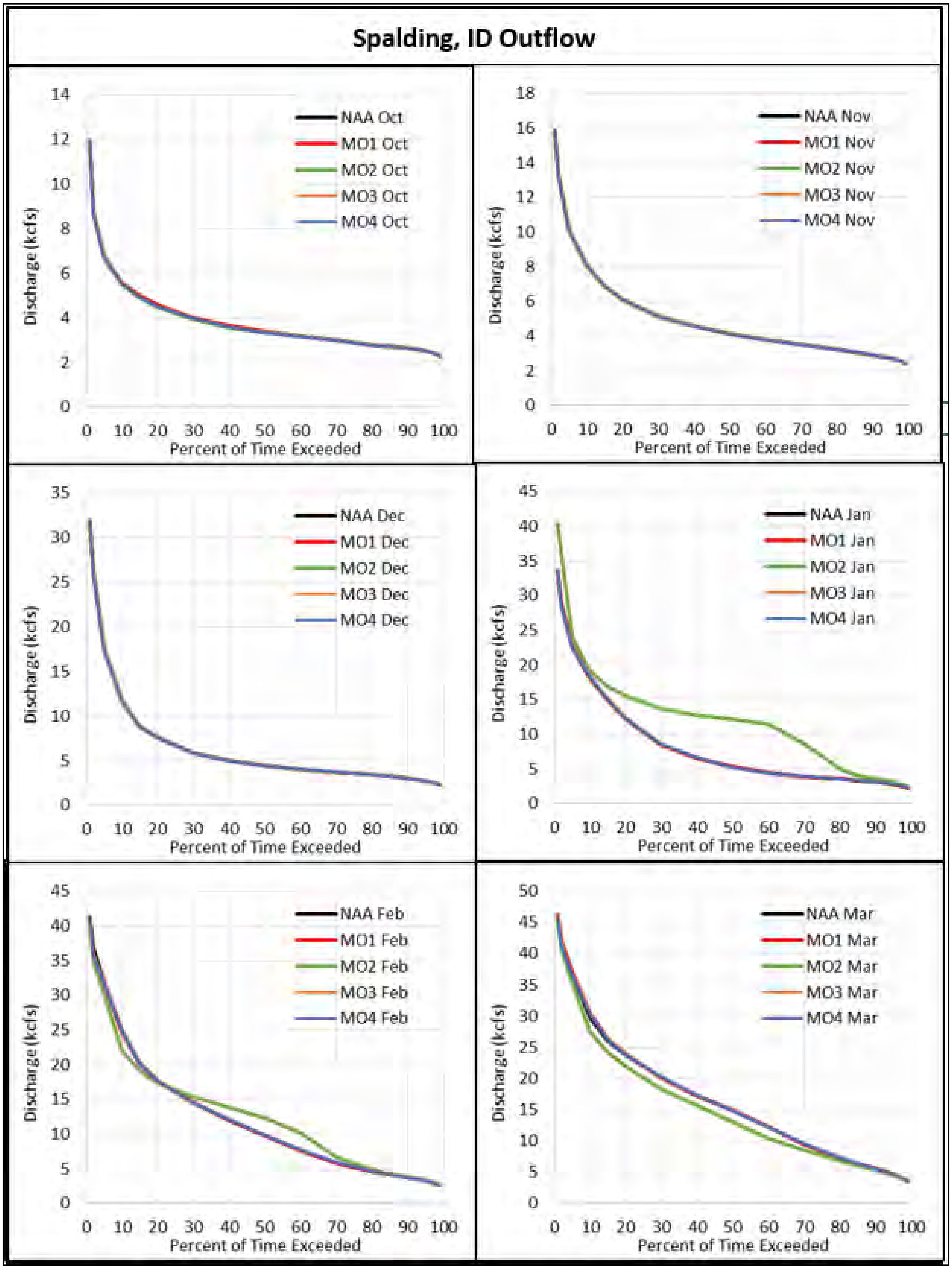


Figure 5-99. Monthly Flow-Duration Curves for Dworshak Dam Outflow (continued)



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3514 **Figure 5-100. Monthly Flow-Duration Curves for Spalding, Idaho**

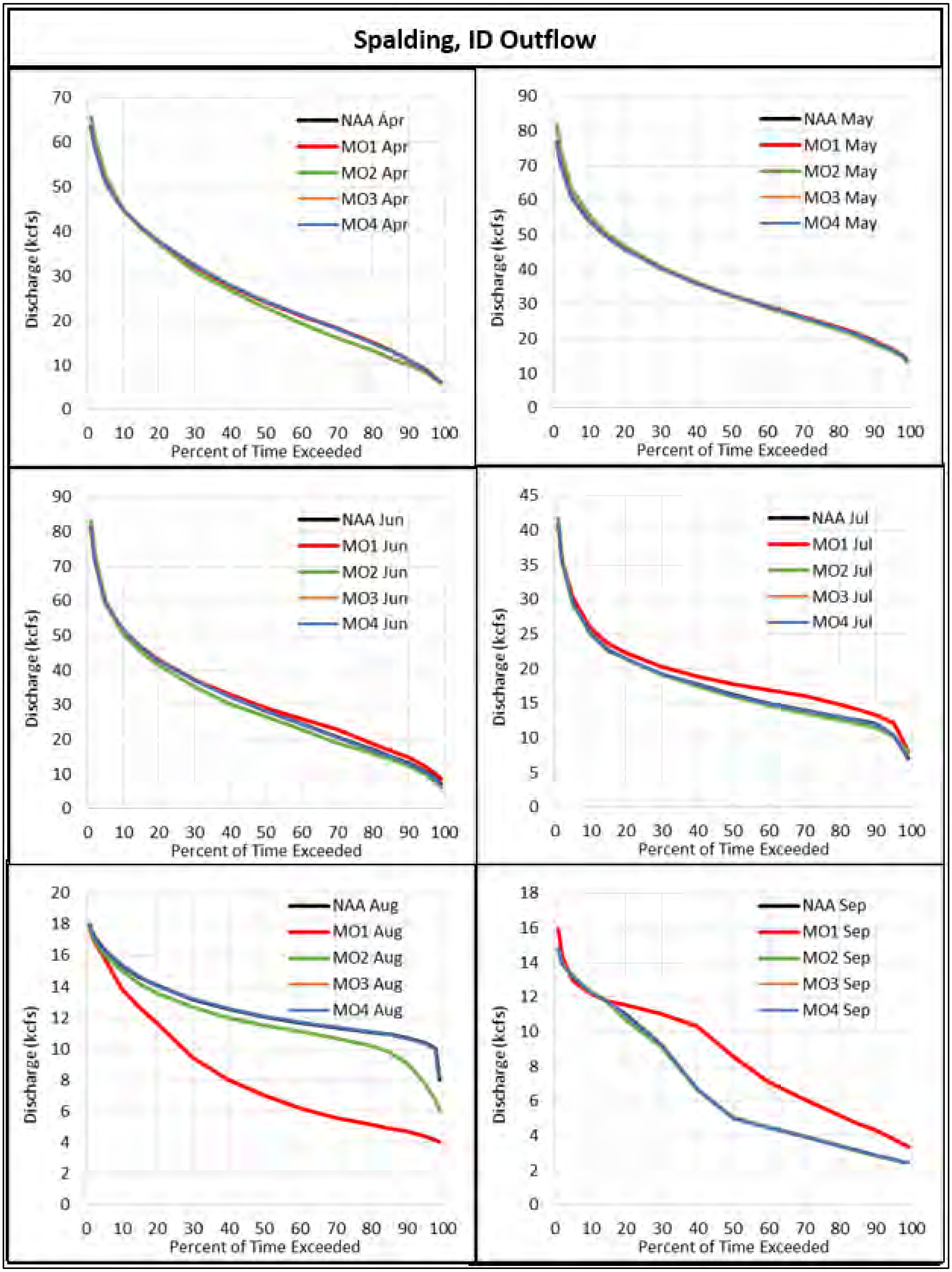


Figure 5-101. Monthly Flow-Duration Curves for Spalding, Idaho (continued)

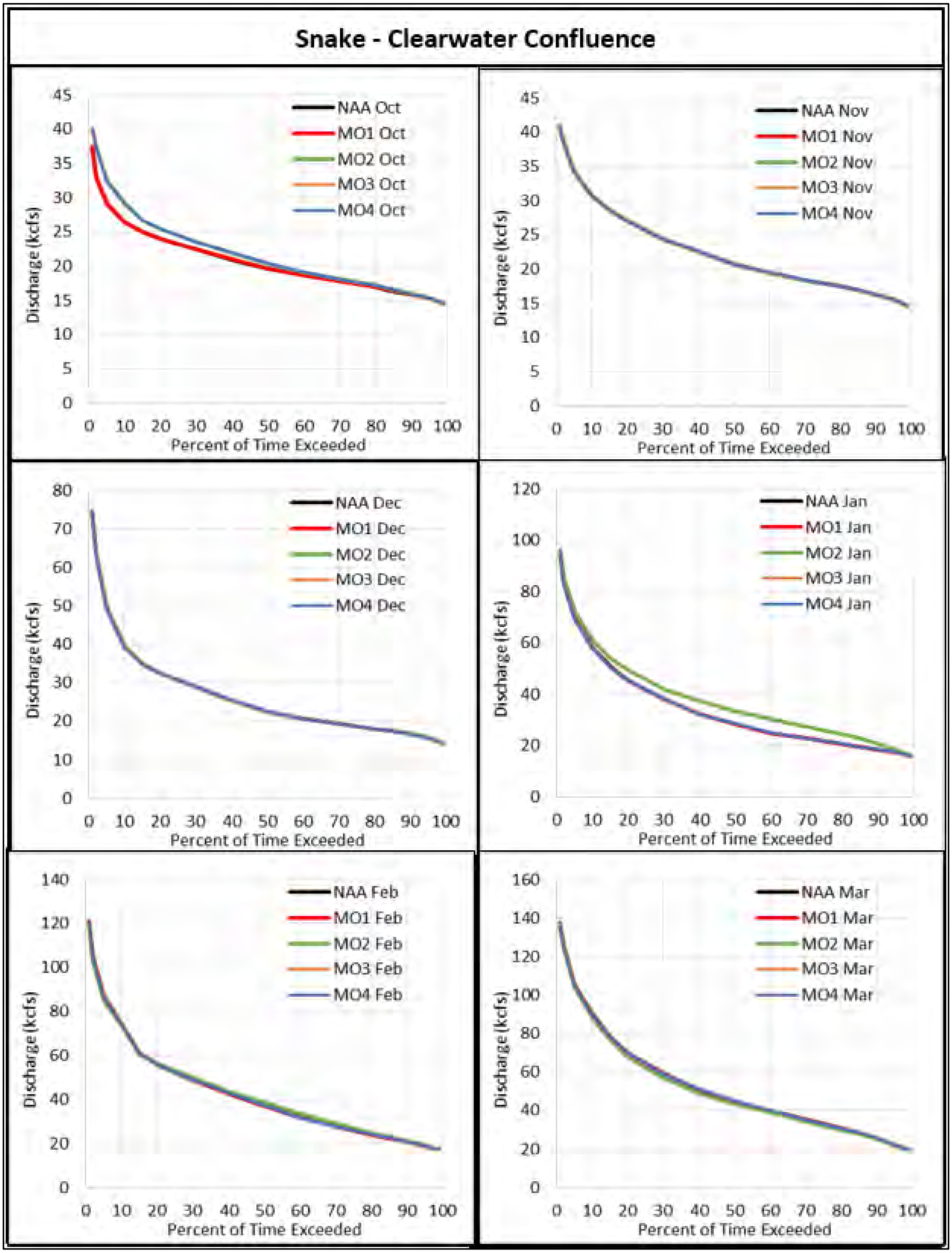
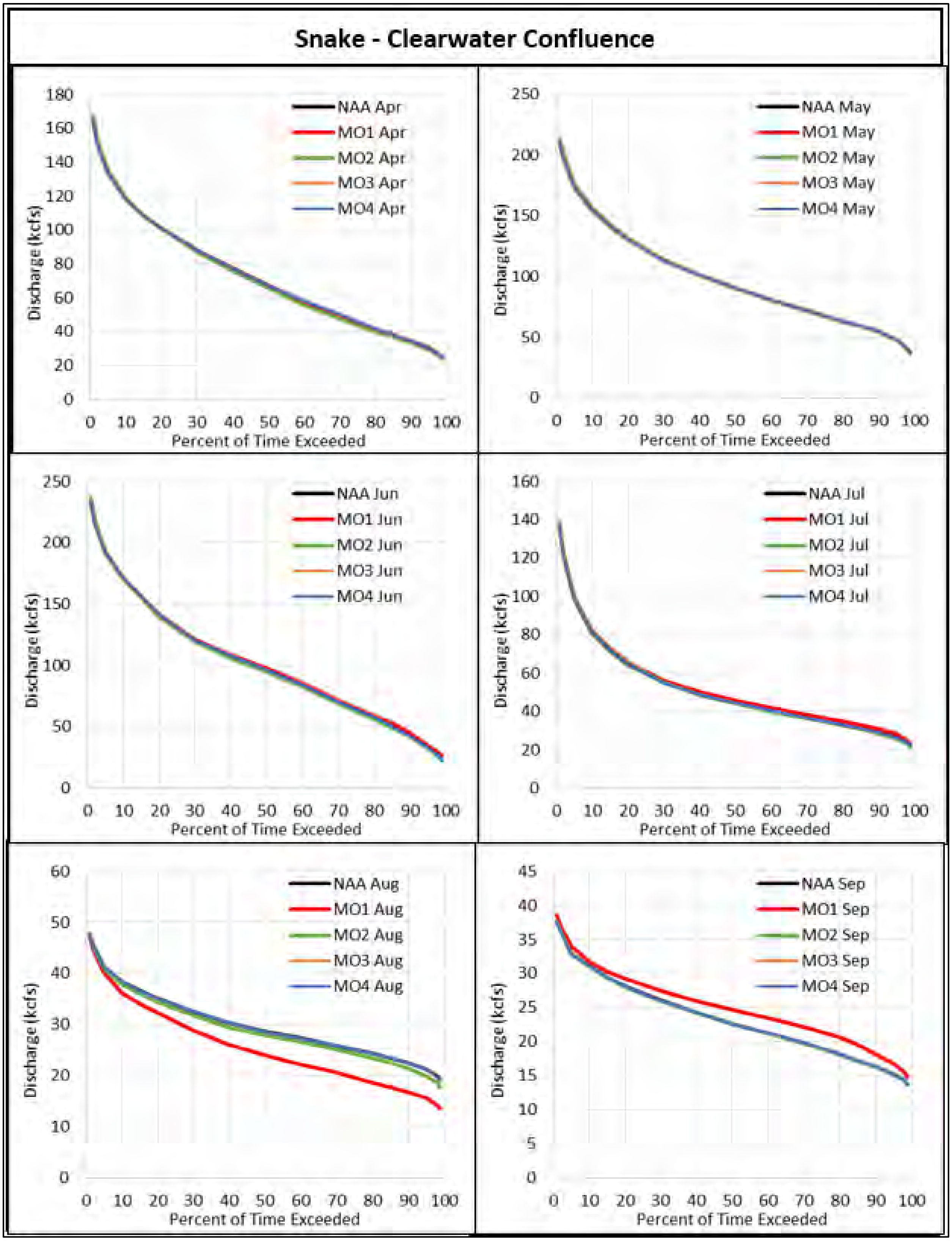


Figure 5-102. Monthly Flow-Duration Curves for the Snake River and Clearwater River Confluence



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3521 **Figure 5-103. Monthly Flow-Duration Curves for the Snake River and Clearwater River**
3522 **Confluence (continued)**

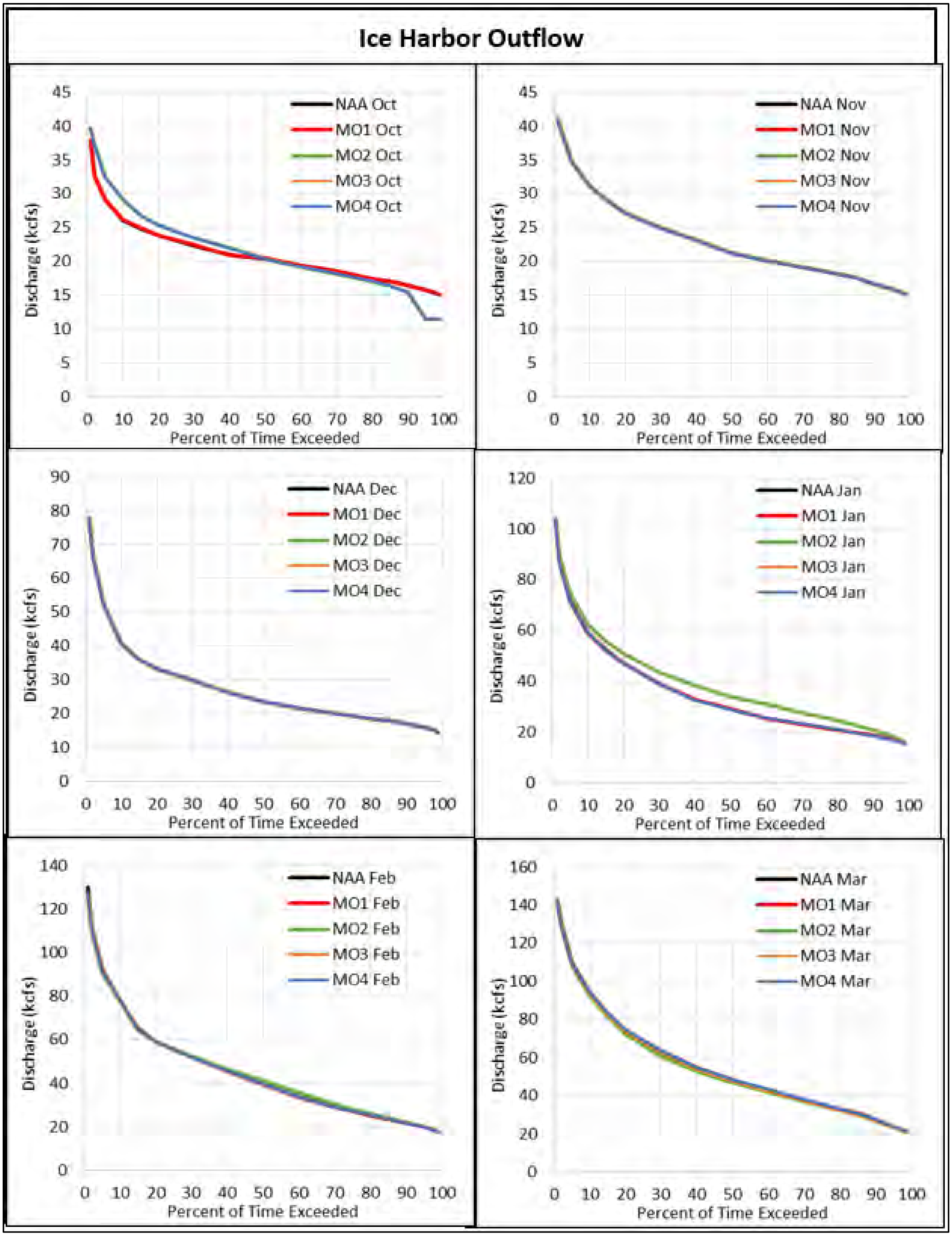


Figure 5-104. Monthly Flow-Duration Curves for the Snake River and Clearwater River Confluence

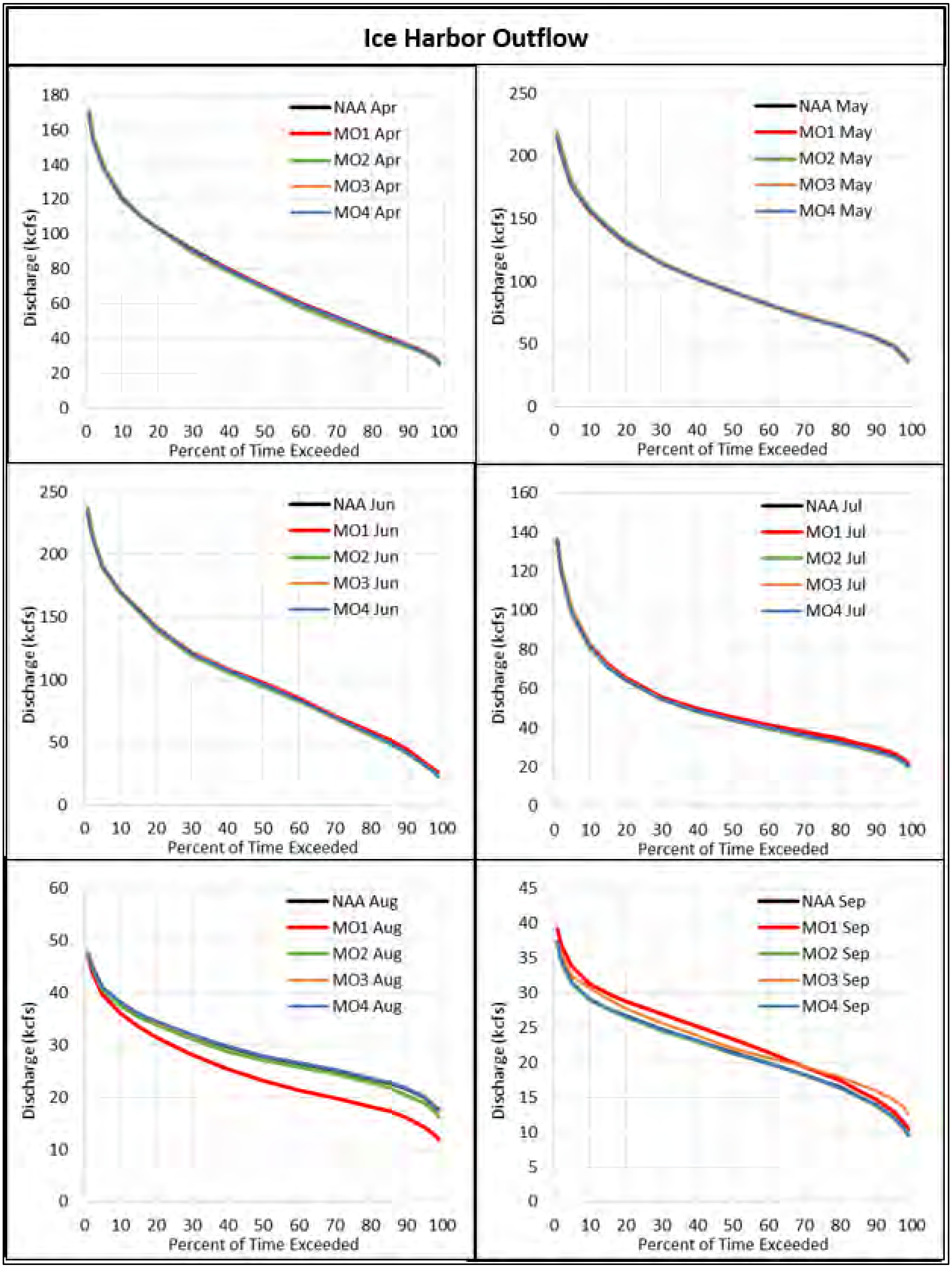


Figure 5-105. Monthly Flow-Duration Curves for Ice Harbor Dam Outflow

5.6.3.10 Peak Flow-Frequency Plots

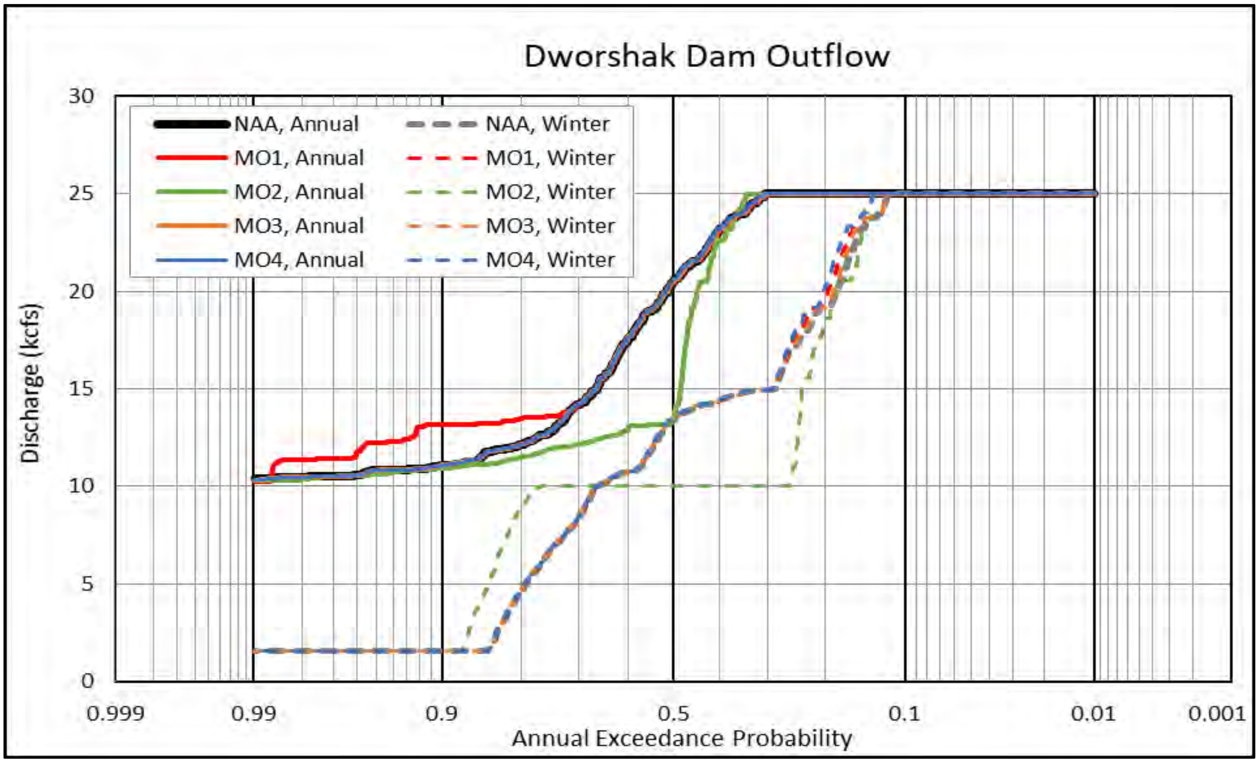


Figure 5-106. Peak Flow-Frequency Curves for Dworshak Dam Outflow

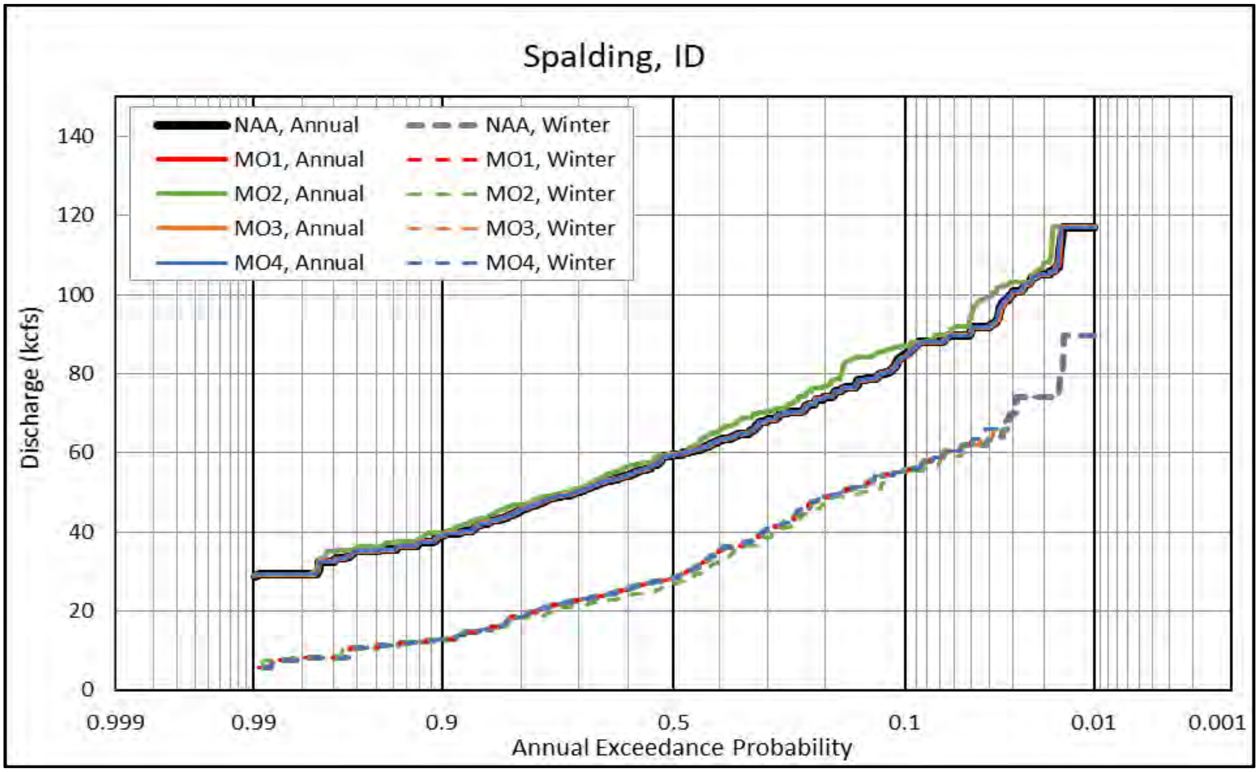


Figure 5-107. Peak Flow-Frequency Curves for Spalding, Idaho

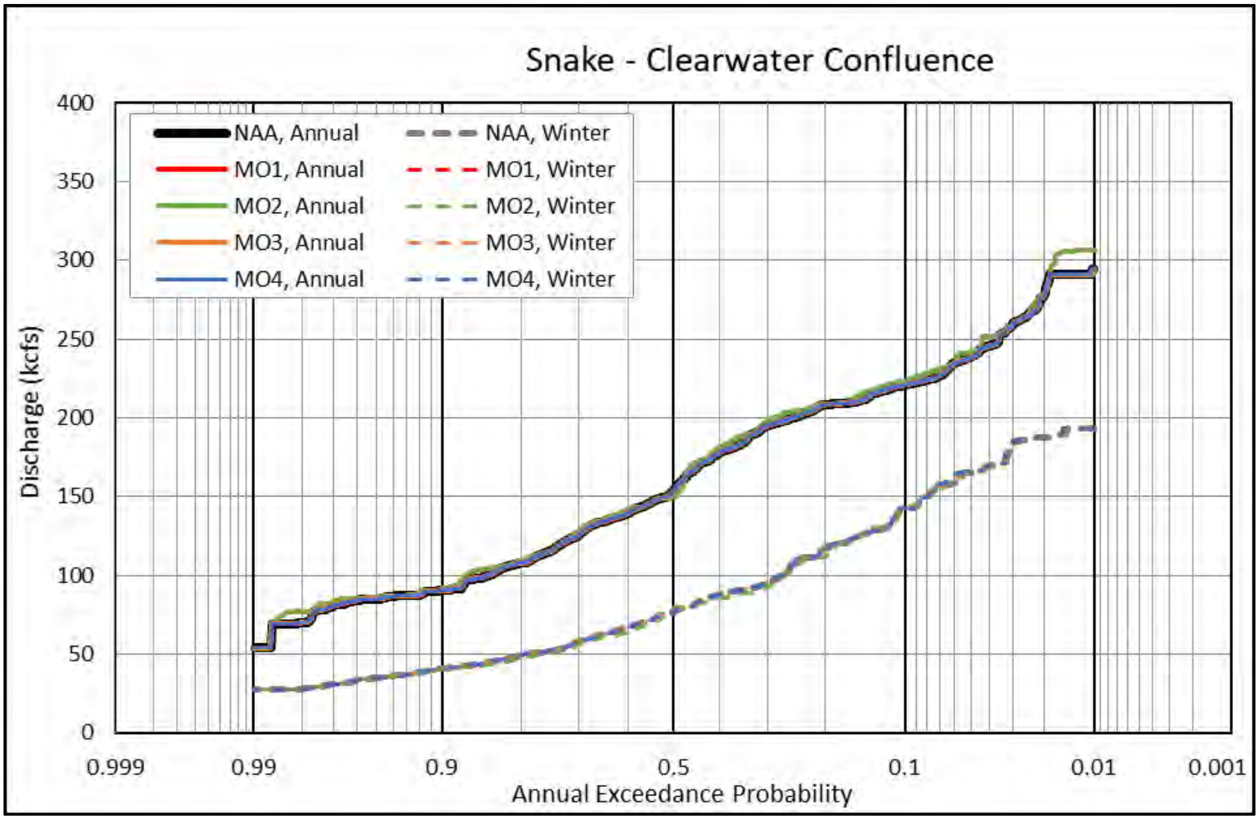


Figure 5-108. Peak Flow-Frequency Curves for the Snake River and Clearwater River Confluence

5.6.4 Region D – Lower Columbia River Basin

5.6.4.1 Summary Flow Hydrographs

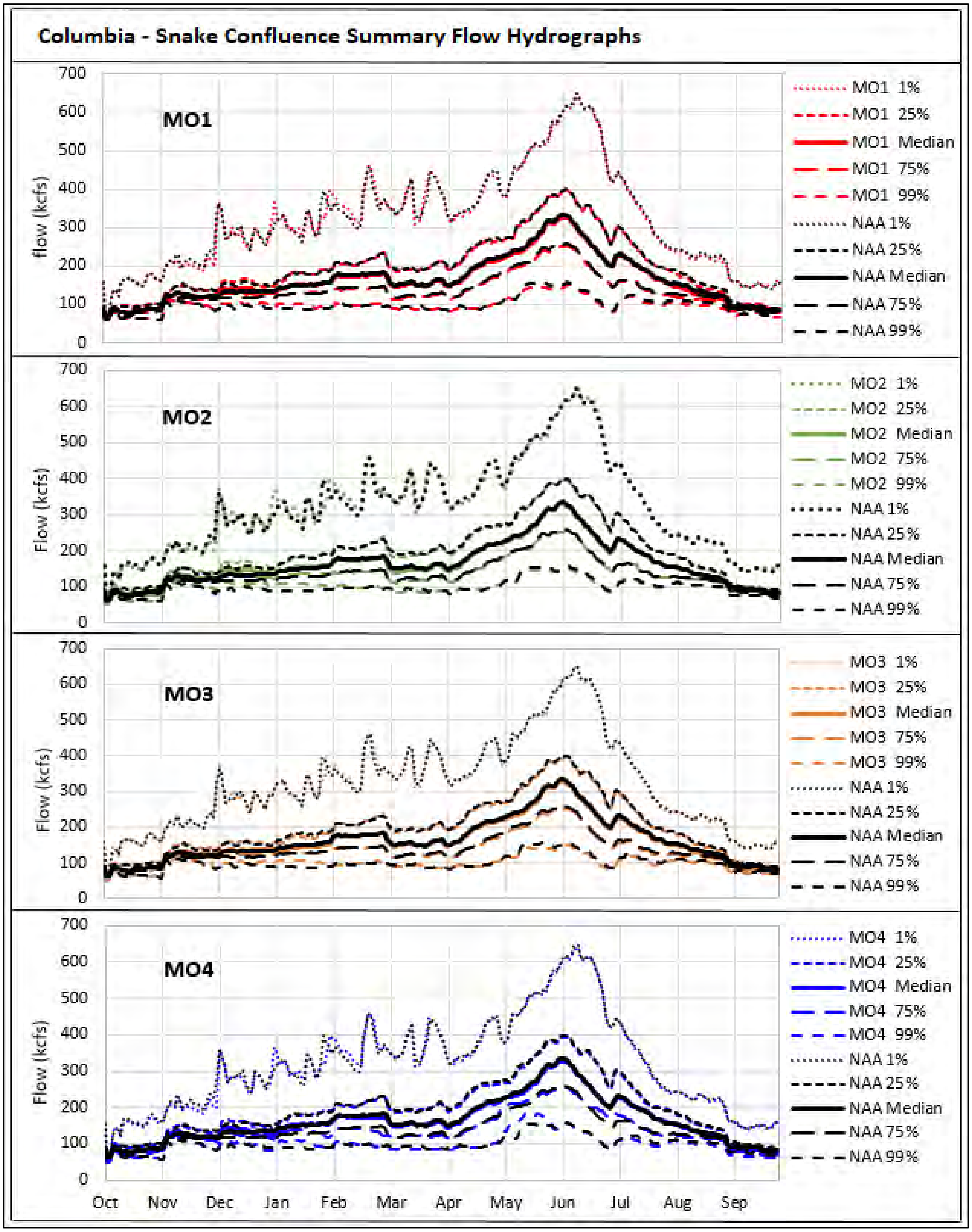
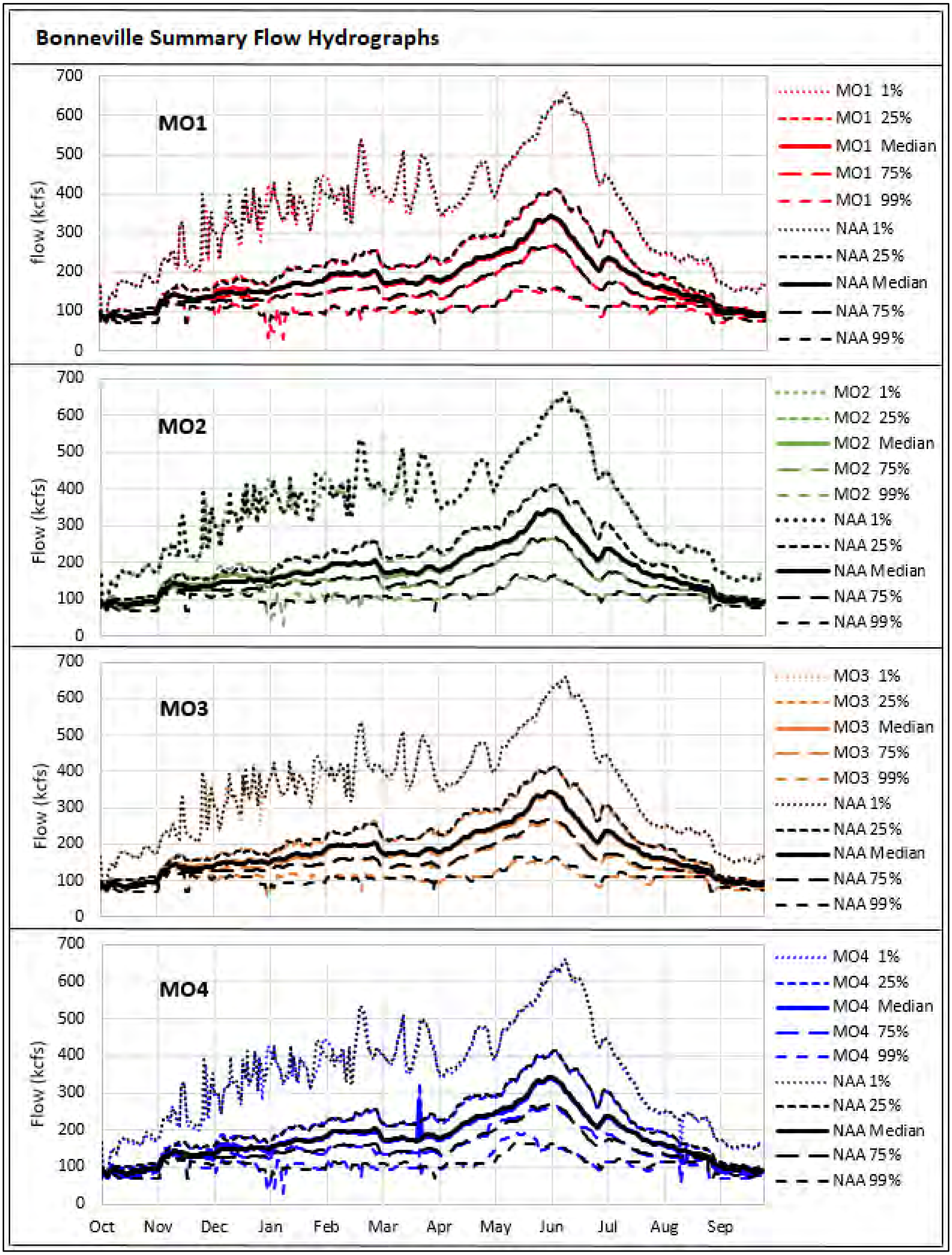


Figure 5-109. Summary Flow Hydrographs for the Columbia River and Snake River Confluence



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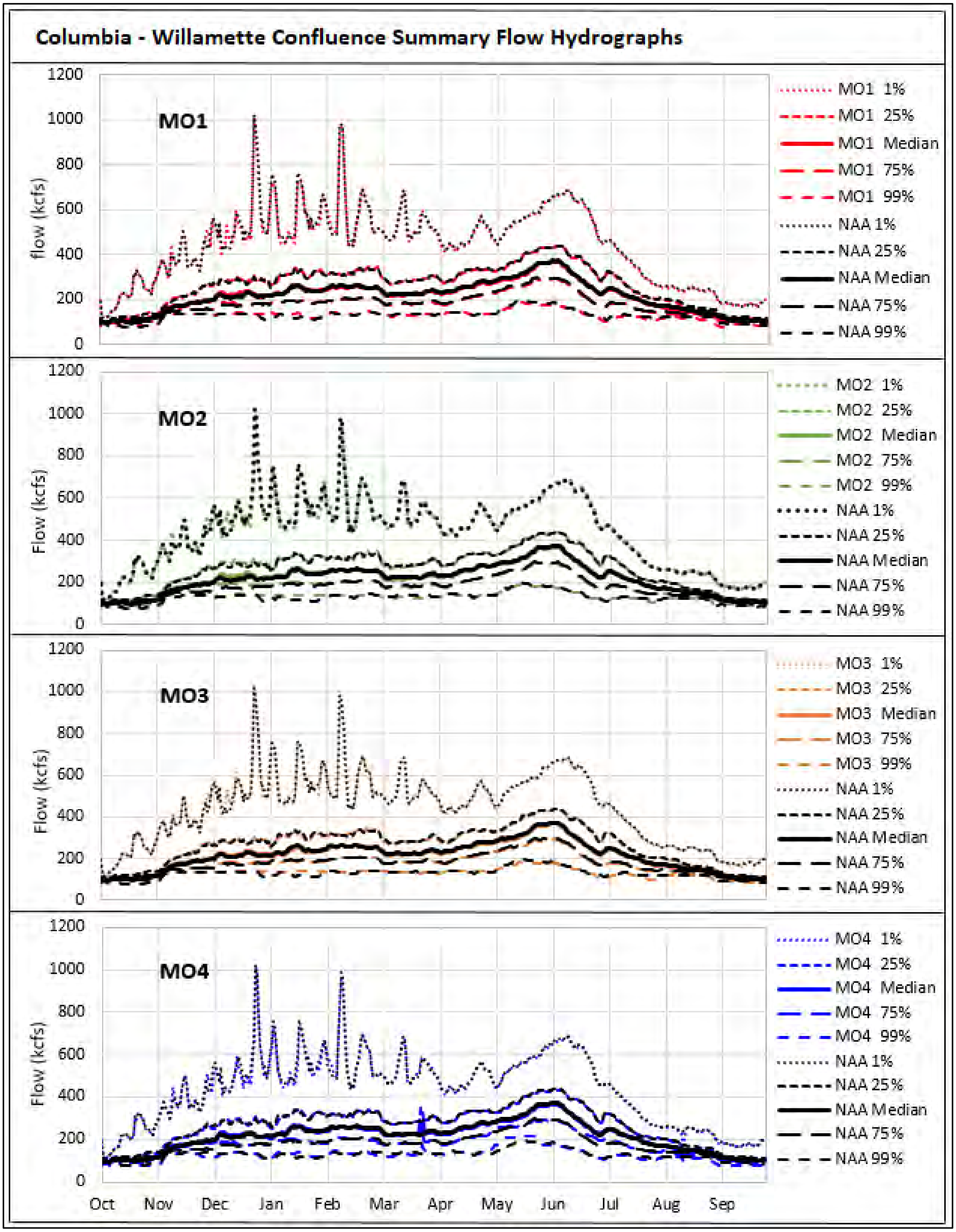
3541 **Figure 5-110. Summary Flow Hydrographs for Bonneville Dam Outflow**



3542

3543 **Figure 5-111. Summary Flow Hydrographs for the Columbia River and Willamette River**
3544 **Confluence**

5.6.4.2 Average Monthly Flow Summaries Tables

Table 5-24. Average Monthly Flow Summary for the Columbia River and Snake River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	138.6	186.2	278.5	270.4	317.5	324.8	341.6	446.1	561.7	345.8	228.5	147.7
		25%	92.9	141.3	153.9	177.2	212.9	196.2	231.6	311.4	349.0	244.0	163.6	99.5
		50%	83.0	122.4	134.1	151.3	180.6	157.3	188.2	259.9	287.9	198.5	140.0	91.0
		75%	76.9	114.3	116.2	129.9	144.9	128.9	147.5	229.1	221.5	146.6	124.0	86.1
		99%	71.3	109.2	107.7	106.7	111.0	105.7	103.7	179.1	161.5	124.7	113.5	80.7
MO1	Change (kcfs)	1%	0.2	-3.0	0.3	5.5	7.5	-0.4	-5.6	-2.7	-6.7	-5.5	-5.4	-1.2
		25%	0.4	-0.9	2.0	-0.8	-2.9	-1.3	-5.2	-5.6	-2.9	-3.5	-7.9	-0.9
		50%	0.4	-0.2	3.3	0.6	-2.5	-1.8	-4.4	-6.1	-3.4	-2.5	-8.3	-0.9
		75%	0.4	0.2	8.6	-0.1	-2.2	-3.1	-3.1	-6.9	-4.5	-2.1	-8.2	-1.0
		99%	0.4	0.0	2.7	5.5	3.8	-2.8	-0.4	-10.4	-2.7	-2.4	-8.4	-1.3
	Percent change	1%	0%	-2%	0%	2%	2%	0%	-2%	-1%	-1%	-2%	-2%	-1%
		25%	0%	-1%	1%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-5%	-1%
		50%	0%	0%	2%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-6%	-1%
		75%	0%	0%	7%	0%	-2%	-2%	-2%	-3%	-2%	-1%	-7%	-1%
		99%	0%	0%	3%	5%	3%	-3%	0%	-6%	-2%	-2%	-7%	-2%
MO2	Change (kcfs)	1%	-2.6	-0.7	4.7	9.8	8.3	-3.0	-4.3	-4.5	-0.7	-0.8	-0.4	0.0
		25%	-2.4	3.3	9.6	2.4	1.1	-6.1	-3.9	-2.3	-2.8	-0.9	-2.5	1.6
		50%	-2.5	4.0	9.9	3.7	0.1	-6.2	-4.3	-3.8	-3.6	-0.9	-1.5	2.6
		75%	-2.8	2.4	16.7	7.0	-2.3	-6.3	-4.6	-3.7	-4.9	-2.2	-3.0	2.7
		99%	-2.9	1.0	8.3	9.5	1.6	-3.5	0.6	-6.8	-2.1	-2.5	-2.4	3.1
	Percent change	1%	-2%	0%	2%	4%	3%	-1%	-1%	-1%	0%	0%	0%	0%
		25%	-3%	2%	6%	1%	1%	-3%	-2%	-1%	-1%	0%	-2%	2%
		50%	-3%	3%	7%	2%	0%	-4%	-2%	-1%	-1%	0%	-1%	3%
		75%	-4%	2%	14%	5%	-2%	-5%	-3%	-2%	-2%	-2%	-2%	3%
		99%	-4%	1%	8%	9%	1%	-3%	1%	-4%	-1%	-2%	-2%	4%
MO3	Change (kcfs)	1%	0.3	-2.7	-4.3	0.1	7.5	1.2	-5.5	-4.0	-4.8	-5.4	-3.1	-1.7
		25%	0.3	3.2	2.3	-9.0	1.1	-1.6	-5.5	-5.4	-4.0	-4.4	-4.5	-1.4
		50%	0.4	3.8	2.5	-4.6	0.6	-2.6	-4.7	-6.9	-4.7	-3.9	-3.4	-1.7
		75%	0.4	2.5	8.8	-0.6	-0.9	-2.2	-3.1	-7.5	-7.1	-5.9	-5.1	-1.7
		99%	0.5	1.0	4.0	7.9	0.9	-1.4	1.0	-9.5	-4.9	-6.5	-4.3	-1.9
	Percent change	1%	0%	-1%	-2%	0%	2%	0%	-2%	-1%	-1%	-2%	-1%	-1%
		25%	0%	2%	2%	-5%	1%	-1%	-2%	-2%	-1%	-2%	-3%	-1%
		50%	0%	3%	2%	-3%	0%	-2%	-2%	-3%	-2%	-2%	-2%	-2%
		75%	1%	2%	8%	0%	-1%	-2%	-2%	-3%	-3%	-4%	-4%	-2%
		99%	1%	1%	4%	7%	1%	-1%	1%	-5%	-3%	-5%	-4%	-2%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-6.5	-3.4	-2.1	2.9	8.2	-2.0	-3.8	-0.6	-6.3	-4.5	-2.4	-3.2
		25%	-2.9	-4.4	0.2	-3.1	-3.4	-1.1	-6.4	-5.6	-3.2	-3.4	-3.2	-3.3
		50%	-2.8	-2.3	2.4	1.3	-3.6	-1.9	-5.8	-4.8	-3.4	0.4	-1.8	-6.0
		75%	-3.6	0.1	5.3	2.7	-5.0	-4.5	-4.6	1.5	4.8	6.1	-3.9	-9.2
		99%	-4.7	-0.8	0.3	7.9	0.7	-6.4	-1.7	20.3	5.1	-6.8	-5.4	-10.4
	Percent change	1%	-5%	-2%	-1%	1%	3%	-1%	-1%	0%	-1%	-1%	-1%	-2%
		25%	-3%	-3%	0%	-2%	-2%	-1%	-3%	-2%	-1%	-1%	-2%	-3%
		50%	-3%	-2%	2%	1%	-2%	-1%	-3%	-2%	-1%	0%	-1%	-7%
		75%	-5%	0%	5%	2%	-3%	-3%	-3%	1%	2%	4%	-3%	-11%
		99%	-7%	-1%	0%	7%	1%	-6%	-2%	11%	3%	-5%	-5%	-13%

Table 5-25. Average Monthly Flow Summary for McNary Dam Outflow

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	141.1	187.3	278.6	280.4	327.0	328.6	346.4	451.5	562.2	342.4	231.4	152.3
		25%	95.1	142.7	155.1	181.4	215.7	199.9	235.8	312.6	351.6	243.5	163.1	100.5
		50%	85.1	124.1	136.4	153.6	182.0	159.2	191.6	260.3	285.2	197.9	141.3	92.6
		75%	79.4	115.6	118.2	132.9	146.6	129.6	147.3	231.4	217.5	146.7	124.1	87.0
		99%	73.3	111.9	109.1	108.2	114.9	107.3	106.0	178.4	160.1	122.4	114.2	81.0
MO1	Change (kcfs)	1%	0.2	-1.5	0.1	5.3	2.9	-1.6	-5.5	-2.9	-5.2	-5.2	-5.5	-1.1
		25%	0.4	-0.9	2.1	-1.4	-3.2	-1.5	-5.6	-4.8	-4.1	-3.8	-7.7	-0.9
		50%	0.5	0.0	4.5	0.5	-2.1	-2.0	-3.9	-6.0	-2.7	-2.0	-8.5	-1.1
		75%	0.4	0.3	8.3	-0.2	-2.8	-2.9	-2.8	-5.7	-1.9	-1.1	-8.1	-0.8
		99%	0.4	-0.1	2.5	5.5	2.8	-2.8	-1.2	-9.4	-3.1	-2.2	-8.4	-1.3
	Percent change	1%	0%	-1%	0%	2%	1%	0%	-2%	-1%	-1%	-2%	-2%	-1%
		25%	0%	-1%	1%	-1%	-1%	-1%	-2%	-2%	-1%	-2%	-5%	-1%
		50%	1%	0%	3%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-6%	-1%
		75%	0%	0%	7%	0%	-2%	-2%	-2%	-2%	-1%	-1%	-7%	-1%
		99%	1%	0%	2%	5%	2%	-3%	-1%	-5%	-2%	-2%	-7%	-2%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MO2	Change (kcfs)	1%	-4.2	1.1	4.5	9.6	4.3	-5.1	-4.4	-4.7	2.1	-1.0	-0.8	0.0
		25%	-4.0	3.1	10.6	1.6	1.2	-6.1	-4.4	-1.7	-3.7	-1.7	-2.4	1.5
		50%	-3.9	4.1	10.8	4.7	0.3	-6.4	-4.7	-3.6	-3.2	-0.5	-1.7	2.7
		75%	-4.5	1.7	16.0	7.1	-2.7	-6.1	-3.6	-2.6	-4.5	-0.8	-1.9	2.7
		99%	-4.3	0.1	8.4	9.6	0.9	-2.9	0.4	-6.8	-2.5	-1.7	-2.9	3.0
	Percent change	1%	-3%	1%	2%	3%	1%	-2%	-1%	-1%	0%	0%	0%	0%
		25%	-4%	2%	7%	1%	1%	-3%	-2%	-1%	-1%	-1%	-1%	1%
		50%	-5%	3%	8%	3%	0%	-4%	-2%	-1%	-1%	0%	-1%	3%
		75%	-6%	1%	14%	5%	-2%	-5%	-2%	-1%	-2%	-1%	-2%	3%
		99%	-6%	0%	8%	9%	1%	-3%	0%	-4%	-2%	-1%	-3%	4%
MO3	Change (kcfs)	1%	-1.2	-1.7	-4.3	-0.4	3.3	0.4	-5.3	-4.1	-3.4	-5.2	-3.1	-1.6
		25%	-1.1	2.8	2.4	-10.3	1.2	-2.0	-5.8	-4.4	-5.7	-5.1	-4.4	-1.4
		50%	-1.1	4.1	3.3	-4.5	0.7	-2.6	-4.4	-6.9	-3.5	-3.7	-3.6	-1.8
		75%	-1.1	1.7	8.1	-1.7	-1.1	-2.0	-3.0	-6.4	-5.0	-4.6	-4.0	-1.5
		99%	-1.0	0.3	3.3	6.3	0.8	-1.0	-0.1	-10.0	-5.4	-6.3	-4.5	-2.0
	Percent change	1%	-1%	-1%	-2%	0%	1%	0%	-2%	-1%	-1%	-2%	-1%	-1%
		25%	-1%	2%	2%	-6%	1%	-1%	-2%	-1%	-2%	-2%	-3%	-1%
		50%	-1%	3%	2%	-3%	0%	-2%	-2%	-3%	-1%	-2%	-3%	-2%
		75%	-1%	2%	7%	-1%	-1%	-2%	-2%	-3%	-2%	-3%	-3%	-2%
		99%	-1%	0%	3%	6%	1%	-1%	0%	-6%	-3%	-5%	-4%	-2%
M04	Change (kcfs)	1%	-8.0	-1.5	-2.3	2.9	4.4	-2.3	-5.1	-1.5	-4.3	-4.5	-2.9	-3.1
		25%	-4.7	-2.4	1.7	-3.6	-3.5	-0.5	-6.8	-5.2	-4.4	-4.3	-3.7	-3.2
		50%	-4.1	-1.8	3.0	1.7	-3.1	-1.4	-5.5	-4.5	-2.5	0.7	-2.3	-6.2
		75%	-5.2	-0.1	5.0	2.6	-5.7	-2.9	-4.0	2.3	8.9	6.1	-4.0	-8.7
		99%	-5.7	-2.8	-0.3	7.5	0.4	-5.7	-2.6	21.5	-1.5	-7.0	-6.6	-10.5
	Percent change	1%	-6%	-1%	-1%	1%	1%	-1%	-1%	0%	-1%	-1%	-1%	-2%
		25%	-5%	-2%	1%	-2%	-2%	0%	-3%	-2%	-1%	-2%	-2%	-3%
		50%	-5%	-1%	2%	1%	-2%	-1%	-3%	-2%	-1%	0%	-2%	-7%
		75%	-7%	0%	4%	2%	-4%	-2%	-3%	1%	4%	4%	-3%	-10%
		99%	-8%	-3%	0%	7%	0%	-5%	-2%	12%	-1%	-6%	-6%	-13%

3549

Table 5-26. Average Monthly Flow Summary for Bonneville Dam Outflow

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	149.0	203.1	288.7	313.1	360.1	357.1	373.1	459.0	577.8	349.7	235.7	159.5
		25%	101.4	155.9	172.0	200.8	238.4	221.6	257.4	330.5	363.5	251.4	170.1	107.8
		50%	91.2	134.5	152.4	170.1	199.1	179.1	213.0	275.3	295.7	204.3	148.6	99.3
		75%	84.7	124.6	128.9	144.8	159.5	148.3	163.9	245.3	228.5	154.8	129.7	93.5
		99%	78.5	119.4	118.8	117.4	123.7	120.7	120.6	189.9	168.7	128.0	119.7	86.2
MO1	Change (kcfs)	1%	0.2	-0.1	-0.7	4.4	4.6	-1.7	-12.0	-4.9	-5.6	-5.1	-5.6	-1.1
		25%	0.5	-1.2	3.4	-1.4	-2.2	-1.3	-6.5	-5.3	-3.8	-3.8	-8.1	-1.3
		50%	0.4	-0.5	3.5	0.4	-2.4	-2.4	-4.4	-6.4	-2.0	-2.0	-8.0	-1.3
		75%	0.4	-0.1	8.8	0.2	-1.5	-2.4	-3.9	-5.3	-1.3	-0.7	-7.3	-1.5
		99%	0.4	0.2	1.3	4.1	3.7	-2.6	-2.2	-9.7	-2.0	-2.3	-7.4	-2.2
	Percent change	1%	0%	0%	0%	1%	1%	0%	-3%	-1%	-1%	-1%	-2%	-1%
		25%	1%	-1%	2%	-1%	-1%	-1%	-3%	-2%	-1%	-1%	-5%	-1%
		50%	0%	0%	2%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-5%	-1%
		75%	0%	0%	7%	0%	-1%	-2%	-2%	-2%	-1%	0%	-6%	-2%
		99%	0%	0%	1%	3%	3%	-2%	-2%	-5%	-1%	-2%	-6%	-3%
MO2	Change (kcfs)	1%	-2.9	3.6	3.8	8.8	2.4	-5.7	-9.2	-7.2	1.3	-0.4	-2.0	0.0
		25%	-2.4	1.5	11.6	2.8	1.8	-6.9	-4.3	-2.4	-4.3	-1.1	-2.7	1.5
		50%	-2.8	3.8	10.7	3.3	0.3	-6.4	-4.1	-3.9	-3.1	-0.6	-2.4	2.4
		75%	-3.0	2.1	16.4	7.7	-1.5	-6.0	-3.9	-2.3	-4.1	-1.0	-2.0	2.3
		99%	-2.8	1.0	6.8	9.6	1.7	-3.2	1.1	-6.2	-1.8	-1.1	-2.6	3.1
	Percent change	1%	-2%	2%	1%	3%	1%	-2%	-2%	-2%	0%	0%	-1%	0%
		25%	-2%	1%	7%	1%	1%	-3%	-2%	-1%	-1%	0%	-2%	1%
		50%	-3%	3%	7%	2%	0%	-4%	-2%	-1%	-1%	0%	-2%	2%
		75%	-4%	2%	13%	5%	-1%	-4%	-2%	-1%	-2%	-1%	-2%	2%
		99%	-4%	1%	6%	8%	1%	-3%	1%	-3%	-1%	-1%	-2%	4%
MO3	Change (kcfs)	1%	0.1	1.4	-4.2	-2.1	7.2	-0.3	-6.1	-5.2	-2.3	-5.1	-3.7	-1.7
		25%	0.2	1.2	3.8	-9.9	0.4	-2.2	-6.0	-5.6	-3.8	-5.0	-4.9	-1.7
		50%	0.2	3.6	2.3	-5.5	1.0	-3.1	-4.5	-7.0	-3.1	-3.7	-4.4	-1.7
		75%	0.2	2.2	9.0	-1.4	-0.6	-1.9	-3.7	-5.9	-4.4	-4.6	-4.1	-1.8
		99%	0.3	1.5	2.9	5.2	1.7	-0.8	-0.1	-9.4	-4.2	-6.1	-4.2	-2.3
	Percent change	1%	0%	1%	-1%	-1%	2%	0%	-2%	-1%	0%	-1%	-2%	-1%
		25%	0%	1%	2%	-5%	0%	-1%	-2%	-2%	-1%	-2%	-3%	-2%
		50%	0%	3%	2%	-3%	1%	-2%	-2%	-3%	-1%	-2%	-3%	-2%
		75%	0%	2%	7%	-1%	0%	-1%	-2%	-2%	-2%	-3%	-3%	-2%
		99%	0%	1%	2%	4%	1%	-1%	0%	-5%	-2%	-5%	-3%	-3%

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
M04	Change (kcfs)	1%	-6.7	-4.2	-3.2	3.2	4.7	0.1	-9.1	-3.1	-6.5	-4.5	-6.5	-3.1
		25%	-3.0	-3.6	2.8	-4.1	-3.1	2.8	-6.9	-6.0	-5.3	-4.1	-7.0	-3.4
		50%	-3.1	-1.9	1.7	1.0	-3.3	1.6	-4.8	-4.4	-2.7	0.6	-5.8	-6.5
		75%	-3.5	-0.1	6.1	2.3	-3.7	0.1	-4.4	2.6	7.7	6.4	-6.6	-9.0
		99%	-4.6	-1.5	-0.4	7.1	1.4	-3.1	-2.7	21.4	-1.5	-6.8	-8.3	-11.1
	Percent change	1%	-4%	-2%	-1%	1%	1%	0%	-2%	-1%	-1%	-1%	-3%	-2%
		25%	-3%	-2%	2%	-2%	-1%	1%	-3%	-2%	-1%	-2%	-4%	-3%
		50%	-3%	-1%	1%	1%	-2%	1%	-2%	-2%	-1%	0%	-4%	-7%
		75%	-4%	0%	5%	2%	-2%	0%	-3%	1%	3%	4%	-5%	-10%
		99%	-6%	-1%	0%	6%	1%	-3%	-2%	11%	-1%	-5%	-7%	-13%

Table 5-27. Average Monthly Flow Summary for the Columbia River and Willamette River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	185.4	300.9	421.6	447.3	534.7	490.2	433.8	497.4	611.0	365.5	246.3	175.5
		25%	119.9	218.9	275.9	308.7	318.8	282.1	307.1	366.7	390.6	265.0	180.3	121.9
		50%	108.1	177.9	225.2	251.7	266.8	232.8	260.4	314.1	319.0	216.5	158.9	111.5
		75%	98.3	155.5	185.6	195.8	216.9	195.0	210.8	274.4	257.0	165.7	138.3	105.4
		99%	89.8	134.1	147.5	148.0	156.9	153.4	152.7	216.8	185.4	138.4	128.6	96.6
MO1	Change (kcfs)	1%	0.5	-0.2	1.4	-4.0	6.4	-6.9	-6.1	-3.0	-6.5	-4.7	-5.3	-1.1
		25%	0.4	0.3	3.6	-0.6	-2.5	-1.4	-5.9	-5.4	-3.6	-4.4	-7.6	-1.5
		50%	0.3	0.6	4.8	0.4	-3.9	-1.6	-4.6	-6.0	-1.7	-1.8	-8.0	-1.6
		75%	0.4	-0.1	6.5	2.9	-2.4	-2.9	-3.1	-5.0	-3.2	-0.6	-6.8	-1.8
		99%	0.4	0.0	1.5	7.3	3.1	-1.9	-1.6	-9.2	-2.3	-2.5	-7.4	-3.3
	Percent change	1%	0%	0%	0%	-1%	1%	-1%	-1%	-1%	-1%	-1%	-2%	-1%
		25%	0%	0%	1%	0%	-1%	-1%	-2%	-1%	-1%	-2%	-4%	-1%
		50%	0%	0%	2%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-5%	-1%
		75%	0%	0%	4%	1%	-1%	-1%	-1%	-2%	-1%	0%	-5%	-2%
		99%	0%	0%	1%	5%	2%	-1%	-1%	-4%	-1%	-2%	-6%	-3%
MO2	Change (kcfs)	1%	-3.1	4.6	2.9	-2.8	3.6	-11.5	-4.4	-6.3	0.9	-0.4	-2.0	-0.2
		25%	-2.6	4.2	11.3	-0.3	-0.4	-5.3	-4.4	-2.6	-3.5	-2.0	-2.4	0.8
		50%	-3.3	3.5	11.5	4.9	0.1	-5.3	-4.4	-3.7	-3.2	-0.6	-2.8	2.3
		75%	-3.3	1.8	15.8	7.3	-1.9	-5.5	-4.4	-2.4	-5.3	-0.9	-2.0	2.1
		99%	-2.4	-0.4	4.0	11.6	2.6	-2.1	0.4	-5.8	-3.3	-2.2	-3.0	3.0

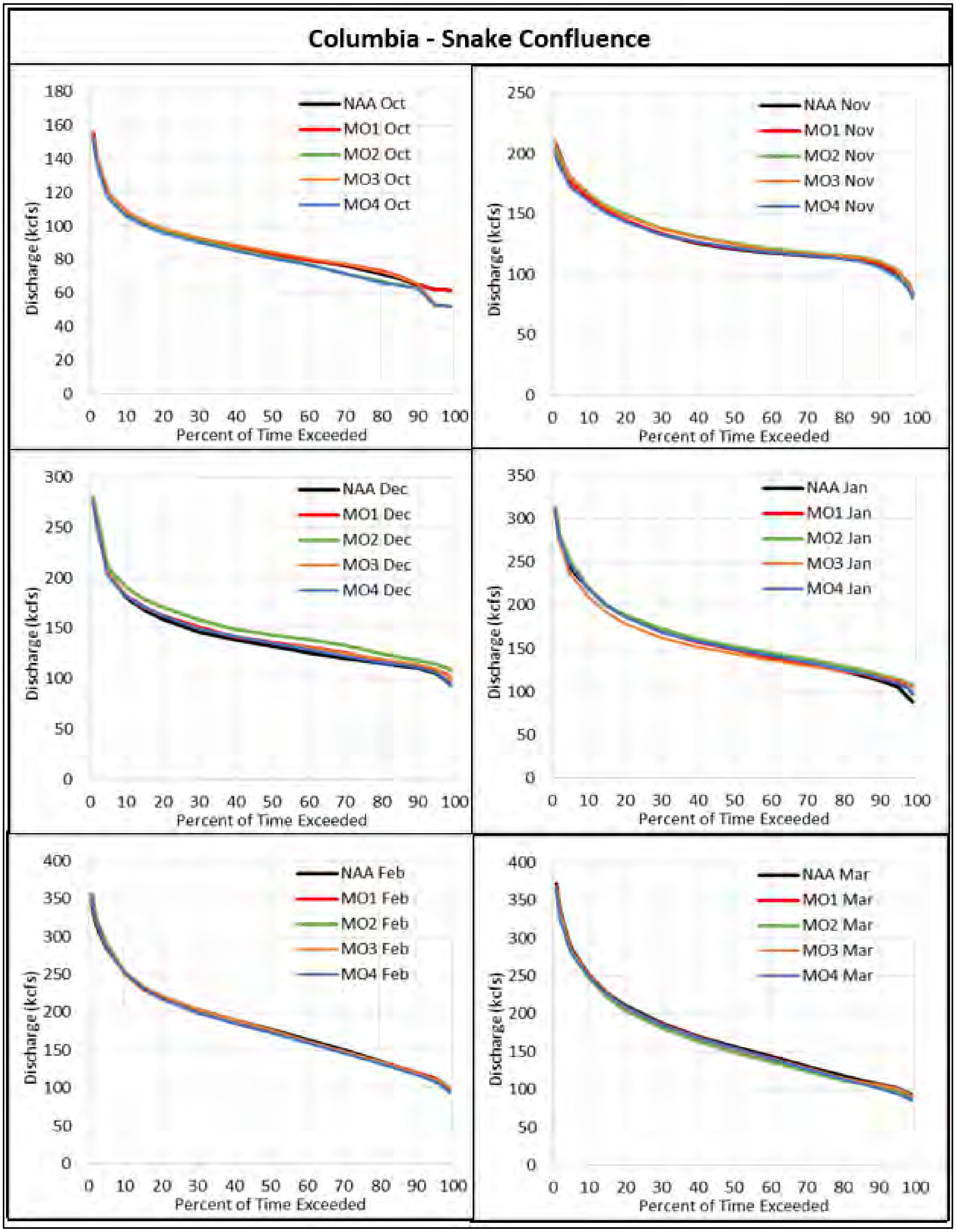
		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
	Percent change	1%	-2%	2%	1%	-1%	1%	-2%	-1%	-1%	0%	0%	-1%	0%
		25%	-2%	2%	4%	0%	0%	-2%	-1%	-1%	-1%	-1%	-1%	1%
		50%	-3%	2%	5%	2%	0%	-2%	-2%	-1%	-1%	0%	-2%	2%
		75%	-3%	1%	9%	4%	-1%	-3%	-2%	-1%	-2%	-1%	-1%	2%
		99%	-3%	0%	3%	8%	2%	-1%	0%	-3%	-2%	-2%	-2%	3%
MO3	Change (kcfs)	1%	-0.1	3.9	-3.8	-6.3	9.8	-2.4	-6.0	-4.0	-2.0	-4.6	-3.5	-1.9
		25%	-0.1	4.1	3.3	-7.2	-0.4	-1.6	-6.2	-6.2	-3.5	-5.0	-4.7	-1.9
		50%	-0.1	3.4	3.5	-4.2	0.1	-2.0	-4.3	-6.2	-3.1	-3.6	-4.5	-1.9
		75%	-0.1	2.4	7.9	1.4	-0.6	-2.3	-3.3	-5.9	-6.0	-4.3	-4.2	-2.2
		99%	0.0	1.1	1.5	7.7	1.9	-0.6	1.0	-9.4	-5.0	-7.1	-4.7	-3.2
	Percent change	1%	0%	1%	-1%	-1%	2%	0%	-1%	-1%	0%	-1%	-1%	-1%
		25%	0%	2%	1%	-2%	0%	-1%	-2%	-2%	-1%	-2%	-3%	-2%
		50%	0%	2%	2%	-2%	0%	-1%	-2%	-2%	-1%	-2%	-3%	-2%
		75%	0%	2%	4%	1%	0%	-1%	-2%	-2%	-2%	-3%	-3%	-2%
		99%	0%	1%	1%	5%	1%	0%	1%	-4%	-3%	-5%	-4%	-3%
MO4	Change (kcfs)	1%	-4.7	-4.0	-3.7	-6.3	7.1	-7.9	-4.1	-3.0	-8.2	-4.7	-6.9	-3.0
		25%	-3.2	-1.2	2.1	-1.4	-2.9	2.3	-6.1	-5.3	-4.4	-4.2	-6.9	-3.2
		50%	-4.2	-1.1	2.1	1.6	-4.1	2.1	-5.2	-4.1	-2.8	0.9	-6.0	-5.9
		75%	-4.0	-0.3	4.8	5.7	-3.7	-1.1	-3.8	2.9	1.5	7.2	-6.4	-9.0
		99%	-3.6	-0.8	-0.8	9.7	0.6	-2.2	-1.3	21.2	0.2	-6.7	-8.7	-11.7
	Percent change	1%	-3%	-1%	-1%	-1%	1%	-2%	-1%	-1%	-1%	-1%	-3%	-2%
		25%	-3%	-1%	1%	0%	-1%	1%	-2%	-1%	-1%	-2%	-4%	-3%
		50%	-4%	-1%	1%	1%	-2%	1%	-2%	-1%	-1%	0%	-4%	-5%
		75%	-4%	0%	3%	3%	-2%	-1%	-2%	1%	1%	4%	-5%	-9%
		99%	-4%	-1%	-1%	7%	0%	-1%	-1%	10%	0%	-5%	-7%	-12%

Table 5-28. Average Monthly Flow Summary for the Columbia River and Willamette River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Outflow (kcfs)	1%	206.6	340.4	483.0	499.9	602.3	550.5	467.9	525.1	637.5	381.3	255.2	183.3
		25%	129.7	251.9	314.6	346.6	351.9	307.5	330.0	386.6	409.0	276.2	186.9	129.7
		50%	115.4	195.8	257.1	281.7	295.0	255.3	283.4	333.9	335.7	225.7	165.1	117.4
		75%	104.3	169.0	206.8	219.0	238.7	216.0	230.2	290.6	278.3	174.8	143.1	111.0
		99%	95.2	138.7	160.6	161.5	168.6	173.1	168.2	227.8	196.4	146.8	134.1	102.3
MO1	Change (kcfs)	1%	0.4	-0.2	0.3	-4.2	7.5	-7.7	-5.7	-3.5	-6.8	-5.4	-4.7	-1.0
		25%	0.2	-0.2	2.0	0.1	-1.2	-0.6	-5.6	-6.3	-3.3	-3.6	-7.6	-1.6
		50%	0.3	0.4	5.1	0.3	-2.8	-2.3	-4.5	-5.2	-2.4	-1.6	-7.5	-1.7
		75%	0.4	-0.6	10.2	1.7	-0.3	-2.5	-4.1	-4.7	-2.9	-0.8	-6.7	-1.7
		99%	0.3	-0.2	-0.5	6.5	3.2	-2.8	-1.1	-7.6	-2.8	-3.0	-7.8	-3.3
	Percent change	1%	0%	0%	0%	-1%	1%	-1%	-1%	-1%	-1%	-1%	-2%	-1%
		25%	0%	0%	1%	0%	0%	0%	-2%	-2%	-1%	-1%	-4%	-1%
		50%	0%	0%	2%	0%	-1%	-1%	-2%	-2%	-1%	-1%	-5%	-1%
		75%	0%	0%	5%	1%	0%	-1%	-2%	-2%	-1%	0%	-5%	-2%
		99%	0%	0%	0%	4%	2%	-2%	-1%	-3%	-1%	-2%	-6%	-3%
MO2	Change (kcfs)	1%	-3.8	4.5	1.8	4.9	4.8	-12.0	-3.4	-7.7	0.2	-0.2	0.0	-0.4
		25%	-3.0	3.3	9.1	2.0	-1.0	-4.0	-4.1	-4.2	-4.2	-1.5	-2.4	-0.4
		50%	-3.0	3.6	13.4	4.1	-1.1	-5.5	-4.1	-3.2	-3.4	-0.6	-2.4	1.9
		75%	-3.3	1.2	18.7	5.5	-1.3	-4.4	-5.4	-1.9	-3.5	-1.7	-2.3	2.1
		99%	-2.5	-1.0	6.7	14.5	3.5	-6.6	0.0	-4.7	-4.4	-3.0	-3.3	2.9
	Percent change	1%	-2%	1%	0%	1%	1%	-2%	-1%	-1%	0%	0%	0%	0%
		25%	-2%	1%	3%	1%	0%	-1%	-1%	-1%	-1%	-1%	-1%	0%
		50%	-3%	2%	5%	1%	0%	-2%	-1%	-1%	-1%	0%	-1%	2%
		75%	-3%	1%	9%	2%	-1%	-2%	-2%	-1%	-1%	-1%	-2%	2%
		99%	-3%	-1%	4%	9%	2%	-4%	0%	-2%	-2%	-2%	-2%	3%
MO3	Change (kcfs)	1%	-0.4	3.9	-4.1	-6.7	10.9	-2.3	-7.1	-4.7	-1.8	-5.1	-2.4	-1.8
		25%	-0.4	1.9	1.5	-9.0	-0.7	-1.0	-5.7	-7.0	-3.3	-4.7	-4.7	-2.6
		50%	-0.3	3.8	4.5	-3.2	-0.5	-2.0	-4.2	-5.7	-3.8	-3.3	-3.9	-2.0
		75%	-0.3	2.0	11.2	4.2	-0.3	-1.7	-4.2	-5.2	-4.5	-5.1	-4.5	-1.9
		99%	-0.3	0.9	2.0	7.1	1.9	-1.1	-0.9	-8.3	-5.9	-7.1	-5.1	-3.2
	Percent change	1%	0%	1%	-1%	-1%	2%	0%	-2%	-1%	0%	-1%	-1%	-1%
		25%	0%	1%	0%	-3%	0%	0%	-2%	-2%	-1%	-2%	-2%	-2%
		50%	0%	2%	2%	-1%	0%	-1%	-1%	-2%	-1%	-1%	-2%	-2%
		75%	0%	1%	5%	2%	0%	-1%	-2%	-2%	-2%	-3%	-3%	-2%
		99%	0%	1%	1%	4%	1%	-1%	-1%	-4%	-3%	-5%	-4%	-3%

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
M04	Change (kcfs)	1%	-5.8	-3.8	-4.9	-4.6	8.2	-8.7	-4.2	-3.6	-8.4	-4.2	-5.3	-2.8
		25%	-3.7	-3.5	0.1	-0.9	-2.3	2.8	-5.9	-5.8	-4.2	-3.4	-6.9	-3.7
		50%	-4.1	0.7	3.0	2.1	-4.0	0.9	-5.5	-4.0	-3.5	1.5	-5.7	-5.8
		75%	-3.8	-0.9	7.7	5.8	-2.8	-1.1	-4.7	5.2	0.5	7.1	-6.7	-8.7
		99%	-4.3	-3.2	-1.0	10.2	1.4	-5.4	-1.9	20.4	2.8	-7.4	-9.1	-11.5
	Percent change	1%	-3%	-1%	-1%	-1%	1%	-2%	-1%	-1%	-1%	-1%	-2%	-2%
		25%	-3%	-1%	0%	0%	-1%	1%	-2%	-2%	-1%	-1%	-4%	-3%
		50%	-4%	0%	1%	1%	-1%	0%	-2%	-1%	-1%	1%	-3%	-5%
		75%	-4%	-1%	4%	3%	-1%	-1%	-2%	2%	0%	4%	-5%	-8%
		99%	-4%	-2%	-1%	6%	1%	-3%	-1%	9%	1%	-5%	-7%	-11%

3556 *5.6.4.3 Monthly Flow-Duration Plots*



3557

3558 **Figure 5-112. Monthly Flow-Duration Curves for the Columbia River and Snake River**
3559 **Confluence**

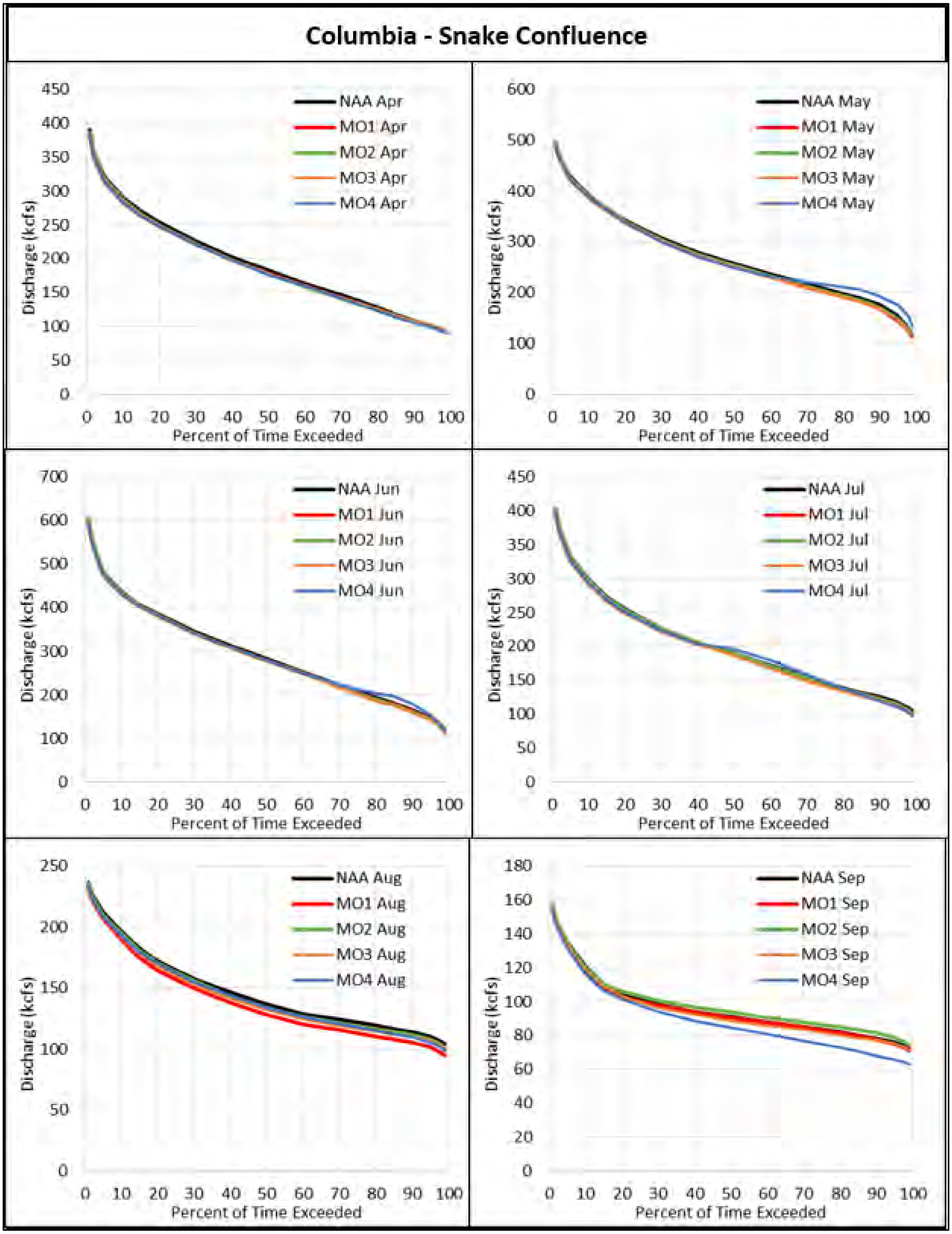


Figure 5-113. Monthly Flow-Duration Curves for the Columbia River and Snake River Confluence (continued)

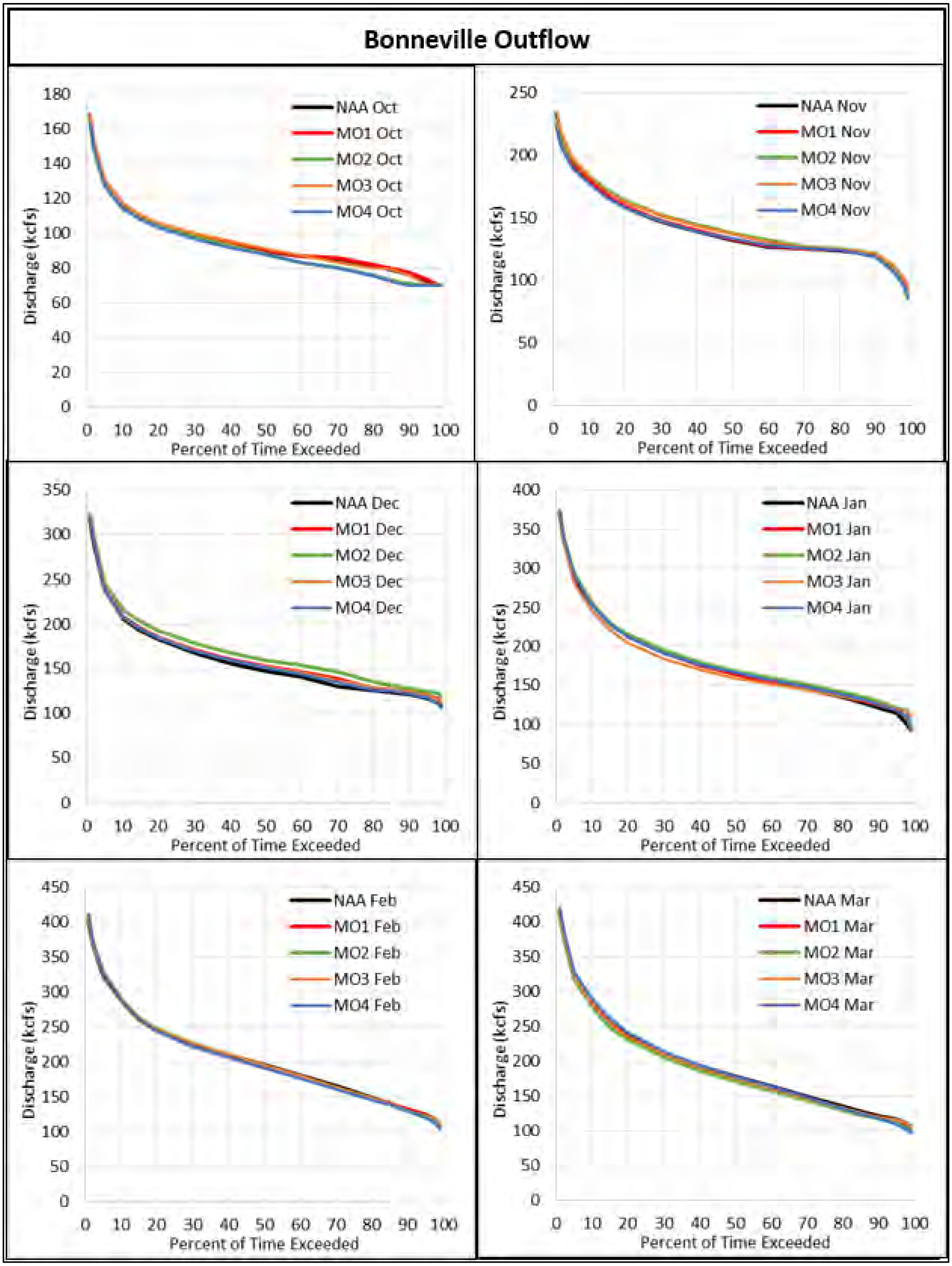
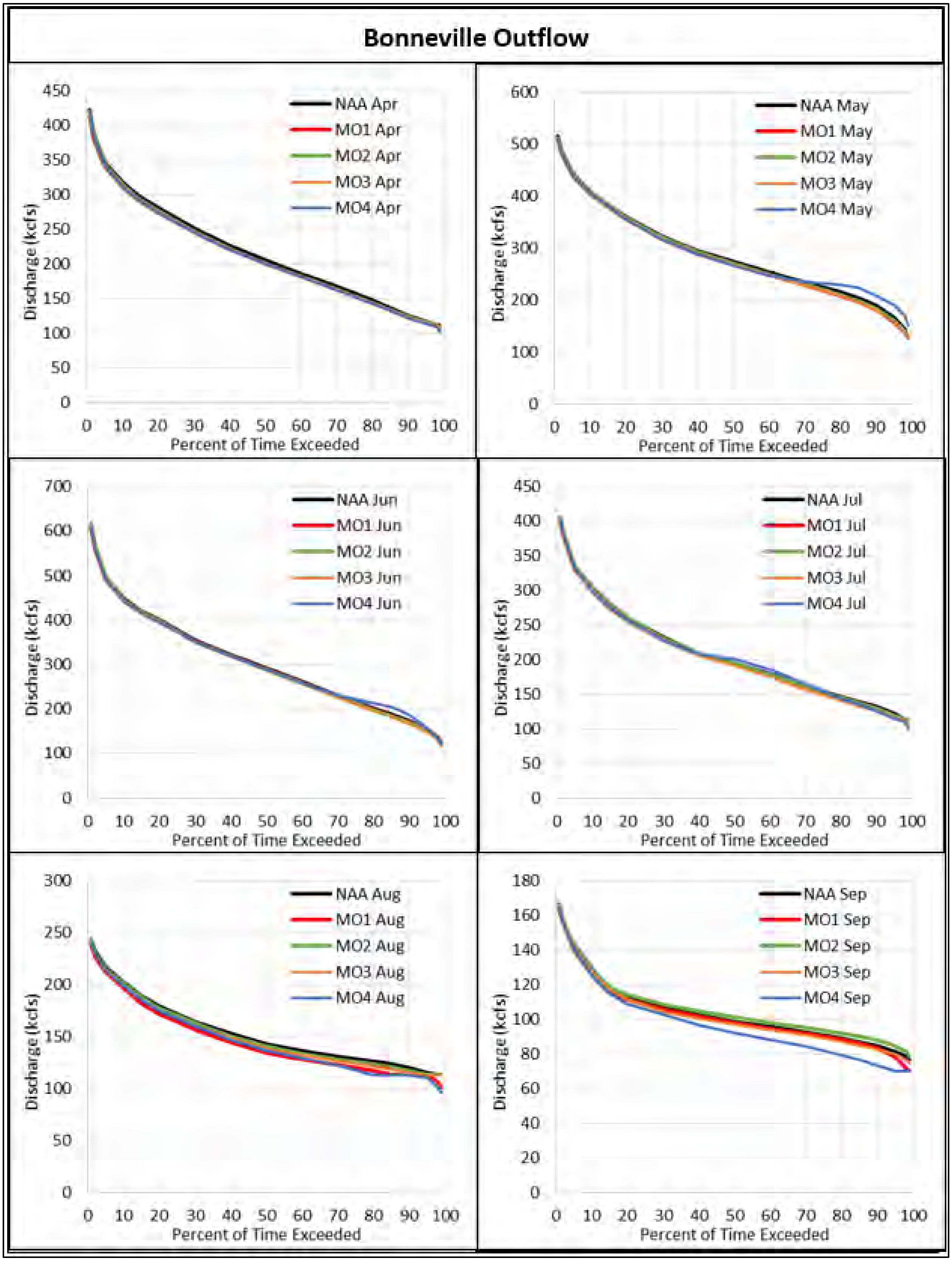


Figure 5-114. Monthly Flow-Duration Curves at Bonneville Dam Outflow



3565

3566 **Figure 5-115. Monthly Flow-Duration Curves at Bonneville Dam (continued)**

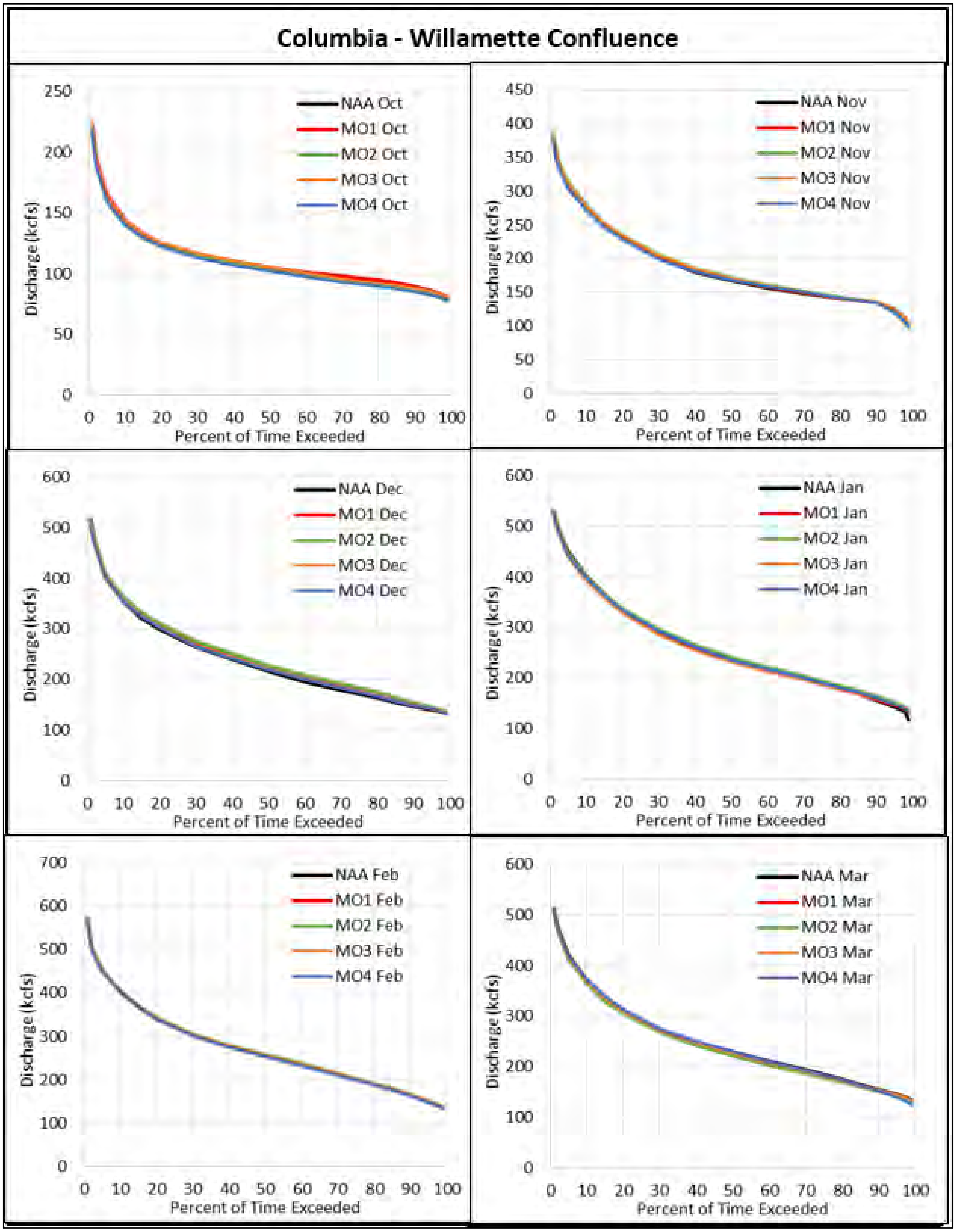
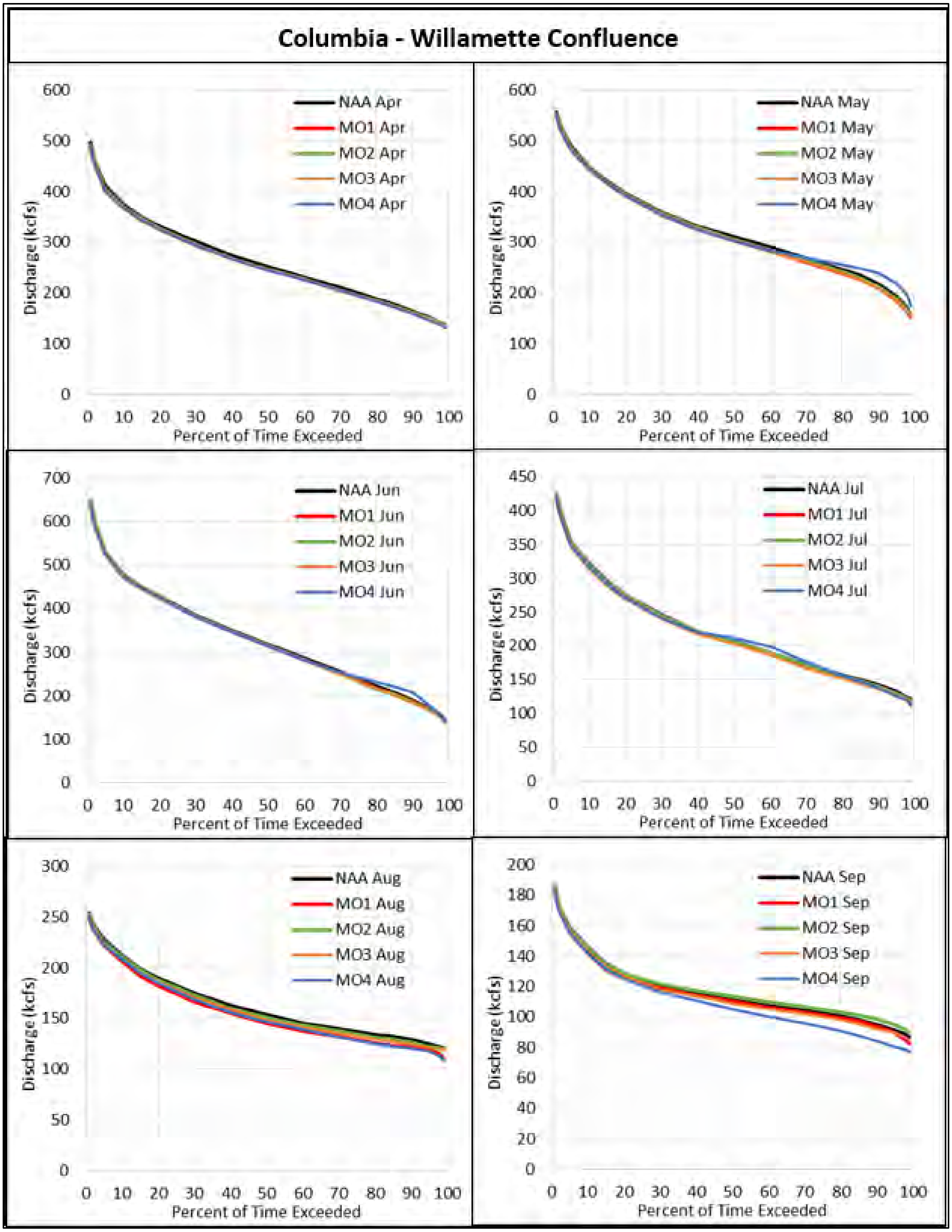


Figure 5-116. Monthly Flow-Duration Curves at the Columbia River and Willamette River Confluence



3570

3571 **Figure 5-117. Monthly Flow-Duration Curves at the Columbia River and Willamette River**
3572 **Confluence**

5.6.4.4 Peak Flow-Frequency Plots

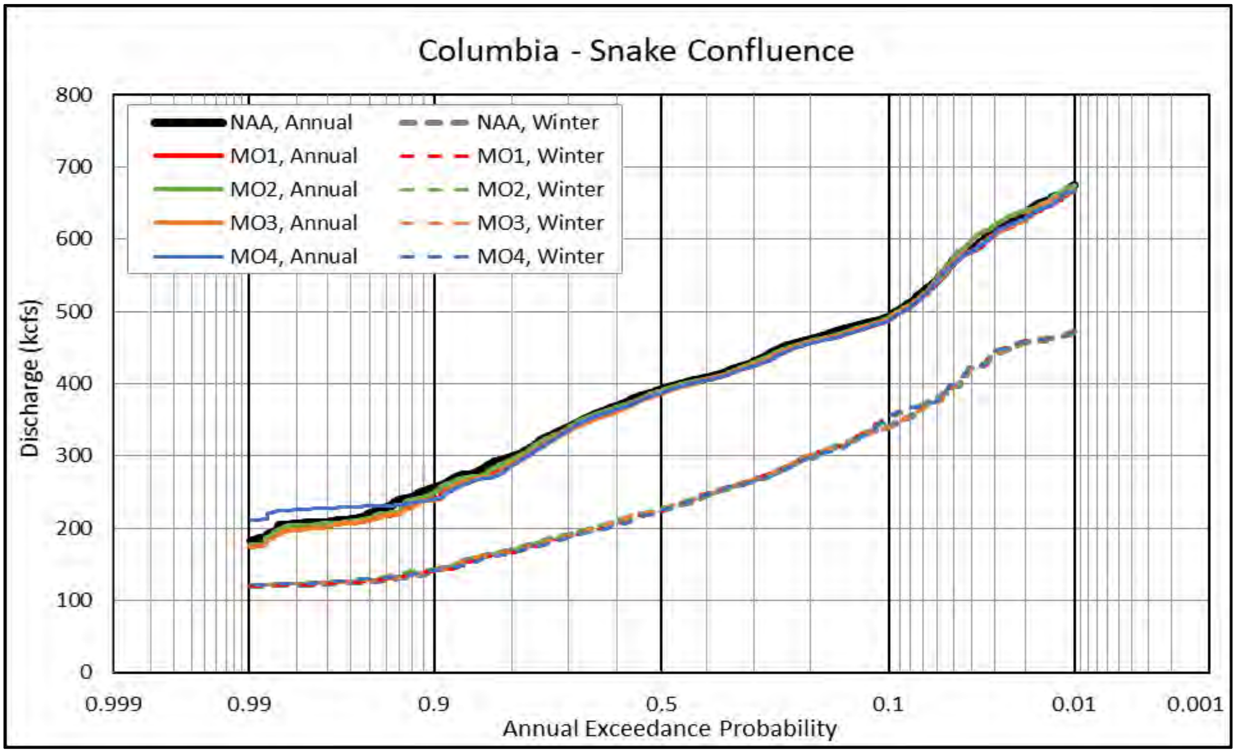


Figure 5-118. Peak Flow-Frequency Curves at the Columbia River and Snake River Confluence

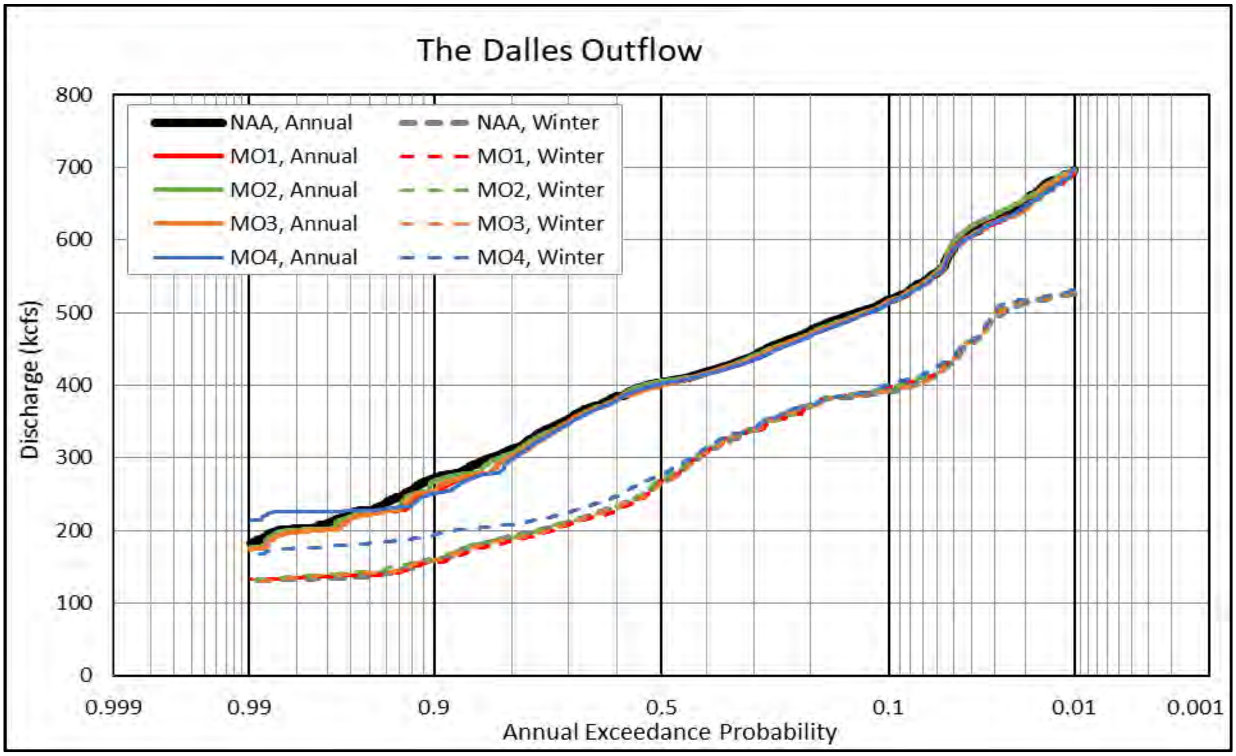


Figure 5-119. Peak Flow-Frequency Curves at The Dalles Dam Outflow

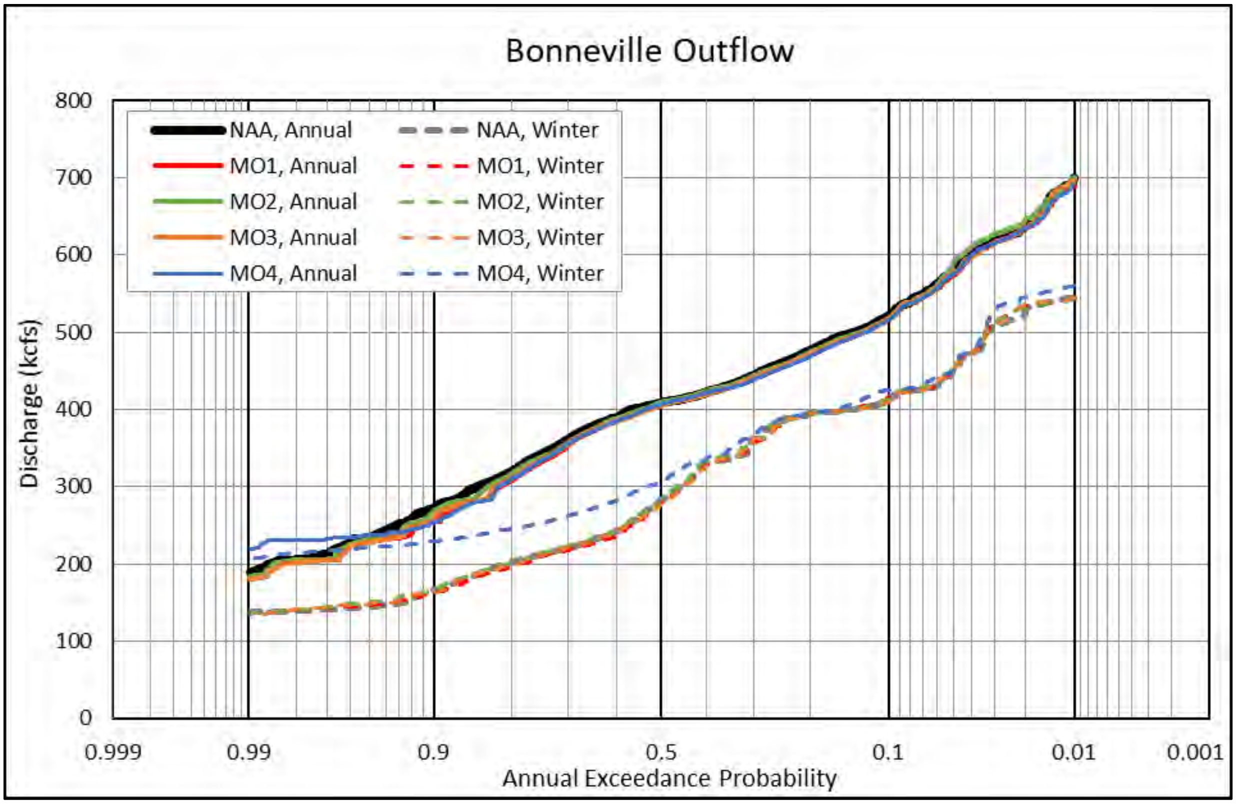


Figure 5-120. Peak Flow-Frequency Curves at Bonneville Dam Outflow

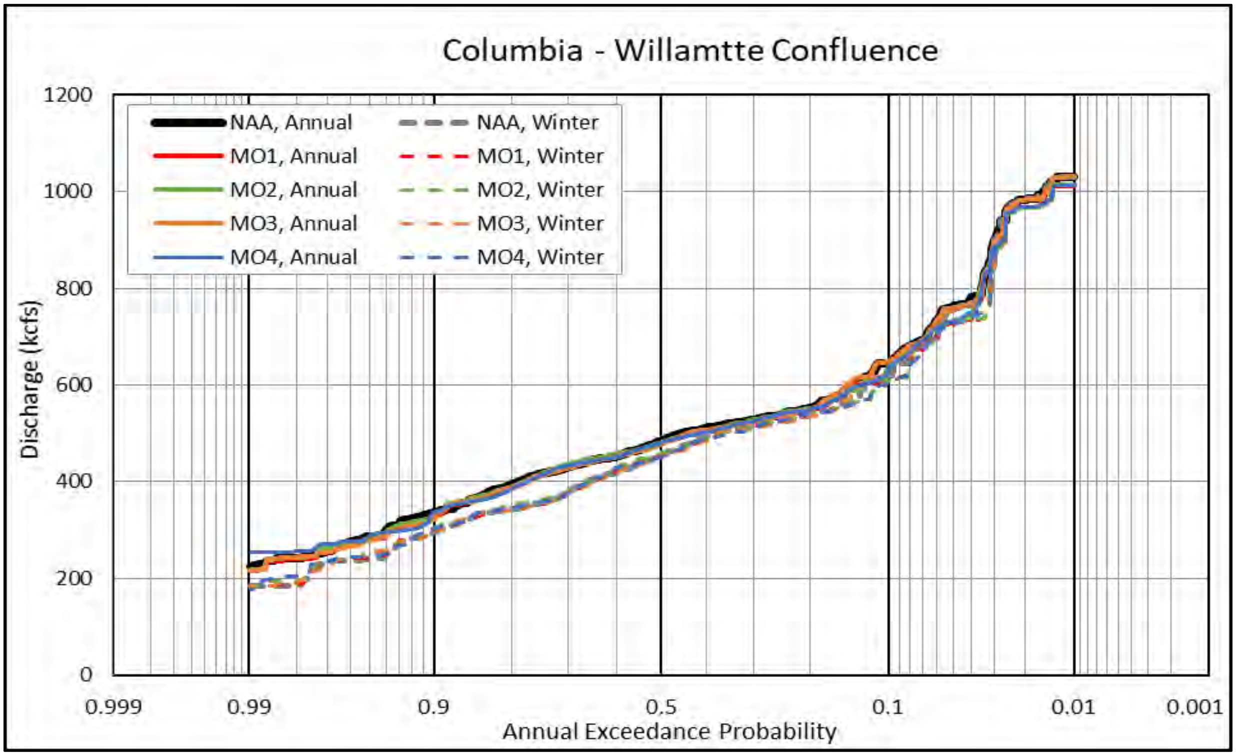


Figure 5-121. Peak Flow-Frequency Curves at the Columbia River and Willamette River Confluence

CHAPTER 6 - OTHER HYDROLOGY AND HYDRAULICS–RELATED DISCUSSION

6.1 POWER AND RAMPING RATE DIFFERENCES NOT CAPTURED IN RESSIM THAT MAY INFLUENCE IMPACT ANALYSES

ResSim does not model the power system and a qualitative description of power operational differences between the No Action Alternative, which describes Columbia River System operations as defined September 2016, and the modeled alternatives, is needed for the impacts analysis. This qualitative assessment does not include structural measure changes.

This section also contains discussion of ramping rate changes.

Included in all the MOs is the **Allow Contingency Reserves to be Carried within Juvenile Fish Passage Spill** measure, which increases the available capacity of hydrogenation on the fish passage projects. Because contingency reserves are rarely deployed, holding the contingency reserves within the fish passage spill won't affect fish spill amounts. When contingency reserves are deployed, they can often be met without reducing fish passage spill even if this measure is in place. This measure will have an effect on spill during force spill condition because the powerhouse will have more capacity.

Also, ResSim does not power shape the flows to be heavier on the weekdays and reduced on the weekends. Nor does the daily timestep of the model capture the within-day and within-hour fluctuations that occur to meet demand. These flow shapings not included in the model are present within the historical range of operations and impacts groups can refer to historical flow changes for their analysis.

6.1.1 Multiple Objective Alternative 1

In MO1, the forebay operating range at the lower Snake River and John Day projects is increased by 0.5 foot during fish passage season. This flexibility is the same range being used in 2019 and is still smaller than the historical range of operations during the fall and winter time frame.

6.1.2 Multiple Objective Alternative 2

MO2 includes the operation of the lower Snake River and John Day projects at full reservoir operating range year-round except as needed for FRM. This type of flexibility is within the historical range of operations, and impacts groups can refer to the historical elevation changes during the fall and winter time frames when the projects operate at the full reservoir range.

Turbines can operate across their full range of capacity all year in MO2. This measure will increase generation and turbine flow capacities to reduce the amount of lack-of-turbine spill. The increased turbine capacity was included in the application of spill to the ResSim results. The increased turbine capacity would increase slightly the amount of within-day shaping to meet fluctuations in demand. The range of turbine operations is within the historical range of operations in the fall and winter. The reader can refer to the historical changes during the winter time frames when the projects operate at the full turbine range to assess how this operation might occur during the spring and summer in MO2.

MO2 also includes the **Zero Generation Operations** measure that allows the lower Snake River projects to shut off generation for brief periods unless limited by grid stability requirements from September through March. This allows the projects to reduce generation when there is little demand and store the water for use at a later time when generation is in peak demand. This operation is within the historical range of operations typically in the mid-December through February winter months. Although the generation reduces the project flow to zero, the tailwater below the dam does not dry out because the downstream reservoir extends to the base of the upstream dam.

In both MO2 and MO3, the ramping rate limitations at all projects will be defined only for safety or geotechnical concerns such as erosion. More flexibility in ramping rates does not increase the total generation but increases the ability to shape flows and power generation within-day to meet fluctuations in demand. Ramping rate changes at Libby and Hungry Horse Dams were not eliminated in modeling because it led to unacceptable modeled outcomes. Instead, ResSim daily ramping rates were doubled.

ResSim models at the daily timestep so within-day ramping was not captured. In power operations projects would be shaped to the extent feasible to maximize generation during peak demand and minimize generation during low demand while passing the necessary water across the day. For example, in the winter, the project would pass the day average flow in a shape where the project was ramped down to minimum generation at night and ramp up over the morning peak demand. If the ramp rates allowed, another ramp down during the midday to save water for the evening peak demand would likely occur with an additional ramp down to minimums again for the overnight low demand period. The ramping limitations for safety or geotechnical concerns would need to be provided to calculate how much within-day shaping of the flow would be allowed. If ramping rates are too restrictive for much within-day ramping, the projects would shape to have higher generation during the weekdays and lower generation on the weekends as allowed. Within-hour shaping would not be used on the headwater projects.

6.1.3 Multiple Objective Alternative 3

As stated above, MO3 includes lifting the flow and ramping restrictions, leaving only those defined for safety or geotechnical concerns such as erosion and expanded John Day Reservoir ranges similar to MO2.

MO3 also includes the allowance for the lower Columbia River projects (lower Snake River projects are removed in this alternative) to operate turbines above the 1 percent peak efficiency. This expands the turbine range on the upper end of the operating range, which increases the turbine capacity to reduce the amount of lack-of-turbine spill. The increased turbine capacity would increase slightly the amount of within-day shaping to meet fluctuations in demand but is within the historical range of operations that occur outside the fish passage season when turbines are allowed to operate across their full operating range. For analysis of the MO3 operation during the fish passage season, impacts groups can assume that the operation in MO3 will be across a broader range than in the No Action Alternative but not as large a range as the historical fall/winter range since MO3 maintains the restriction not to operate below the 1 percent peak efficiency range.

6.1.4 Multiple Objective Alternative 4

MO4 also includes the allowance for the lower Columbia River and lower Snake River projects to operate turbines above the 1 percent peak efficiency. This operation is the same as in MO3, described above, but here also applies to the lower Snake River projects.

MO4 includes additional reservoir drawdowns to the lower Columbia River projects. This will restrict the ability of those projects to meet fluctuations in power demand, which will require other projects (most likely Grand Coulee and Chief Joseph) to fluctuate more.

6.2 ADDITIONAL MAINTENANCE

6.2.1 Grand Coulee Dam Drum Gate Maintenance – Need Consideration for Decadal Control Valve Maintenance

Drum gate and valve maintenance at Grand Coulee is planned to occur in the spring of most years. The ability to perform inspections and maintenance has a direct link to Lake Roosevelt water levels, requiring water levels to be at or below critical elevations for a certain period of time. Because the MOs contain operational measures that impact spring water levels and draft timing, notably the **Planned Draft Rate at Grand Coulee** and **Update System FRM Calculation** measures, the potential exists for impacts to drum gate maintenance.

Regular drum gate maintenance at Grand Coulee Dam is planned to occur annually during March, April, and May, but it is not conducted in all years. The reservoir must be at or below elevation 1,255 feet NGVD29 for eight weeks to complete drum gate maintenance. In addition to the annual drum gate maintenance, an annual inspection and maintenance activity is planned for the 57-inch butterfly drum gate intake valves in late April or early May. Some inspection and maintenance on these valves can occur regardless of water levels, but some maintenance requires water levels at or below 1,219 feet NGVD29. The external inspection and maintenance that requires water levels at or below 1,219 feet, for a week duration, must occur once every 10 years. This inspection takes advantage of spring drafts for FRM, but in some years may require an additional draft below FRM requirements to conduct this maintenance. This could result in additional outflow, a longer duration of ferry outage, and elevated spill and TDG.

To quantify the potential effects of these measures, the percentage of years in which maintenance can occur is compared between the various MOs. The results are shown in Table 6-1.

Table 6-1. Percentage of Years in Which Drum Gate Maintenance Can Occur at Grand Coulee Dam

Maintenance Activity	NAA	MO1	MO2	MO3	MO4
Drum gate maintenance[1/]	65%	65%	65%	65%	65%
57-inch butterfly drum gate intake valves maintenance[2/]	7%	11%	11%	8%	11%
57-inch butterfly drum gate intake valves maintenance with 3.7 feet additional draft[3/]	9%	16%	15%	13%	15%

1/ Drum gate maintenance: water surface elevation less than 1,255 feet NGVD29 for minimum of 8 weeks.

2/ 57-inch butterfly drum gate intake valves maintenance: water surface elevation is less than or equal to 1,219 feet NGVD29 for 1 week.

3/ Elevation 1,219 feet is approximately 3.7 feet below the Grand Coulee SRD “flat spot,” which is an FRM elevation requirement over a range of water supply conditions.

The results show that drum gate maintenance can occur in 65 percent of years under the No Action Alternative, and that there is no change in the percent of years in which drum gate maintenance can occur under the four MOs. The results also show an increase in the percent of years the inspection and maintenance of the 57-inch butterfly drum gates can occur for each of the MOs, particularly in MO1, MO2, and MO4, where the percent of years increases form 7 percent under the No Action Alternative to 11 percent.

The changes in elevations relative to the No Action Alternative that influence the decision to conduct drum gate maintenance (April 30 FRM elevation target at or below 1,255 feet NGVD29) do not change with MO1, MO3, and MO4. That is not to say the spring elevations are the same for the alternatives, but rather there are a similar number of years that elevations would allow for drum gate maintenance. For these alternatives, including the No Action Alternative, drum gate maintenance would be achievable in approximately 65 percent of the years.

Under MO2, in rare events, a winter FRM event fills Grand Coulee Dam, and this can preclude drum gate maintenance later that year. The results show a decreased occurrence of drum gate maintenance years under MO2 compared to the No Action Alternative. Once the event is abandoned, there would be less space in the dam to later manage high spring flows.

6.2.2 General Grand Coulee Dam Maintenance Discussion

Ongoing routine and overhaul maintenance requires multiple units out at a time in the Grand Coulee Dam power plant. These activities are scheduled to minimize impacts on operations while also conducting necessary maintenance for reliable and safe operations of the project. For most conditions and times of year, the third power plant at Grand Coulee Dam must have units available for voltage and frequency support, ensure transmission stability, and meet load. Additional outages of 1 to 2 weeks are scheduled annually to work on components that cause frequent forced outages. These outages are taken to try to address troubled components on a scheduled basis to reduce forced outages. This could include removing all six of the third power plant units (out of service) for one week at a time during a period when the flows and power demands are low. The timeframe would be from October through January (fall and winter), but only if this maintenance can be conducted without impacting flows and power generation. There are no pool elevation requirements for this maintenance, and this maintenance does not impact total outflows or require additional spill due to the timing of the activity. If conditions arose requiring additional outflow and/or spill, this maintenance can be deferred.

6.2.2.1 Hungry Horse Surface Water Withdrawal System

Hungry Horse Reservoir thermally stratifies in the summer and can provide some downstream water temperature management through use of the selective withdrawal system (SWS). The SWS is required to operate from June to the end of September but is typically operated into November when the reservoir becomes isothermal and the benefits of SWS operations are negated. The SWS has an operational range when the reservoir is between full (3,560 feet NGVD29) and drafted 160 feet (3,400 feet NGVD29). Annually, inspection and maintenance are planned in the spring. The reservoir must be at or below elevation 3,526 feet NGVD29 to allow for annual inspection and maintenance (with the relief gate hanging, the bottom of the gate is located at 3,526 feet NGVD29, allowing for access by maintenance personnel (lowered via man-basket from the top of dam gantry crane) for inspection and repair. Note that missing or damaged relief gate panels or other related equipment restricts or potentially disables the function of the SWS. Continuance of routine maintenance of this system is critical to ensure reliable uninterrupted operation of temperature-controlled water releases for fish. The U.S. Bureau of Reclamation maintenance directives dictate annual maintenance.

The SWS inspection, maintenance, and repair is planned to occur annually during late April or early May. When site conditions disallow spring maintenance (flood control/reservoir elevation/weather conditions), maintenance is deferred to the fall, if reservoir elevations allow, or the following spring. However, deference of such maintenance is not recommended for the previously noted reasons (e.g., restricted or loss of SWS function). If deferral occurs for several consecutive years, reshaping refill to allow maintenance may be necessary. This inspection takes advantage of spring drafts for FRM. The reservoir must be at or below elevation 3,526 feet NGVD29 to complete SWS inspection and maintenance. The key indicator for this metric is the percentage of years when SWS maintenance would be possible. The results are summarized in Table 6-2.

Table 6-2. Percentage of Years where the Hungry Horse Selective Withdrawal System Maintenance Would be Possible

Maintenance Activity	NAA	MO1	MO2	MO3	MO4
Hungry Horse SWS maintenance	66%	74%	74%	74%	75%

6.2.2.2 Hungry Horse Dam Power Plant Modernization and Overhaul Project

One year in the next five, Hungry Horse Dam operations will be limited to two units available. In any given year, additional outages can occur due to grid reliability requirements or unexpected events/equipment failures, which may limit the ability to pass water through the power plant and, in some cases, may result in additional spill. Additionally, the U.S. Bureau of Reclamation is planning a Hungry Horse Dam power plant modernization and overhaul project in the next 10 years. This overhaul would take place over 4 years and is currently scheduled to start around 2020 or 2021. During one of the four years, maintenance would require outages for one year in the power plant, limiting the power plant to two units available for one year, reducing the hydraulic capacity to approximately 6 kcfs. This could result in additional spill in this one year, and the maximum TDG anticipated from the overhaul study was 120 percent. In most years, the reduced hydraulic capacity would not result in significantly more spill and would not result in higher TDG than presented in this analysis. As spill typically occurs during the spring when it is cold, it takes a substantial increase in spill to raise TDG above 115 percent. Often during this period, the resident fish have migrated out of the South Fork Flathead River, and elevated TDG is diluted when flowing into the mainstem Flathead River.

6.3 BROWNLEE SHIFT

System FRM space can be temporarily shifted, if possible, from Dworshak and Brownlee to Grand Coulee until April 15 with the volume used for flow augmentation by April 30 (transferring the space requirements back to Dworshak and Brownlee). At Brownlee, the temporary transfer of system FRM space to Grand Coulee is subject to the availability of space at Grand Coulee. The shifted FRM space requirements are shifted back to Brownlee by April 30 and Grand Coulee’s space requirement reverts back to the non-shifted amount. Shifts from Brownlee to Grand Coulee are not normally executed during in-season operations since there is generally not enough space after performing a shift from Dworshak to Grand Coulee; therefore, the Brownlee shift has not been incorporated in the CRS Model.

CHAPTER 7 - PREFERRED ALTERNATIVE

7.1 OVERVIEW

This chapter contains only summary plots and tables. See Chapter 7.5.1 in the main body of the EIS for discussion of operational measures and modeled H&H changes.

Similar to section 5.6, the plots and tables in the following section (7.2) show changes various H&H metrics at key locations throughout the basin; however, section 7.2 contains only a comparison of the Preferred Alternative (PA) and the No Action Alternative. See section 3.2 for a description of the various plot and table types.

Some plots included in section 5.6 are not included here because there are no notable difference between the PA and No Action Alternative for that particular location and metric.

7.2 SUMMARY PLOTS AND TABLES

7.2.1 Region A – Kootenai, Flathead, and Pend Oreille Basins

7.2.1.1 Water Year Plots, Elevation

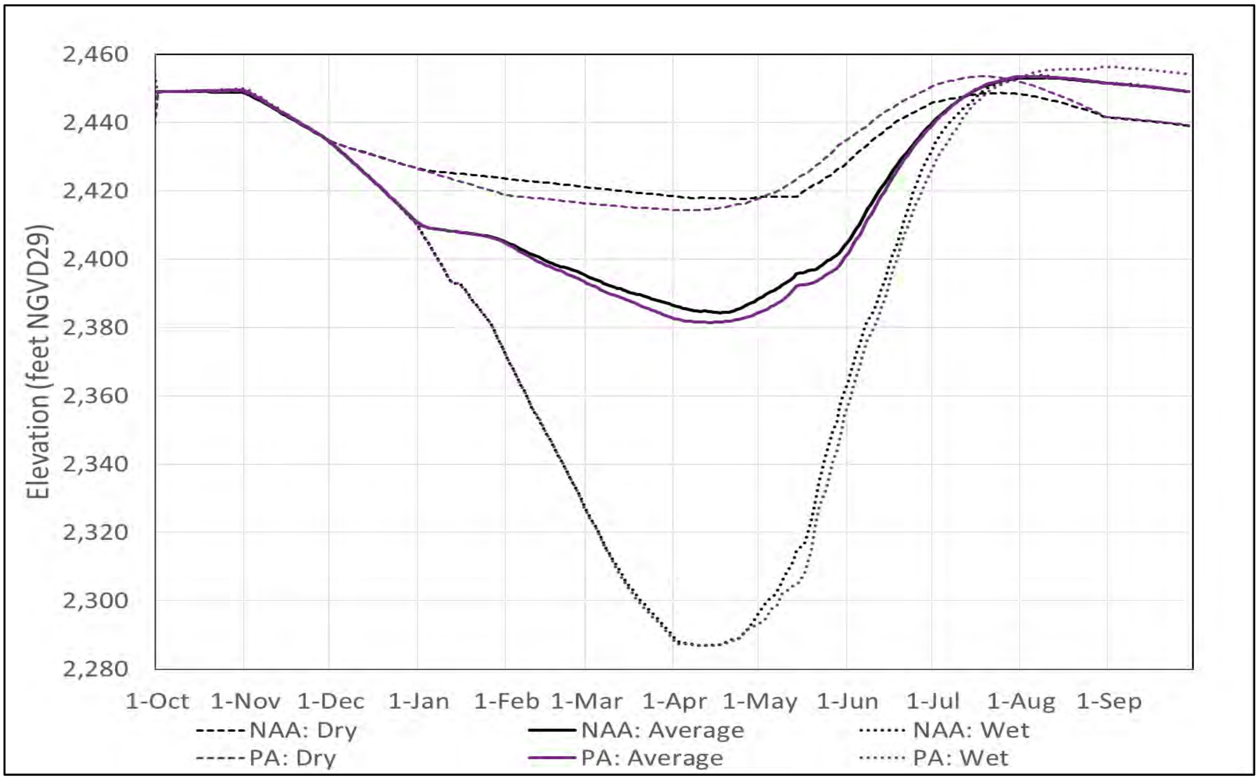


Figure 7-1. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Libby Reservoir (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

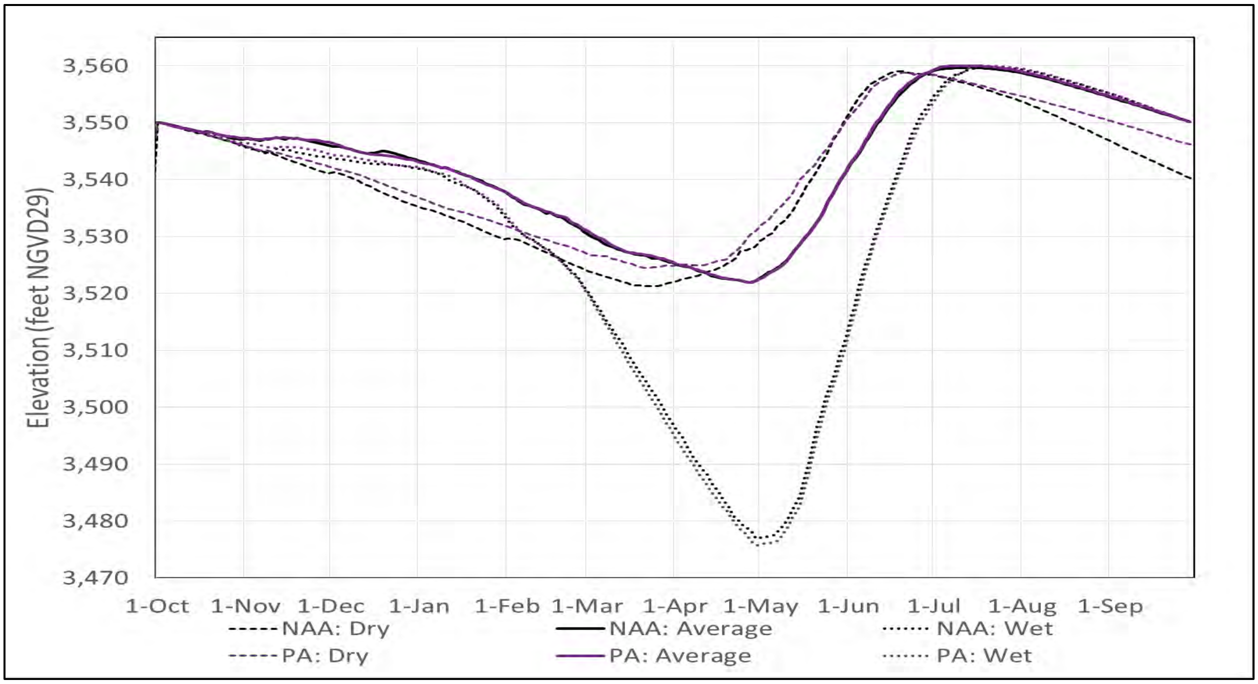


Figure 7-2. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Hungry Horse Reservoir for the Preferred Alternative and No Action Alternative

7.2.1.2 Summary Elevation Hydrographs

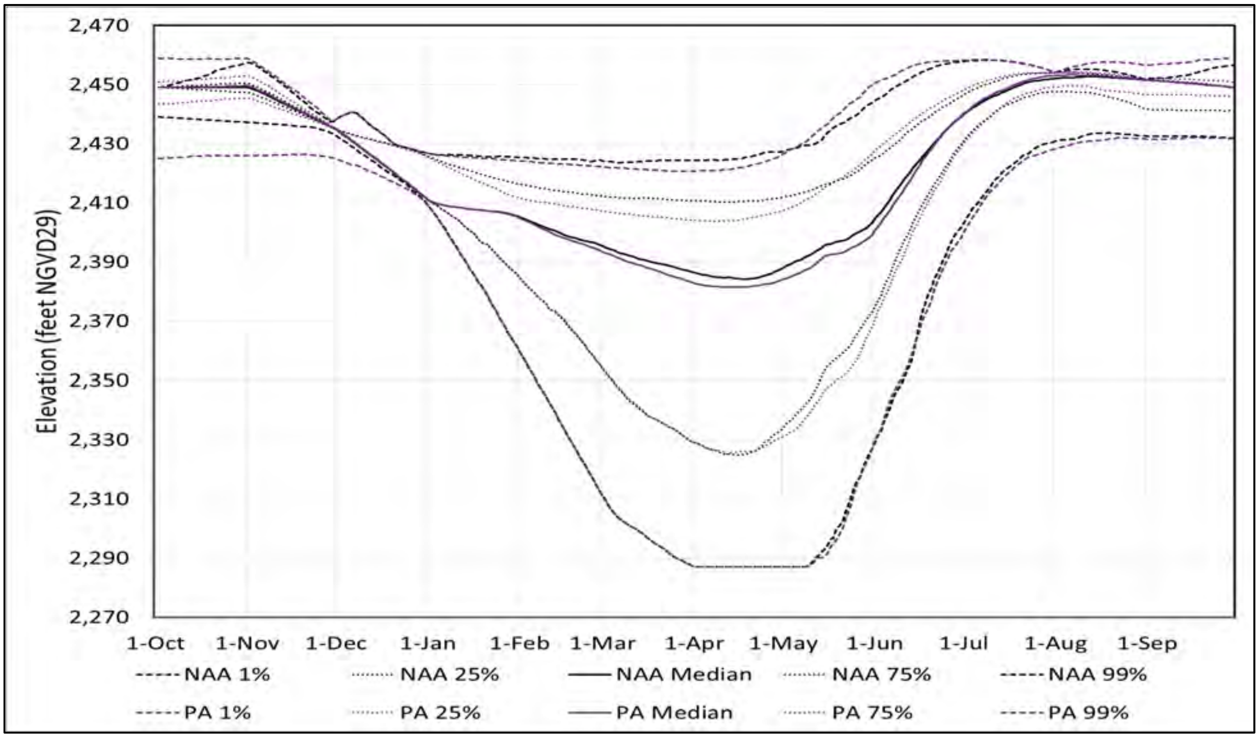


Figure 7-3. Summary Elevation Hydrographs at Libby Reservoir (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

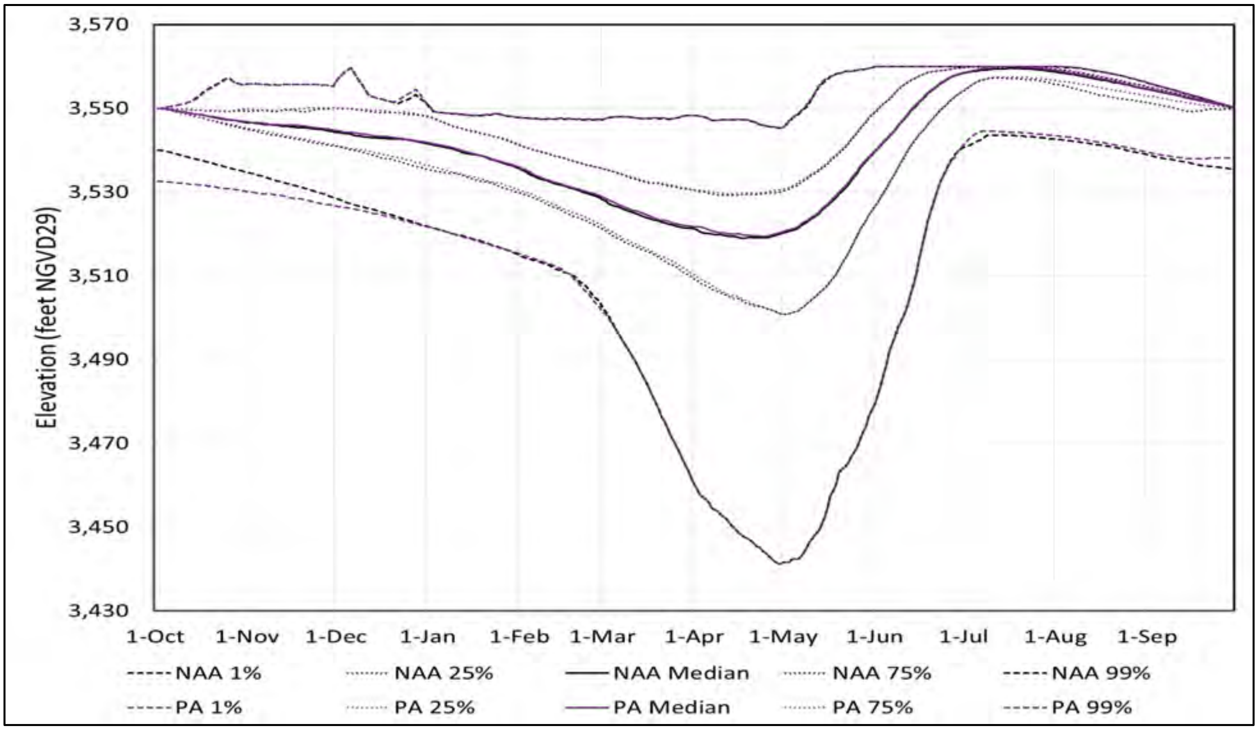


Figure 7-4. Summary Elevation Hydrographs at Hungry Horse Reservoir for the Preferred Alternative and No Action Alternative

7.2.1.3 Reservoir Target Date Elevation-Frequency Plots

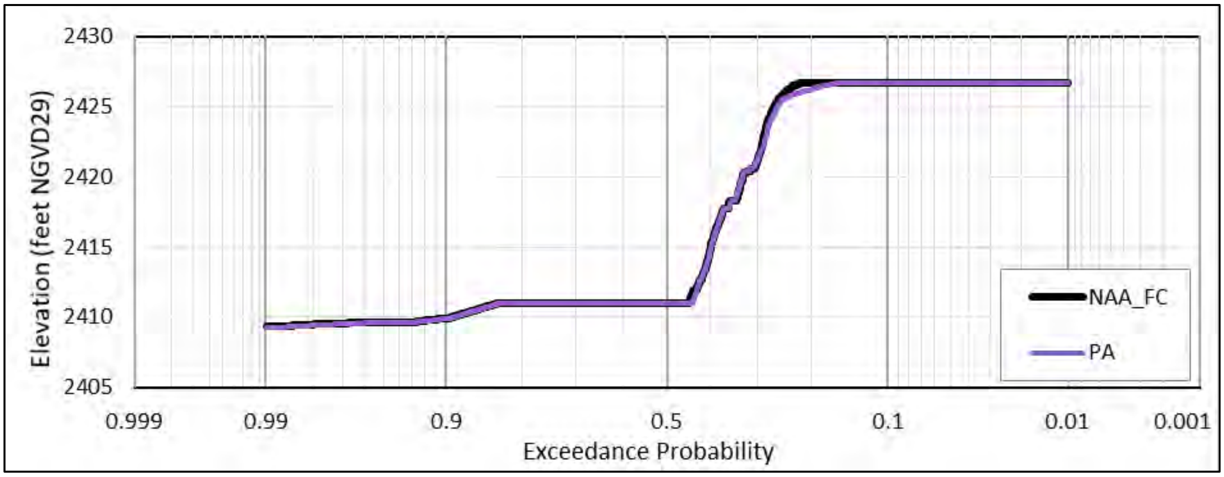


Figure 7-5. Elevation-Frequency Curves for December 31 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

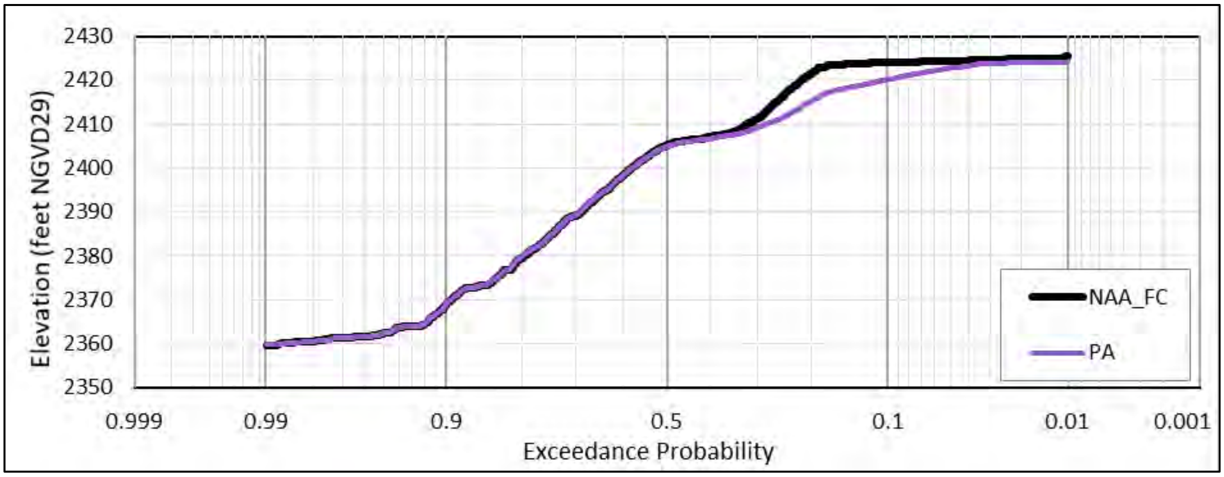


Figure 7-6. Elevation-Frequency Curves for January 31 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

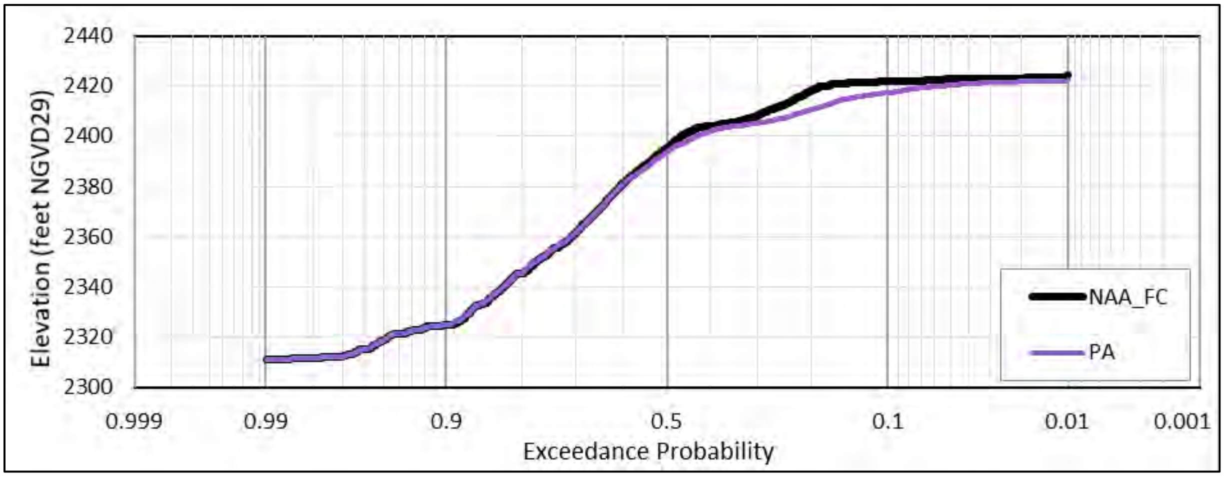


Figure 7-7. Elevation-Frequency Curves for February 28 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

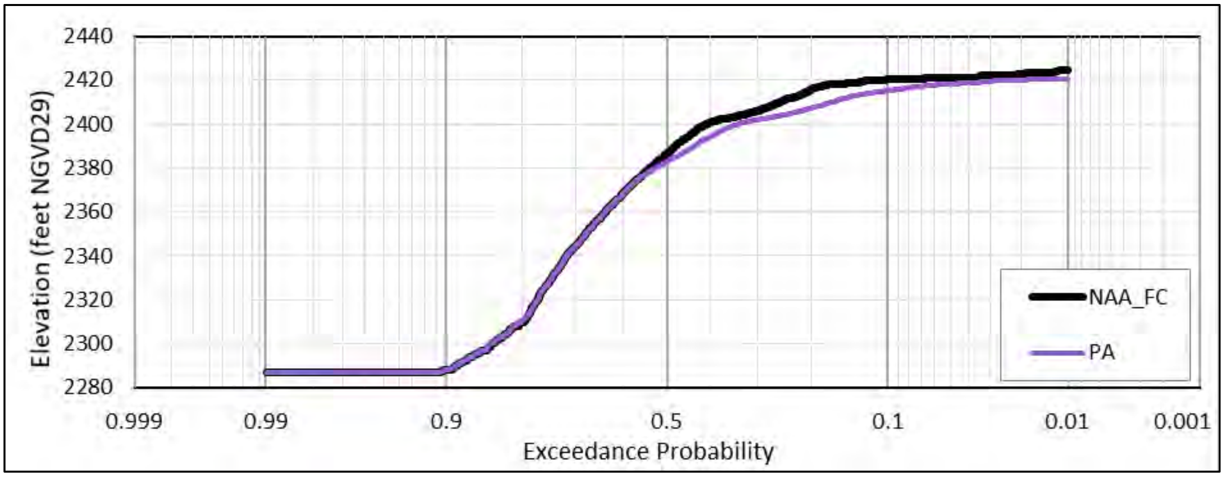


Figure 7-8. Elevation-Frequeny Curves for March 31 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

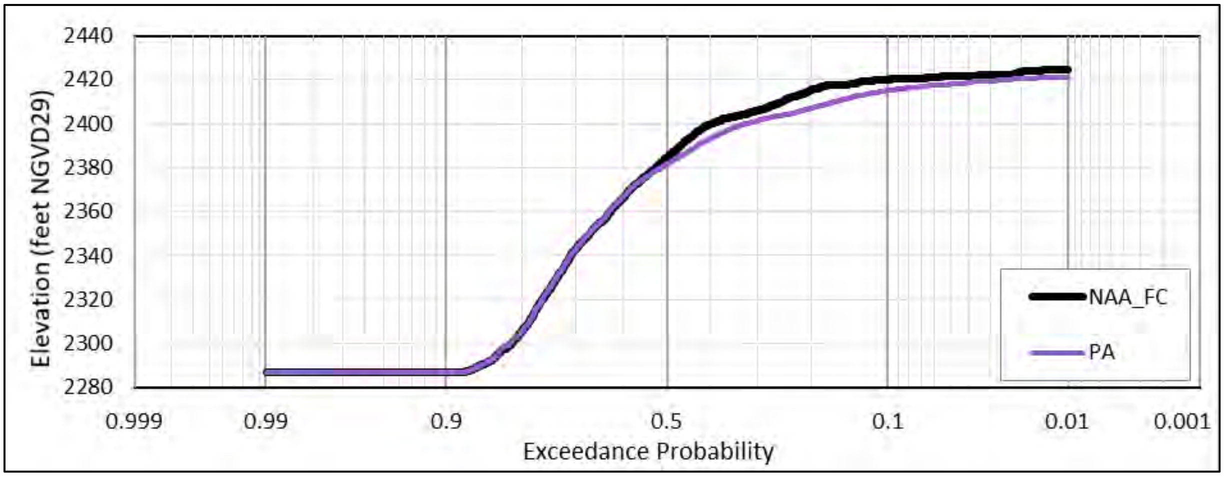


Figure 7-9. Elevation-Frequency Curves for April 10 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

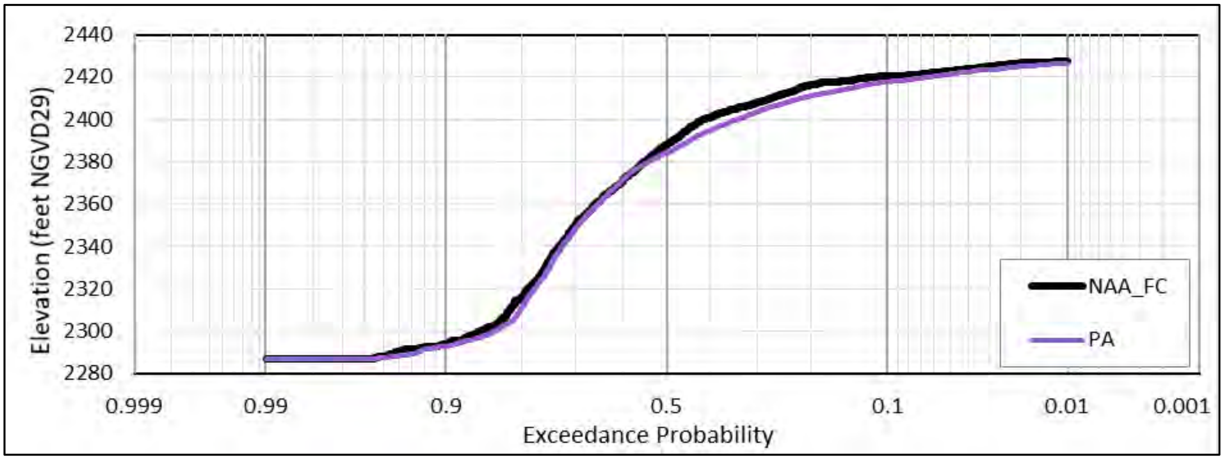


Figure 7-10. Elevation-Frequency Curves for April 30 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

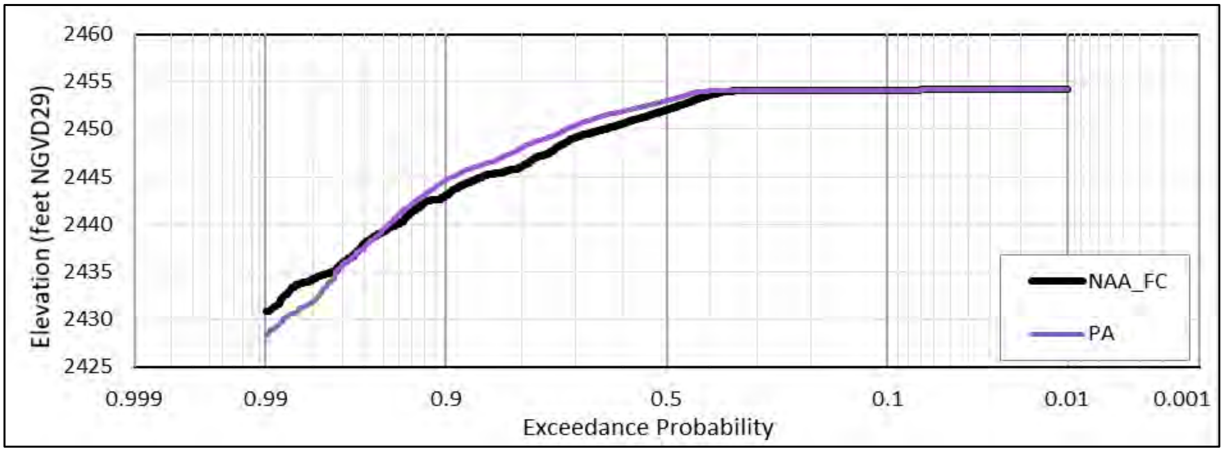


Figure 7-11. Elevation-Frequency Curves for July 31 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

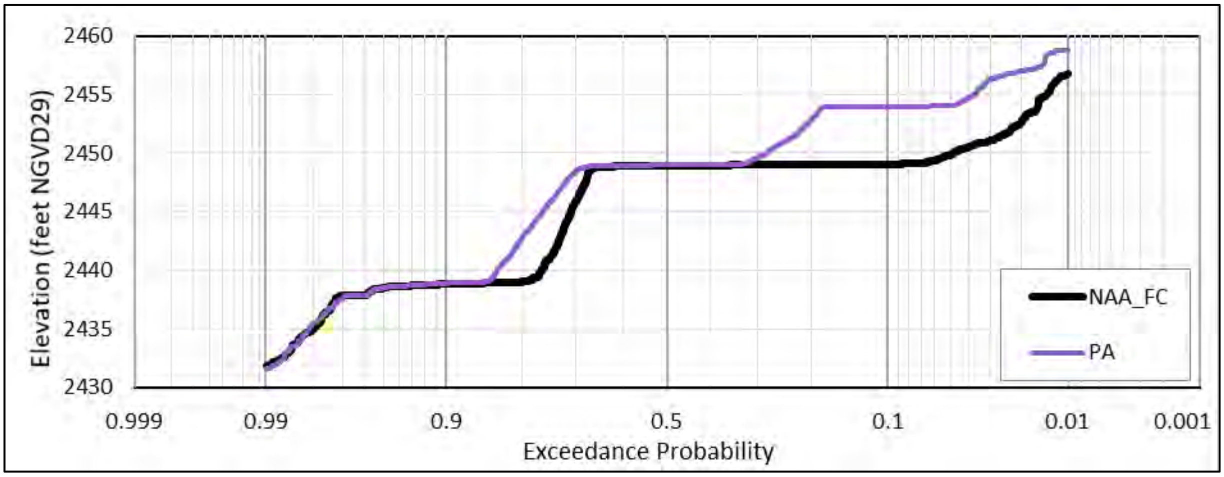


Figure 7-12. Elevation-Frequency Curves for September 30 at Libby Dam (Lake Koocanusa) for the Preferred Alternative and No Action Alternative

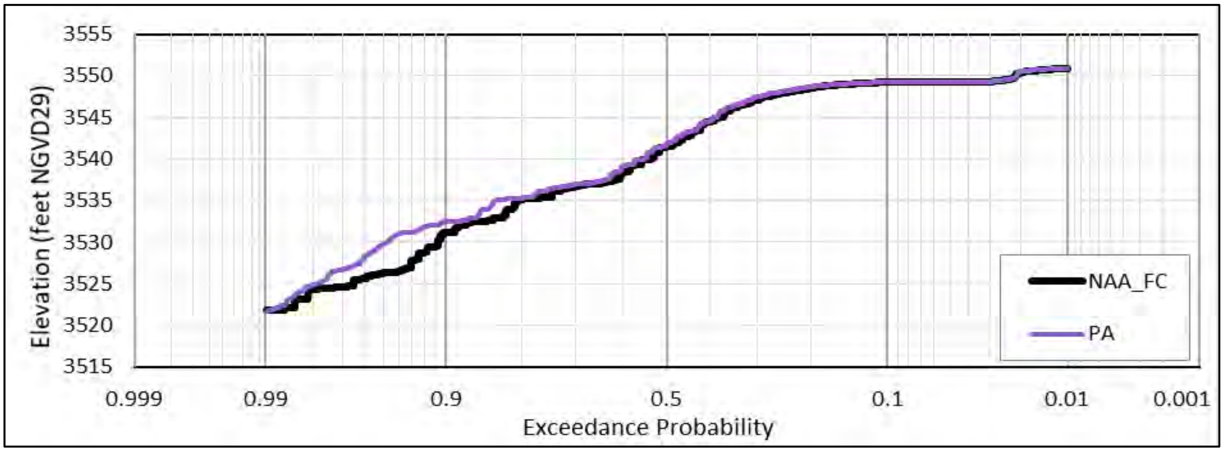
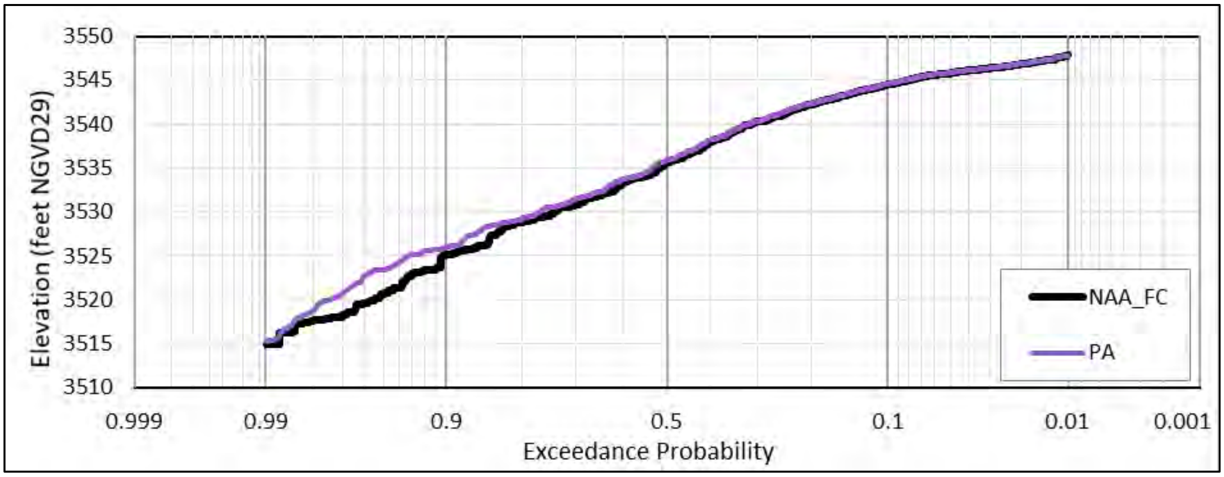


Figure 7-13. Elevation-Frequency Curves for December 31 at Hungry Horse Reservoir for the Preferred Alternative and No Action Alternative



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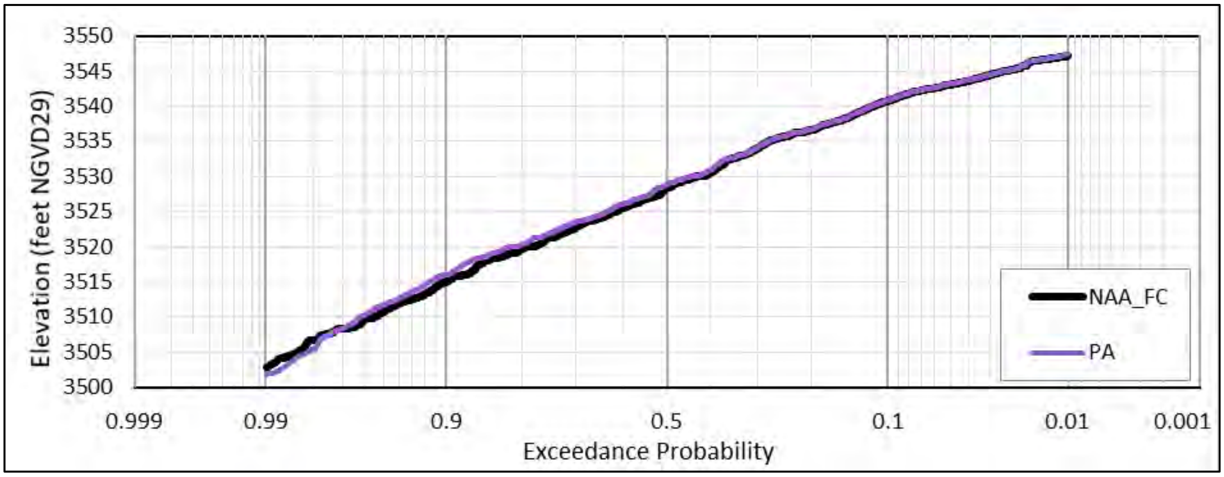
3840 **Figure 7-14. Elevation-Frequency Curves for January 31 at Hungry Horse Reservoir for the**
3841 **Preferred Alternative and No Action Alternative**



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3843 **Figure 7-15. Elevation-Frequency Curves for February 28 at Hungry Horse Reservoir for the**
3844 **Preferred Alternative and No Action Alternative**

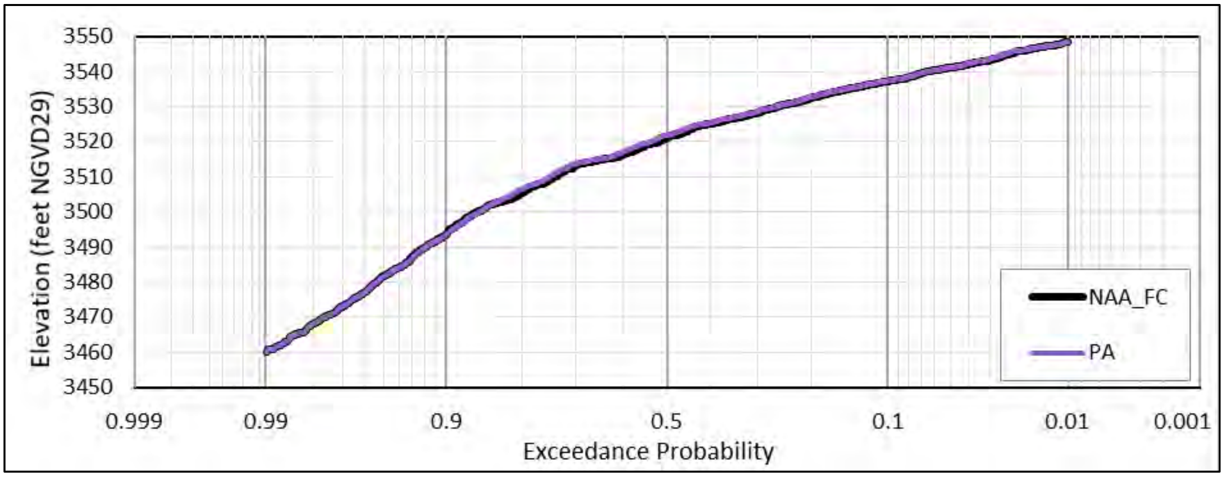


Figure 7-16. Elevation-Frequency Curves for March 31 at Hungry Horse Reservoir for the Preferred Alternative and No Action Alternative

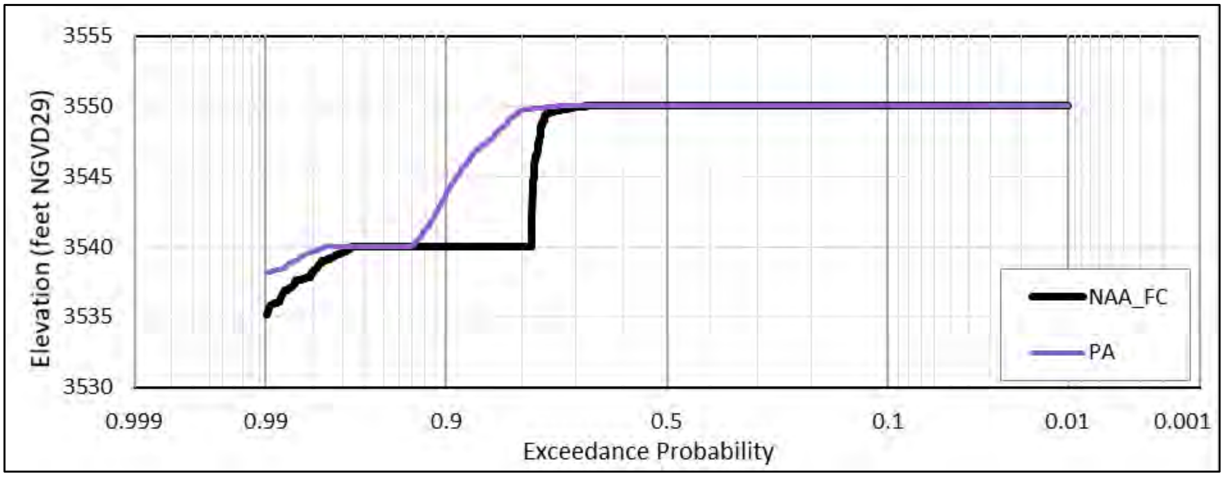


Figure 7-17. Elevation-Frequency Curves for September 30 at Hungry Horse Reservoir for the Preferred Alternative and No Action Alternative

7.2.1.4 Water Year Plots, Flow

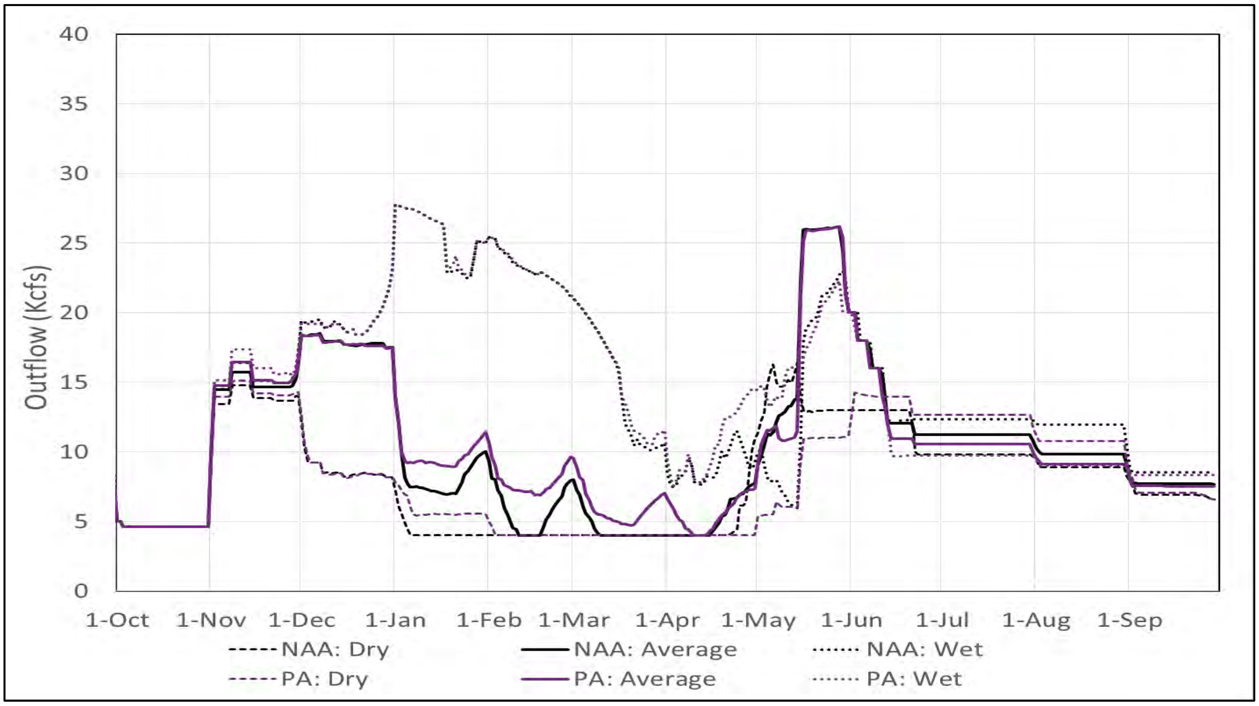


Figure 7-18. Summary Outflow Hydrograph for Dry, Average, and Wet Water Years at Libby Dam for the Preferred Alternative and No Action Alternative

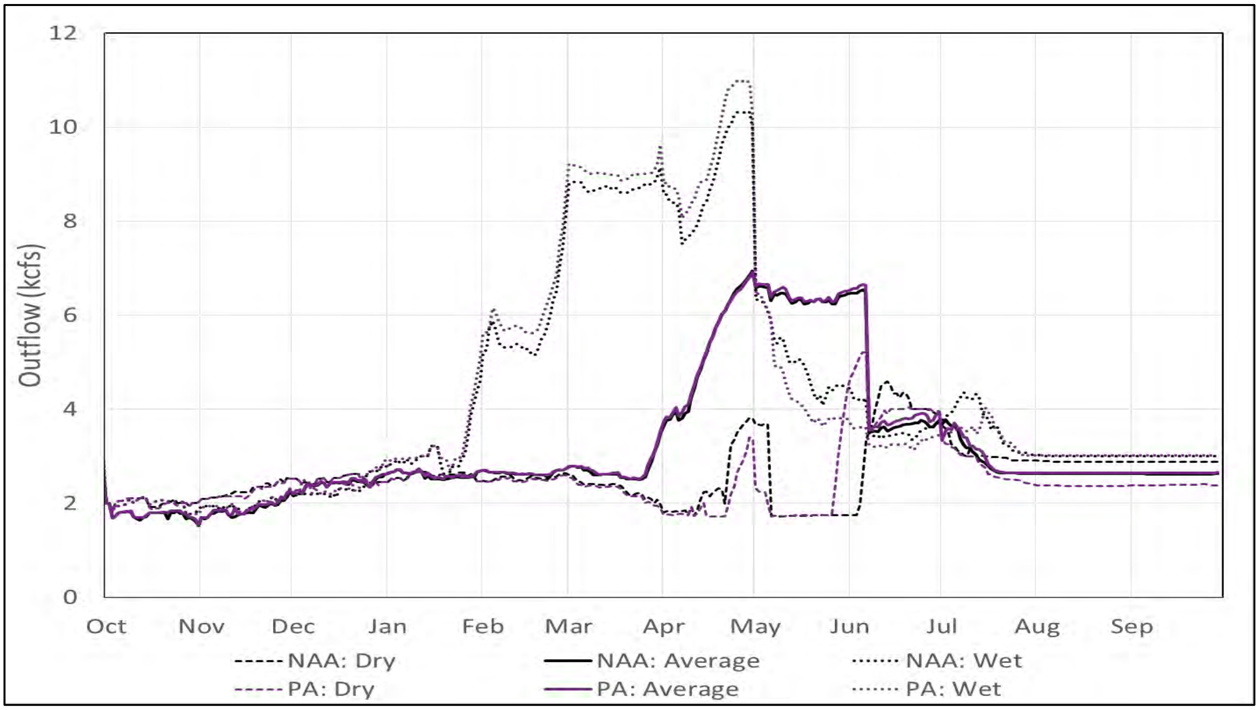
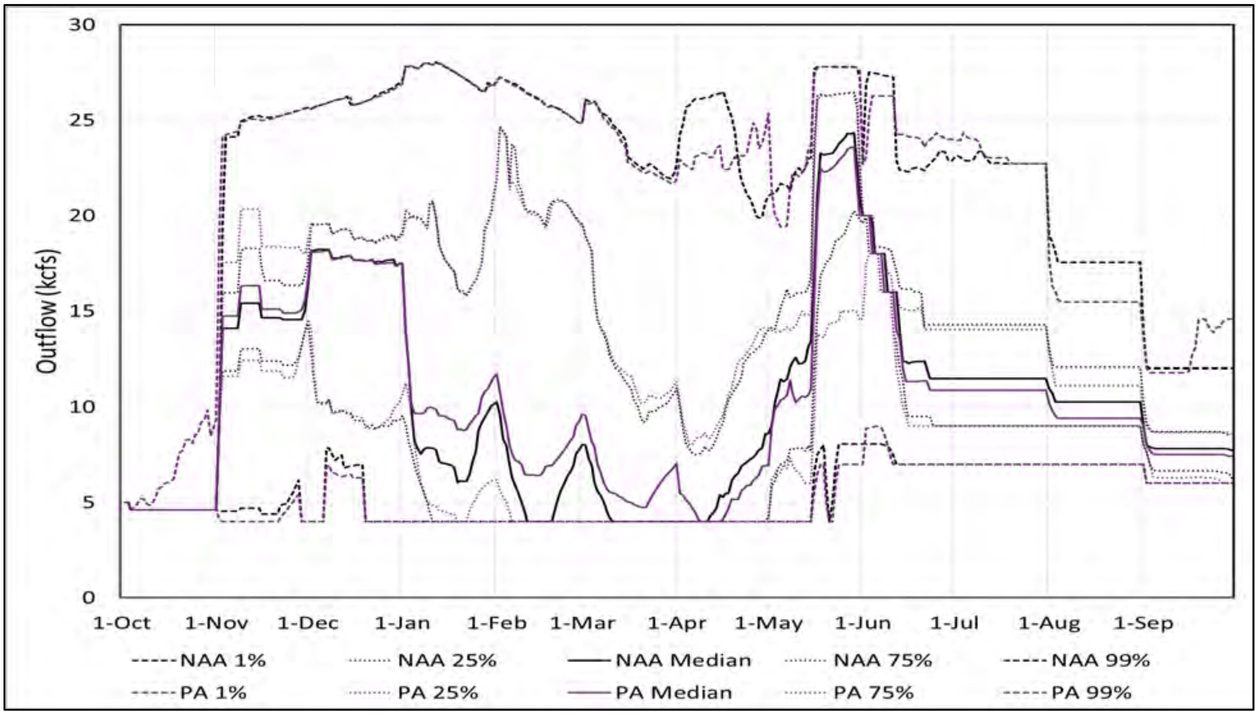


Figure 7-19. Summary Outflow Hydrograph for Dry, Average, and Wet Water Years at Hungry Horse Dam for the Preferred Alternative and No Action Alternative

3858 ### *7.2.1.5 Summary Flow Hydrographs*



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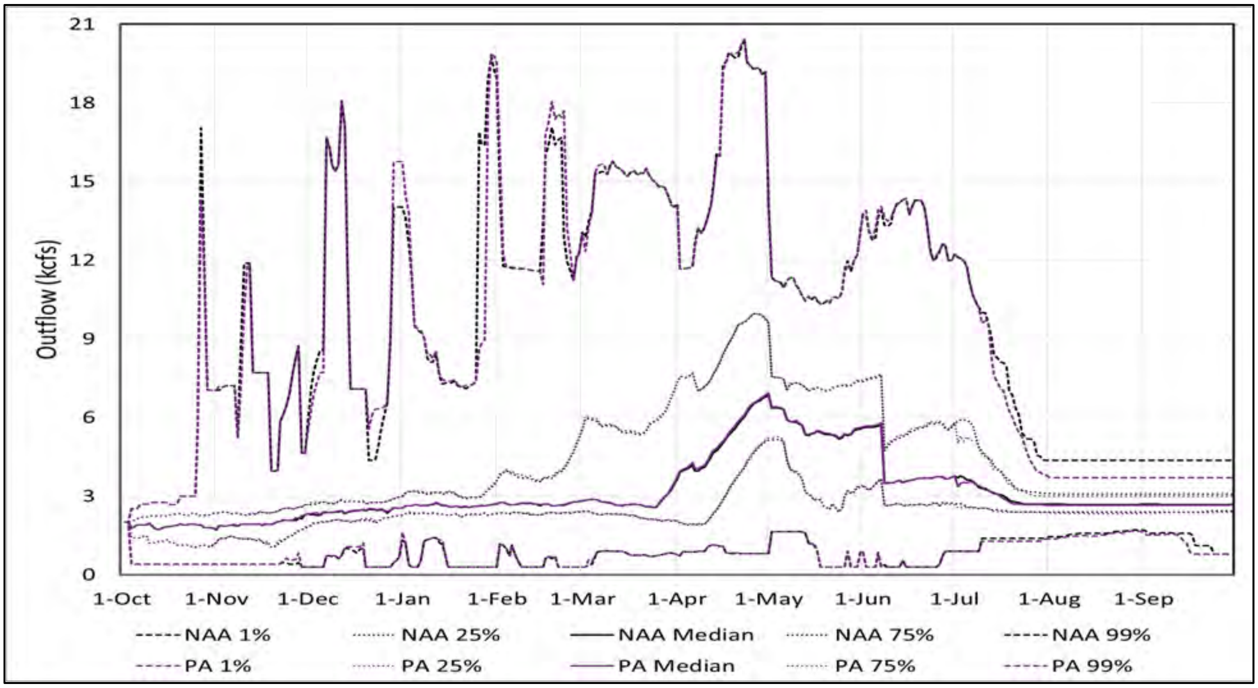
3860 **Figure 7-20. Summary Outflow Hydrographs at Libby Dam for the Preferred Alternative and**
3861 **No Action Alternative**



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3863 **Figure 7-21. Summary Outflow Hydrographs at Hungry Horse Dam for the Preferred**
3864 **Alternative and No Action Alternative**

7.2.1.6 Average Monthly Flow Summary Tables

Table 7-1. Average Monthly Outflow Summary for Libby Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	4.9	23.5	22.0	27.1	25.8	23.0	20.8	22.7	22.6	22.9	17.8	12.0
		25%	4.7	16.2	18.9	18.3	20.0	12.2	9.9	19.2	17.1	14.3	12.1	8.8
		50%	4.7	14.3	17.7	8.8	6.3	5.5	7.0	16.4	14.2	11.5	10.3	7.9
		75%	4.7	12.0	9.9	5.6	4.0	4.0	4.4	14.0	12.9	9.0	9.0	6.8
		99%	4.7	7.0	8.2	4.3	4.0	4.0	4.0	11.6	8.8	7.1	7.1	6.0
PA	Change (kcfs)	1%	2.0	0.4	0.2	0.0	0.0	-0.4	-0.6	-0.6	0.7	0.2	-2.2	0.0
		25%	0.0	1.8	0.0	0.0	-0.2	0.2	0.6	0.0	-1.0	-0.2	-0.9	-0.1
		50%	0.0	0.4	0.1	1.6	1.6	1.0	-1.0	0.0	-0.7	-0.6	-0.9	-0.3
		75%	0.0	-0.4	0.1	0.7	0.5	0.0	-0.4	-2.1	-0.4	0.0	0.0	-0.4
		99%	0.0	-1.3	0.0	0.5	0.0	0.0	0.0	-5.0	1.3	0.9	0.7	0.1
	Percent change	1%	40%	2%	1%	0%	0%	-2%	-3%	-2%	3%	1%	-12%	0%
		25%	0%	11%	0%	0%	-1%	2%	6%	0%	-6%	-2%	-8%	-1%
		50%	0%	3%	0%	19%	26%	18%	-14%	0%	-5%	-5%	-8%	-4%
		75%	0%	-3%	1%	13%	13%	0%	-9%	-15%	-3%	0%	0%	-5%
		99%	0%	-19%	-1%	11%	0%	0%	0%	-43%	14%	12%	9%	1%

Table 7-2. Average Monthly Flow Summary for Bonners Ferry, Idaho

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	9.0	26.6	29.2	31.3	29.7	27.5	30.4	40.8	40.7	27.2	19.0	13.3
		25%	6.1	18.1	20.7	21.0	23.2	15.3	19.4	34.3	27.8	17.3	13.3	9.7
		50%	5.6	15.4	18.9	10.4	8.5	8.4	14.6	31.1	23.8	14.6	11.4	8.6
		75%	5.4	13.0	11.4	6.5	5.1	5.9	10.2	27.6	20.3	11.8	9.9	7.4
		99%	5.1	7.7	9.0	5.1	4.5	4.9	7.0	18.3	12.6	9.0	8.1	6.7
PA	Change (kcfs)	1%	0.7	0.6	0.0	0.0	0.0	0.1	2.8	1.3	1.0	-0.4	-2.6	0.3
		25%	0.0	1.7	0.0	-0.1	-0.3	0.3	0.4	0.3	-1.0	-0.8	-0.9	-0.1
		50%	0.0	0.6	-0.1	1.5	1.3	1.0	-0.7	0.0	-0.5	-0.4	-0.8	-0.4
		75%	0.0	-0.2	0.0	1.1	0.6	0.3	-0.3	-3.7	-0.4	0.1	0.0	-0.2
		99%	0.0	-0.9	-0.1	0.5	0.1	0.0	0.0	-3.8	1.1	0.4	0.3	-0.1
	Percent change	1%	8%	2%	0%	0%	0%	0%	9%	3%	2%	-2%	-13%	2%
		25%	0%	9%	0%	-1%	-1%	2%	2%	1%	-4%	-5%	-7%	-1%
		50%	0%	4%	-1%	14%	16%	12%	-5%	0%	-2%	-3%	-7%	-4%
		75%	0%	-1%	0%	16%	11%	5%	-3%	-13%	-2%	1%	0%	-3%
		99%	0%	-11%	-1%	10%	2%	0%	0%	-21%	9%	5%	4%	-1%

Table 7-3. Average Monthly Outflow Summary for Hungry Horse Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	2.5	4.7	6.9	7.1	11.5	14.5	15.6	9.6	10.7	6.9	4.4	4.4
		25%	2.2	2.4	2.7	3.1	4.0	5.7	8.1	7.0	6.1	4.2	3.1	3.1
		50%	1.9	2.0	2.4	2.6	2.7	2.7	5.4	5.7	4.3	3.4	2.7	2.7
		75%	1.4	1.4	2.1	2.3	2.4	2.2	3.1	4.1	3.2	2.6	2.4	2.4
		99%	0.8	0.8	1.6	2.0	1.7	1.5	1.7	1.7	1.7	1.8	1.9	2.0
PA	Change (kcfs)	1%	0.0	-0.3	0.0	-0.1	0.1	0.0	0.0	0.0	0.0	-0.1	-0.7	-0.7
		25%	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-0.1	0.0	0.0
		99%	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
	Percent change	1%	0%	-7%	0%	-1%	1%	0%	0%	0%	0%	-1%	-15%	-15%
		25%	0%	0%	1%	2%	2%	1%	0%	1%	1%	-3%	-3%	-3%
		50%	0%	1%	0%	1%	0%	0%	1%	1%	1%	-5%	-1%	-1%
		75%	0%	0%	0%	1%	0%	0%	2%	1%	0%	-3%	-2%	-1%
		99%	0%	1%	3%	1%	1%	0%	0%	0%	0%	-3%	-5%	-7%

Table 7-4. Average Monthly Flow Summary for Columbia Falls, Montana

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	8.9	14.4	14.8	11.0	14.2	17.4	30.5	38.0	43.2	23.9	8.8	8.7
		25%	4.0	4.2	4.5	5.0	5.8	7.9	15.9	29.7	31.5	15.1	6.9	5.4
		50%	3.8	3.7	3.7	3.8	3.8	4.5	12.3	25.5	24.8	11.5	5.8	4.7
		75%	3.6	3.6	3.6	3.6	3.6	3.7	8.5	21.4	20.0	8.4	4.9	4.2
		99%	3.5	3.5	3.5	3.5	3.5	3.5	5.4	15.7	12.4	5.5	3.9	3.6
PA	Change (kcfs)	1%	0.0	-0.3	0.0	-0.2	0.2	0.0	0.0	0.0	-0.2	-0.1	0.0	-0.7
		25%	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	-0.1	-0.1	-0.1
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-0.2	-0.2	-0.1
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.1
	Percent change	1%	0%	-2%	0%	-2%	1%	0%	0%	0%	0%	0%	0%	-8%
		25%	0%	0%	3%	1%	1%	1%	0%	0%	0%	0%	-1%	0%
		50%	0%	0%	0%	1%	1%	1%	1%	0%	0%	-1%	-2%	-1%
		75%	0%	0%	0%	0%	0%	0%	1%	0%	0%	-2%	-5%	-3%
		99%	0%	0%	0%	0%	0%	0%	1%	0%	0%	-1%	-5%	-3%

Table 7-5. Average Monthly Outflow Summary for Albeni Falls Dam

		Exceedance Probability	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
NAA	Ave. mo. outflow (kcfs)	1%	36.4	30.8	46.3	49.9	40.5	39.6	54.5	99.1	126.5	57.6	21.0	23.0
		25%	24.9	19.2	18.5	17.7	20.3	24.3	32.4	64.2	77.9	37.2	14.9	15.7
		50%	23.7	16.7	15.3	14.5	16.6	19.8	25.2	50.7	55.6	27.4	12.0	13.7
		75%	22.6	15.1	13.5	12.5	14.0	16.9	18.3	36.4	39.6	18.6	9.5	11.9
		99%	21.6	13.2	12.1	10.9	11.5	14.2	9.2	24.7	22.3	13.5	6.6	9.3
PA	Change (kcfs)	1%	0.0	0.6	0.0	-0.1	0.0	0.1	0.0	0.0	0.0	-0.1	0.0	-0.2
		25%	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.2
		75%	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	-0.3	-0.6	-0.1
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.7
	Percent change	1%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%
		25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-2%
		75%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-2%	-6%	-1%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-2%	-8%

7.2.1.7 Monthly Flow-Duration Plots

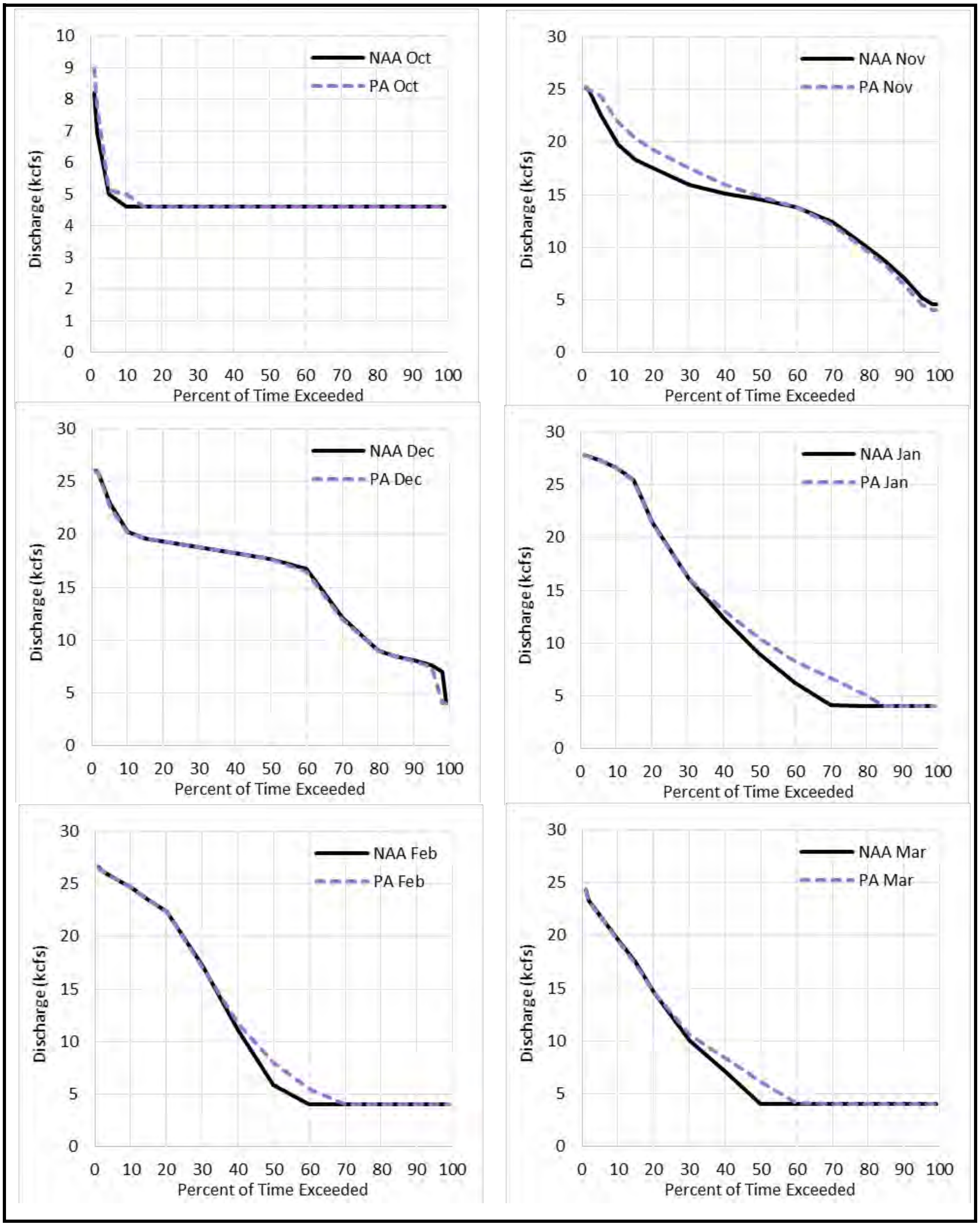


Figure 7-22. Monthly Flow-Duration Curves for Libby Dam Outflow for the Preferred Alternative and No Action Alternative, October through March

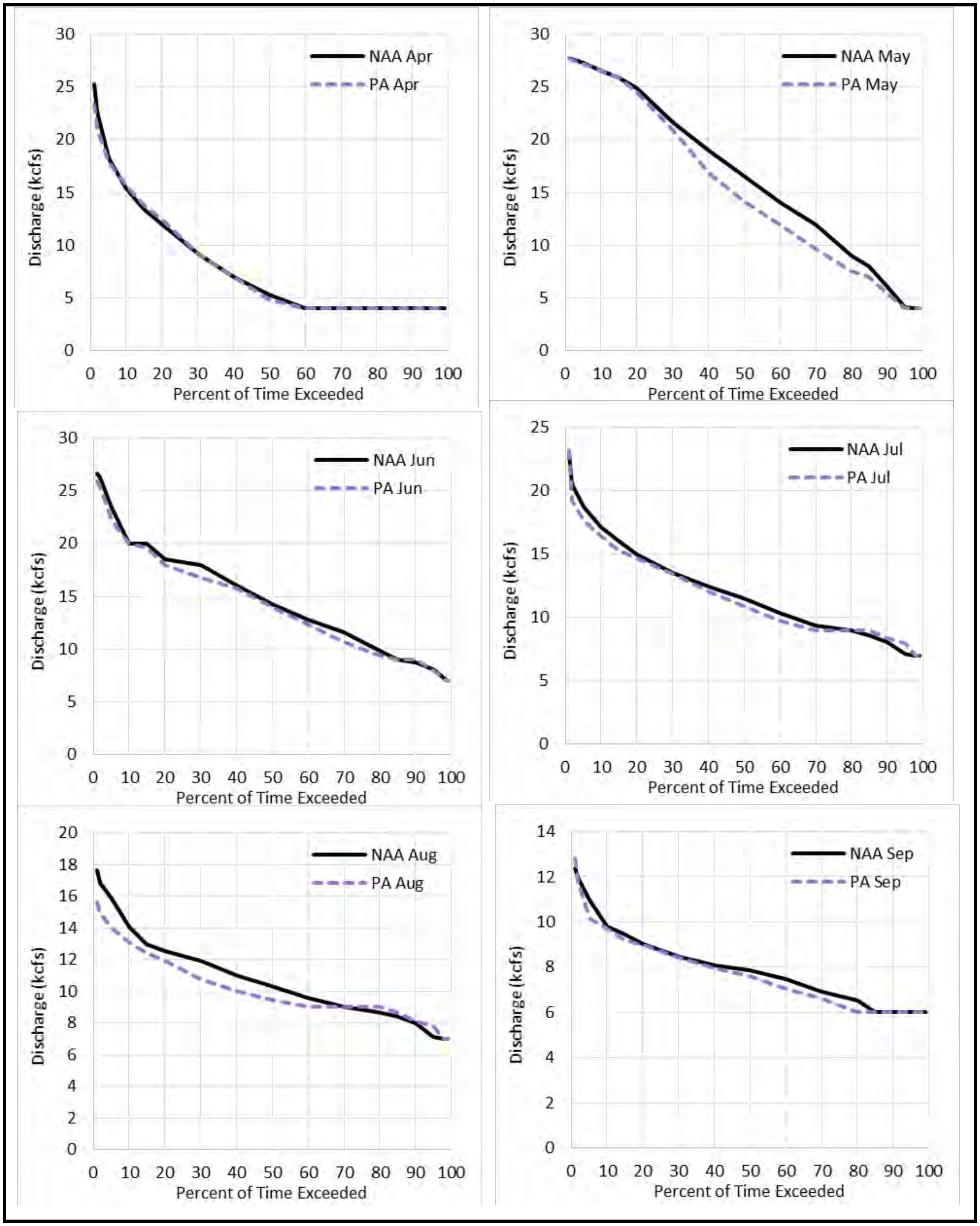


Figure 7-23. Monthly Flow-Duration Curves for Libby Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

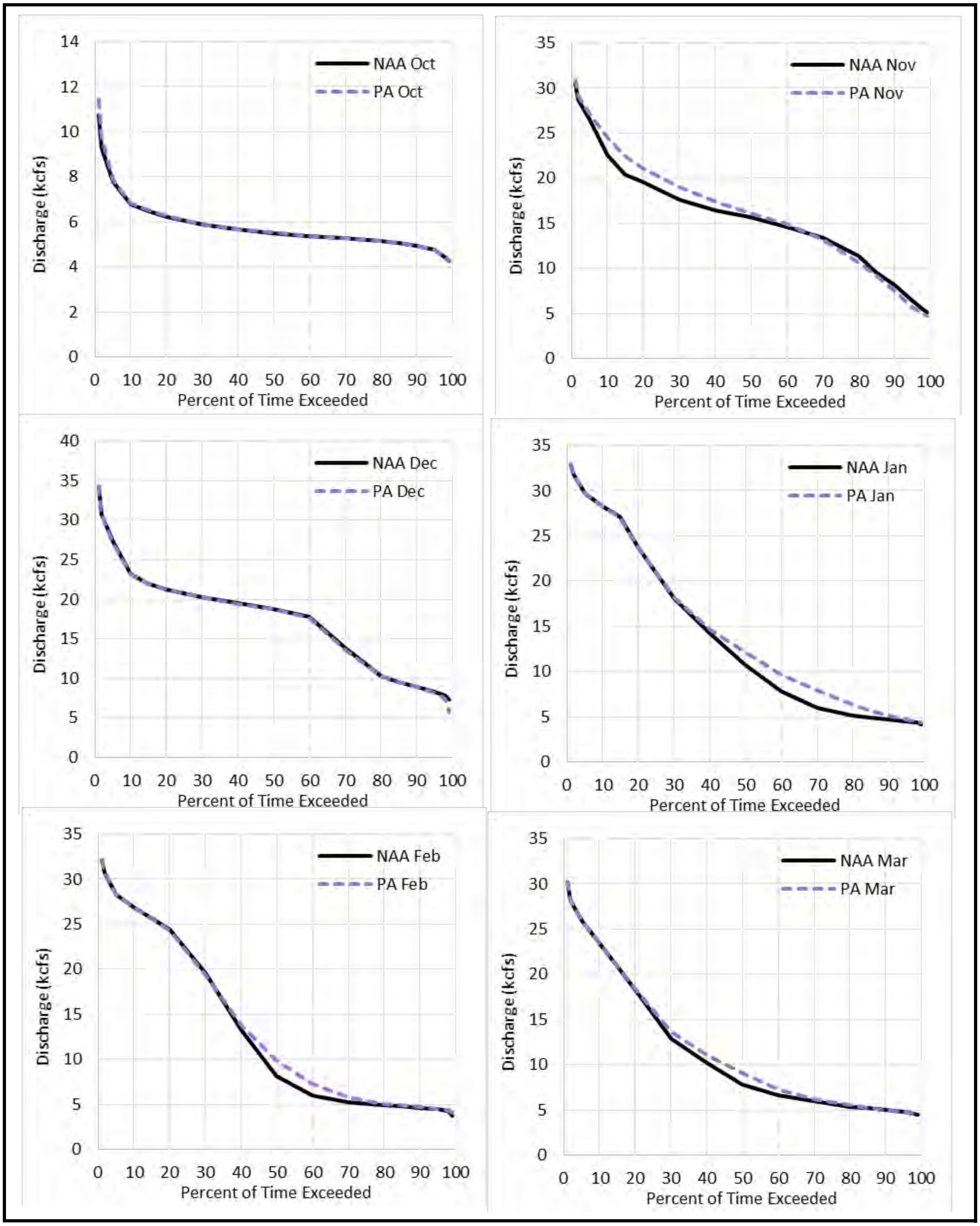


Figure 7-24. Monthly Flow-Duration Curves for Bonners Ferry, Idaho for the Preferred Alternative and No Action Alternative, October to March

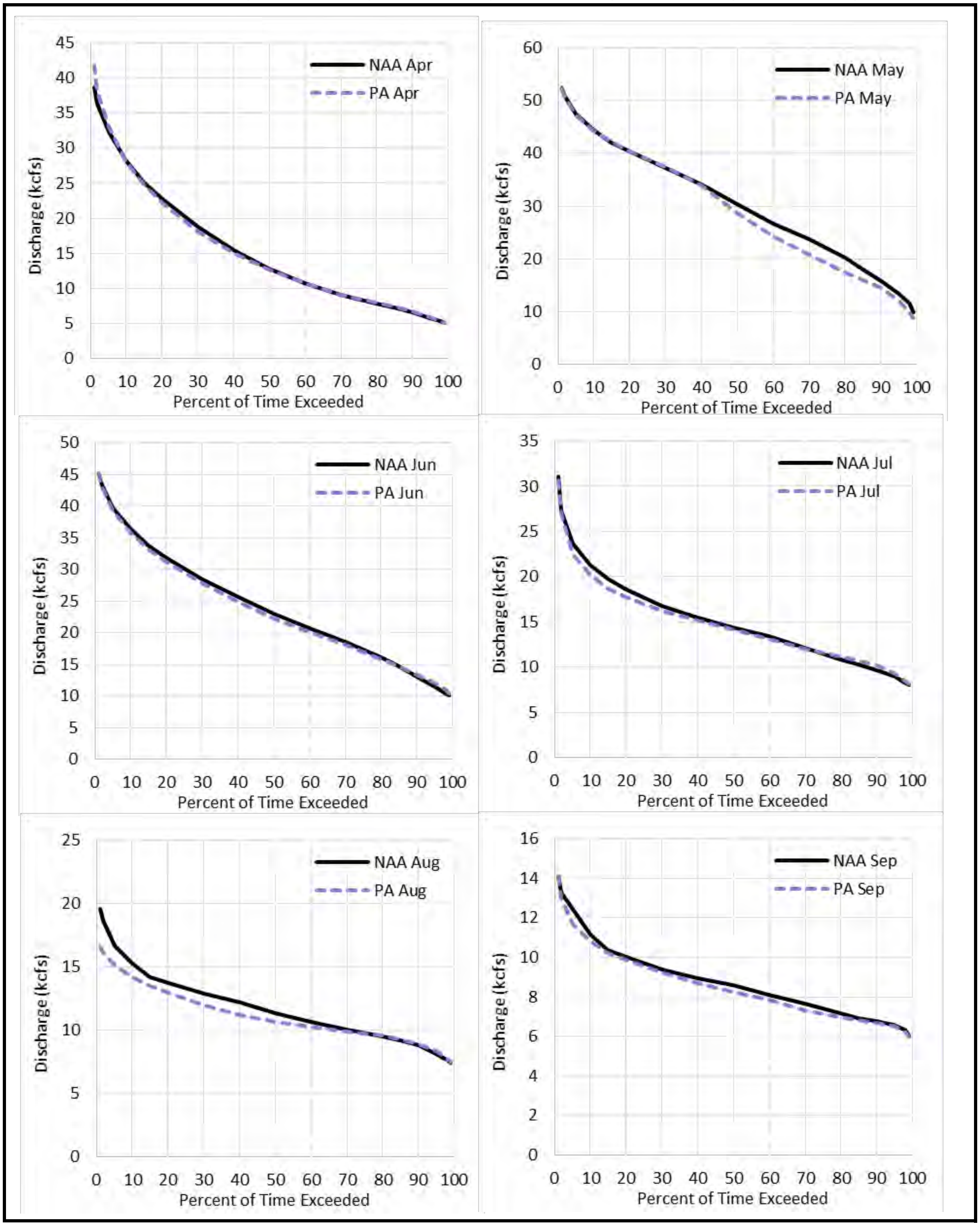


Figure 7-25. Monthly Flow-Duration Curves for Bonners Ferry, Idaho for the Preferred Alternative and No Action Alternative, April through September

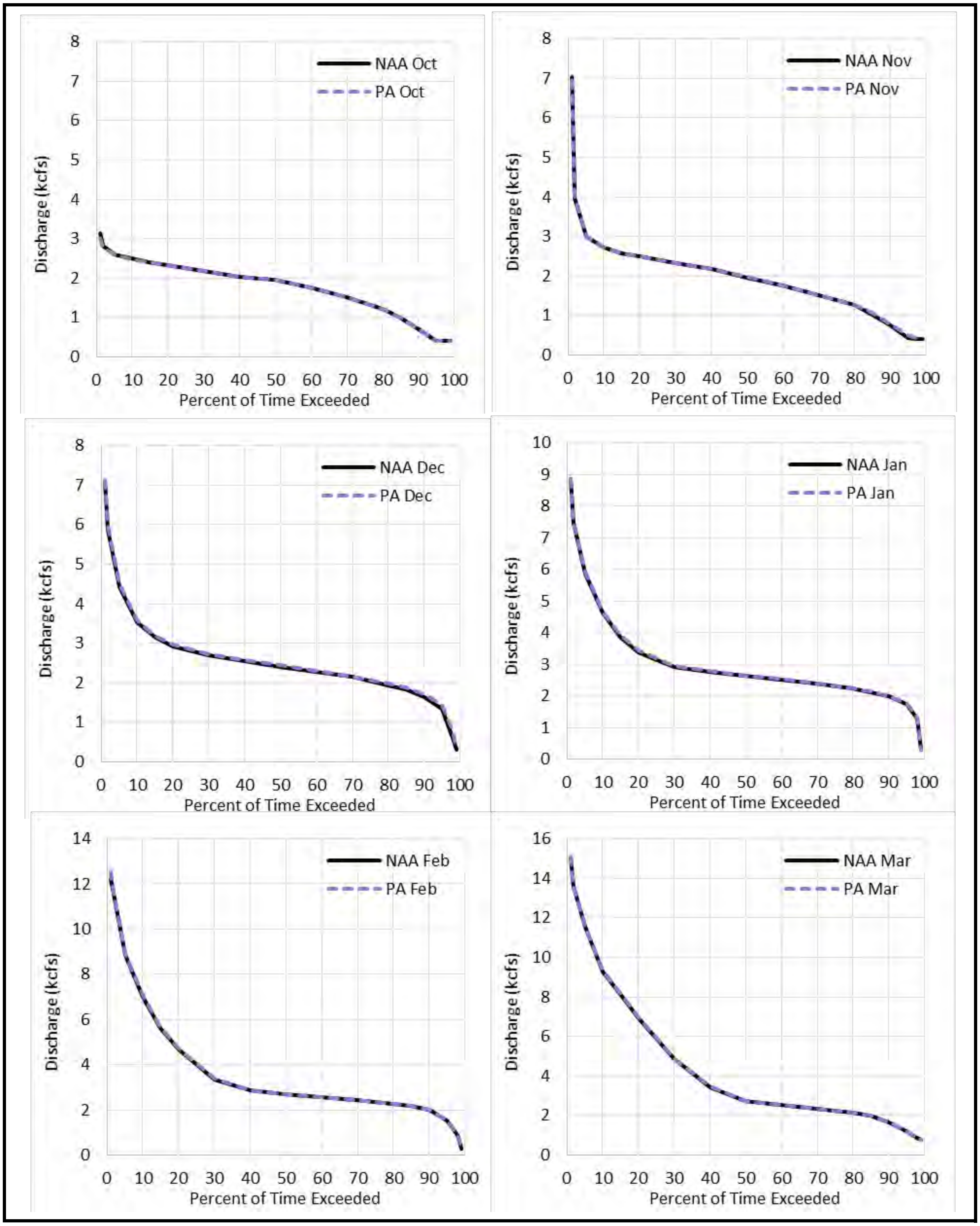


Figure 7-26. Monthly Flow-Duration Curves for Hungry Horse Dam Outflow for the Preferred Alternative and No Action Alternative, October through March

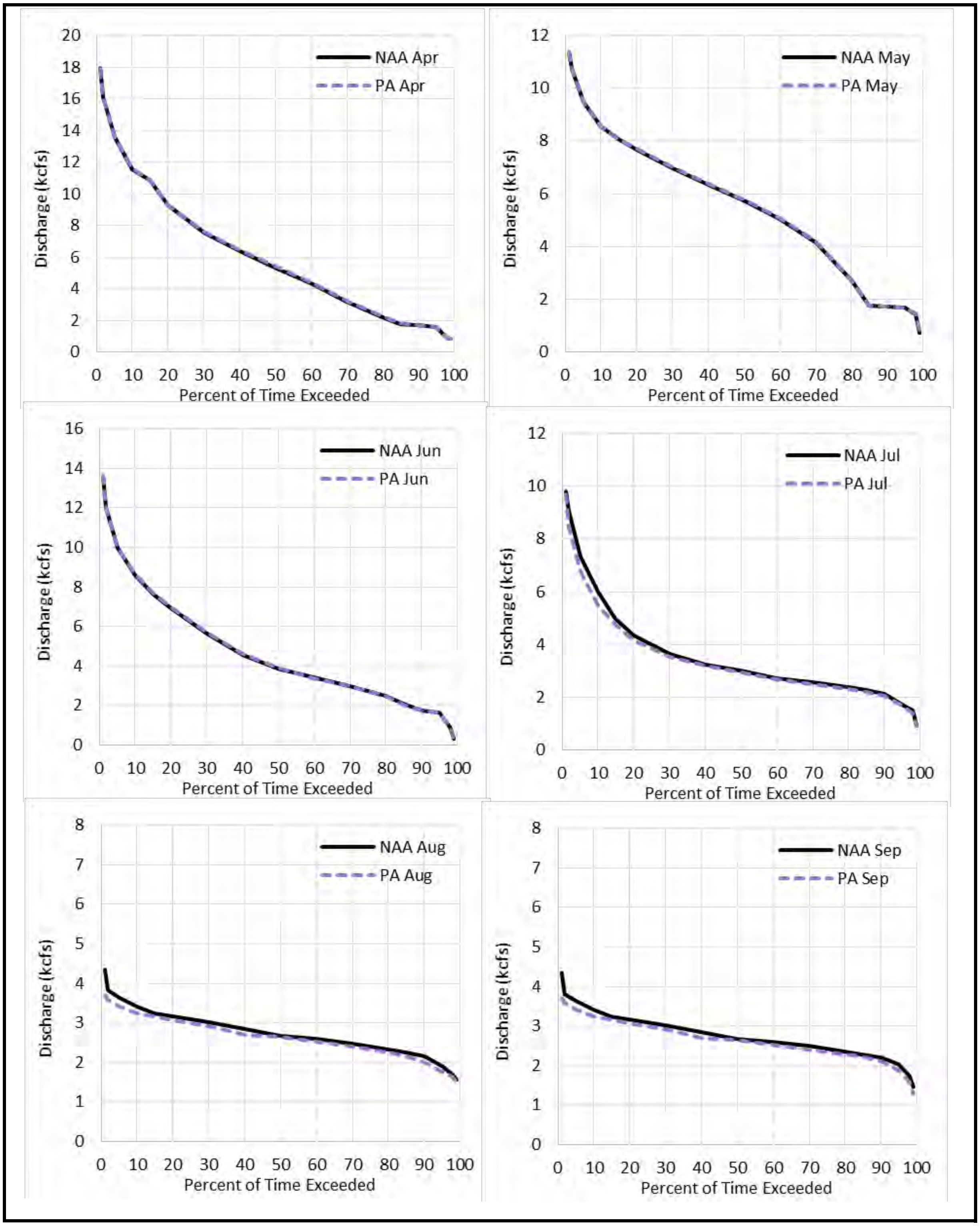


Figure 7-27. Monthly Flow-Duration Curves for Hungry Horse Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

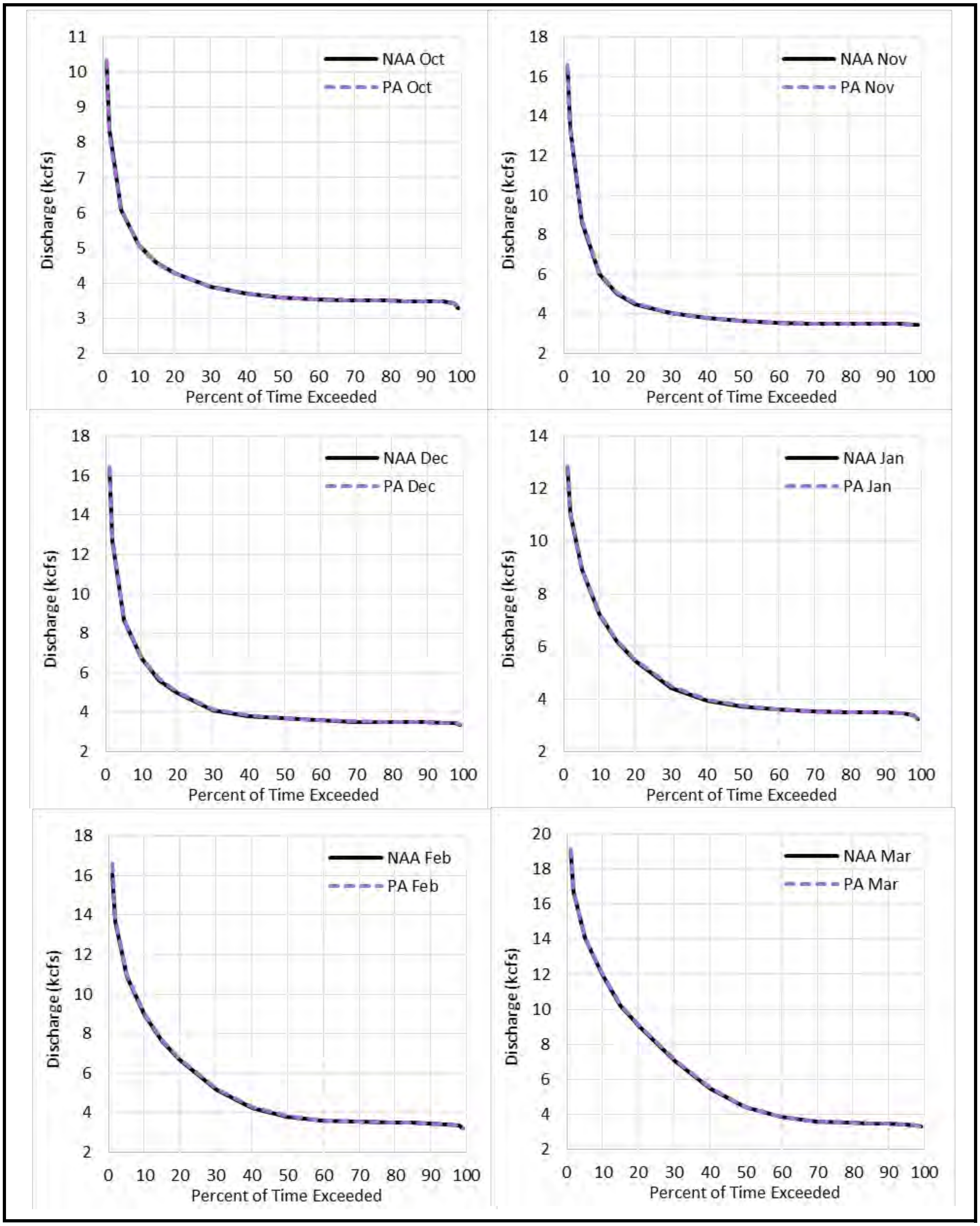


Figure 7-28. Monthly Flow-Duration Curves for Columbia Falls, Montana for the Preferred Alternative and No Action Alternative, October through March

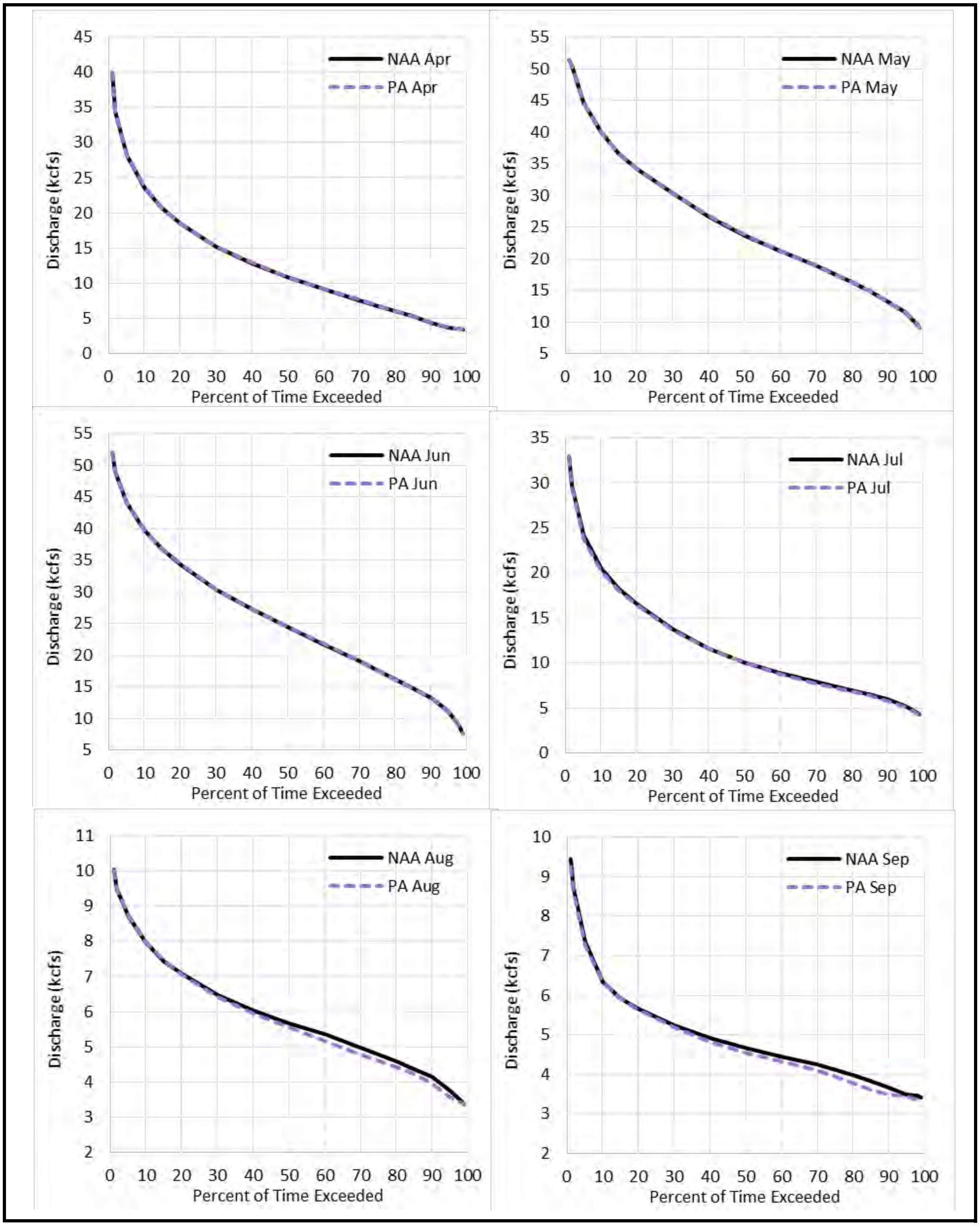


Figure 7-29. Monthly Flow-Duration Curves for Columbia Falls, Montana for the Preferred Alternative and No Action Alternative, April through September

7.2.1.8 Peak Flow-Frequency Plots

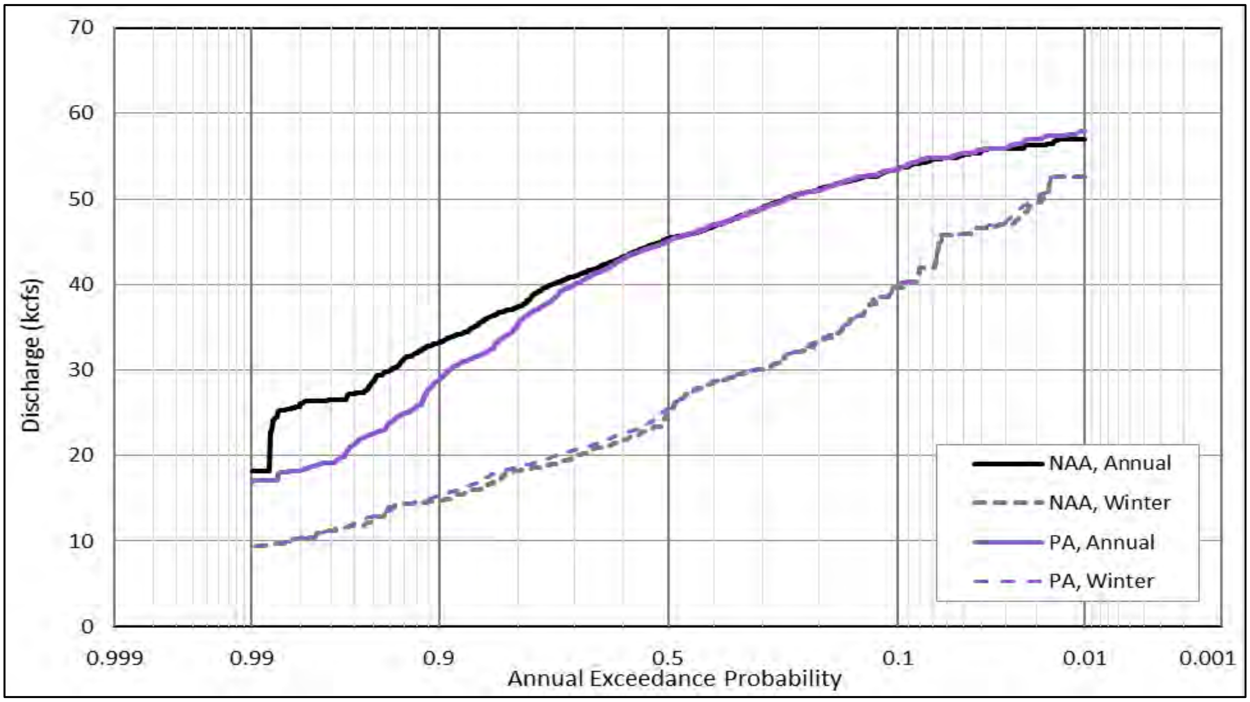


Figure 7-30. Peak Flow-Frequency Curves at Bonners Ferry, Idaho for the Preferred Alternative and No Action Alternative

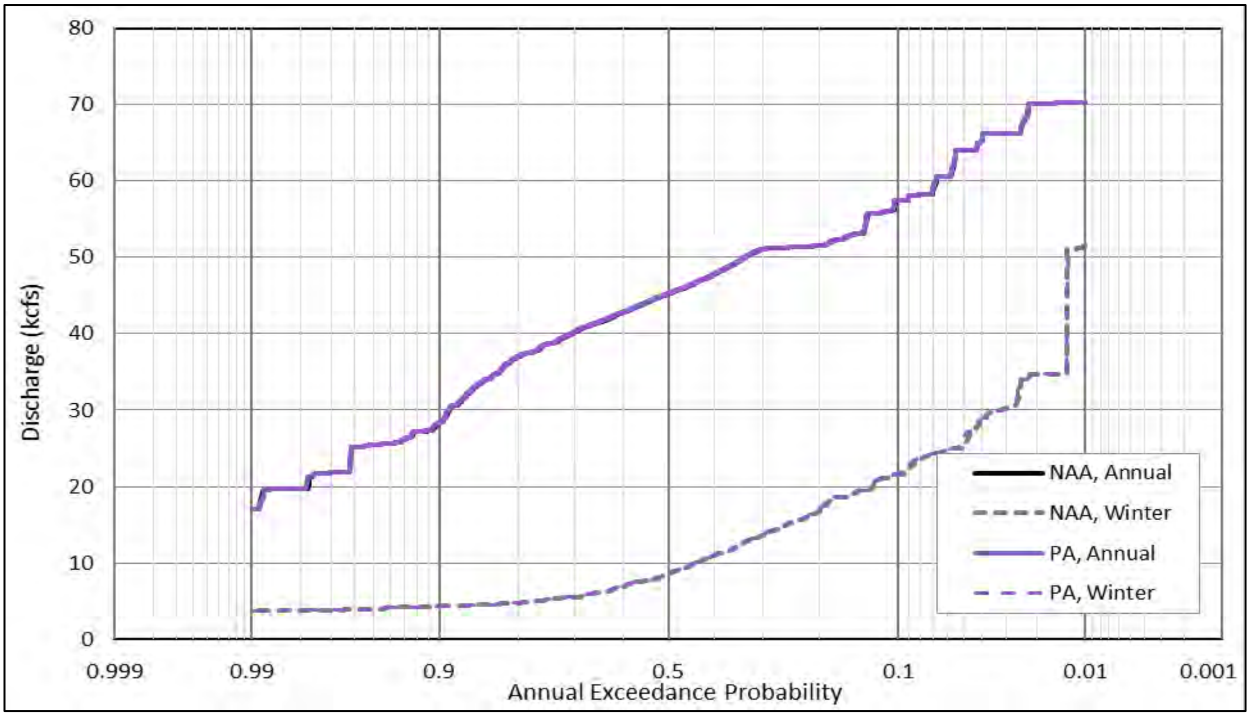


Figure 7-31. Peak Flow-Frequency Curves at Columbia Falls, Montana for the Preferred Alternative and No Action Alternative

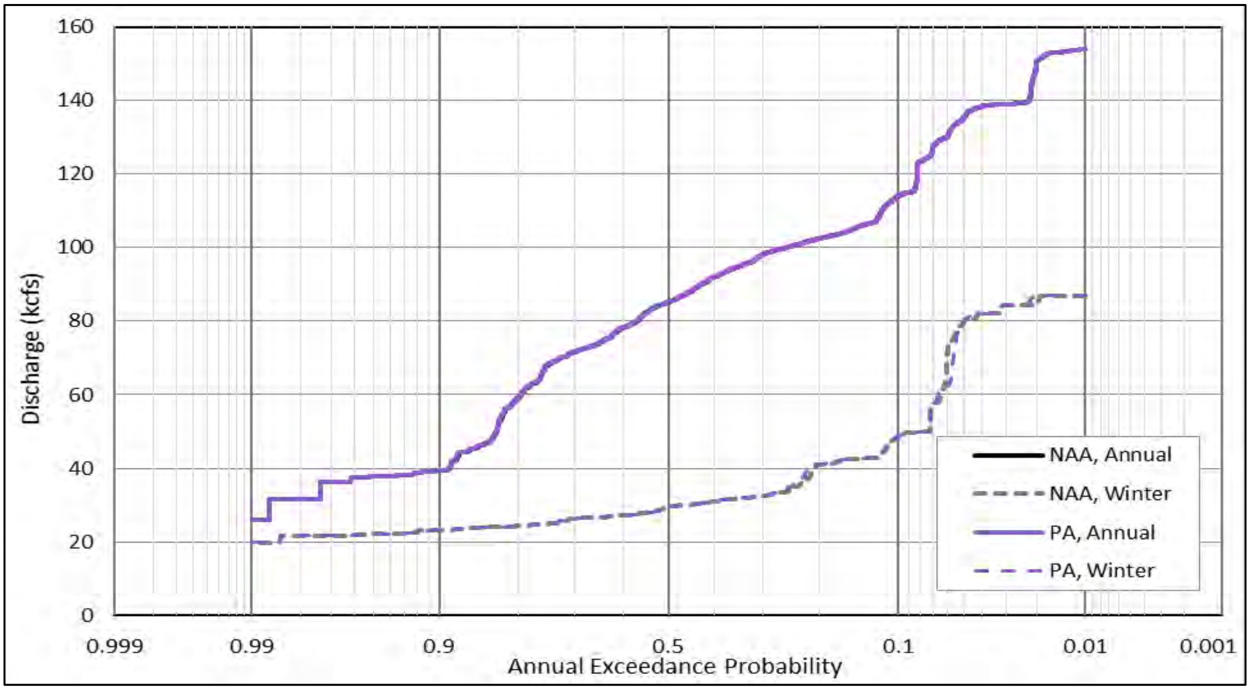


Figure 7-32. Peak Outflow-Frequency Curves for Albeni Falls Dam for the Preferred Alternative and No Action Alternative

7.2.2 Region B – Middle Columbia River Basin

7.2.2.1 Water Year Plots, Elevation

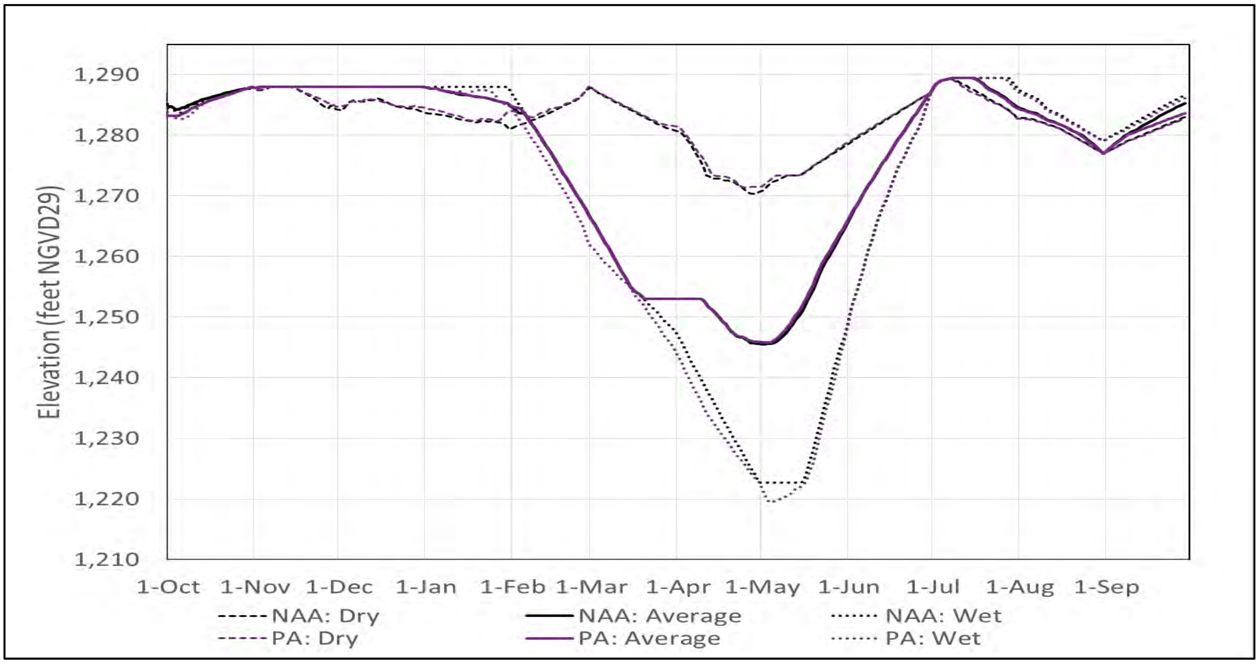


Figure 7-33. Summary Elevation Hydrograph for Dry, Average, and Wet Water Years at Grand Coulee (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

7.2.2.2 Summary Elevation Hydrographs

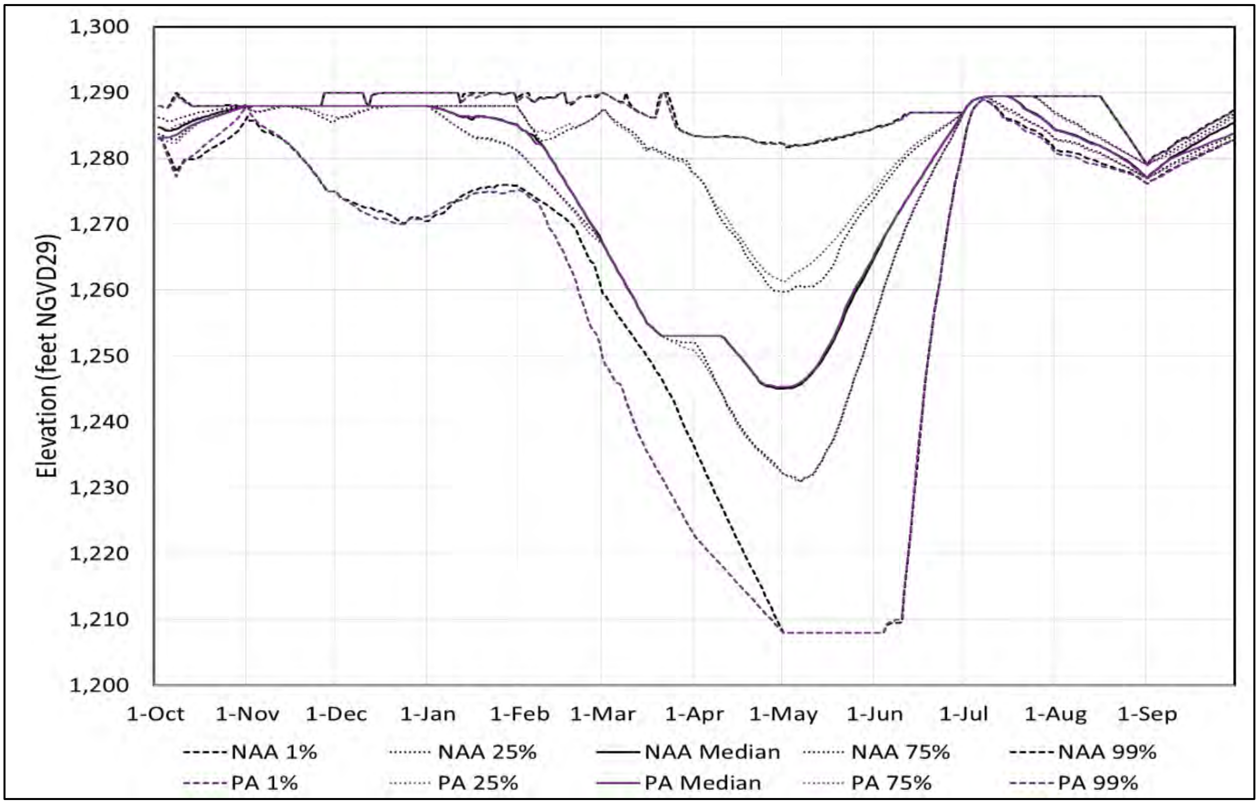


Figure 7-34. Summary Elevation Hydrograph at Grand Coulee (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

7.2.2.3 Reservoir Target Date Elevation-Frequency Plots

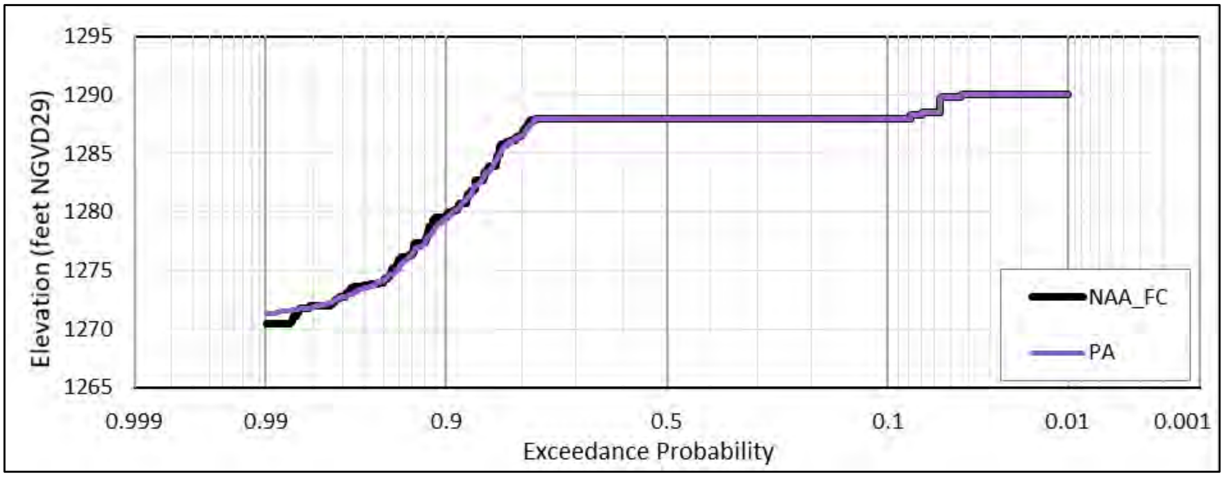


Figure 7-35. Elevation-Frequency Curves for December 31 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

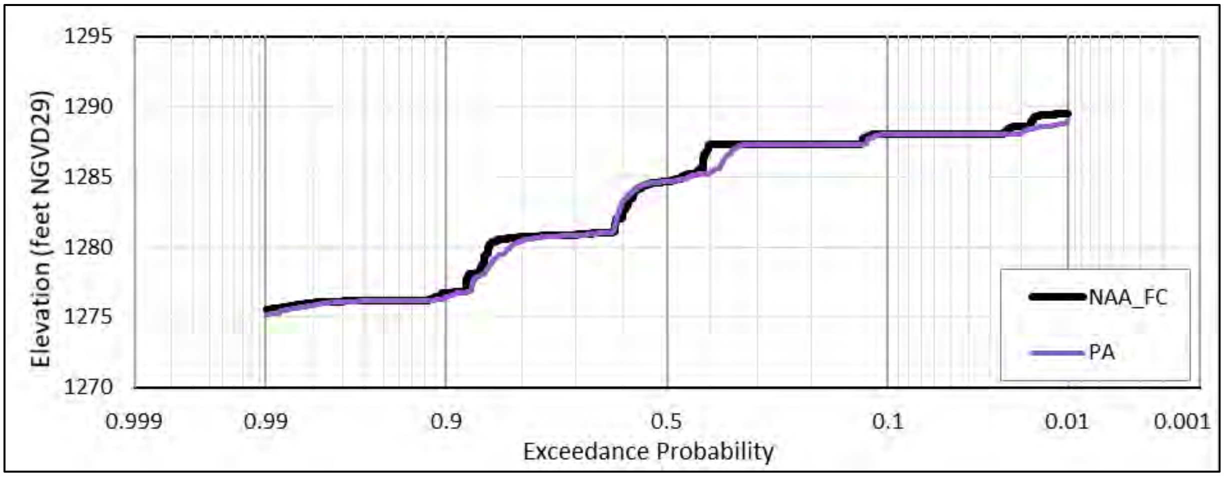


Figure 7-36. Elevation-Frequency Curves for January 31 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

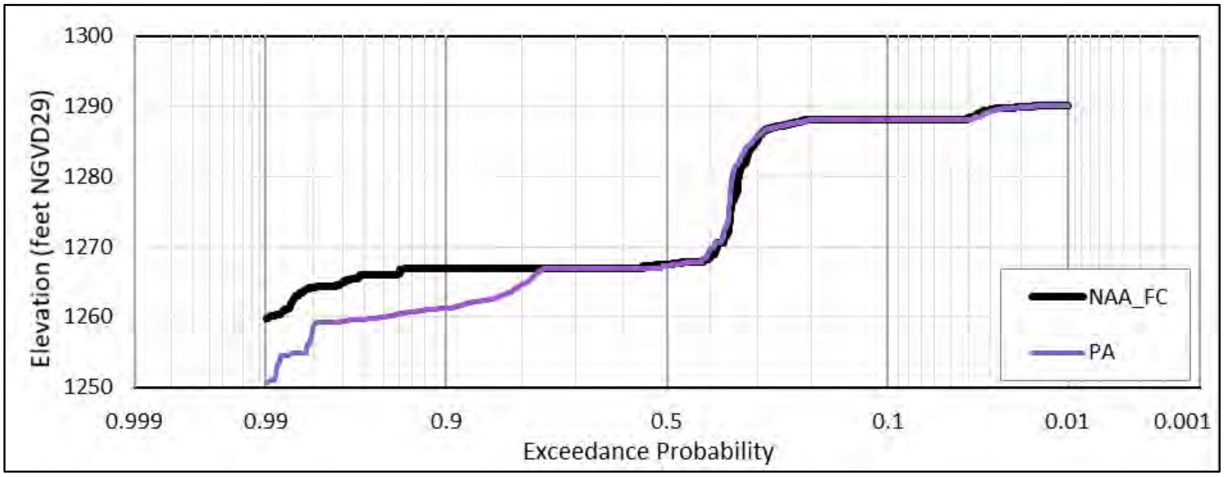


Figure 7-37. Elevation-Frequency Curves for February 28 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

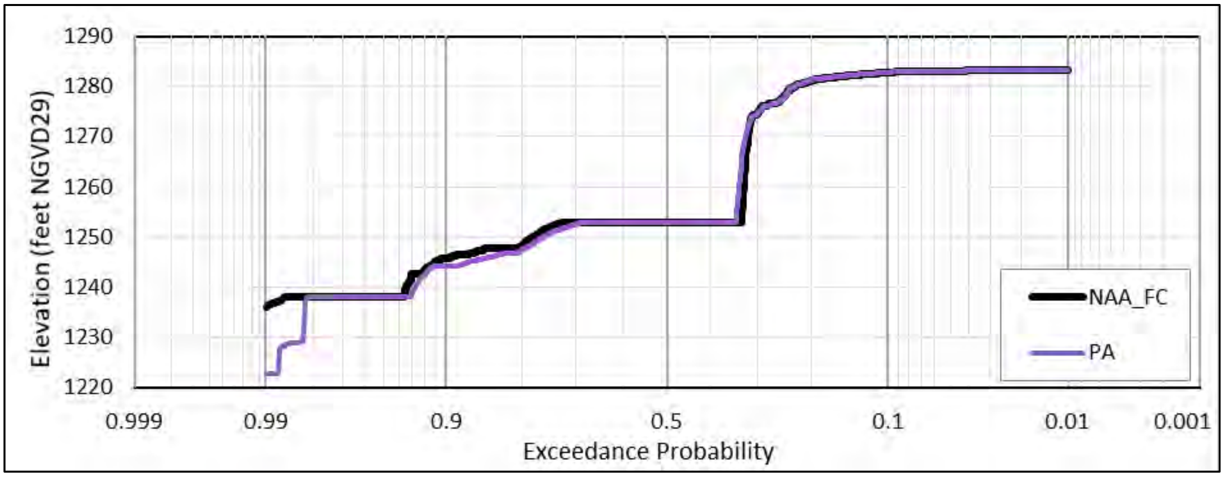


Figure 7-38. Elevation-Frequency Curves for March 31 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

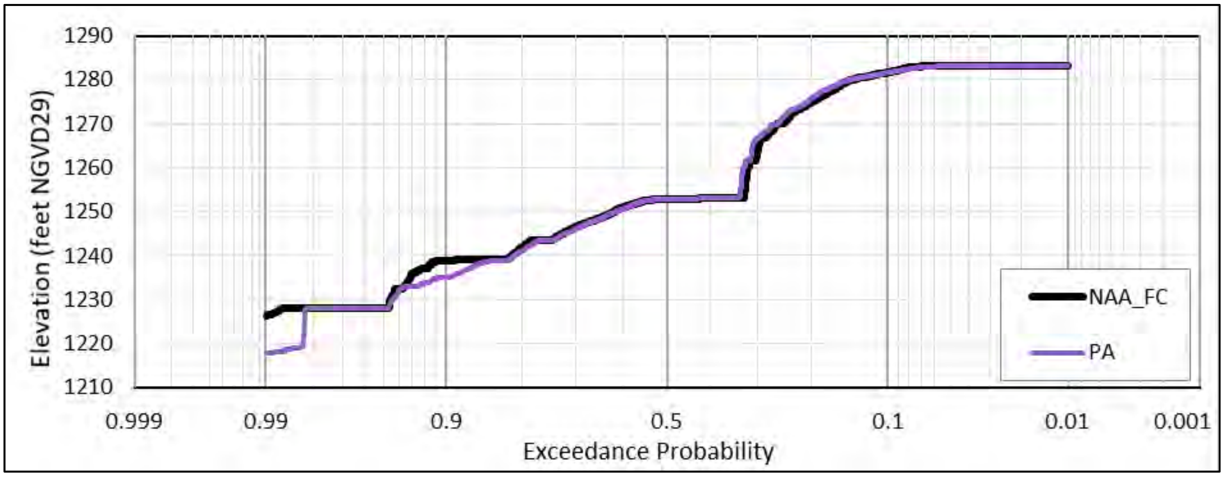


Figure 7-39. Elevation-Frequency Curves for April 10 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

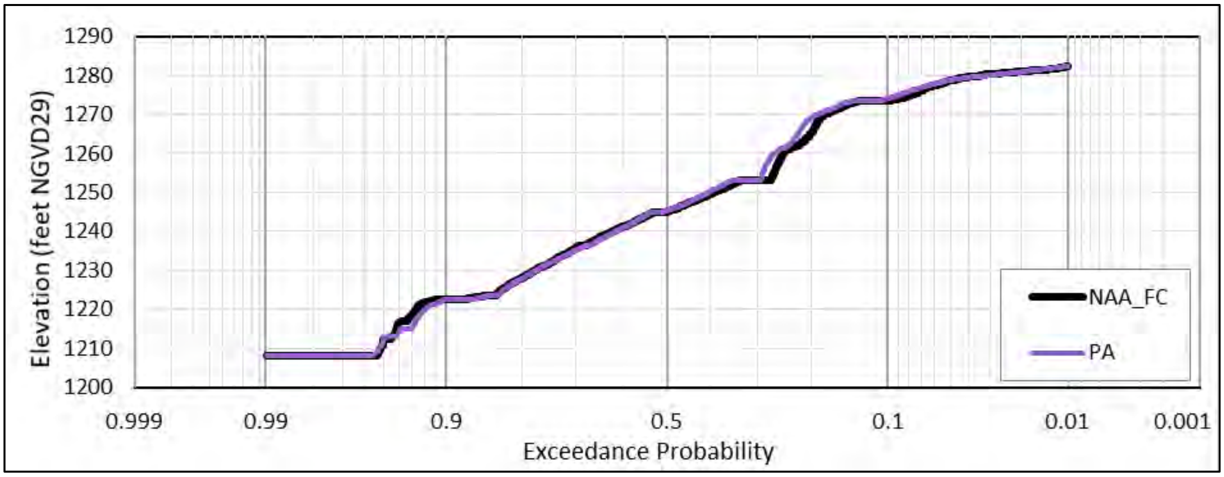


Figure 7-40. Elevation-Frequency Curves for April 30 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

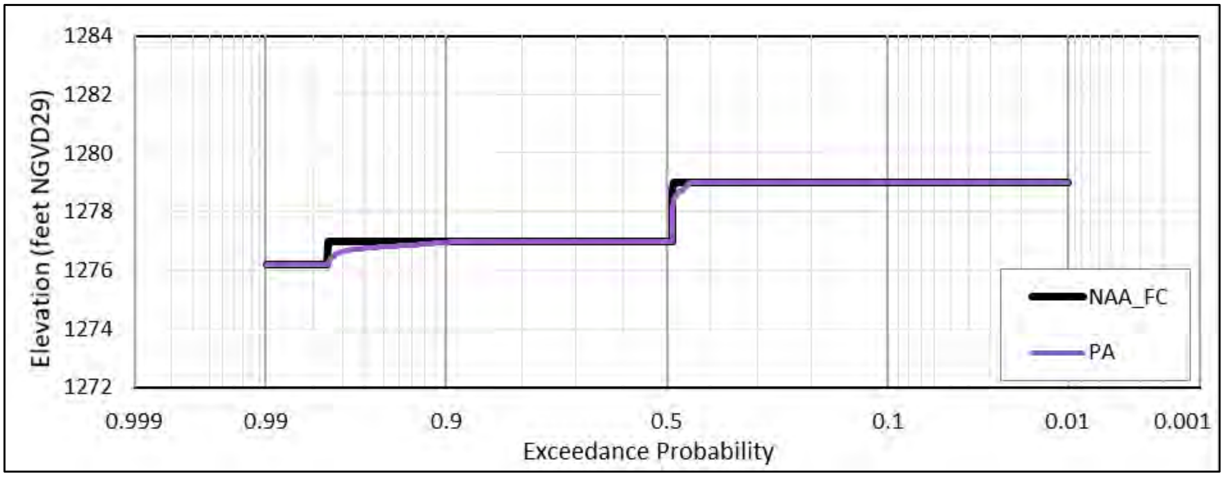


Figure 7-41. Elevation-Frequency Curves for August 31 at Grand Coulee Dam (Lake Roosevelt) for the Preferred Alternative and No Action Alternative

7.2.2.4 Annual Elevation-Duration Plots

7.2.2.5 Water Year Plots, Flow

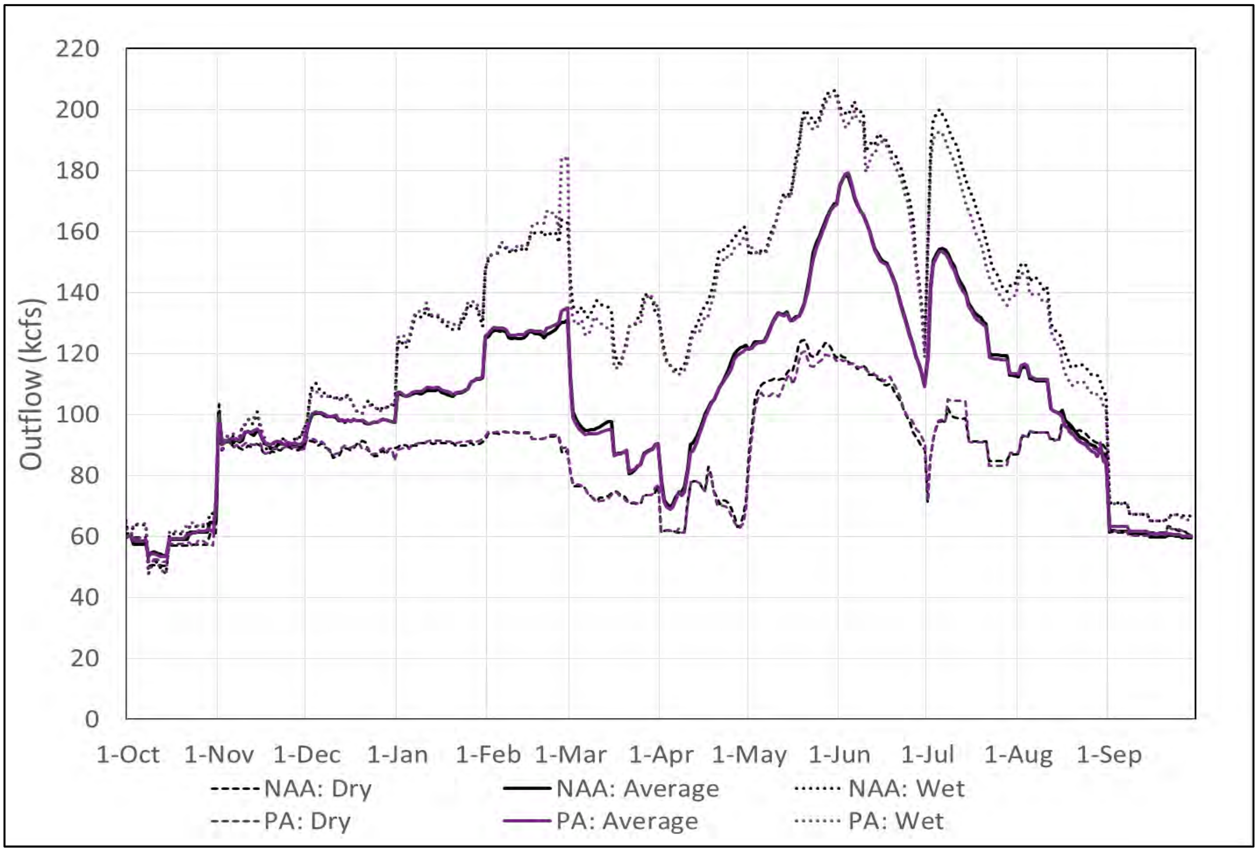


Figure 7-42. Summary Outflow Hydrograph for Dry, Average, and Wet Water Years at Grand Coulee Dam for the Preferred Alternative and No Action Alternative

7.2.2.6 Summary Flow Hydrographs

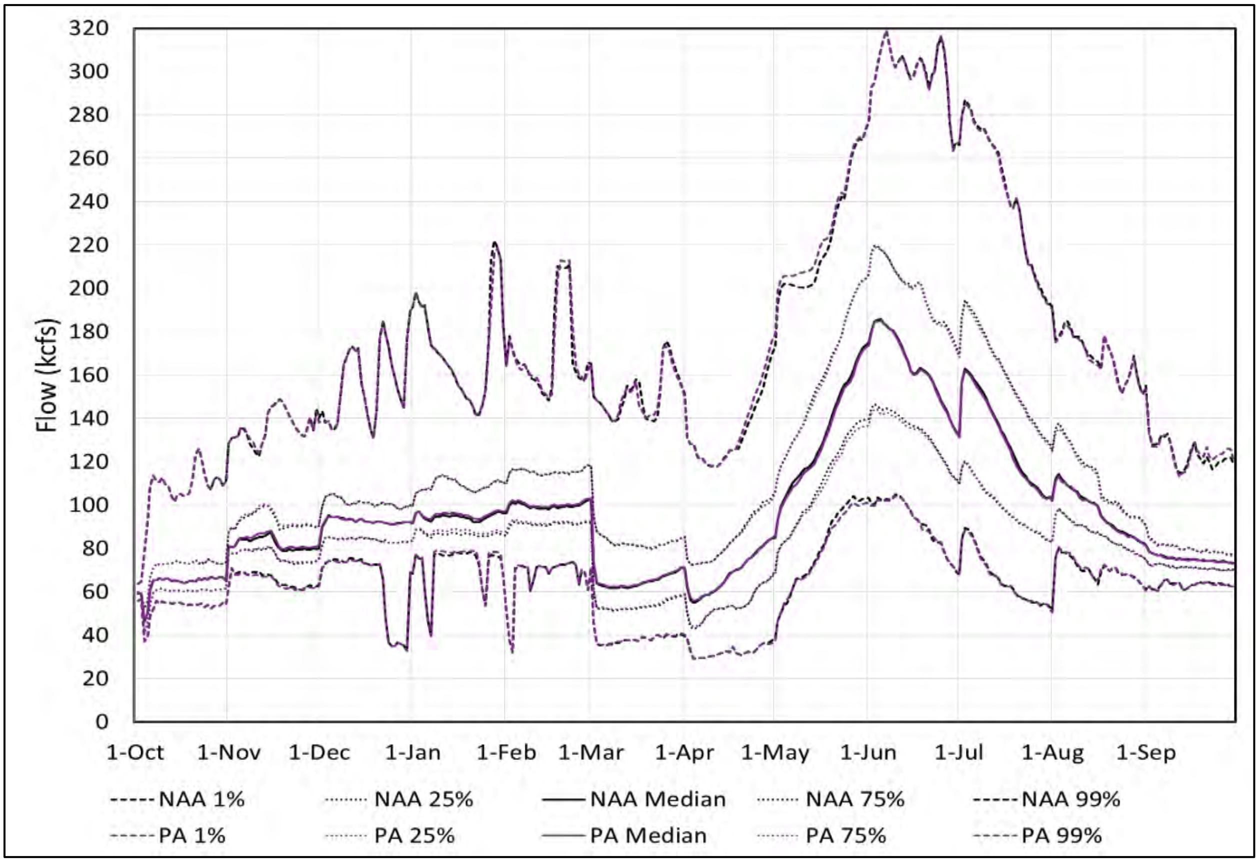


Figure 7-43. Summary Inflow Hydrograph for Lake Roosevelt for the Preferred Alternative and No Action Alternative

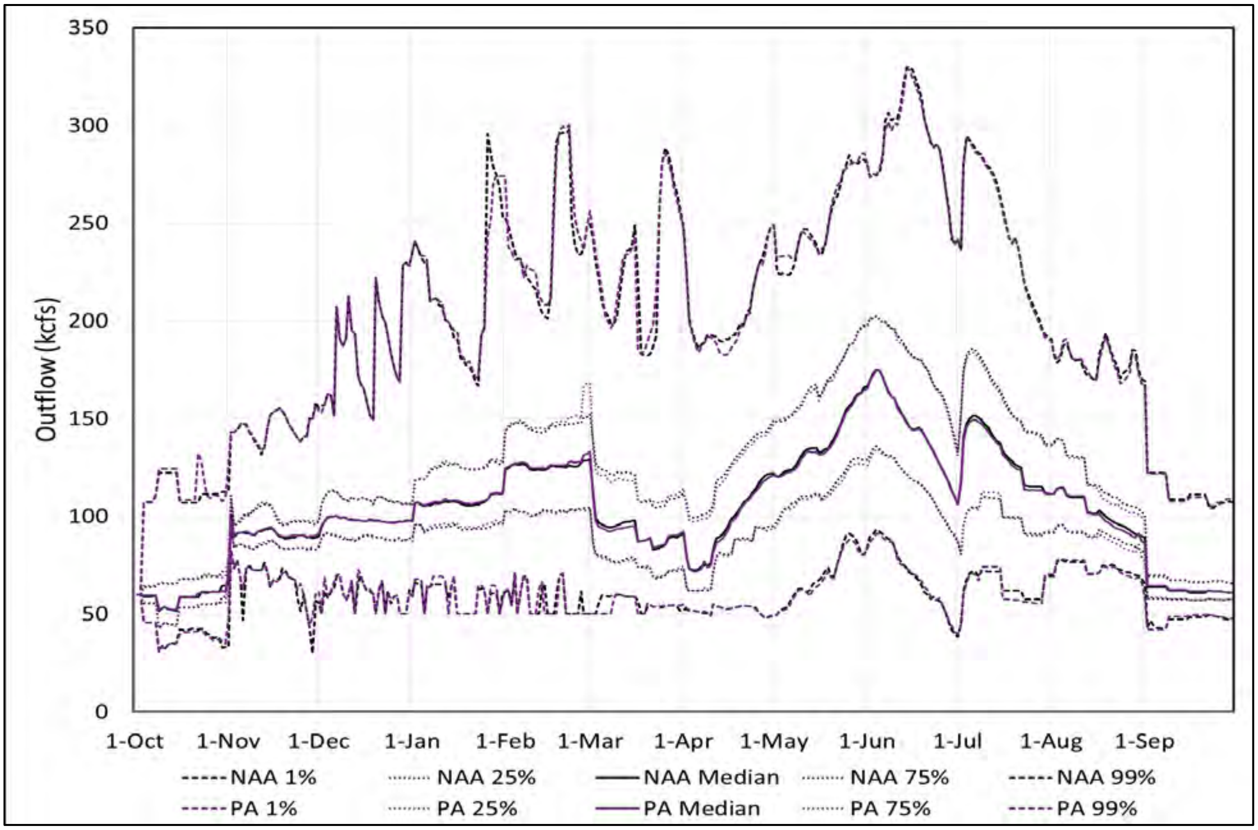


Figure 7-44. Summary Outflow Hydrograph for Grand Coulee Dam for the Preferred Alternative and No Action Alternative

7.2.2.7 Average Monthly Flow Summary Tables

Table 7-6. Average Monthly Inflow Summary for Lake Roosevelt

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	98	125	151	155	153	142	125	206	284	243	163	119
		25%	71	93	100	110	115	84	81	154	197	160	111	80
		50%	64	82	92	95	100	65	69	131	166	133	98	75
		75%	60	76	84	87	92	55	58	113	136	99	88	72
		99%	56	71	77	81	80	46	40	96	106	81	78	67
PA	Change (kcfs)	1%	0.0	0.0	0.0	0.4	1.0	0.6	1.8	6.2	0.0	-0.8	-0.9	-0.6
		25%	0.0	0.7	0.1	0.1	0.1	0.1	0.0	-0.9	-0.4	-1.4	-1.4	-0.4
		50%	0.0	1.3	0.0	0.6	0.9	0.4	-0.7	-1.2	-0.2	-1.0	-0.6	-0.2
		75%	0.0	0.8	-0.1	1.5	0.7	0.6	0.1	-1.6	-1.3	0.6	-0.6	-0.6
		99%	0.0	-0.8	0.0	0.9	0.5	0.5	0.0	-1.6	0.3	0.3	0.7	0.1
	Percent change	1%	0%	0%	0%	0%	1%	0%	1%	3%	0%	0%	-1%	-1%
		25%	0%	1%	0%	0%	0%	0%	0%	-1%	0%	-1%	-1%	0%
		50%	0%	2%	0%	1%	1%	1%	-1%	-1%	0%	-1%	-1%	0%
		75%	0%	1%	0%	2%	1%	1%	0%	-1%	-1%	1%	-1%	-1%
		99%	0%	-1%	0%	1%	1%	1%	0%	-2%	0%	0%	1%	0%

Table 7-7. Average Monthly Outflow Summary for Grand Coulee Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	94	130	174	190	213	186	191	231	275	247	175	111
		25%	67	99	109	124	147	117	120	165	181	158	118	68
		50%	59	91	97	108	126	93	97	138	150	134	102	63
		75%	54	84	88	96	105	78	79	118	121	98	92	59
		99%	49	78	79	76	81	66	60	97	91	81	81	53
PA	Change (kcfs)	1%	0.8	0.7	0.0	1.3	8.8	0.8	-6.9	-0.8	2.0	-1.5	-1.8	-0.5
		25%	0.1	0.6	0.0	0.5	1.8	-0.4	-1.8	-1.5	-0.3	-1.5	-2.4	0.4
		50%	0.4	0.3	-0.1	0.5	1.6	-0.4	-1.6	-1.0	-0.3	-1.8	-0.9	0.0
		75%	0.2	0.6	0.1	1.1	-0.6	-0.1	0.0	-1.3	-0.3	-0.3	-0.6	0.2
		99%	0.4	0.6	0.5	1.6	0.0	0.1	0.3	-3.0	0.8	0.3	-0.5	0.3
	Percent change	1%	1%	1%	0%	1%	4%	0%	-4%	0%	1%	-1%	-1%	0%
		25%	0%	1%	0%	0%	1%	0%	-1%	-1%	0%	-1%	-2%	1%
		50%	1%	0%	0%	0%	1%	0%	-2%	-1%	0%	-1%	-1%	0%
		75%	0%	1%	0%	1%	-1%	0%	0%	-1%	0%	0%	-1%	0%
		99%	1%	1%	1%	2%	0%	0%	1%	-3%	1%	0%	-1%	1%

Table 7-8. Average Monthly Outflow Summary for Chief Joseph Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	94	132	177	190	212	185	188	230	275	246	171	105
		25%	66	98	109	125	148	118	120	164	182	158	119	69
		50%	58	91	96	108	127	94	98	139	150	135	103	63
		75%	54	84	88	96	106	78	80	119	122	99	92	59
		99%	50	79	80	77	83	67	61	97	91	82	83	53
PA	Change (kcfs)	1%	1.0	0.6	0.0	1.3	8.8	-1.4	-5.2	-1.6	1.9	-1.2	-2.2	-0.8
		25%	-0.4	1.1	0.0	0.3	1.7	-0.6	-1.6	-1.1	-0.2	-1.5	-2.2	0.2
		50%	0.3	0.4	0.1	0.6	1.4	-0.6	-1.4	-1.4	-0.4	-1.9	-0.5	0.1
		75%	0.2	0.6	0.2	0.9	-0.5	0.0	0.0	-1.5	-0.3	-0.3	-0.6	0.2
		99%	0.3	0.4	0.8	1.1	0.1	0.1	0.0	-3.0	0.4	0.1	-0.6	0.4
	Percent change	1%	1%	0%	0%	1%	4%	-1%	-3%	-1%	1%	0%	-1%	-1%
		25%	-1%	1%	0%	0%	1%	0%	-1%	-1%	0%	-1%	-2%	0%
		50%	0%	0%	0%	1%	1%	-1%	-1%	-1%	0%	-1%	-1%	0%
		75%	0%	1%	0%	1%	0%	0%	0%	-1%	0%	0%	-1%	0%
		99%	1%	0%	1%	1%	0%	0%	0%	-3%	0%	0%	-1%	1%

7.2.2.8 Monthly Flow-Duration Plots

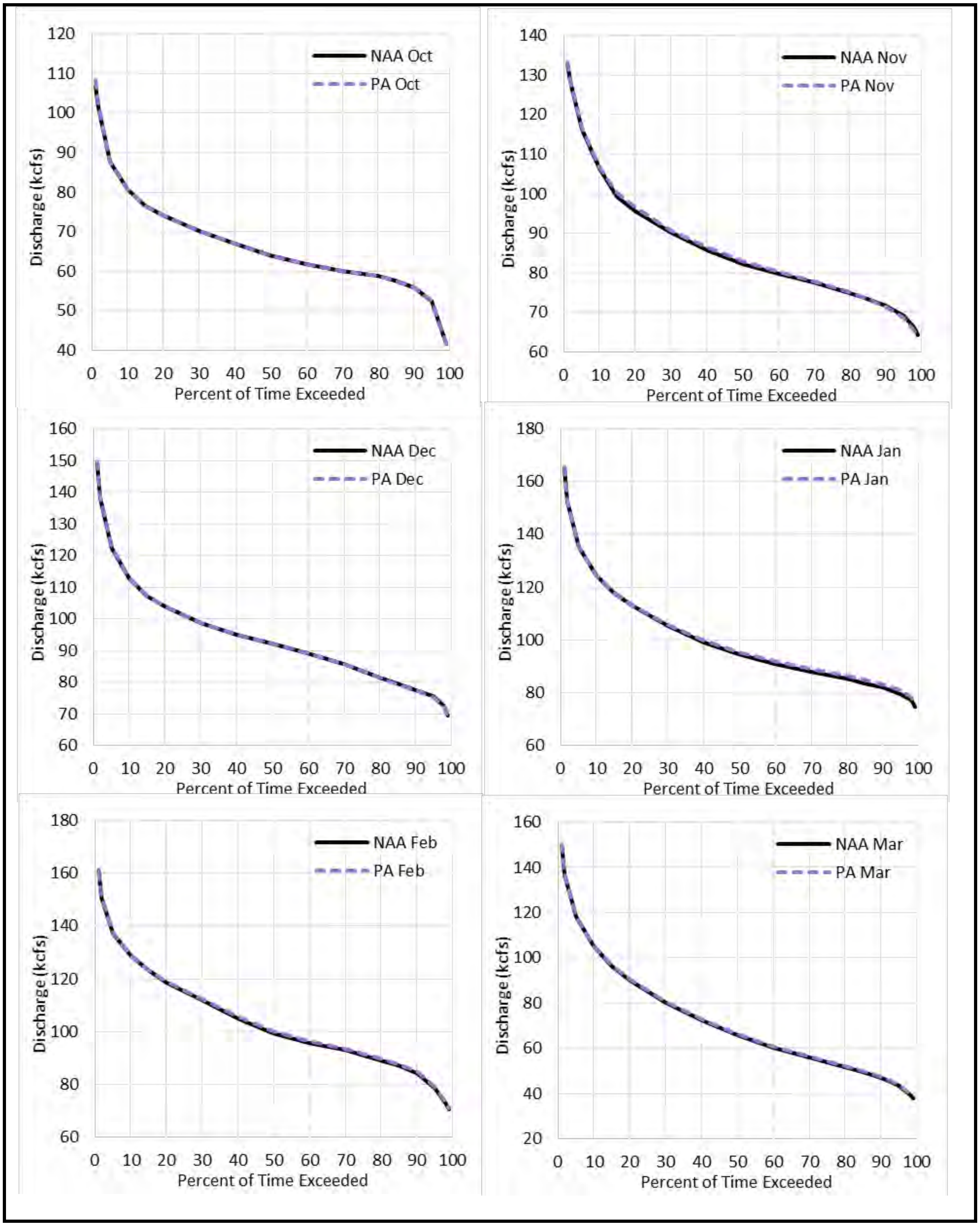
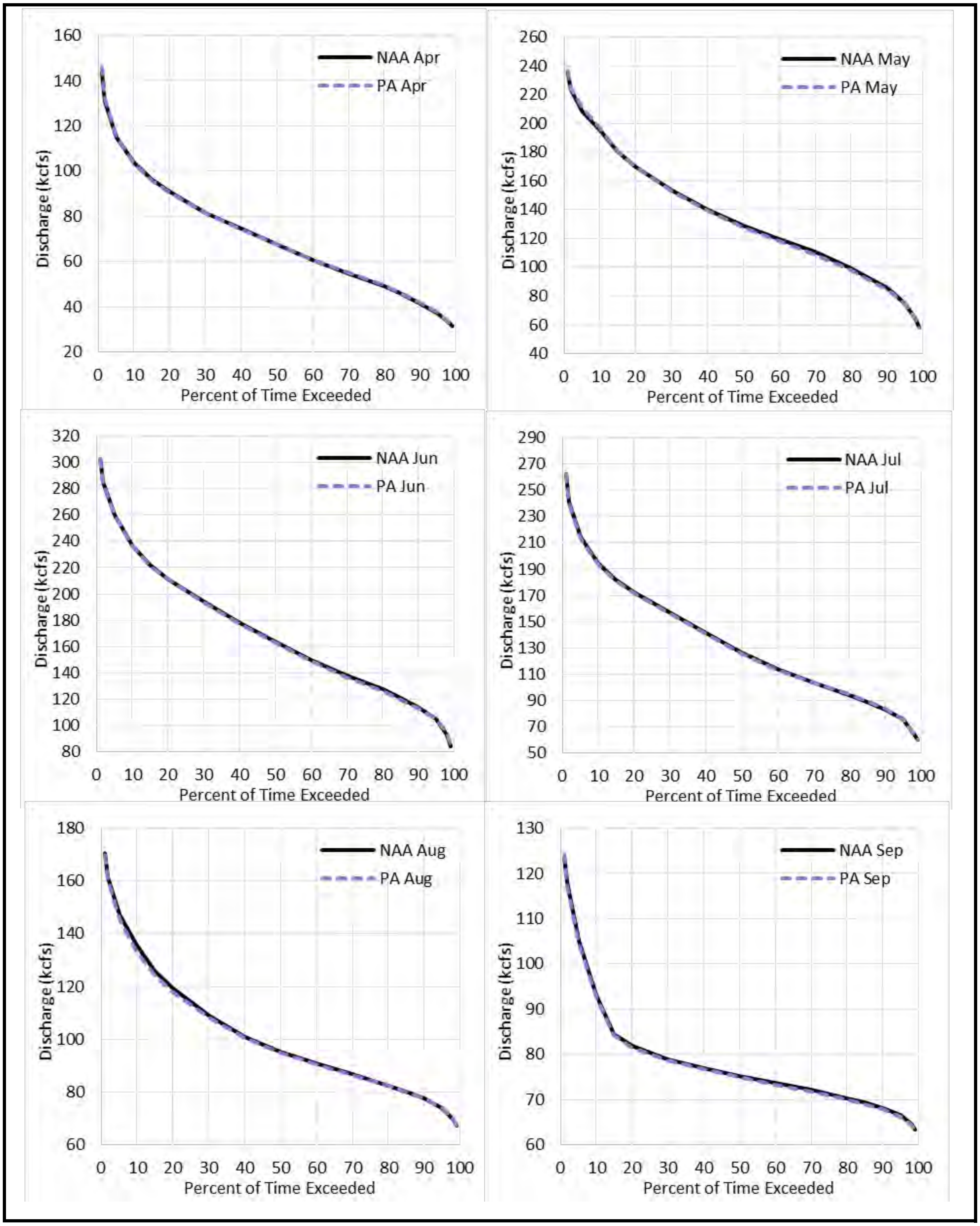


Figure 7-45. Monthly Flow-Duration Curves for Lake Roosevelt Inflow for the Preferred Alternative and No Action Alternative, October through March



3957

3958 **Figure 7-46. Monthly Flow-Duration Curves for Lake Roosevelt Inflow for the Preferred**
3959 **Alternative and No Action Alternative, April through September**

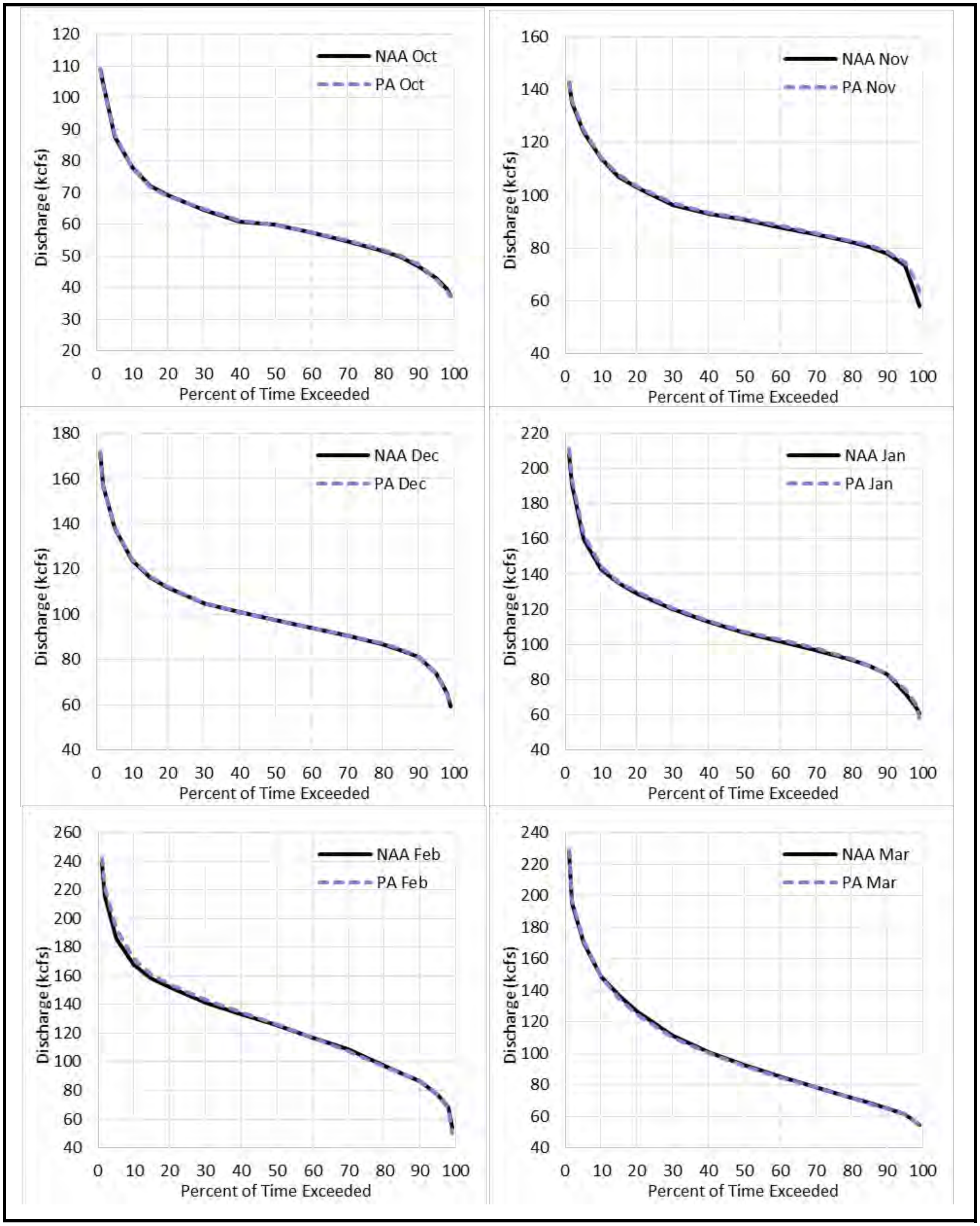


Figure 7-47. Monthly Flow-Duration Curves for Grand Coulee Outflow for the Preferred Alternative and No Action Alternative, October through March

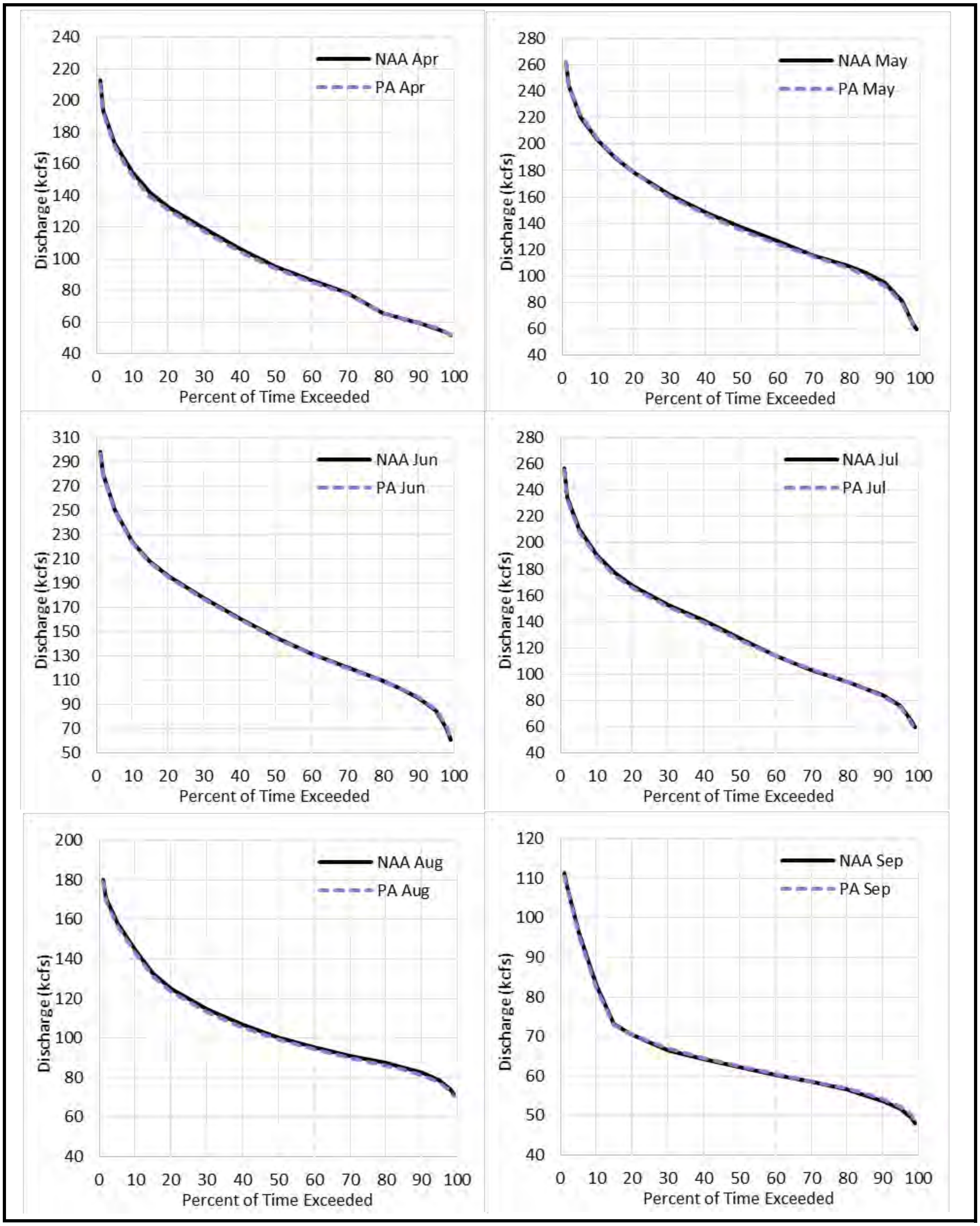


Figure 7-48. Monthly Flow-Duration Curves for Grand Coulee Outflow for the Preferred Alternative and No Action Alternative, April through September

7.2.2.9 Peak Flow-Frequency Plots

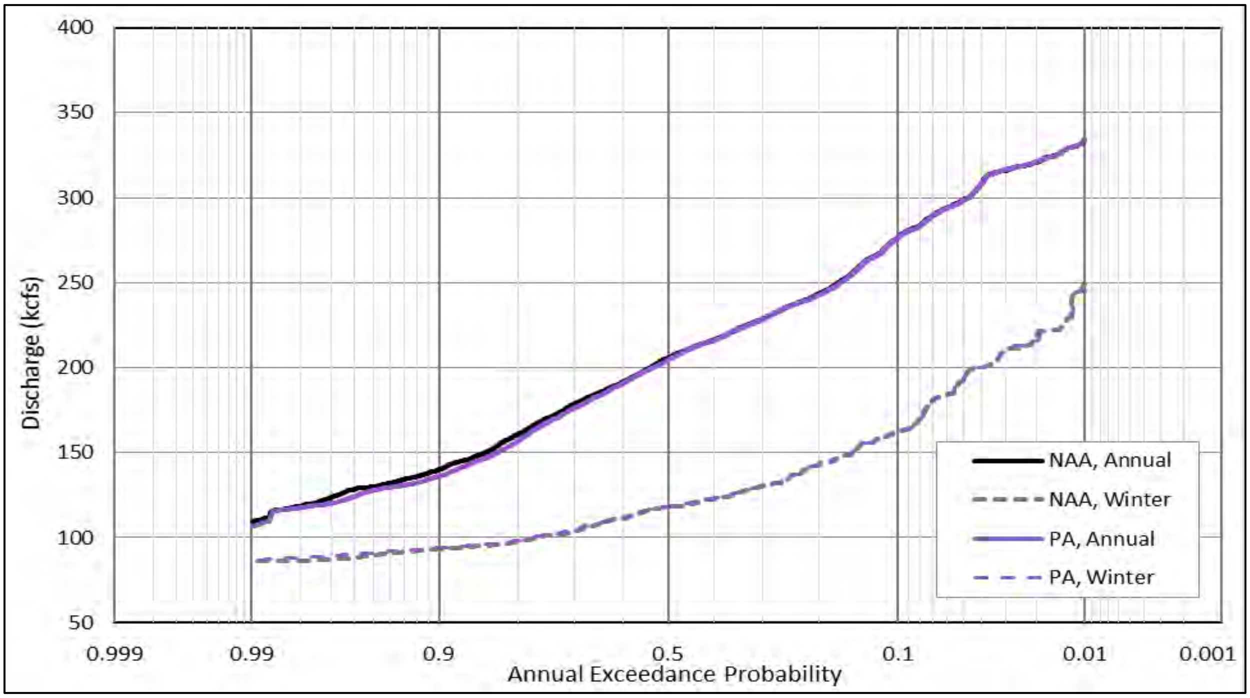


Figure 7-49. Peak Inflow-Frequency Curves for Lake Roosevelt for the Preferred Alternative and No Action Alternative

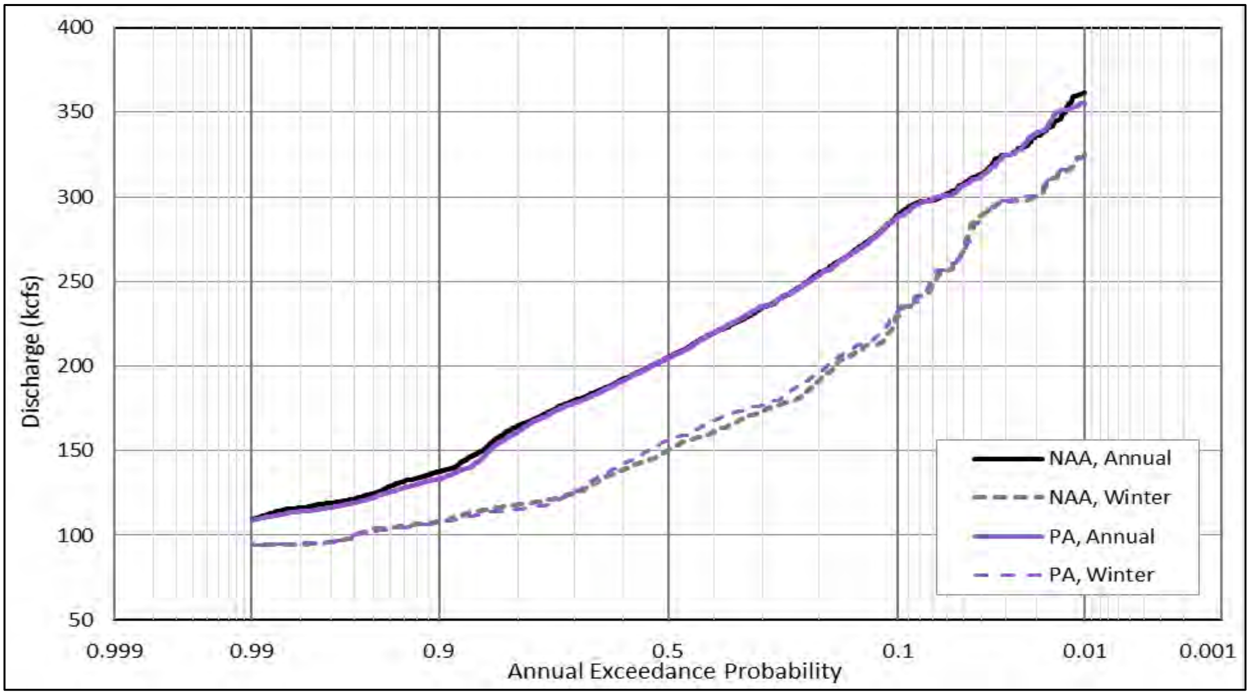


Figure 7-50. Peak Outflow-Frequency Curves for Grand Coulee Dam for the Preferred Alternative and No Action Alternative

7.2.3 Region C – Lower Snake River Basin

7.2.3.1 Water Year Plots, Elevation

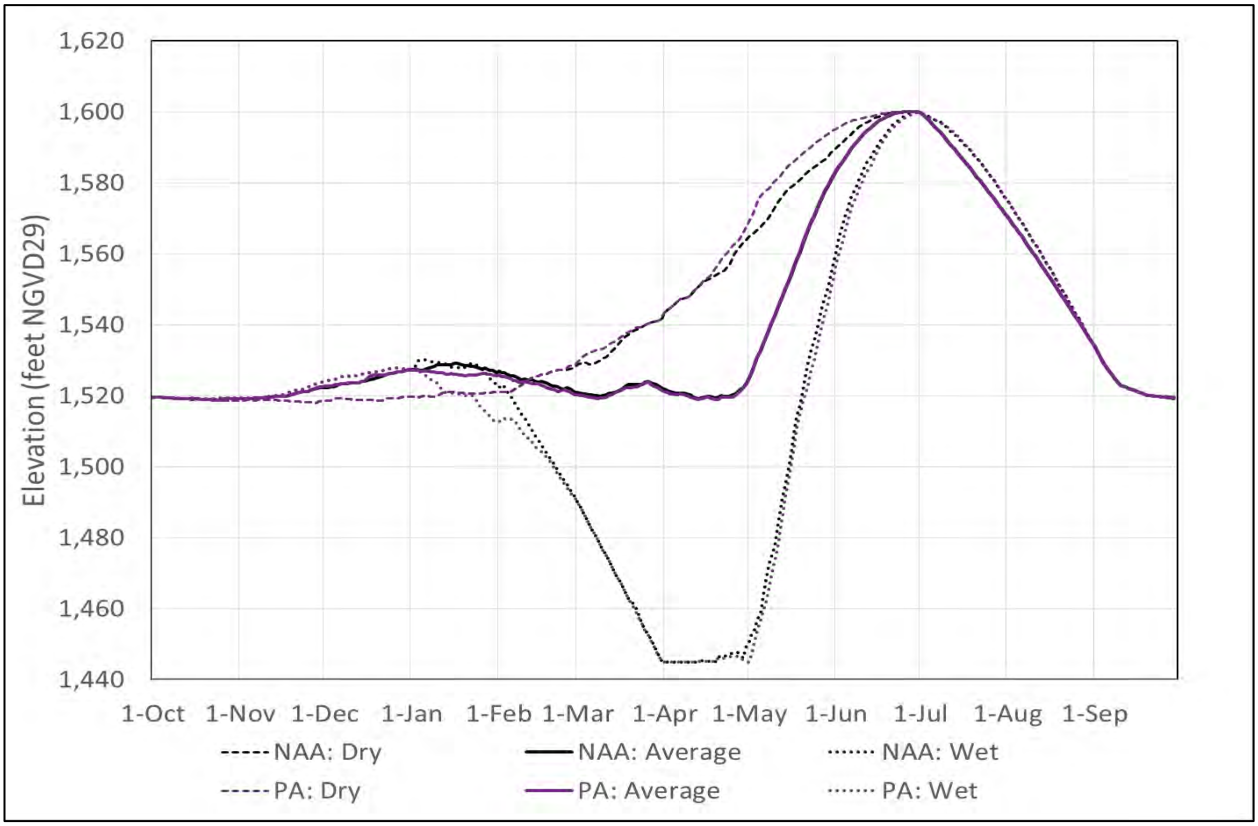


Figure 7-51. Summary Elevation Hydrographs for Dry, Average, and Wet Water Years at Dworshak Reservoir for the Preferred Alternative and No Action Alternative

7.2.3.2 Summary Elevation Hydrographs

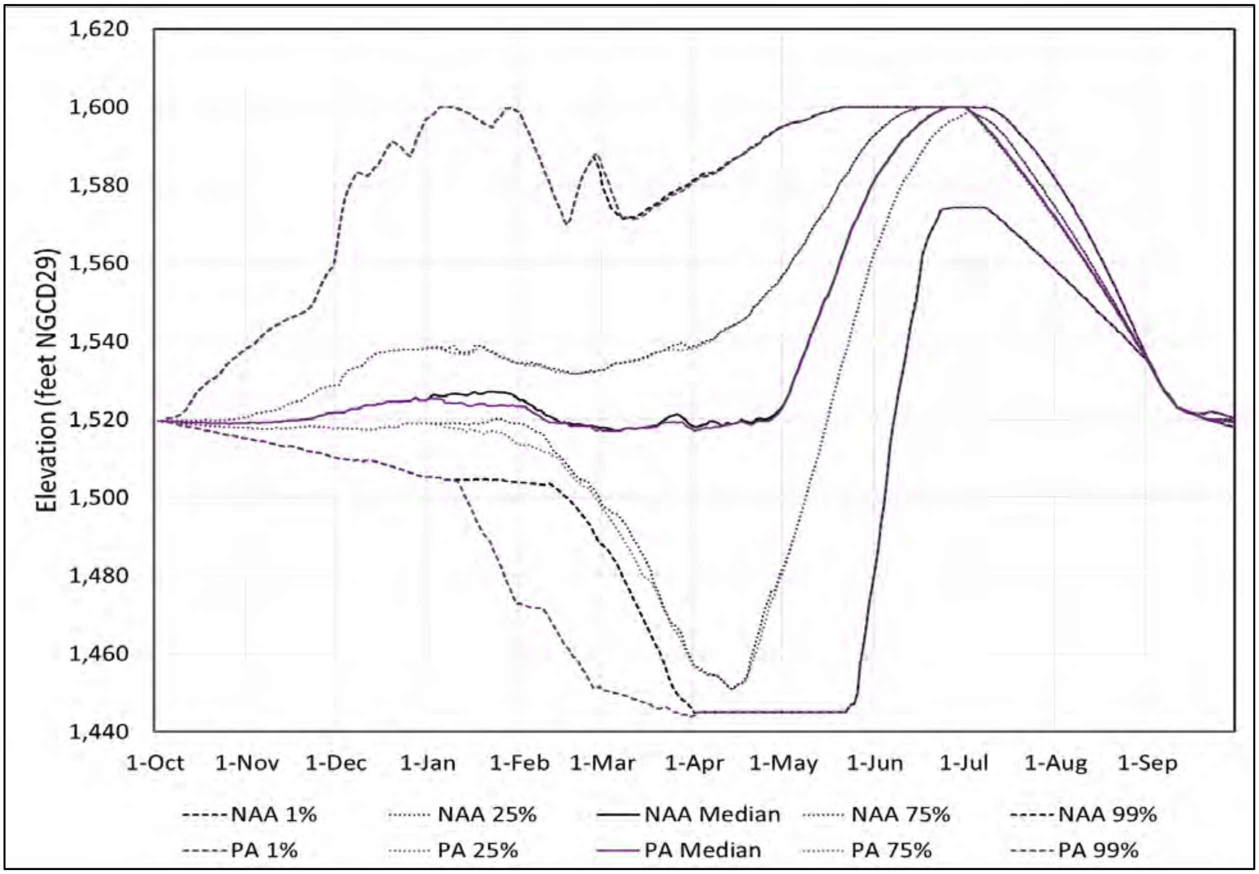


Figure 7-52. Summary Elevation Hydrographs for Dworshak Reservoir for the Preferred Alternative and No Action Alternative

7.2.3.3 Reservoir Target Date Elevation-Frequency Plots

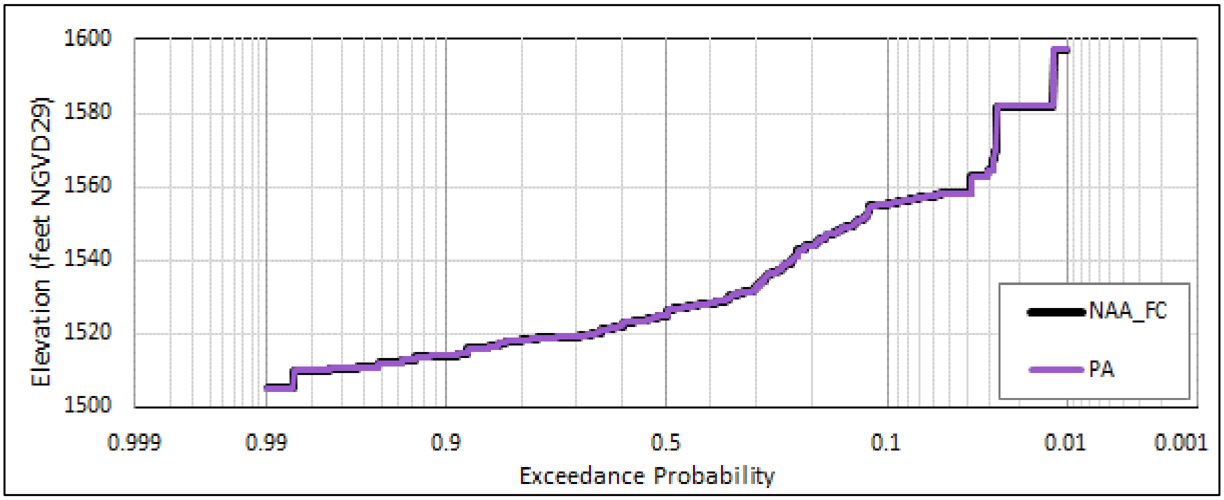


Figure 7-53. Elevation-Frequency Curves for December 31 at Dworshak Reservoir for the Preferred Alternative and No Action Alternative

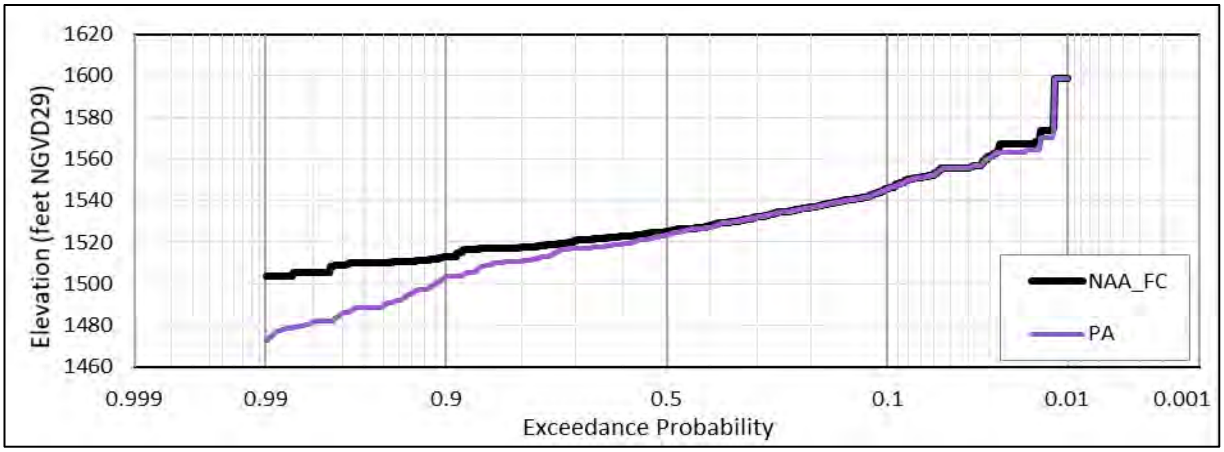


Figure 7-54. Elevation-Frequency Curves for January 31 at Dworshak Reservoir for the Preferred Alternative and No Action Alternative

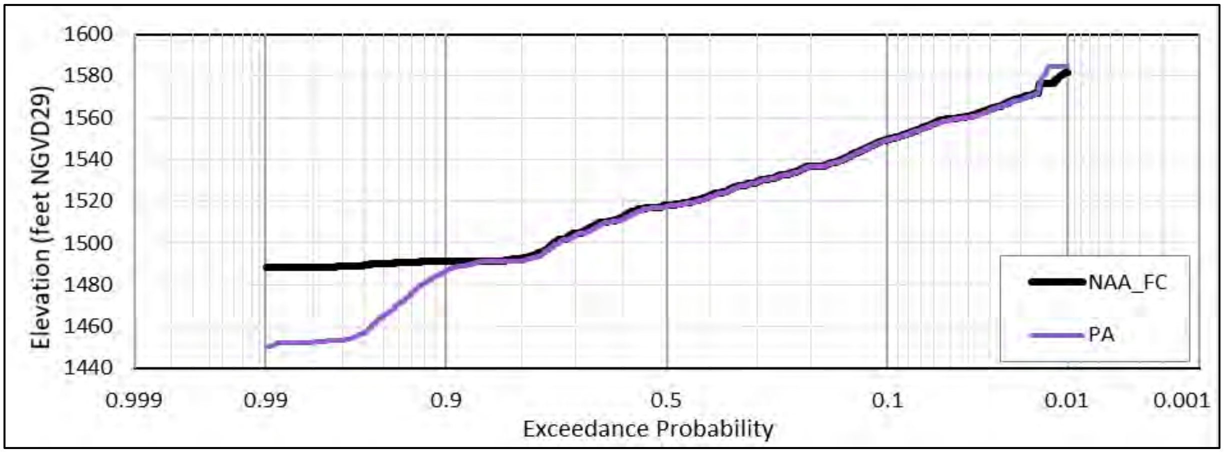


Figure 7-55. Elevation-Frequency Curves for February 28 at Dworshak Reservoir for the Preferred Alternative and No Action Alternative

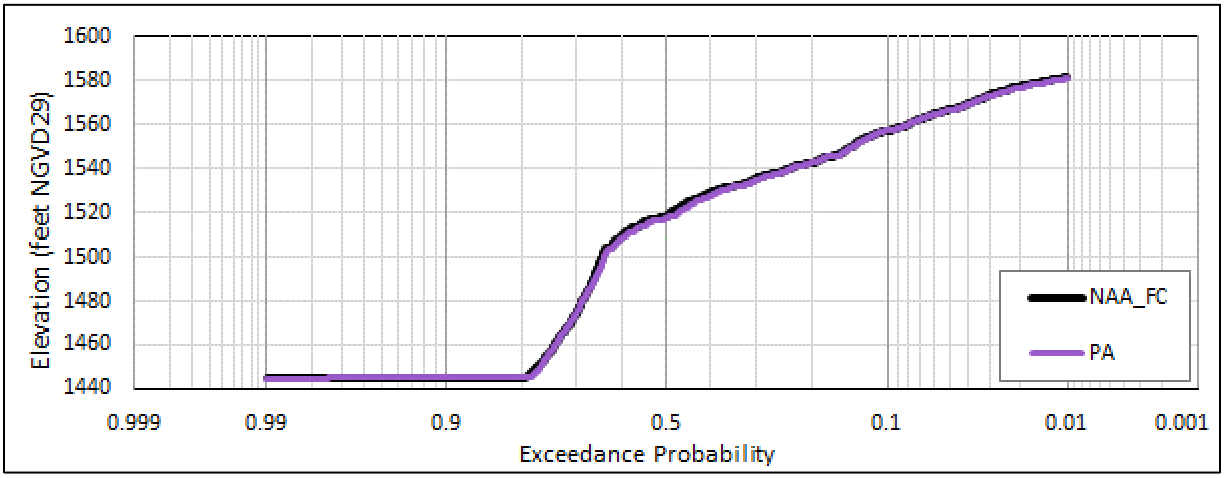


Figure 7-56. Elevation-Frequency Curves for March 31 at Dworshak Reservoir for the Preferred Alternative and No Action Alternative

7.2.3.4 Annual Elevation-Duration Plots

7.2.3.5 Water Year Plots, Flow

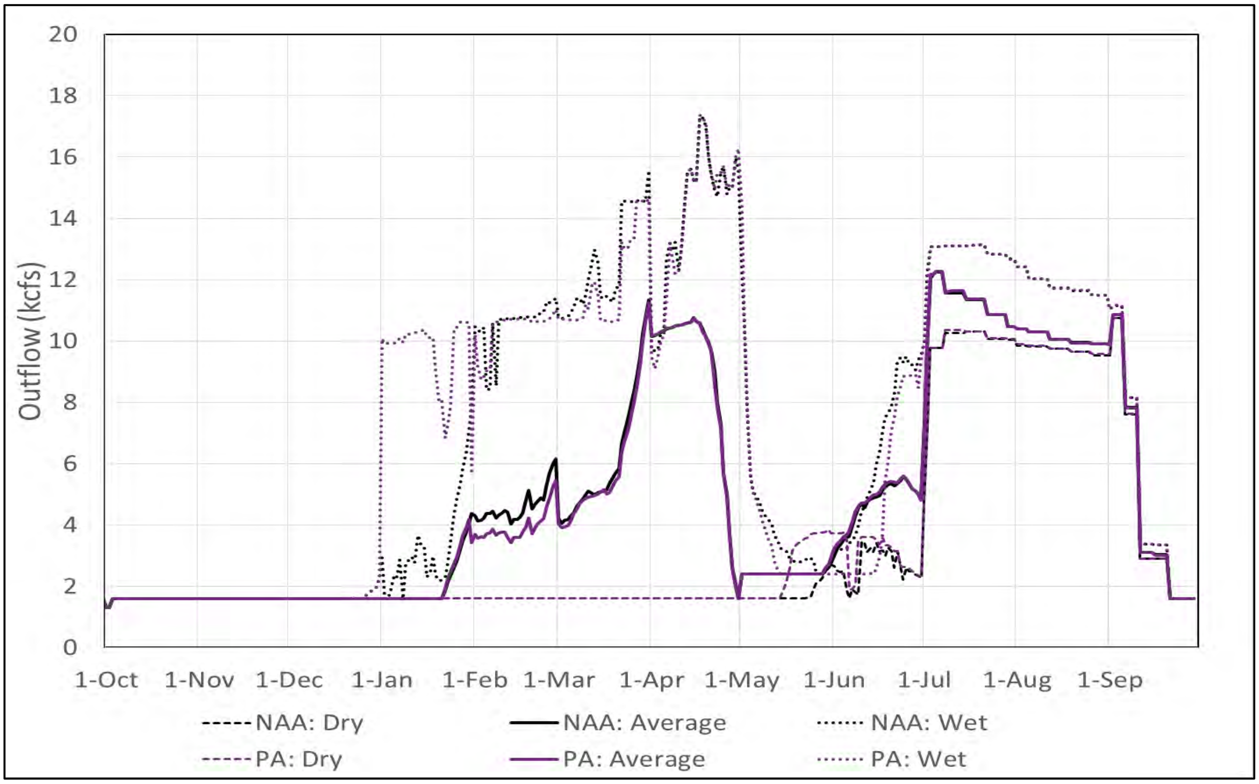


Figure 7-57. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at Dworshak Dam for the Preferred Alternative and No Action Alternative

7.2.3.6 Summary Flow Hydrographs

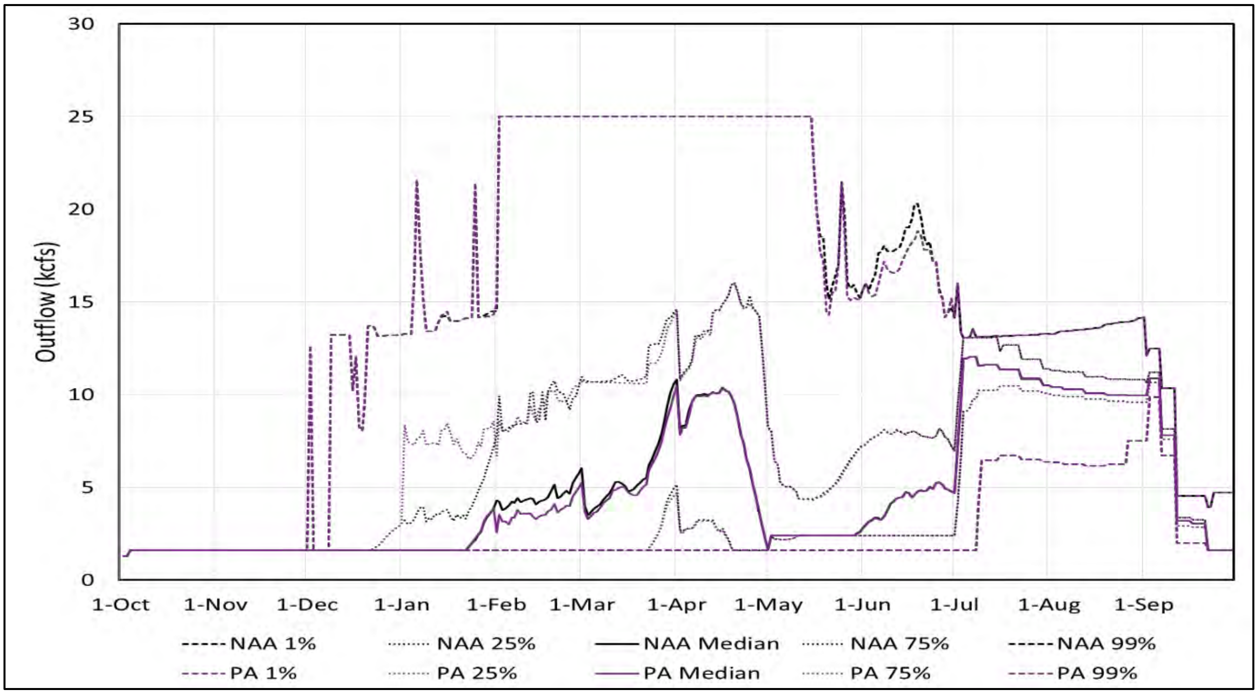


Figure 7-58. Summary Outflow Hydrographs for Dworshak Dam for the Preferred Alternative and No Action Alternative

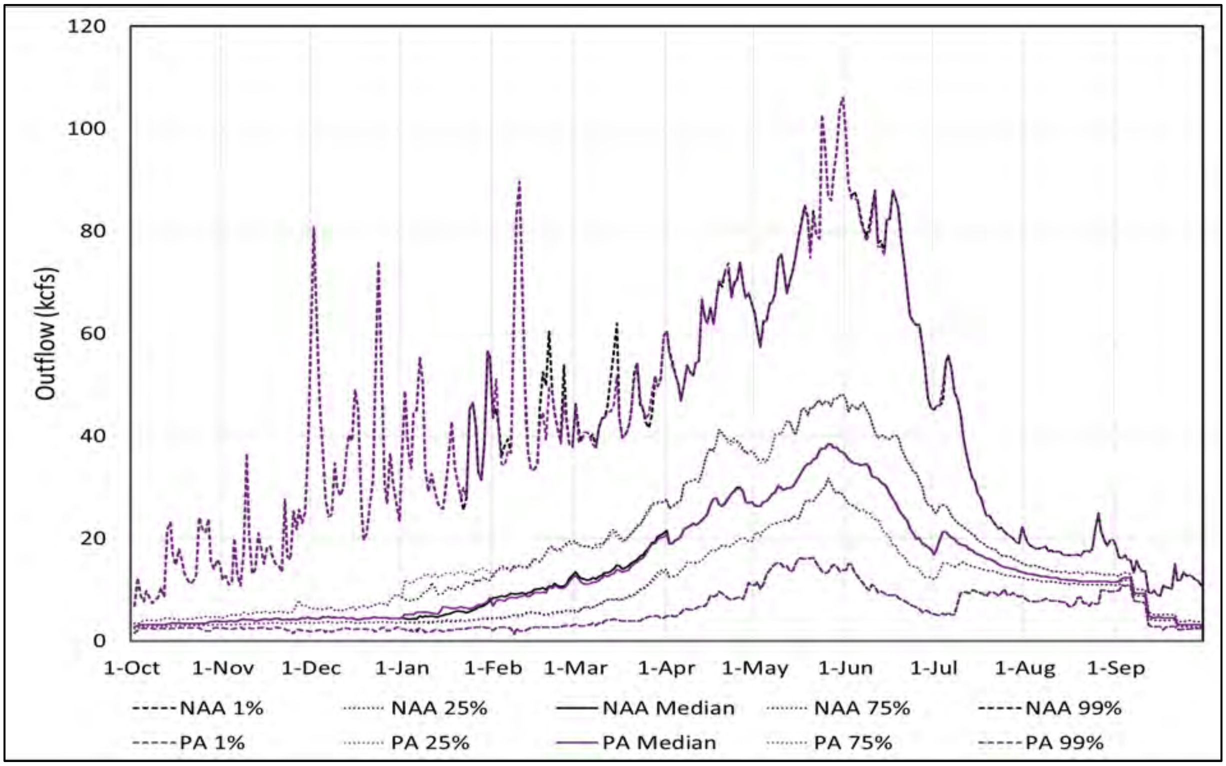


Figure 7-59. Summary Flow Hydrographs for Spalding, Idaho for the Preferred Alternative and No Action Alternative

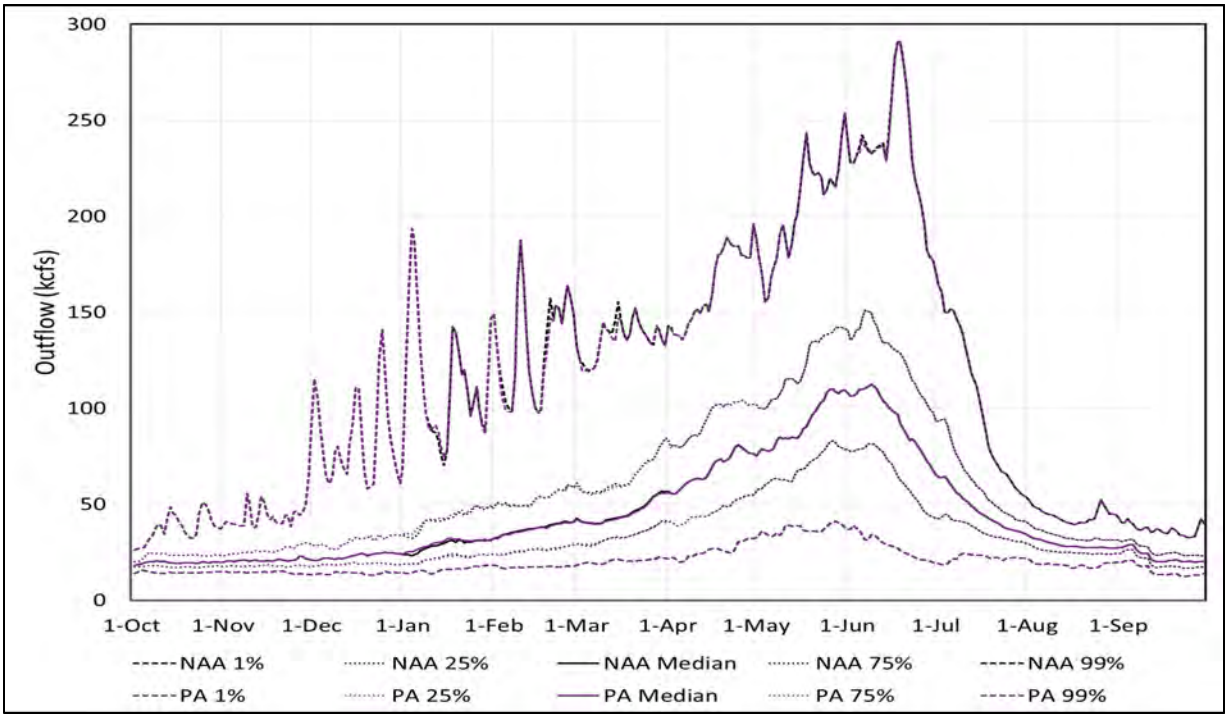


Figure 7-60. Summary Flow Hydrographs for Snake River and Clearwater River Confluence for the Preferred Alternative and No Action Alternative

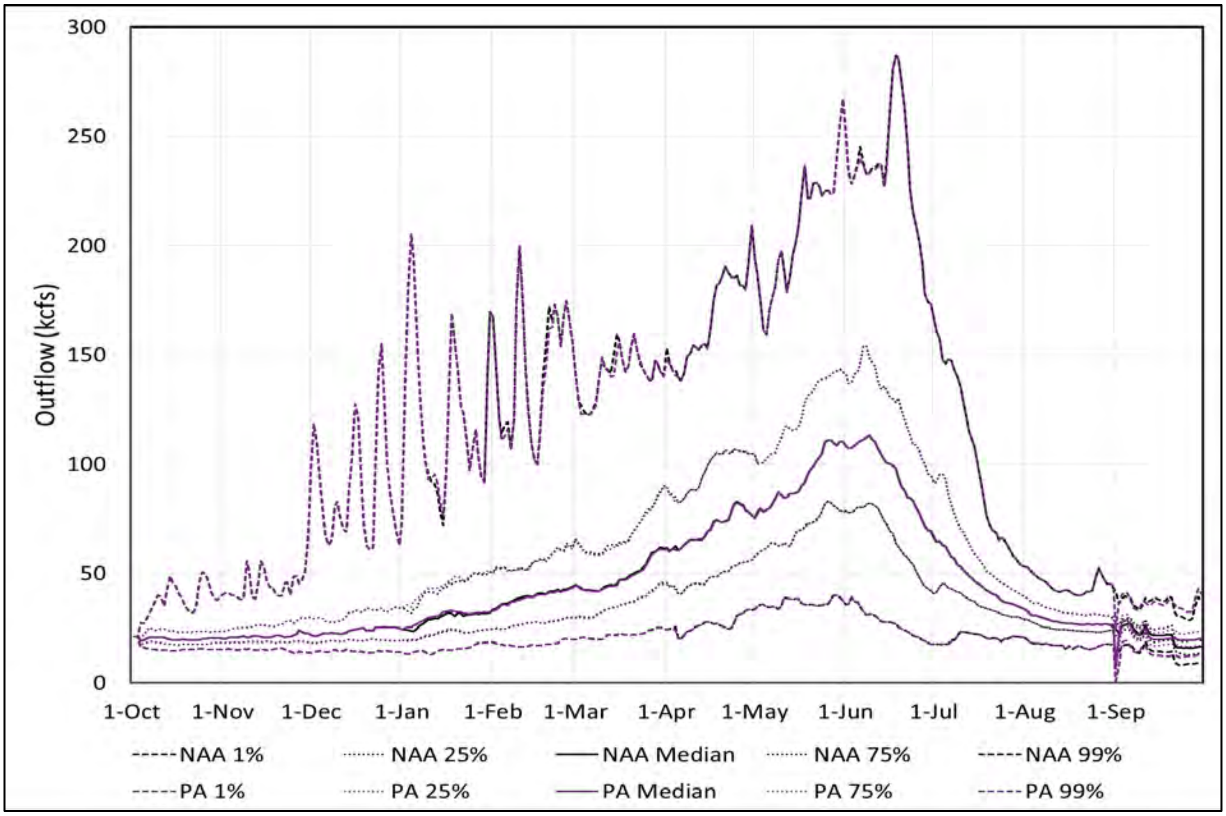


Figure 7-61. Summary Outflow Hydrographs for Ice Harbor Dam for the Preferred Alternative and No Action Alternative

7.2.3.7 Average Monthly Flow Summary Tables

Table 7-9. Average Monthly Outflow Summary for Dworshak Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	1.7	1.6	8.7	13.5	23.3	25.0	25.0	17.3	15.6	13.2	13.6	6.4
		25%	1.6	1.6	1.9	4.2	9.3	11.8	13.2	6.2	7.5	11.9	11.0	5.2
		50%	1.6	1.6	1.6	2.1	5.1	6.2	9.6	3.5	4.8	10.7	10.2	5.0
		75%	1.6	1.6	1.6	1.6	1.6	2.3	4.6	2.4	2.4	9.6	9.8	4.8
		99%	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	7.4	9.3	4.5
PA	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-1.0	0.0	-1.0	0.0	-0.2	0.0	0.0	0.0
		25%	0.0	0.0	0.0	3.3	-0.7	-0.8	0.0	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.3	-0.8	-0.3	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	0%	0%	0%	-4%	0%	-4%	0%	-1%	0%	0%	0%
		25%	0%	0%	0%	77%	-7%	-6%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	12%	-15%	-5%	0%	-1%	0%	0%	0%	0%
		75%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 7-10. Average Monthly Flow Summary for Spalding, Idaho

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	12.6	13.5	30.3	28.2	35.3	37.1	46.8	65.7	69.0	31.3	17.6	10.6
		25%	4.3	5.7	6.6	9.6	16.4	20.8	33.9	39.1	38.6	20.0	13.5	7.1
		50%	3.4	4.5	4.7	5.9	10.6	15.5	26.8	33.4	28.7	17.0	12.2	6.5
		75%	3.1	3.5	3.9	4.1	5.9	9.8	18.5	28.3	21.1	14.0	11.4	6.0
		99%	2.7	2.9	3.1	3.1	3.5	6.0	11.2	21.4	12.7	11.7	10.6	5.7
PA	Change (kcfs)	1%	0.0	0.0	0.0	0.0	-0.8	0.0	0.0	-0.1	-2.4	0.0	0.0	0.0
		25%	0.0	0.0	0.0	3.2	-0.2	-0.2	-0.2	0.0	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	0.8	-0.3	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.2	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	0%	0%	0%	-2%	0%	0%	0%	-4%	0%	0%	0%
		25%	0%	0%	0%	33%	-1%	-1%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	13%	-3%	-4%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	6%	-1%	-1%	0%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 7-11. Average Monthly Flow Summary for the Snake River and Clearwater River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	35.3	37.0	64.1	93.2	104.6	122.1	149.3	169.0	206.5	100.2	42.7	33.3
		25%	23.8	26.1	31.7	41.9	52.4	61.0	92.1	121.2	133.4	63.2	33.6	26.0
		50%	19.7	20.9	23.9	28.3	39.0	47.2	69.7	94.4	96.4	47.9	29.2	22.6
		75%	17.7	18.4	19.1	22.5	27.4	35.3	50.0	73.4	70.6	37.2	25.2	20.1
		99%	15.8	15.9	16.4	18.4	19.9	24.8	33.6	60.2	35.5	28.0	22.0	17.3
PA	Change (kcfs)	1%	0.0	0.0	0.0	2.4	-0.8	-0.8	-0.4	0.1	-0.6	0.0	0.0	0.0
		25%	0.0	0.0	0.0	1.7	-0.4	-0.8	-0.1	-0.7	0.0	0.0	0.0	0.0
		50%	0.0	0.0	0.0	1.6	-0.5	-0.2	-0.1	0.0	0.0	0.0	0.0	0.0
		75%	0.0	0.0	0.0	0.4	-0.3	-0.2	-0.1	0.0	0.0	0.0	0.0	0.0
		99%	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent change	1%	0%	0%	0%	3%	-1%	-1%	0%	0%	0%	0%	0%	0%
		25%	0%	0%	0%	4%	-1%	-1%	0%	-1%	0%	0%	0%	0%
		50%	0%	0%	0%	6%	-1%	0%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	2%	-1%	-1%	0%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 7-12. Average Monthly Outflow Summary for Ice Harbor Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	34.9	36.5	66.2	97.1	107.3	127.5	151.0	164.5	203.4	97.2	42.4	31.3
		25%	23.6	26.5	31.6	43.7	55.5	64.7	94.7	120.8	134.6	62.8	33.0	24.0
		50%	20.2	21.4	24.5	29.4	42.0	50.7	73.0	95.4	97.2	48.4	28.1	21.2
		75%	18.3	19.2	19.5	23.1	28.3	37.9	51.6	75.4	69.9	36.5	24.7	18.7
		99%	16.3	16.3	16.9	17.9	20.7	27.1	35.9	60.2	34.8	26.6	20.3	15.3
PA	Change (kcfs)	1%	0.0	0.0	0.0	2.5	-0.8	-0.7	-0.2	0.0	0.0	0.0	0.0	0.1
		25%	0.0	0.0	0.0	1.0	-0.4	-0.5	-0.4	-0.5	0.0	0.0	0.0	0.1
		50%	0.0	0.0	0.0	1.0	-0.8	-0.3	-0.2	0.0	0.0	0.0	0.0	0.1
		75%	0.0	0.0	0.0	0.8	-0.2	-0.2	-0.1	0.0	0.0	0.0	0.0	0.1
		99%	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.1
	Percent change	1%	0%	0%	0%	3%	-1%	-1%	0%	0%	0%	0%	0%	0%
		25%	0%	0%	0%	2%	-1%	-1%	0%	0%	0%	0%	0%	0%
		50%	0%	0%	0%	3%	-2%	-1%	0%	0%	0%	0%	0%	0%
		75%	0%	0%	0%	3%	-1%	-1%	0%	0%	0%	0%	0%	0%
		99%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

7.2.3.8 Monthly Flow-Duration Plots

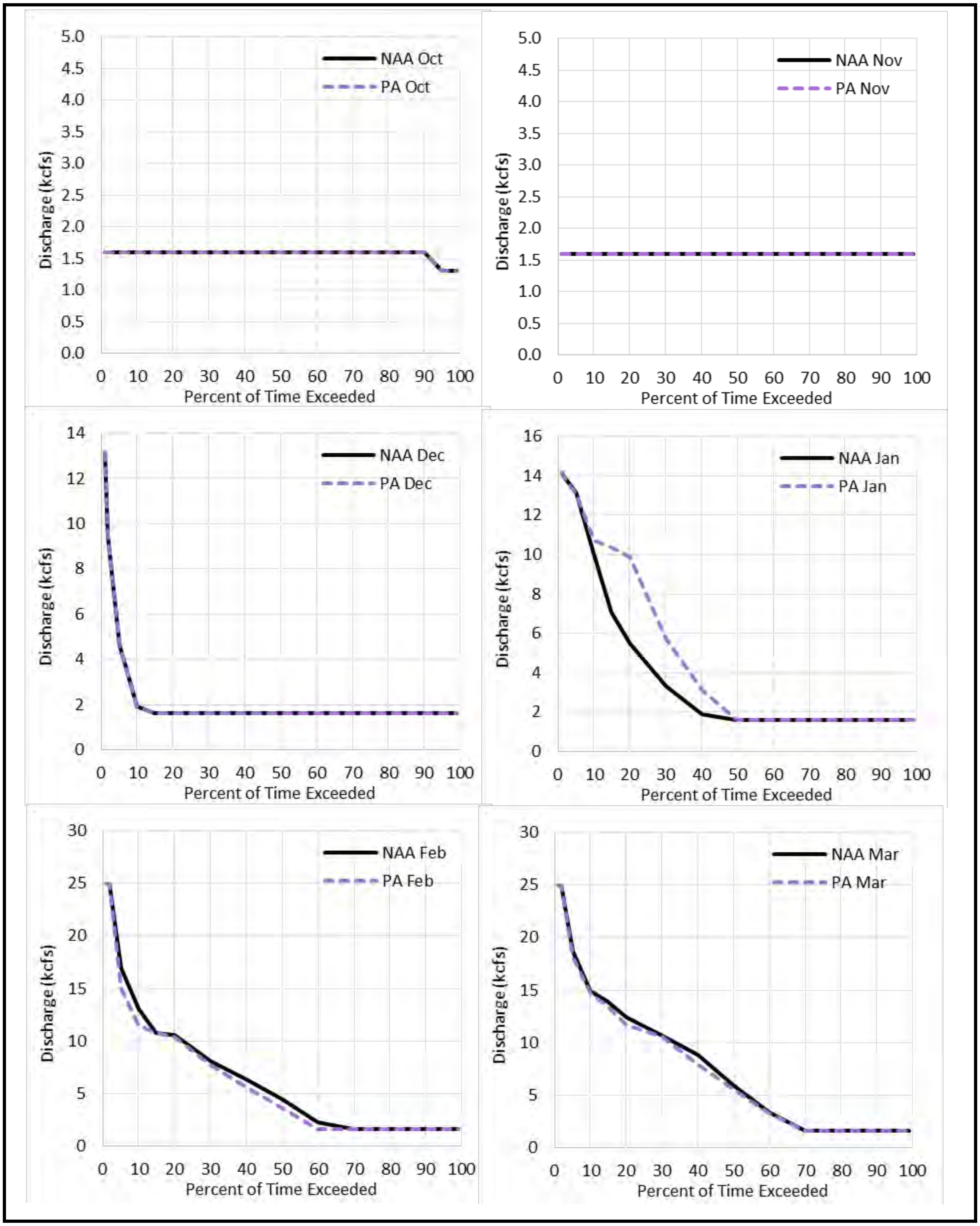


Figure 7-62. Monthly Flow-Duration Curves for Dworshak Dam Outflow for the Preferred Alternative and No Action Alternative, October through March

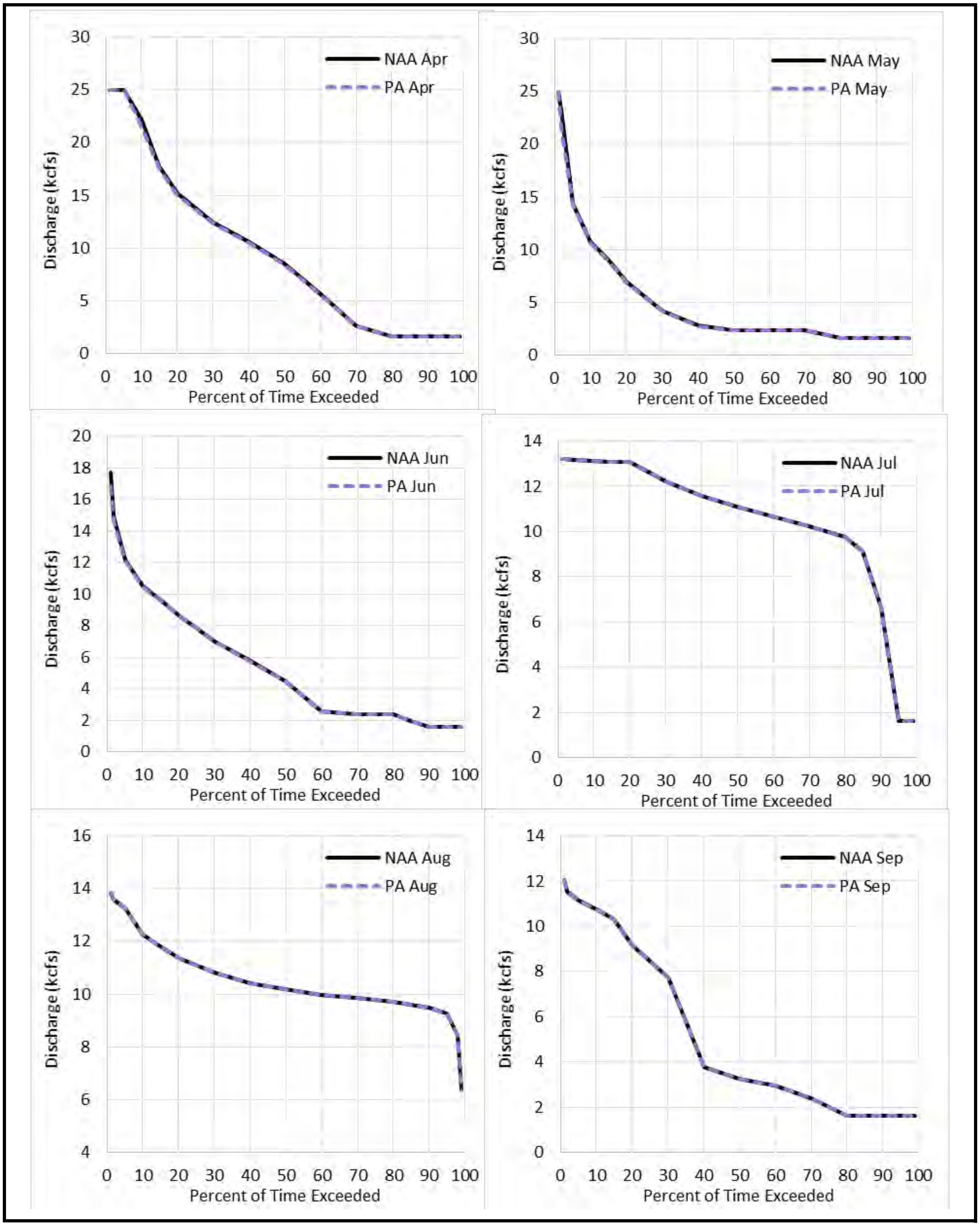


Figure 7-63. Monthly Flow-Duration Curves for Dworshak Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

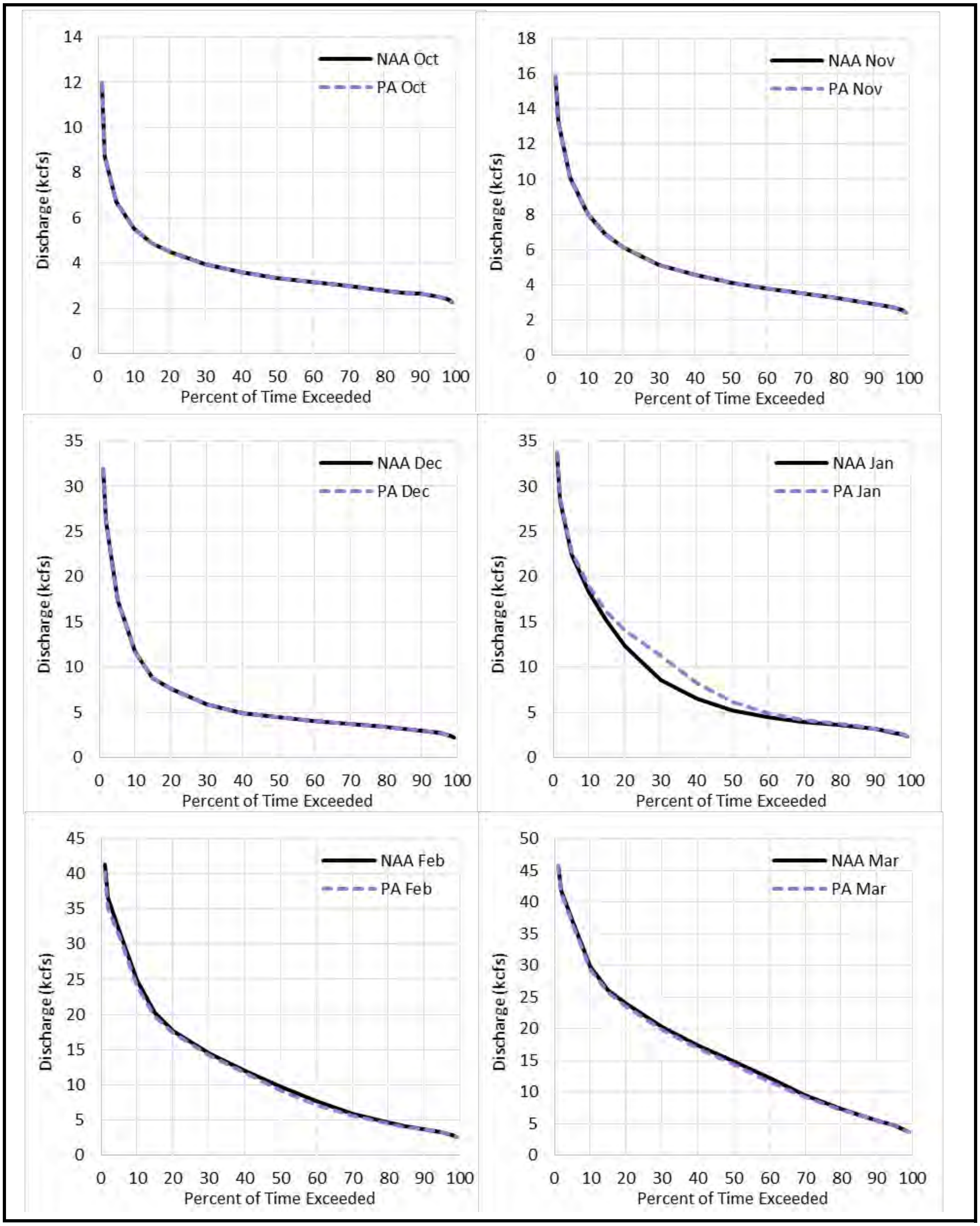


Figure 7-64. Monthly Flow-Duration Curves for Spalding, Idaho for the Preferred Alternative and No Action Alternative, October through March

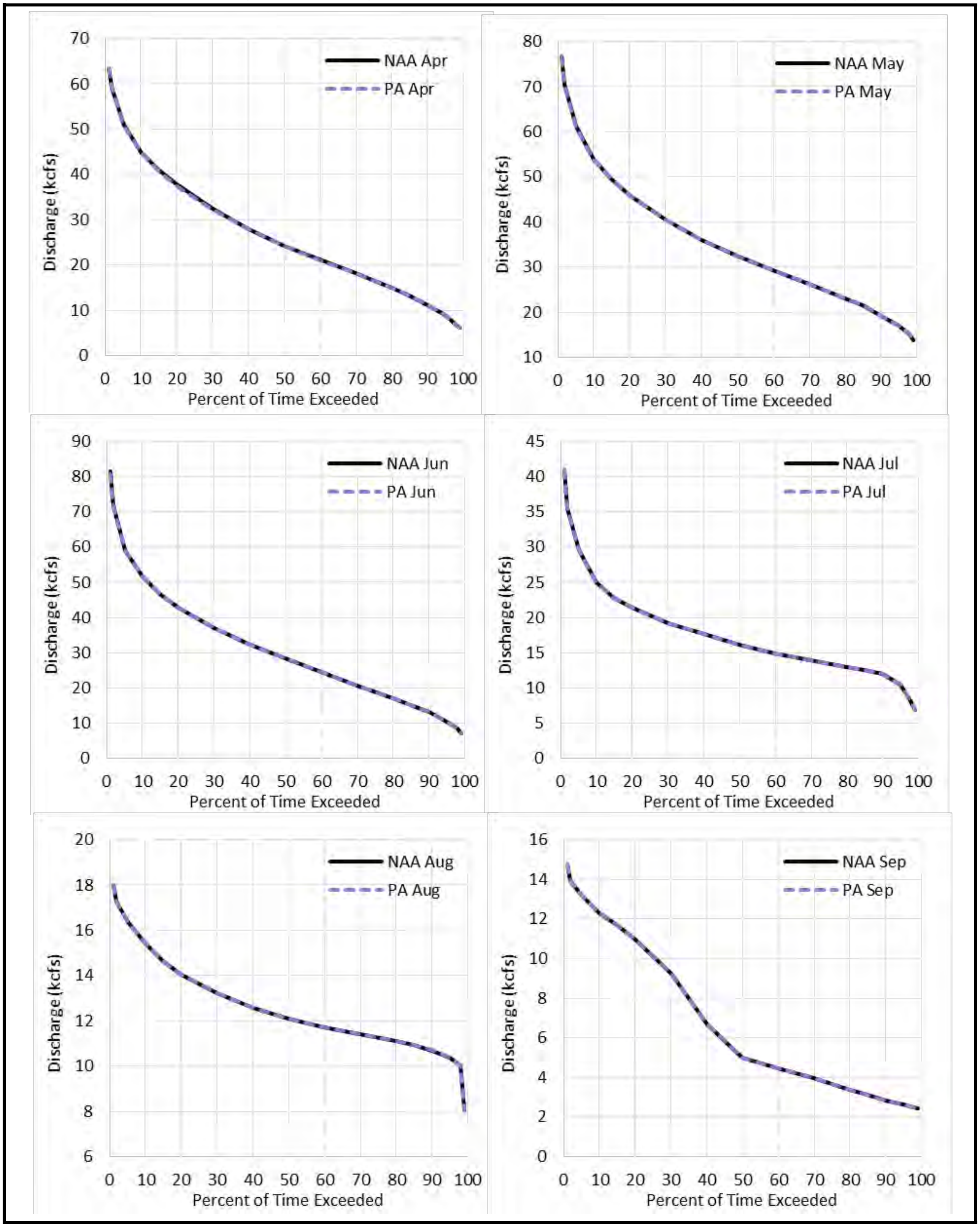
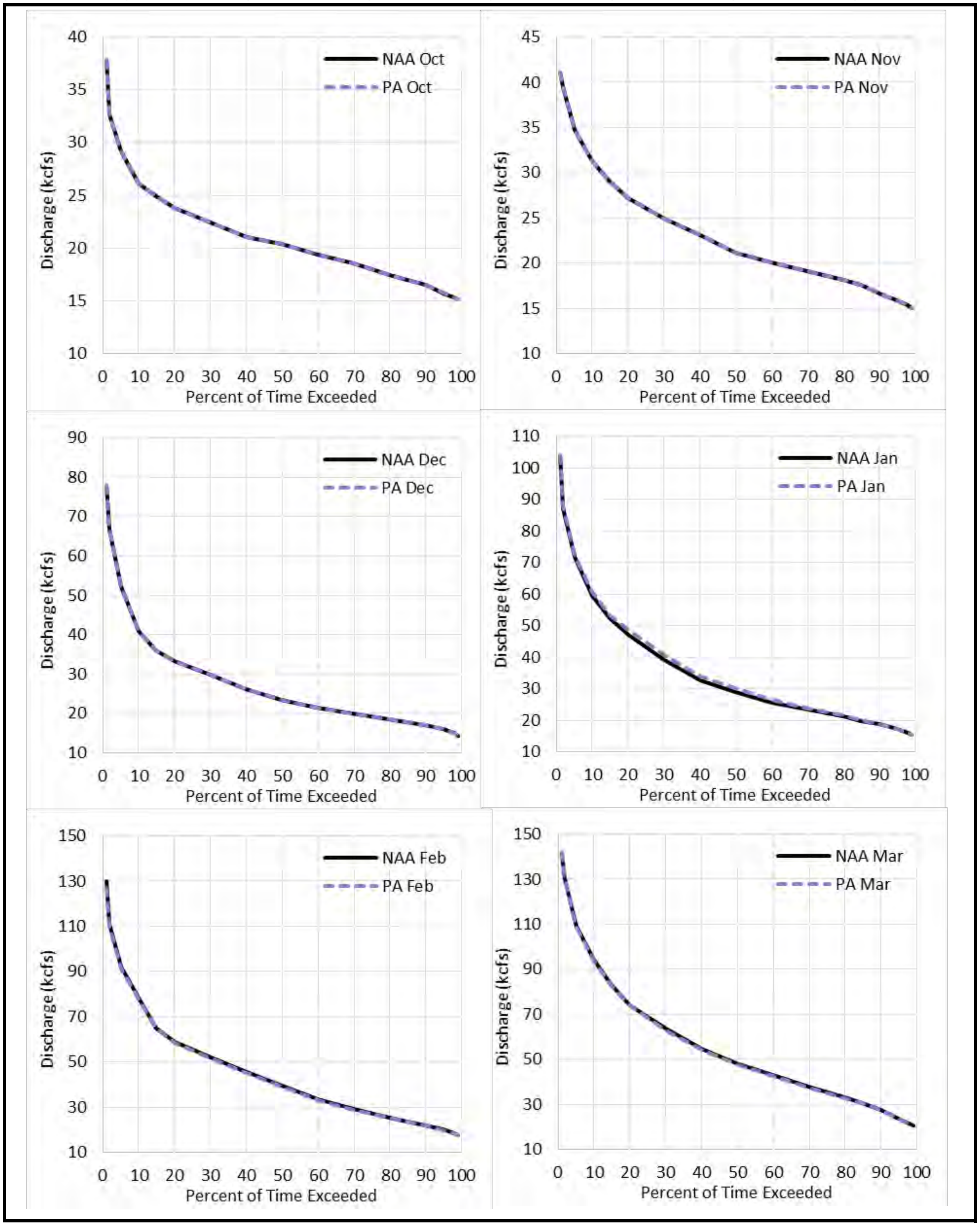


Figure 7-65. Monthly Flow-Duration Curves for Spalding, Idaho for the Preferred Alternative and No Action Alternative, April through September



4032

4033 **Figure 7-66. Monthly Flow-Duration Curves for Ice Harbor Dam Outflow for the Preferred**
4034 **Alternative and No Action Alternative, October through March**

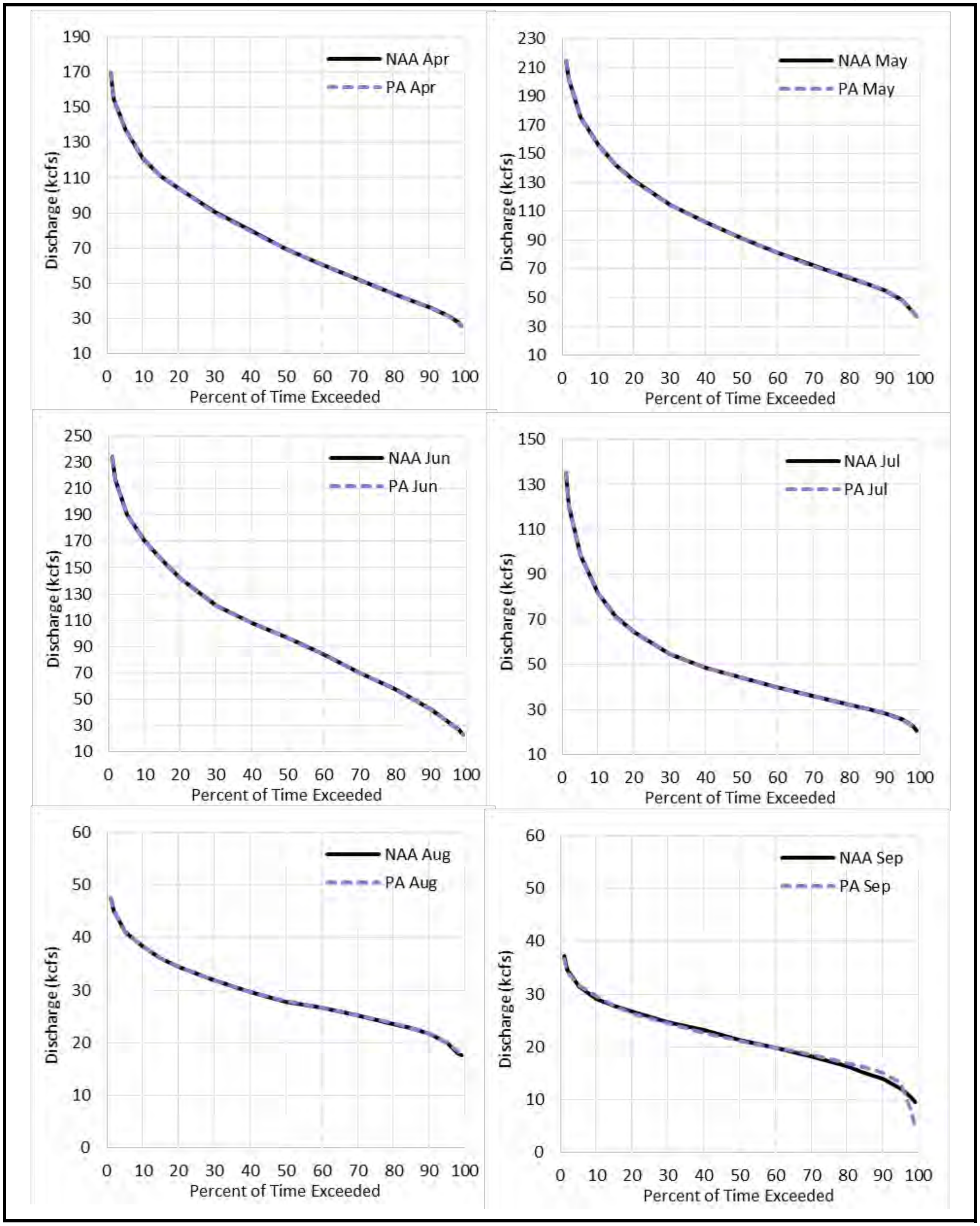


Figure 7-67. Monthly Flow-Duration Curves for Ice Harbor Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

7.2.3.9 Peak Flow-Frequency Plots

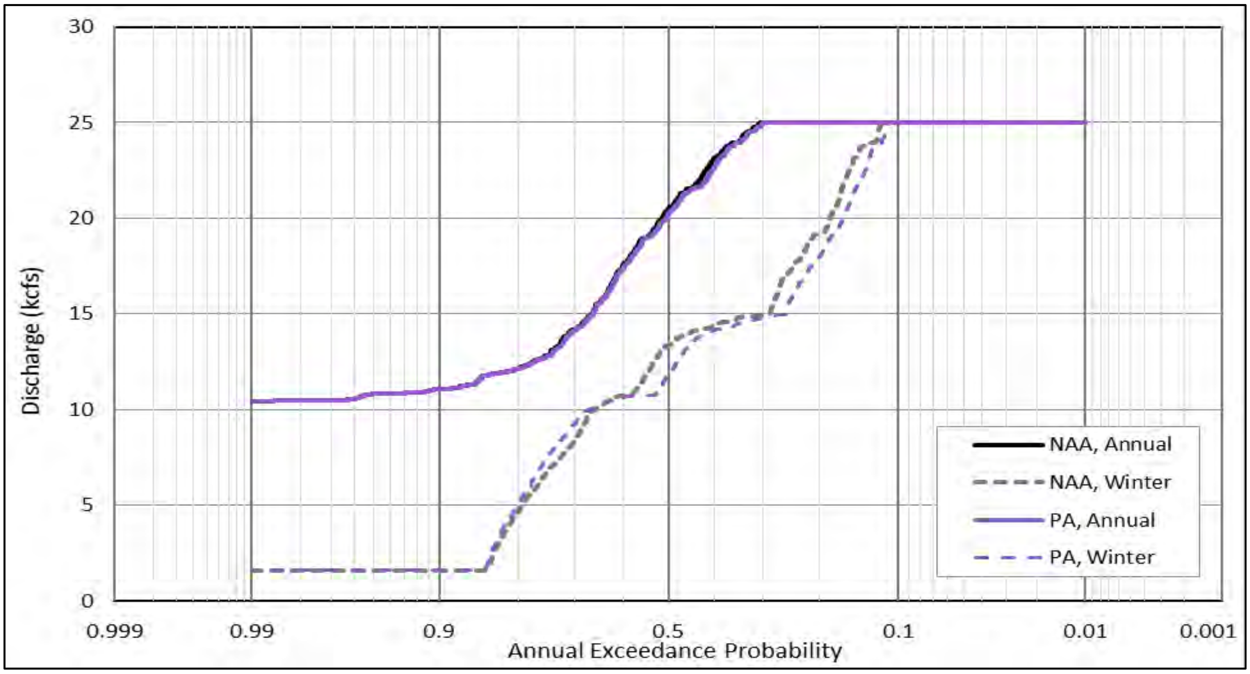


Figure 7-68. Peak Outflow-Frequency Curves for Dworshak Dam for the Preferred Alternative and No Action Alternative

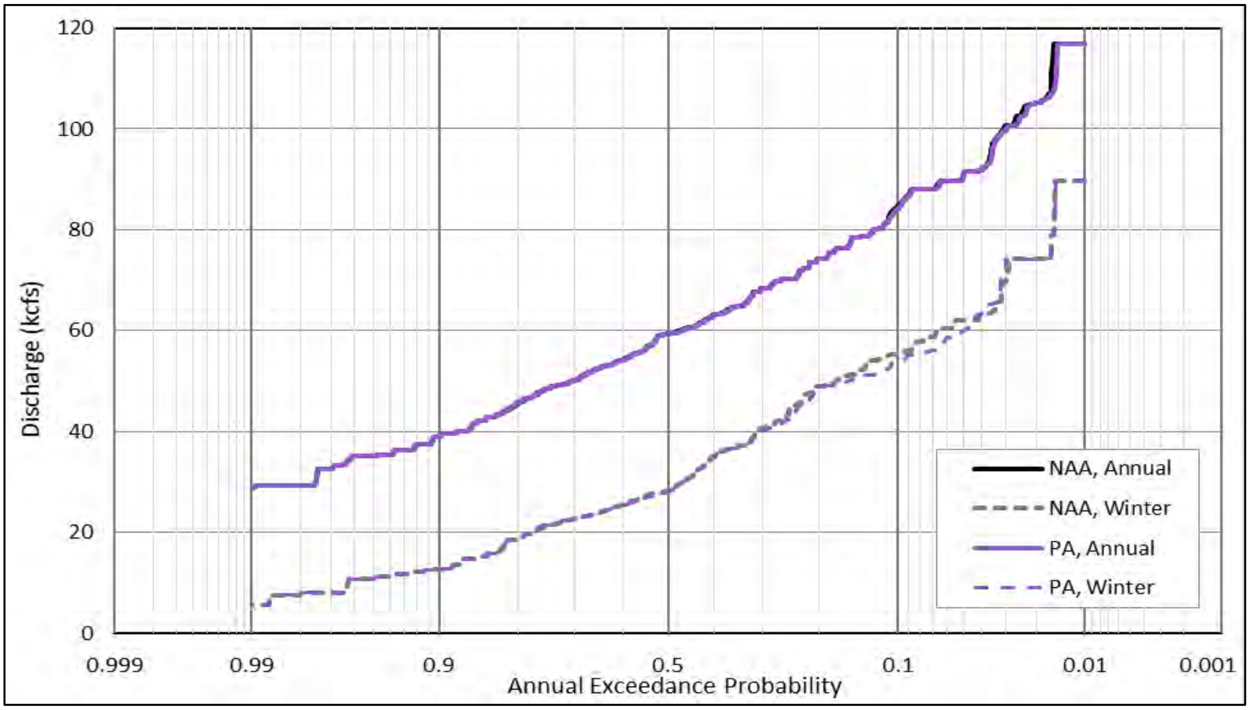


Figure 7-69. Peak Flow-Frequency Curves for Spalding, Idaho for the Preferred Alternative and No Action Alternative

7.2.4 Region D – Lower Columbia River Basin

7.2.4.1 Water Year Plots, Flow

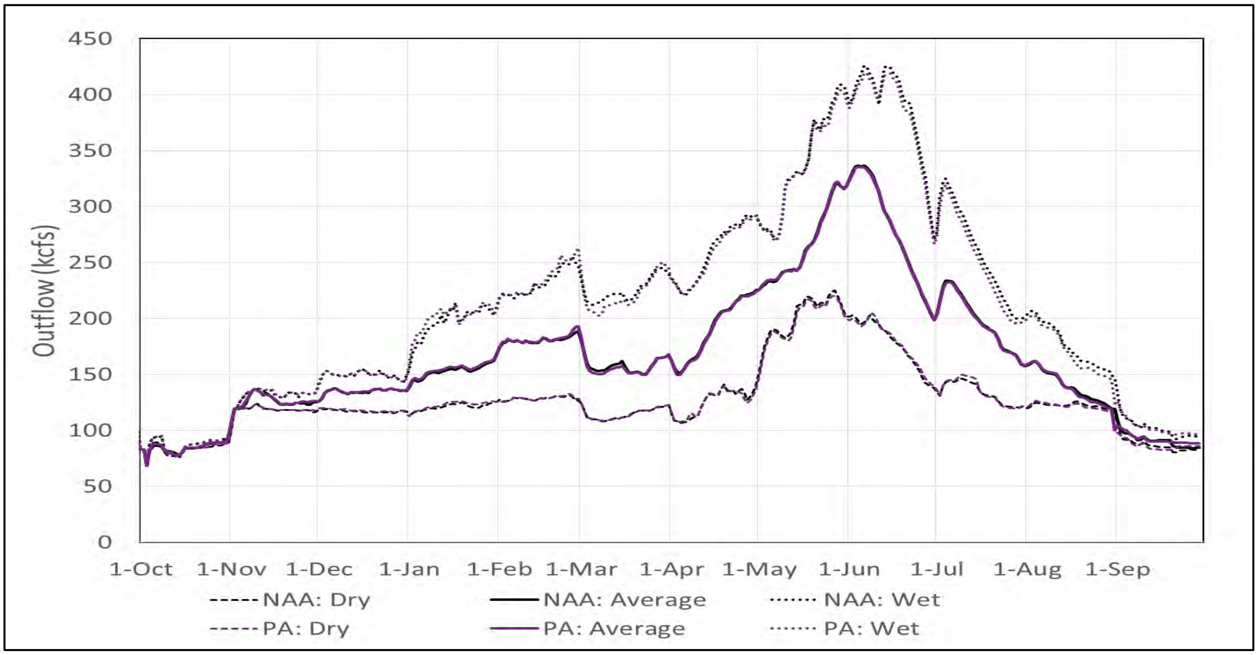


Figure 7-70. Summary Outflow Hydrographs for Dry, Average, and Wet Water Years at McNary Dam for the Preferred Alternative and No Action Alternative

7.2.4.2 Summary Flow Hydrographs

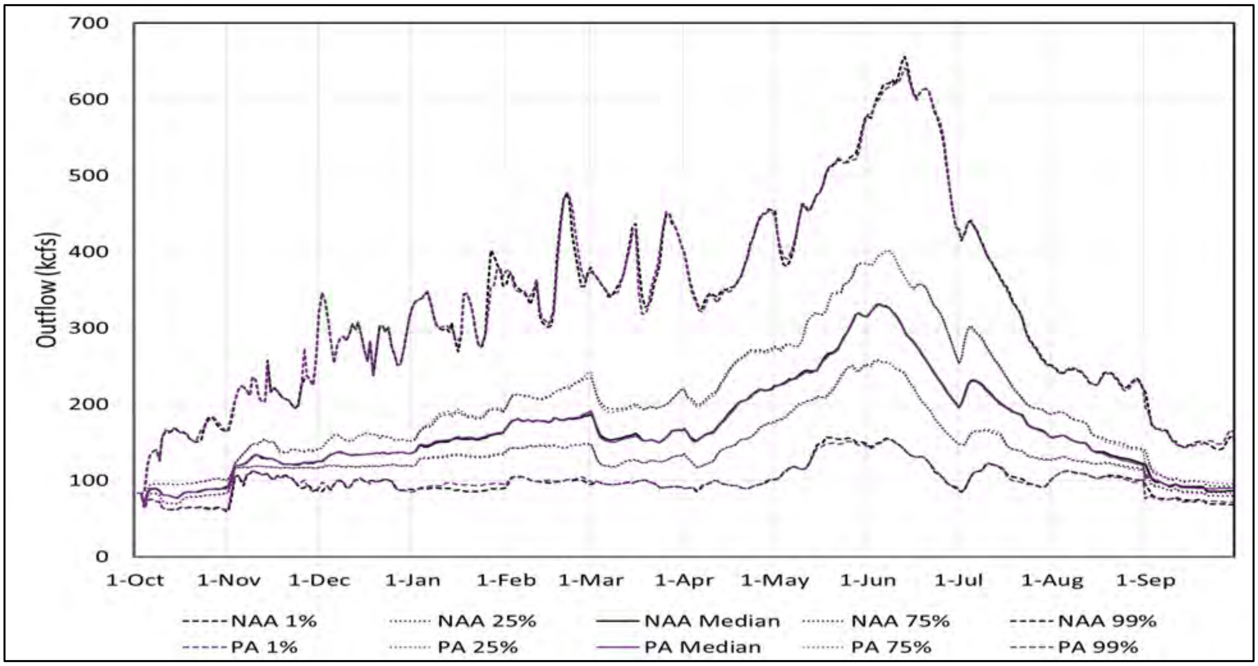


Figure 7-71. Summary Outflow Hydrographs for McNary Dam for the Preferred Alternative and No Action Alternative

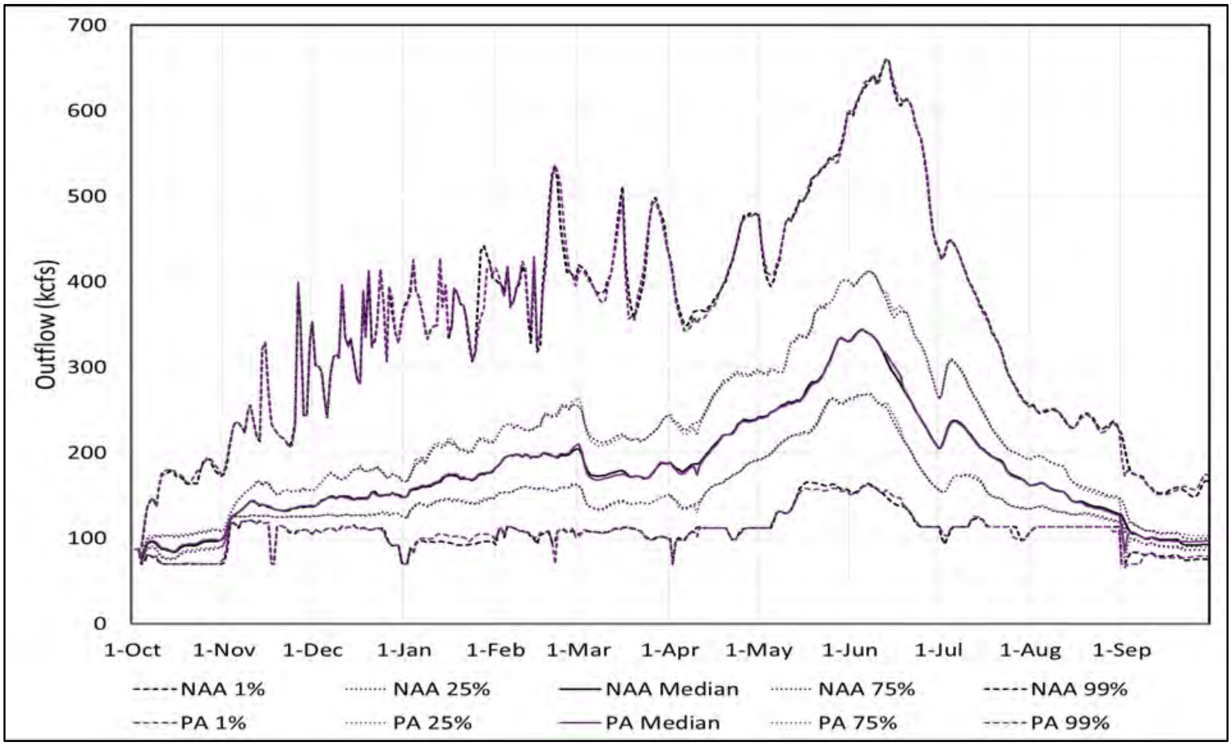


Figure 7-72. Summary Outflow Hydrographs for Bonneville Dam for the Preferred Alternative and No Action Alternative

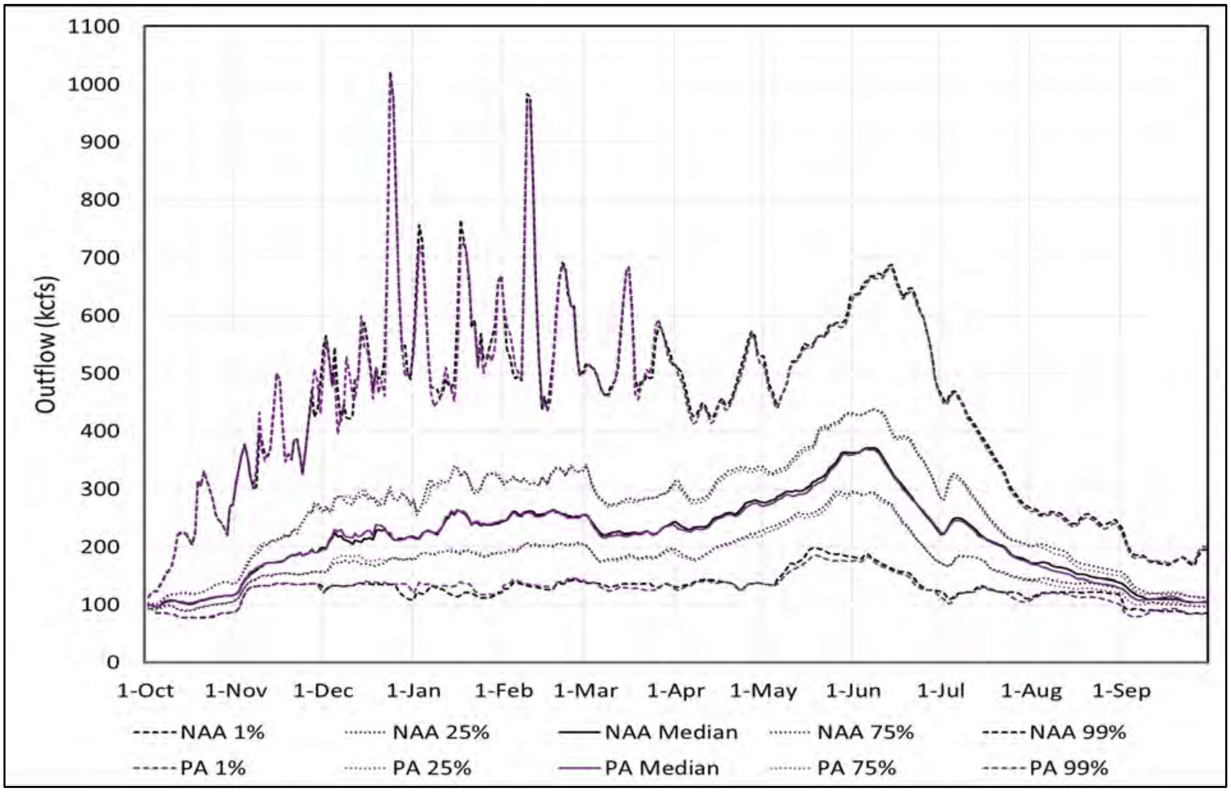


Figure 7-73. Summary Flow Hydrographs for the Columbia River and Willamette River Confluence for the Preferred Alternative and No Action Alternative

7.2.4.3 Average Monthly Flow Summary Tables

Table 7-13. Average Monthly Flow Summary for the Columbia River and Snake River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	139	186	278	270	318	325	342	446	562	346	228	148
		25%	93	141	154	177	213	196	232	311	349	244	164	100
		50%	83	122	134	151	181	157	188	260	288	199	140	91
		75%	77	114	116	130	145	129	147	229	221	147	124	86
		99%	71	109	108	107	111	106	104	179	162	125	114	81
PA	Change (kcfs)	1%	0.5	-1.6	0.0	4.5	3.3	3.4	-3.5	0.2	-2.2	-1.4	-1.4	-0.9
		25%	0.2	0.1	-0.1	3.3	1.3	-1.0	-2.6	0.3	-0.5	-1.6	-2.5	0.4
		50%	0.2	0.1	0.0	1.6	1.3	-0.9	-1.7	-1.3	-0.2	-1.6	-1.1	0.2
		75%	0.2	0.6	0.8	1.8	-0.5	-0.4	-0.3	-2.3	-2.0	-0.4	-0.3	0.4
		99%	0.4	0.2	0.0	-0.3	1.1	0.3	0.7	-3.9	0.2	-0.5	-0.4	-0.5
	Percent change	1%	0%	-1%	0%	2%	1%	1%	-1%	0%	0%	0%	-1%	-1%
		25%	0%	0%	0%	2%	1%	-1%	-1%	0%	0%	-1%	-2%	0%
		50%	0%	0%	0%	1%	1%	-1%	-1%	-1%	0%	-1%	-1%	0%
		75%	0%	1%	1%	1%	0%	0%	0%	-1%	-1%	0%	0%	0%
		99%	1%	0%	0%	0%	1%	0%	1%	-2%	0%	0%	0%	-1%

Table 7-14. Average Monthly Outflow Summary for McNary Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	141	187	279	280	327	329	346	451	562	342	231	152
		25%	95	143	155	181	216	200	236	313	352	243	163	100
		50%	85	124	136	154	182	159	192	260	285	198	141	93
		75%	79	116	118	133	147	130	147	231	217	147	124	87
		99%	73	112	109	108	115	107	106	178	160	122	114	81
PA	Change (kcfs)	1%	0.5	0.3	0.0	3.9	2.2	1.3	-3.5	-0.2	-1.5	-1.7	-0.7	-0.8
		25%	0.4	0.2	0.1	2.7	1.2	-0.9	-2.3	0.3	-1.6	-1.7	-2.3	0.4
		50%	0.4	0.3	0.0	1.9	1.7	-1.0	-1.2	-1.3	-0.2	-1.4	-0.9	0.1
		75%	0.4	0.7	0.8	1.4	-0.8	-0.1	0.1	-1.3	-0.8	0.6	-0.2	0.7
		99%	0.5	0.1	0.3	-1.1	0.6	0.4	0.5	-4.4	-0.9	0.4	-0.7	-0.5
	Percent change	1%	0%	0%	0%	1%	1%	0%	-1%	0%	0%	-1%	0%	-1%
		25%	0%	0%	0%	1%	1%	0%	-1%	0%	0%	-1%	-1%	0%
		50%	0%	0%	0%	1%	1%	-1%	-1%	0%	0%	-1%	-1%	0%
		75%	0%	1%	1%	1%	-1%	0%	0%	-1%	0%	0%	0%	1%
		99%	1%	0%	0%	-1%	1%	0%	0%	-2%	-1%	0%	-1%	-1%

Table 7-15. Average Monthly Outflow Summary for John Day Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	140	192	283	283	335	342	355	452	573	340	225	147
		25%	95	143	158	186	221	205	243	320	355	241	162	100
		50%	85	125	140	156	185	165	198	267	288	197	141	93
		75%	78	116	121	136	150	136	152	235	218	146	123	88
		99%	72	112	111	110	116	110	110	180	162	122	113	80
PA	Change (kcfs)	1%	2.0	0.2	-0.8	4.1	1.2	-0.9	-6.4	0.8	-0.8	-0.6	-0.8	-2.1
		25%	1.5	0.3	-0.8	2.8	1.3	-0.7	-3.7	0.0	0.5	-1.8	-2.7	-0.8
		50%	1.8	0.2	-0.6	1.6	1.6	-0.9	-1.8	-1.5	1.5	-1.2	-0.9	-0.9
		75%	1.7	0.5	-0.9	1.4	-1.3	-0.3	-1.0	-1.8	0.7	-0.1	-0.5	-1.0
		99%	1.8	0.2	-0.4	0.0	1.0	-0.1	0.4	-3.7	0.8	0.1	-1.0	-1.7
	Percent change	1%	1%	0%	0%	1%	0%	0%	-2%	0%	0%	0%	0%	-1%
		25%	2%	0%	-1%	1%	1%	0%	-2%	0%	0%	-1%	-2%	-1%
		50%	2%	0%	0%	1%	1%	-1%	-1%	-1%	1%	-1%	-1%	-1%
		75%	2%	0%	-1%	1%	-1%	0%	-1%	-1%	0%	0%	0%	-1%
		99%	2%	0%	0%	0%	1%	0%	0%	-2%	1%	0%	-1%	-2%

Table 7-16. Average Monthly Outflow Summary for Bonneville Dam

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	149	203	289	313	360	357	373	459	578	350	236	159
		25%	101	156	172	201	238	222	257	330	363	251	170	108
		50%	91	135	152	170	199	179	213	275	296	204	149	99
		75%	85	125	129	145	160	148	164	245	229	155	130	93
		99%	79	119	119	117	124	121	121	190	169	128	120	86
PA	Change (kcfs)	1%	2.0	0.2	-0.8	1.3	8.5	1.1	-3.8	-1.9	-2.1	-1.7	-1.3	-2.1
		25%	1.6	-0.6	-0.7	2.9	1.0	-0.9	-3.4	-0.6	0.4	-1.9	-2.9	-1.3
		50%	1.8	0.6	-0.9	1.1	1.6	-1.4	-1.9	-1.8	1.6	-1.4	-1.1	-1.2
		75%	1.8	0.3	-0.5	1.2	-0.8	-0.4	-0.5	-1.2	0.8	0.5	-0.2	-0.9
		99%	1.6	0.2	0.1	-0.8	1.4	0.4	0.0	-3.6	1.2	0.2	-0.8	-1.8
	Percent change	1%	1%	0%	0%	0%	2%	0%	-1%	0%	0%	0%	-1%	-1%
		25%	2%	0%	0%	1%	0%	0%	-1%	0%	0%	-1%	-2%	-1%
		50%	2%	0%	-1%	1%	1%	-1%	-1%	-1%	1%	-1%	-1%	-1%
		75%	2%	0%	0%	1%	-1%	0%	0%	0%	0%	0%	0%	-1%
		99%	2%	0%	0%	-1%	1%	0%	0%	-2%	1%	0%	-1%	-2%

Table 7-17. Average Monthly Flow Summary for the Columbia River and Willamette River Confluence

		Exceedance Probability	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NAA	Ave. mo. outflow (kcfs)	1%	185	301	422	447	535	490	434	497	611	366	246	175
		25%	120	219	276	309	319	282	307	367	391	265	180	122
		50%	108	178	225	252	267	233	260	314	319	216	159	111
		75%	98	155	186	196	217	195	211	274	257	166	138	105
		99%	90	134	148	148	157	153	153	217	185	138	129	97
PA	Change (kcfs)	1%	2.9	0.5	-0.8	-0.2	10.9	-3.6	-3.5	-1.0	-2.1	-1.7	-1.5	-2.4
		25%	2.0	0.2	-1.4	1.9	1.6	-1.3	-3.3	-0.8	0.9	-2.1	-2.6	-1.4
		50%	2.0	1.5	-0.8	1.5	1.5	-1.1	-2.1	-0.8	1.6	-1.2	-1.1	-1.2
		75%	2.0	0.2	-0.7	1.6	0.4	-0.3	-1.2	-1.0	-0.1	0.6	0.3	-1.0
		99%	1.9	0.2	-0.8	0.1	1.0	0.1	-0.2	-4.4	0.8	-0.1	-1.1	-2.8
	Percent change	1%	2%	0%	0%	0%	2%	-1%	-1%	0%	0%	0%	-1%	-1%
		25%	2%	0%	0%	1%	1%	0%	-1%	0%	0%	-1%	-1%	-1%
		50%	2%	1%	0%	1%	1%	0%	-1%	0%	1%	-1%	-1%	-1%
		75%	2%	0%	0%	1%	0%	0%	-1%	0%	0%	0%	0%	-1%
		99%	2%	0%	-1%	0%	1%	0%	0%	-2%	0%	0%	-1%	-3%

7.2.4.4 Monthly Flow-Duration Plots

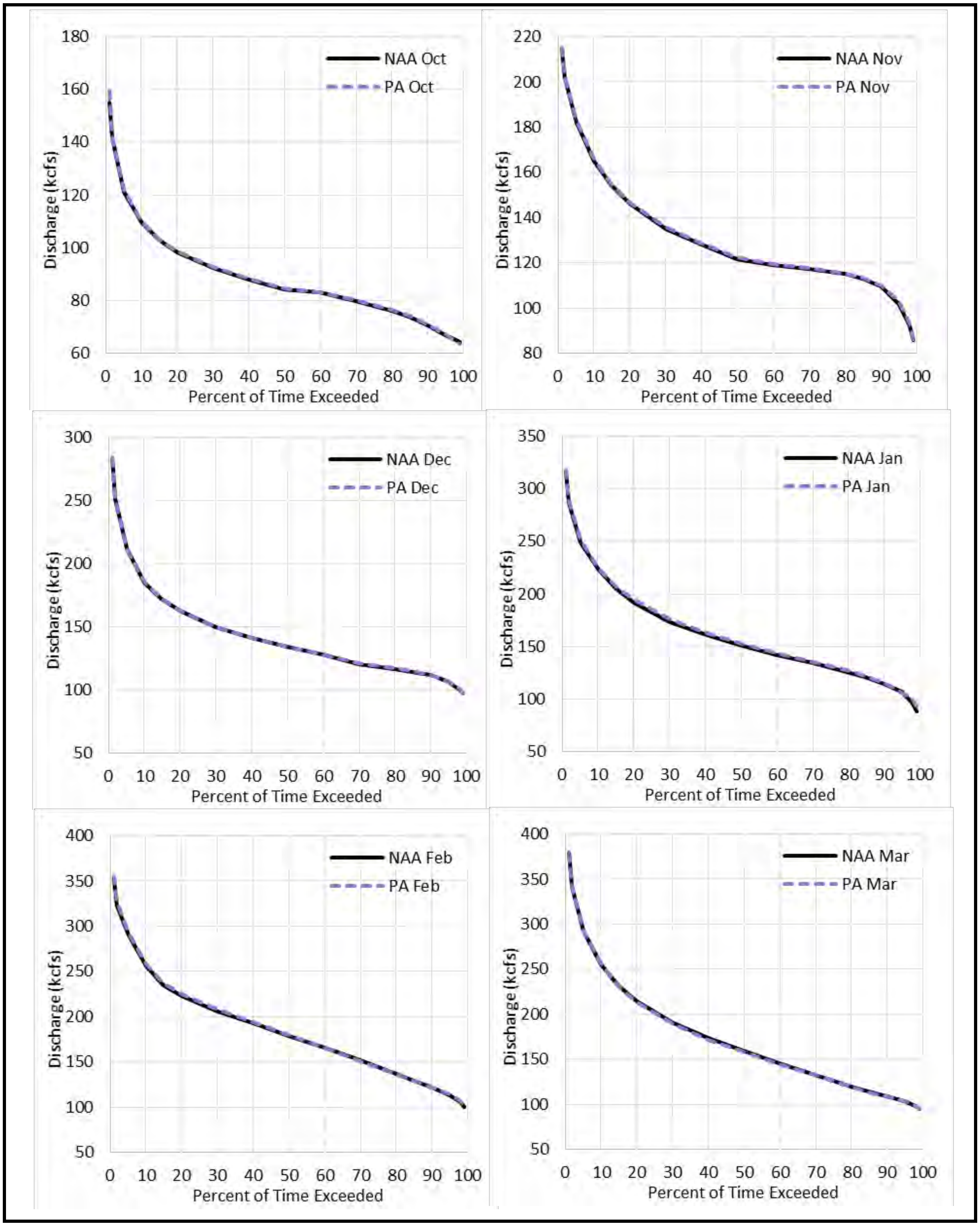


Figure 7-74. Monthly Flow-Duration Curves for McNary Dam Outflow for the Preferred Alternative and No Action Alternative, October through March

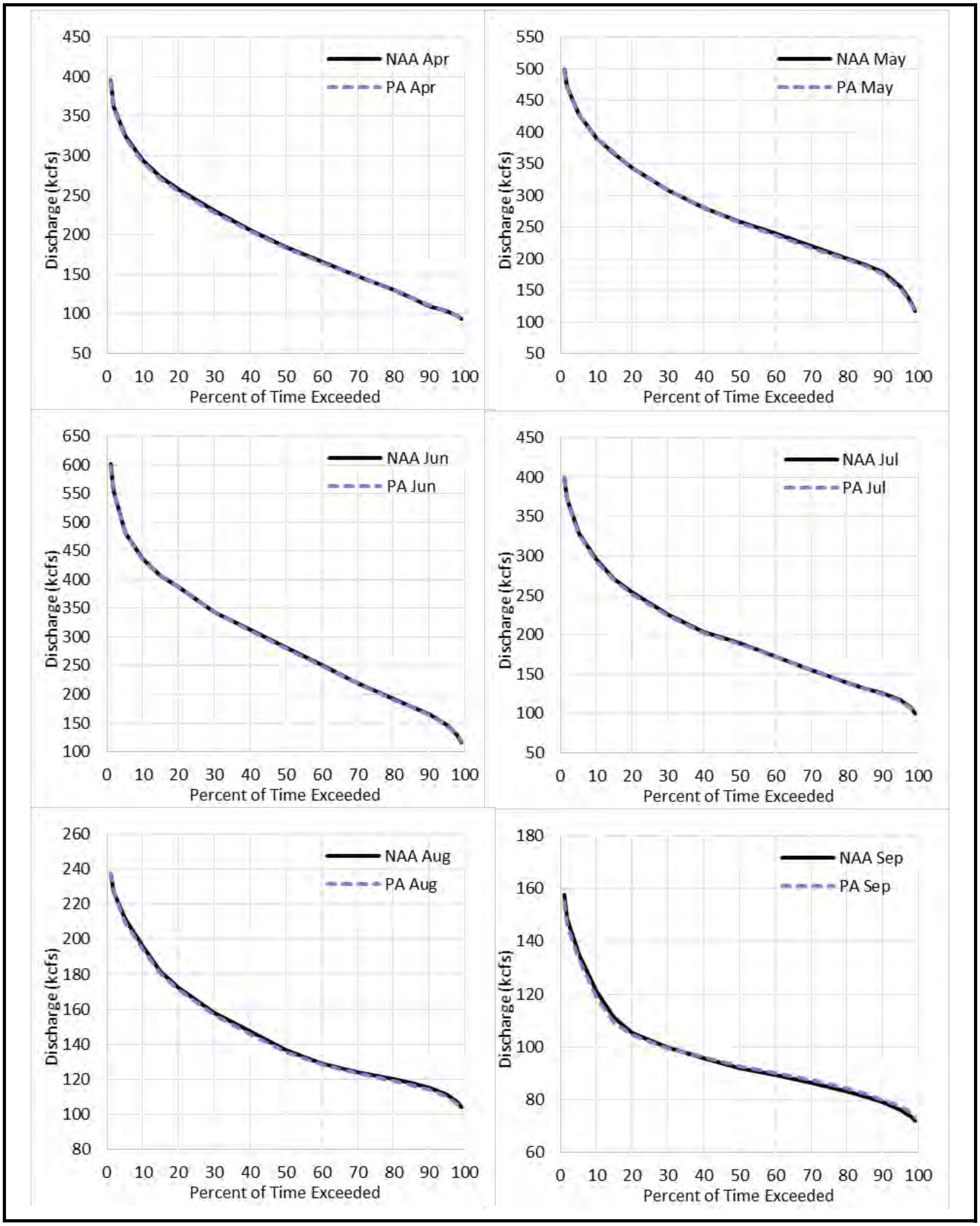


Figure 7-75, Monthly Flow-Duration Curves for McNary Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

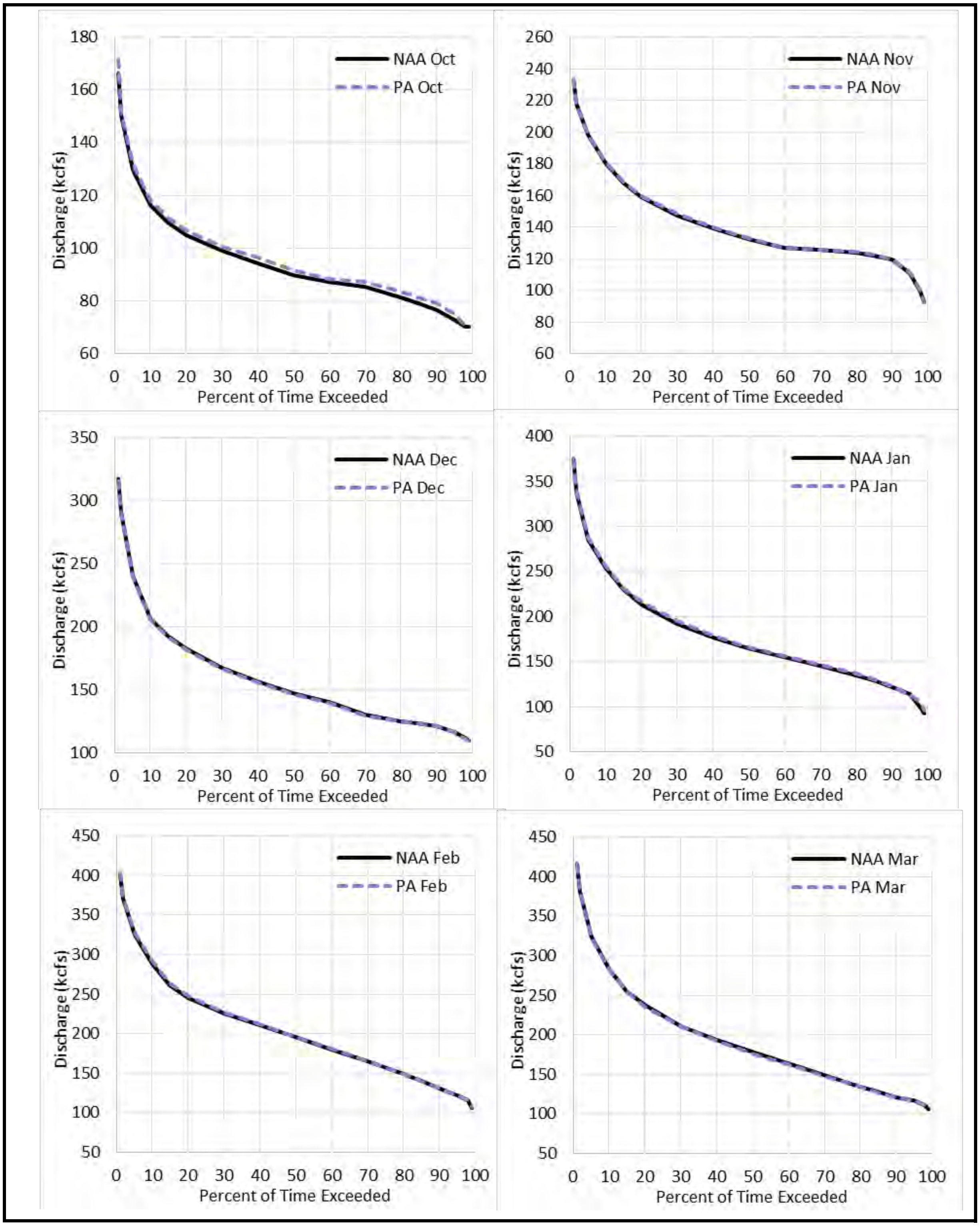


Figure 7-76. Monthly Flow-Duration Curves for Bonneville Dam Outflow for the Preferred Alternative and No Action Alternative, October through March

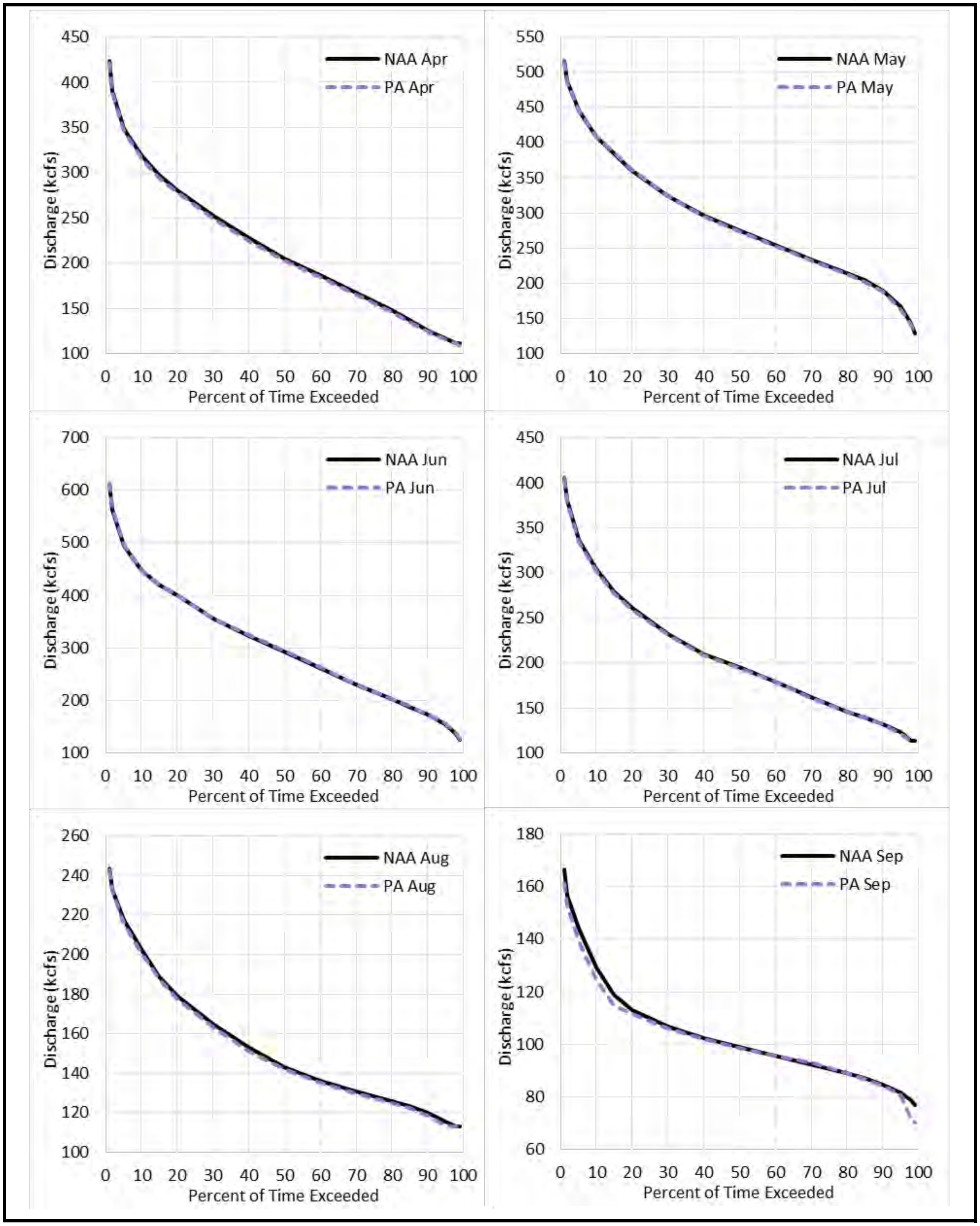


Figure 7-77. Monthly Flow-Duration Curves for Bonneville Dam Outflow for the Preferred Alternative and No Action Alternative, April through September

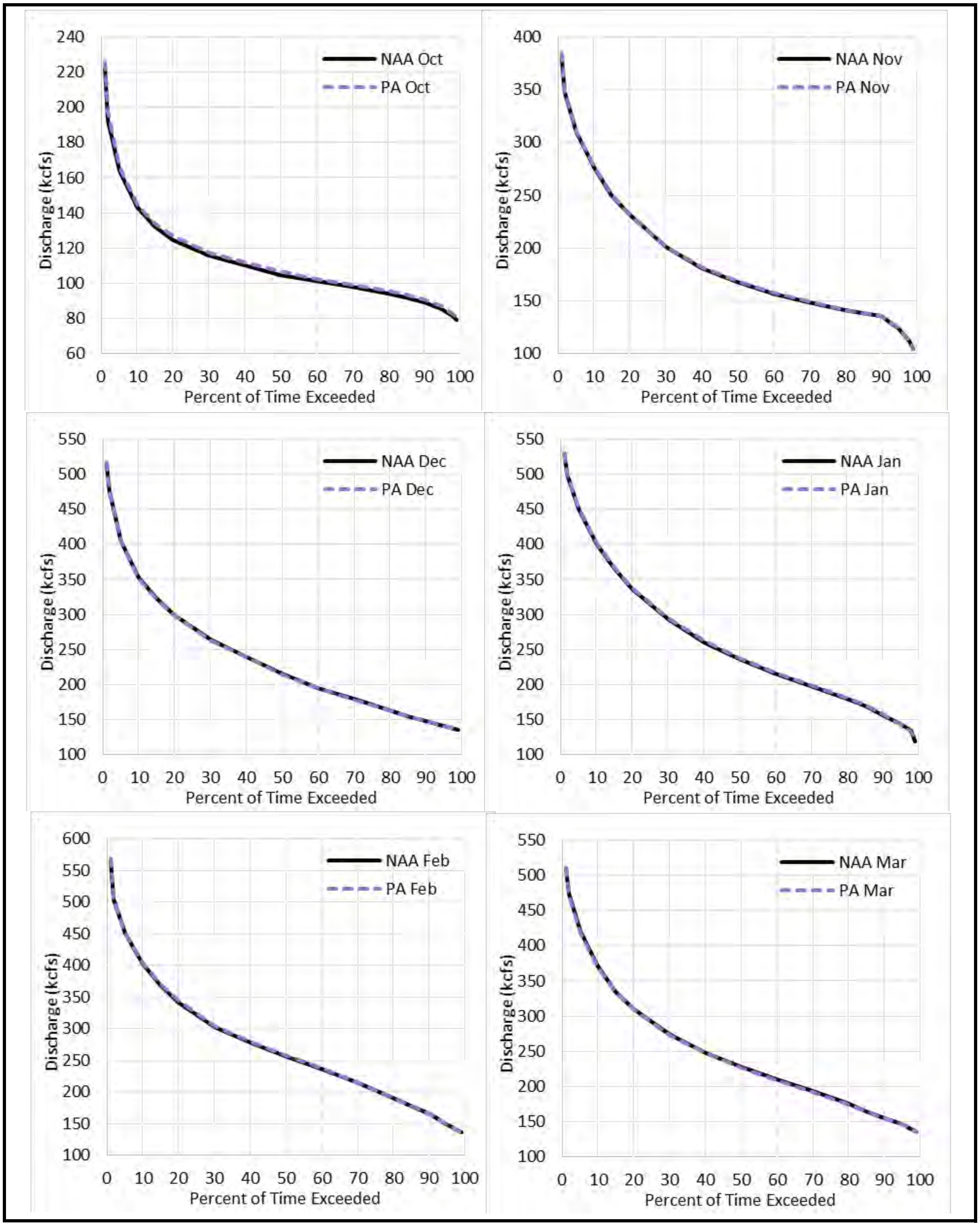


Figure 7-78. Monthly Flow-Duration Curves for Columbia River and Willamette River Confluence for the Preferred Alternative and No Action Alternative, October through March

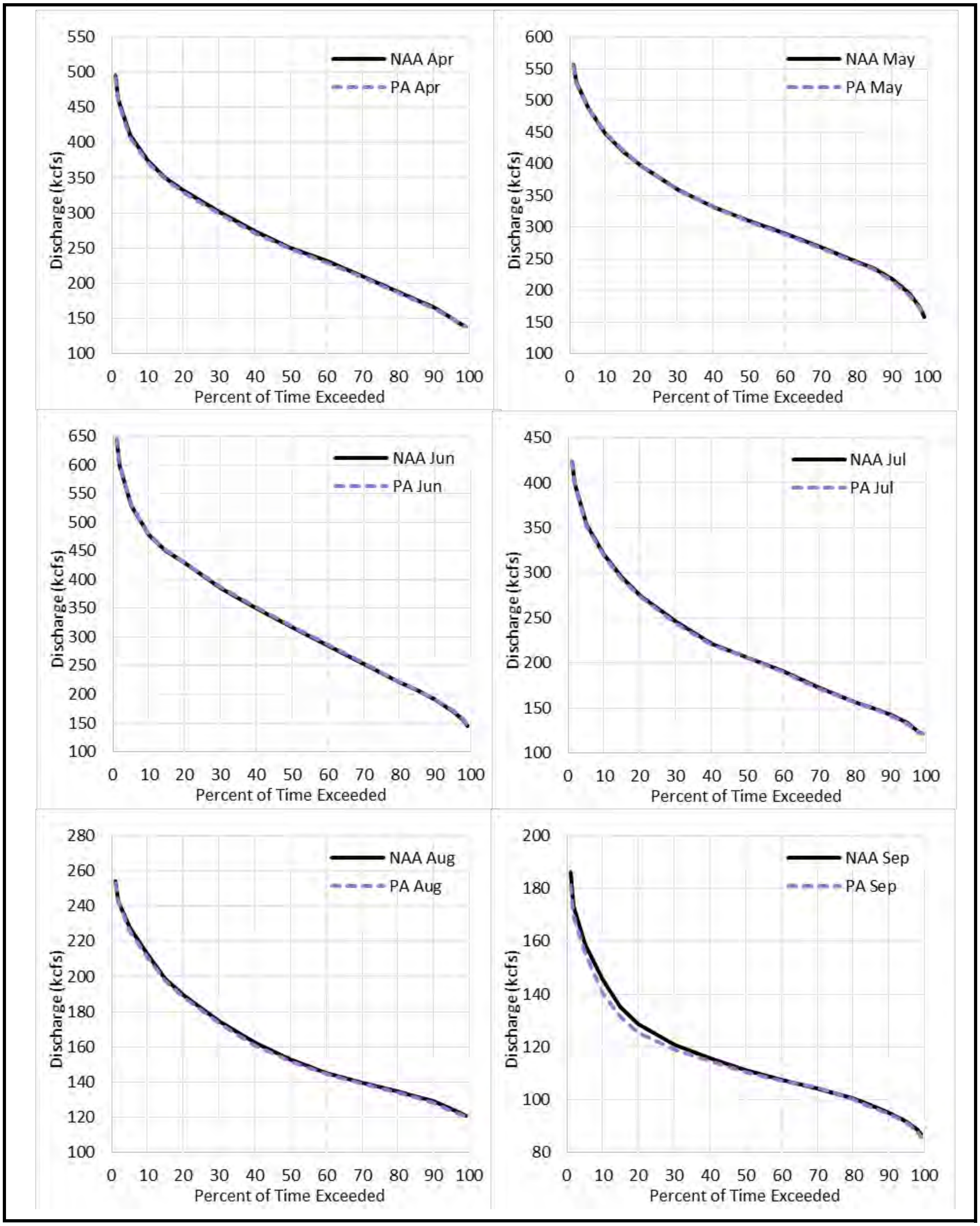


Figure 7-79. Monthly Flow-Duration Curves for Columbia River and Willamette River Confluence for the Preferred Alternative and No Action Alternative, April through September

7.2.4.5 Peak Flow-Frequency Plots

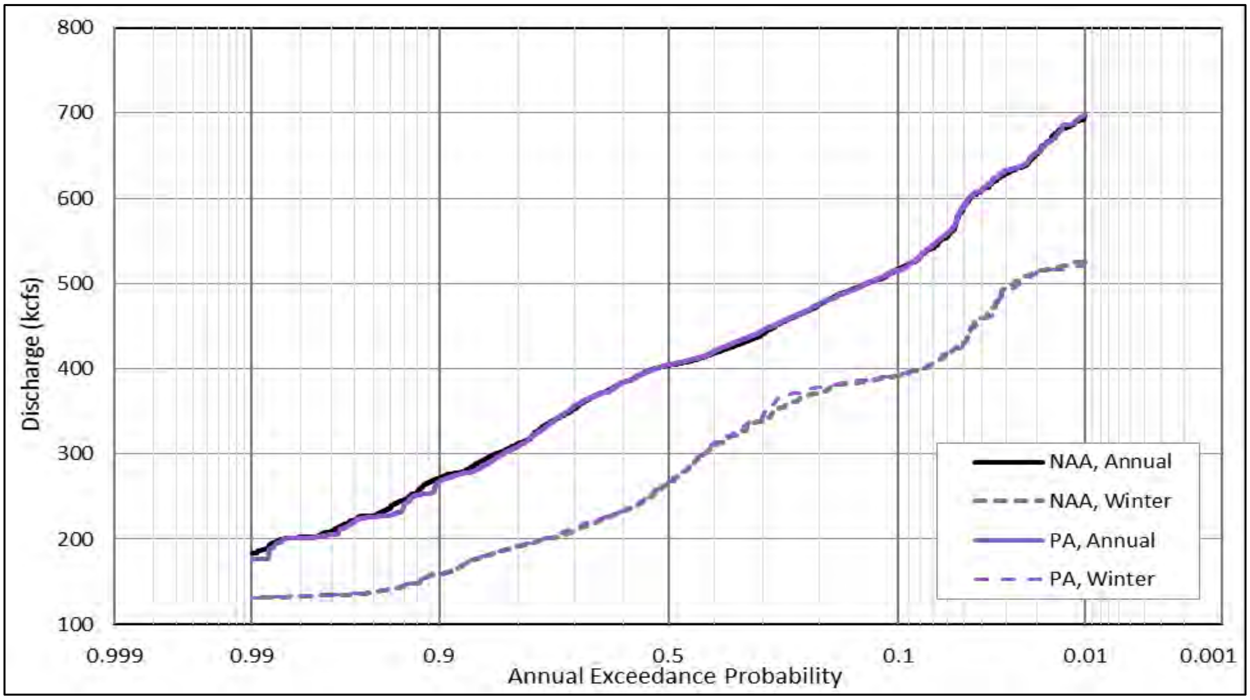


Figure 7-80. Peak Outflow-Frequency Curves for The Dalles Dam for the Preferred Alternative and No Action Alternative

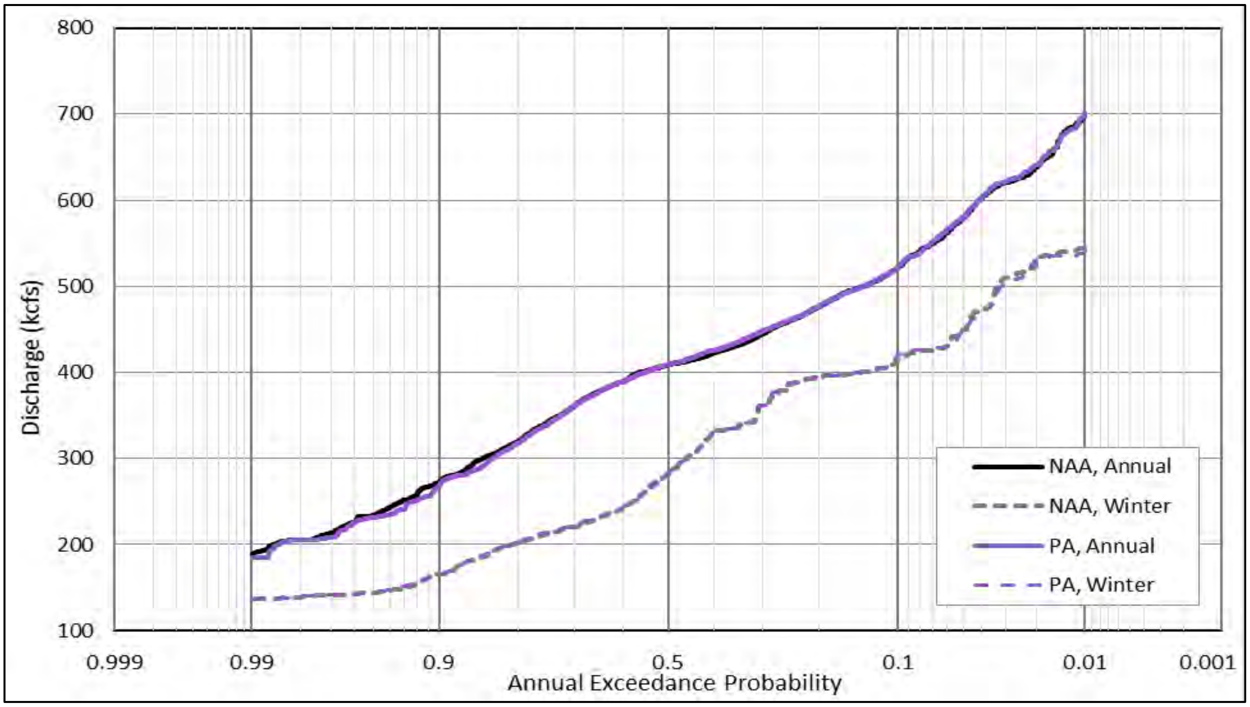


Figure 7-81. Peak Outflow-Frequency Curves for Bonneville Dam for the Preferred Alternative and No Action Alternative

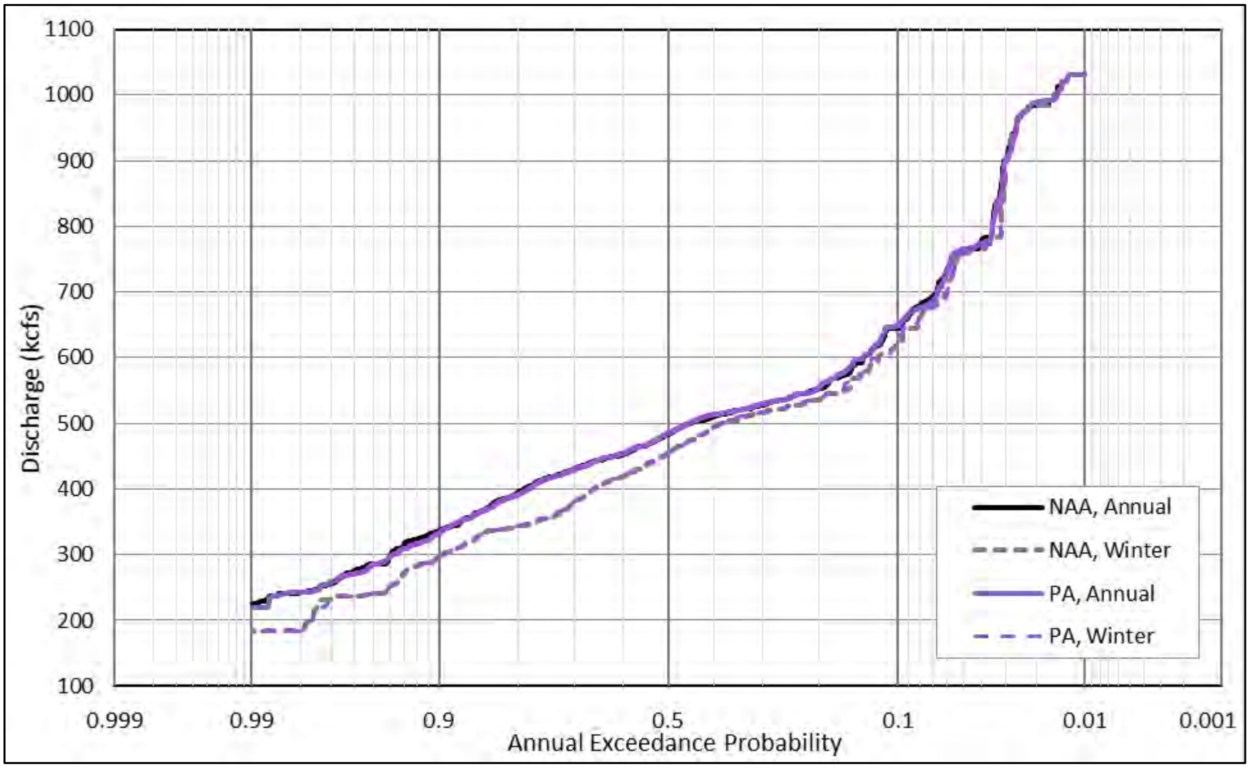


Figure 7-82. Peak Flow-Frequency Curves for the Columbia River and Willamette River Confluence for the Preferred Alternative and No Action Alternative

Draft Columbia River System Operations Environmental Impact Statement

Appendix B, Part 2
Spill Analysis

EXECUTIVE SUMMARY

PURPOSE OF TECHNICAL APPENDIX

This technical appendix documents the analysis of results from the Columbia River System hydroregulation modeling (Appendix B, Part 1) of the Columbia River System Operations (CRSO) Multiple Objective Alternatives (MOs), No Action Alternative, and the Preferred Alternative. The analysis presents results in terms of flow computed using the U.S. Army Corps of Engineers' (Corps') spill modeling tool.

ORGANIZATION OF THIS APPENDIX

This appendix consists of three parts:

- An overview of the methodology used to apply logic associated with reservoir operations and partition outflow into spill.
- A description of the analysis approach used to evaluate spill differences among alternatives. This section also elaborates on some caveats and other key details relating to different methods required for specific alternatives.
- An alternatives analysis, including a systemwide overview of differences amongst alternatives, followed by a more detailed evaluation of spill at each hydroelectric project.

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ACRONYMS AND ABBREVIATIONS

af	acre-feet
AEP	annual exceedance probability
ASW	adjustable spillway weir
BiOp	biological opinion
Bonneville	Bonneville Power Administration
CFD	computational fluid dynamics
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
EIS	environmental impact statement
HEC	Hydrologic Engineering Center
HydSim	Hydro System Simulator
IFP	improved fish passage
kaf	thousand acre-feet
kcfs	thousand cubic feet per second
LOM	lack of market
Maf	million acre-feet
MO	Multiple Objective Alternative
MOA	memorandum of agreement
MOP	Minimum Operating Pool
MW	megawatts
PA	Preferred Alternative
ResSim	Hydrologic Engineering Center Reservoir System Simulation software
TDG	total dissolved gas
WSE	water surface elevation
WAT	Watershed Analysis Tool

CHAPTER 1 - INTRODUCTION

This technical appendix documents the analysis of results from the Columbia River System Operations (CRSO) spill modeling of the CRSO Multiple Objective Alternatives (MOs), Preferred Alternative (PA), and the No Action Alternative (NAA). This appendix consists of three parts: (1) methodology, (2) analysis approach, and (3) alternatives analysis. The methodology reviews the algorithm and key concepts used to generate spill data for the CRSO analysis. The analysis approach section provides an overview of metrics, methods for examining causality of changes to spill flows, and modeling caveats. Lastly, the alternatives analysis section examines results from a systemwide perspective, then examines spill changes at individual hydroelectric projects (a dam and its associated reservoir).

This technical appendix has been prepared as documentation for the CRSO Environmental Impact Statement (EIS). Effects of the alternatives on river mechanics (e.g., sediment transport), groundwater, power, fish passage, etc., all of which may generally fall under the hydrology and hydraulics umbrella, are covered in separate appendices. Projects may occasionally be referred to using an acronym instead of the full name (e.g., LWG instead of Lower Granite) in tables, or as a group (e.g., lower Snake instead of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) in text or tables. Table 1-1 below may be used as a guide.

Table 1-1. Project Groupings

Acronym	Common Name	Project Group
BON	Bonneville	Lower Columbia
TDA	The Dalles	
JDA	John Day	
MCN	McNary	
IHR	Ice Harbor	Lower Snake
LMN	Lower Monumental	
LGS	Little Goose	
LWG	Lower Granite	
DWR	Dworshak	Dworshak
PRD	Priest Rapids	Middle Columbia
WAN	Wanapum	
RIS	Rock Island	
RRH	Rocky Reach	
WEL	Wells	
CHJ	Chief Joseph	
GCL	Grand Coulee	
HGH	Hungry Horse	Hungry Horse
LIB	Libby	Libby

CHAPTER 2 - SPILL METHODOLOGY

2.1 SUMMARY

The Corps Spill Allocator tool partitions the daily project outflows into powerhouse, force spill, fish spill, powerhouse bypass, lack of market (LOM), and miscellaneous spill at designated projects. The tool applies logic that accounts for thresholds imposed by spill caps and maximum/minimum powerhouse generation capability. Spill is computed at the following locations: lower Columbia, middle Columbia, lower Snake, Dworshak, and Hungry Horse. Spill at Libby Dam is computed by Hydrologic Engineering Center Reservoir System Simulation software (ResSim) because the project does not have any fish spill requirements nor is LOM spill allocated. Spill flows at Libby Dam are solely induced by flows above powerhouse capacity, which ResSim is capable of modeling.

2.2 SPILL COMPONENTS AND DATA SOURCES

Table 2-1 tabulates the input files used by the Spill Allocator script.

Table 2-1. U.S. Army Corps of Engineers Spill Allocator Data Sources and Descriptions

Input	Data Source	Description	Changing with CRSO MOs?
Availability Factor	Bonneville	Powerhouse availability	Yes
Spill Priority and Spill Cap	Corps	Sequential list of projects to allocate LOM spill	Yes
Waiver Spill	Corps	Default spill cap	Yes
Minimum Turbine Flow	Bonneville	Lower limit of powerhouse generation	No
Miscellaneous Spill	Corps (2018–2019 Data Submittal)	Lockage, leakage, sluiceway, fish ladder, etc.	No
Monthly LOM Spill (MW)	Bonneville, Aurora	MW value required for allocation of LOM spill	Yes
Fish Attraction Spill	Alternative Detailed Description	Time windows and flows for fish attraction to spillways at John Day and Bonneville Dam	Yes
Fish Spill	Alternative Detailed Description	Mandated fish spill	Yes
Powerhouse Bypass Flows	Alternative Detailed Description	Powerhouse surface passage flows (Additional Powerhouse Surface Passage measure)	Yes
Total Project Outflow	ResSim		Yes
H/K	ResSim	MW generation / kcfs turbine flow computed from ResSim efficiency and head (see H/K section in this document)	Yes
- Efficiency	ResSim		
- Head (ft)	ResSim		
Generation Capability (MW)	ResSim	Maximum possible generation accounting for hydraulic and generation limitations	No

Note: Bonneville = Bonneville Power Administration; kcfs = thousand cubic feet per second; MW = megawatts.

2.2.1 Availability Factors

Availability data is provided by Bonneville and used to define the fraction of available powerhouse flow/power. The availability is used in computing the maximum power generation:

$$\boldsymbol{P_{max} = \min\left(P_{capability}, P_{capacity} \cdot A\right)} \qquad \text{Equation 1}$$

where,

$P_{capability}$ = power if all available flow were routed through the powerhouse (MW)

$P_{capacity}$ = power from head-flow capacity rating curves (MW)

= $f_{Qout}(elev) \cdot {}^{h}\!/_{k}$

A = fraction powerhouse availability (unitless), (from Bonneville)

${}^{h}\!/_{k}$ = generation per unit flow (MW/kcfs), see Section 2.2.2

The P_{max} term is used to compute the limit used in Equation 2:

$$\boldsymbol{QT_{max} = \frac{P_{max}}{{}^{h}\!/_{k}}} \qquad \text{Equation 2}$$

The $P_{capability}$ term accounts for flow limitations because ResSim has already computed total outflows prior to the spill allocator process. The $P_{capacity}$ term accounts for availability limitations but ignores the actual outflow. Availability data is provided on a 14-period basis (Table 2-2). The months of April and August are both split mid-month to provide additional detail for those time periods; for additional detail, see Section 4.1.1.

Table 2-2. Example Percent Availability by Project

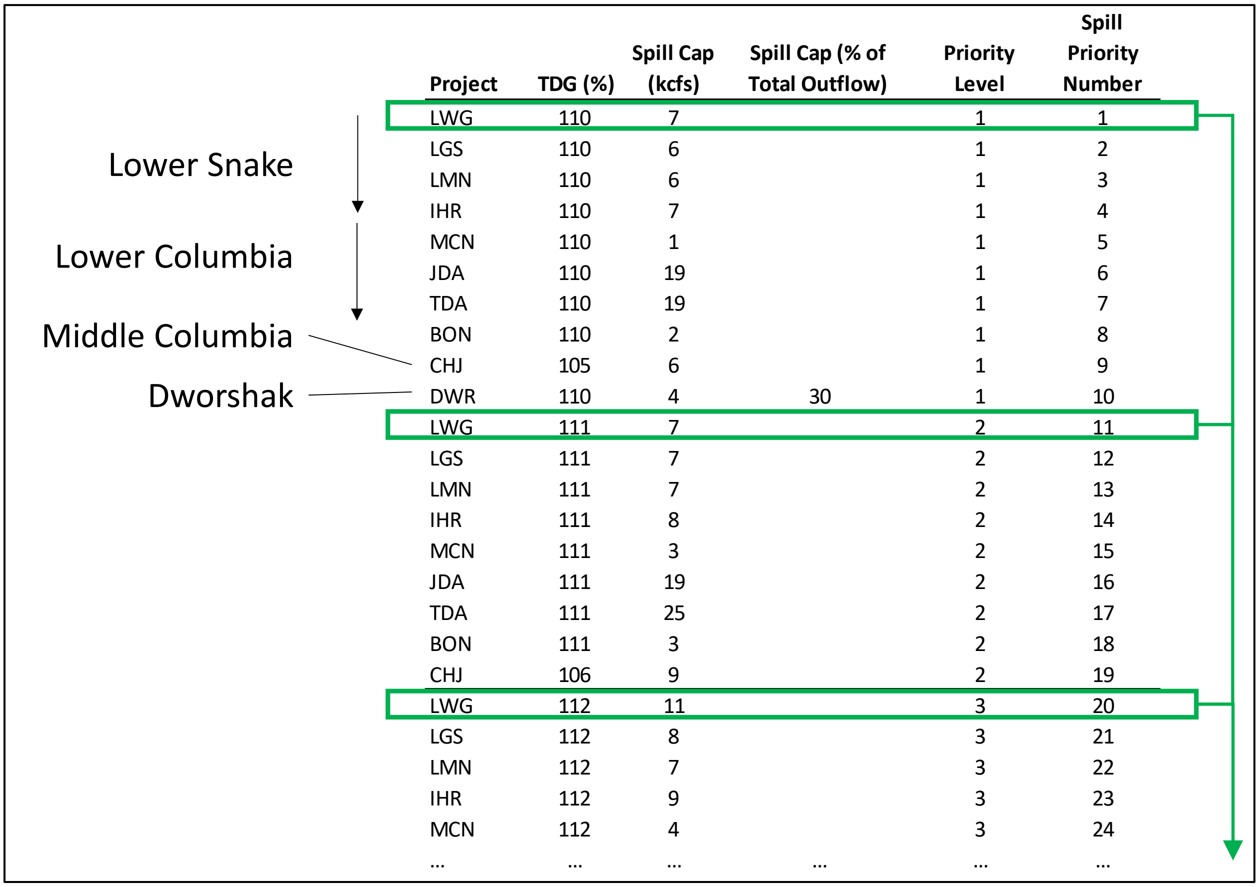
Project	JUL	AG1	AG2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN
GCL	68	67	67	58	53	53	53	53	58	57	60	60	61	65
LWG	76	63	63	69	70	70	82	76	82	83	85	85	85	85
MCN	76	75	75	65	62	64	69	71	71	71	76	76	76	71
PRD	100	100	99	90	100	100	100	93	90	96	100	100	100	100
RIS	88	96	96	92	88	88	90	96	88	88	88	88	88	89
RRH	90	90	90	90	90	90	90	90	90	90	90	90	90	84
TDA	75	74	74	82	74	77	79	84	77	76	75	75	77	76
WAN	100	91	90	90	90	90	90	90	90	90	90	90	90	99
WEL	100	92	92	82	87	92	92	92	92	92	92	92	100	100

2.2.2 Spill Priority List

The spill priority list dictates the order of projects in which to allocate LOM spill. In the No Action Alternative, Lower Granite Dam is the first project at which LOM spill is allocated from April through August; Bonneville Dam is first on the list from September through March. Middle

Columbia projects and Dworshak are always further down the spill priority list than the fish passage projects. There can be over 100 spill priority numbers, but with repeating projects. Each instance the project is listed on the spill priority list, the spill cap is increased from the prior entry (Figure 2-1). Dworshak is the only project that has a dual constraint for the spill cap; where the spill cap is the minimum of a flat flow rate and a percentage of the total outflow. The spill rates on the spill priority list are associated with percent total dissolved gas (TDG) values. The term priority level is used to define a set of projects and TDG values, which is a subset of the spill priority list for a given month. With each advancement of the priority level, the TDG is increased, and the projects from the previous level are repeated (Figure 2-1).

Chief Joseph Dam is prominent on the spill priority list because the project has spillway deflectors that are used to manage system TDG. In real-time operations, spill is often shifted from Coulee Dam to Chief Joseph under certain conditions to limit TDG production. In modeling, LOM spill is first applied at the Chief Joseph project via the spill priority list, mimicking the real-time preference for spill at Chief Joseph over Grand Coulee. Documentation of the differences between the spill priority lists used in current, real-time operations, Bonneville's Hydro System Simulator (HydSim) modeling, and Corps spill modeling are provided in Section 3.2.7.



Project	TDG (%)	Spill Cap (kcfs)	Spill Cap (% of Total Outflow)	Priority Level	Spill Priority Number
LWG	110	7		1	1
LGS	110	6		1	2
LMN	110	6		1	3
IHR	110	7		1	4
MCN	110	1		1	5
JDA	110	19		1	6
TDA	110	19		1	7
BON	110	2		1	8
CHJ	105	6		1	9
DWR	110	4	30	1	10
LWG	111	7		2	11
LGS	111	7		2	12
LMN	111	7		2	13
IHR	111	8		2	14
MCN	111	3		2	15
JDA	111	19		2	16
TDA	111	25		2	17
BON	111	3		2	18
CHJ	106	9		2	19
LWG	112	11		3	20
LGS	112	8		3	21
LMN	112	7		3	22
IHR	112	9		3	23
MCN	112	4		3	24
…	…	…	…	…	…

Figure 2-1. Example Spill Priority List for July, Highlighting Instances of Lower Granite

2.2.3 Waiver Spill

During the initialization process of computing spill flows, LOM conditions are ignored. However, a spill cap to set limits for fish spill is still required. In these instances, the waiver spill is used as a default spill cap. The waiver spill corresponds to a percentage TDG, and changes among MOs. For some of the MOs, the fish spill and waiver spill are equal (e.g., 120 percent TDG). The TDG tables that relate spill in thousand cubic feet per second (kcfs) to percentage TDG were generated through coordination between Bonneville and Corps.

2.2.4 Minimum Generation

To meet a base generation rate, all projects have a constant minimum generation that must be met at all times. Minimum generation flows are only superseded by miscellaneous and powerhouse bypass flows; all other flows including fish spill and LOM spill are decreased if minimum generation flows will not be met. The minimum generation values are unchanged among alternatives (Table 2-3).

Table 2-3. Minimum Generation Flows

Project	BON	TDA	JDA	MCN	IHR	LMN	LGS	LWG	DWR	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	HGH
Minimum Generation (kcfs)	30	50	50	50	9.5	11.5	11.5	11.5	1.5	10	10	10	10	10	50	30	3.65

2.2.5 Miscellaneous Spill

From the 2018–2019 Corps data submittal, miscellaneous flows are defined as follows:

> Miscellaneous flows include flows through fish ladders, juvenile bypass systems, ice and trash sluiceways, the Bonneville Powerhouse 2 Corner Collector, auxiliary water supply for fishways, and lockages. (Corps 2018, A-2)

For the lower Snake, lower Columbia, Chief Joseph, and Dworshak projects, this data was provided in the 2018–2019 Corps data submittal (Corps 2018). For the remaining middle Columbia projects, the following data was extracted from the 2015 Pacific Northwest Coordination Agreement (Table 2-4). No miscellaneous flows were assumed for Priest Rapids, Wanapum, Chief Joseph, or Grand Coulee. Miscellaneous flows are partitioned from the other flow categories in results plots. However, the miscellaneous flows are very small relative to the other flow types and may be visually indistinguishable on plots.

Table 2-4. Miscellaneous Flows (kcfs)

Project	JUL	AG1	AG2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN
DWR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
LWG	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.1	0.1	0.2	0.4	0.4	0.4	0.5
LGS	0.6	0.6	0.5	0.8	0.6	0.5	0.5	0.1	0.2	0.4	0.5	0.6	0.7	0.6
LMN	0.8	0.9	0.8	0.8	0.8	0.8	0.7	0.5	0.4	0.6	0.8	0.8	0.8	0.8
IHR	0.8	0.9	0.8	0.8	0.9	0.7	0.6	0.4	0.4	0.5	0.7	0.8	0.8	0.8
MCN	4.7	4.7	4.7	4.7	4.7	4.7	4.5	2.8	2.5	4.2	4.7	4.7	4.7	4.7
JDA	1.3	1.4	1.3	1.3	1.4	1.3	1.0	0.8	0.8	1.1	1.3	1.3	1.4	1.3
TDA	6.1	6.2	6.1	6.1	6.2	6.0	0.9	1.0	0.7	1.1	6.1	6.1	6.1	6.1
BON	11.5	11.5	11.5	6.9	6.5	7.0	5.0	3.2	3.8	10.6	11.5	11.5	11.5	11.5
RIS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
RRH	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4
WEL	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PRD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GCL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CHJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

2.2.6 Fish Ladder Attraction Flows

The Bonneville and John Day Dams have unique requirements for ladder attraction flows. As stated in the 2017 Fish Passage Plan (Corps 2017), ladder attraction flows are:

> John Day Dam: approximately 1.6 kcfs of spill occurs from Bay 2 during daylight hours between September 1 and November 30
>
> Bonneville Dam: approximately 1 to 2 kcfs of spill occurs from Bays 1 and 18 during daylight hours between September 1 and April 9

Ladder attraction flows are unchanged among CRSO alternatives, but the timing of ladder attraction is adjusted to accommodate different start and end dates of fish spill in the MOs.

2.2.7 Powerhouse Bypass Flows

Powerhouse bypass flows are included in each MO (see Table 2-5 for details). The flow is not included in the total spill summaries but is noted in plots and documentation where applicable. The powerhouse bypass flows produce an equivalent amount of TDG as spillway flows, and are therefore included in average daily total spill plots as additions to spill. The Increase Juvenile Fish Transportation measure in Multiple Objective Alternative 2 (MO2) dictates that juveniles should be collected from the bypass flow at McNary. The diverted flow at McNary used for collection would not contribute additional TDG. So, the McNary average daily total spill plot does not include the powerhouse bypass flows as an addition to total spill for MO2.

In the spill computation process, powerhouse bypass flows are treated identically to miscellaneous flows, in their own category of flow. Also, powerhouse bypass flows are deemed uncontrollable, and do not ramp down if they might encroach on minimum generation flows.

2.2.8 Lack of Market Spill

In general, lack of market (LOM) spill is caused by an imbalance of supply and demand in the power grid. The presence of the LOM condition does not indicate there is an excess power generation all of the time. In actual operations, LOM spill can change due to power grid demand, renewable energy generation changes, or other market impacts not directly related to system flow. An LOM condition occurs when there is greater supply than demand for a given time period (e.g., the total systemwide generation is 11 gigawatts, but the demand is 10.5 gigawatts). In these instances, hydropower generation must be reduced to meet demand by lowering generation across the system. Thus, the term “allocating lack of market” refers to the balancing of generation with supply by sequentially lowering generation at projects throughout the Columbia River Basin.

Bonneville provides monthly LOM spill data in MW of generation (Figure 2-2). This data is then modified to a daily basis with the assumptions that LOM spill is proportionate to the total daily system outflow. A daily modulation process is used to preserve the monthly megawatt-hours of LOM generation:

$$\boldsymbol{G_{LOM,\,Daily\ Total,\,i} = \left(\frac{Q_{system,i}}{Q_{system,\,monthly\ avg,\,i}}\right) G_{LOM,monthly\ avg,\,i}} \qquad \text{Equation 3}$$

where,

$Q_{system,i}$ $= \sum Q_{out,\,i}$ (for all projects on spill priority list)

$Q_{system,\,monthly\ avg,\,i}$ = monthly average LOM spill from Aurora

i = date index

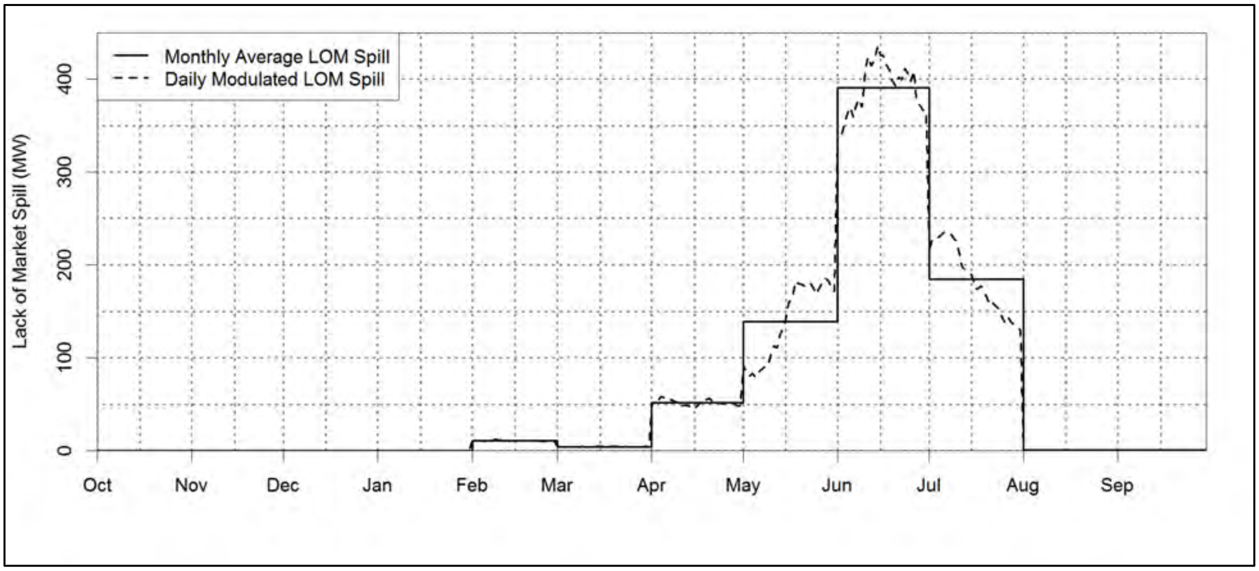


Figure 2-2. Monthly Lack of Market and Daily Modulated Lack of Market Spill (MW)

The ResSim model used to generate project outflows for the spill analysis does not have any power market input. Additionally, the LOM data is provided on a monthly basis from Bonneville and downscaled to daily, resulting in a smoothed LOM signal. The phenomena of LOM occurs on an approximately hourly time scale, and is much more abrupt than the smoothed daily signal used in the spill analysis. Thus, the volume of LOM flow maintained on a monthly basis is a more accurate representation than LOM predictions on a daily time scale.

Another consequence of the monthly-to-daily Hydsim-to-ResSim methodology is the occurrence of consecutive periods of force spill conditions followed by flows lower than turbine capacity. Because ResSim daily flows were calculated without consideration of power market conditions, there are periods where total outflows exceed the maximum turbine flow limits causing force spill directly adjacent to days where flows are significantly less than the maximum turbine limits. In current real-time operations, project outflows would be managed on a daily basis, operating to avoid force spill due to reaching maximum hydraulic capacity in the turbines. This would be accomplished by increasing outflows in anticipation of future force spill conditions, or by reducing total outflows to maximum turbine capacity and extending those flows into subsequent days. The result is the same volume of water being released but reallocated between adjacent days.

2.2.9 Fish Spill

The spill mandated for fish can be defined in several ways:

- Flat flow rate (e.g., 10 kcfs)
- Percentage of total outflow (e.g., 30 percent)
- Conditional upon another project's outflow

  e.g., Wells Dam fish spill is computed as a function of Chief Joseph Dam outflow:

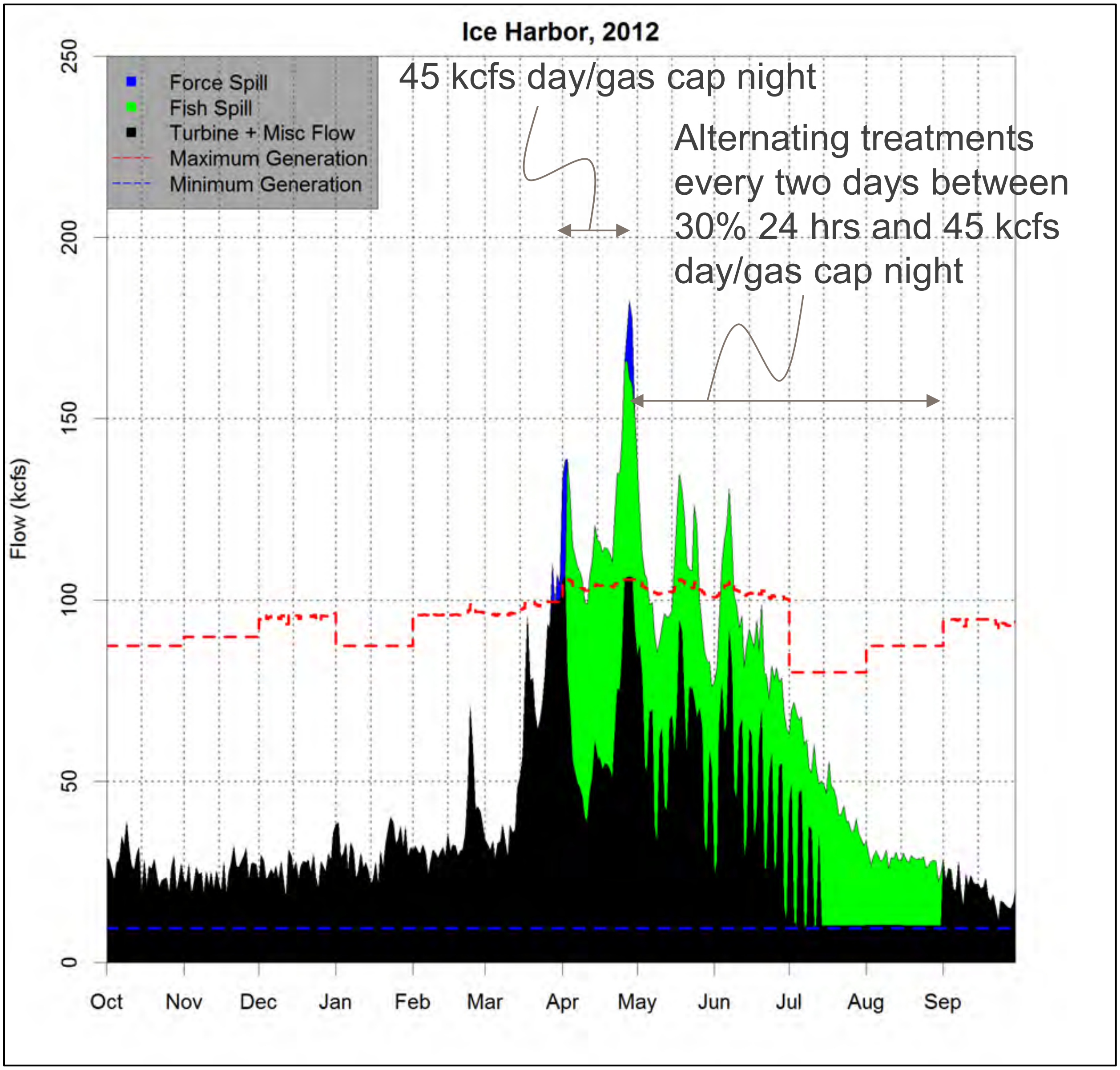
$$\boldsymbol{Q_{out,Wells}} = \begin{Bmatrix} (\mathbf{6.5}\%) \cdot \boldsymbol{Q_{out,Chief\ Joseph}} & \boldsymbol{Q_{out,Chief\ Joseph}} \geq \mathbf{140}\ \boldsymbol{kcfs} \\ \mathbf{10.2}\ \boldsymbol{kcfs} & \boldsymbol{Q_{out,Chief\ Joseph}} < \mathbf{140}\ \boldsymbol{kcfs} \end{Bmatrix} \quad \text{Equation 4}$$

Fish spill may also be defined on a sub-daily basis, with different flow types defined for day and night. For example, the requirement may be to spill 45 kcfs during the day and spill to the gas cap at night. In these instances, the fraction of day- or night-time hours are defined, and the average daily flow is computed as the hourly-weighted mean.

Additionally, fish spill may have a treatment component, where requirements alternate between blocks specified for a certain time period. For example, for Ice Harbor Dam, the requirements as specified in the 2017 Fish Passage Plan are as follows:

- **Spring Spill Operations April 3 through June 20:** Spill will begin at 45 kcfs day/gas cap night on April 3 and continue until April 28. On April 28, spill will alternate between 2-day blocks of 45 kcfs day/gas cap night and 30% /30% with the spillway weir operating and continue through the spring season. Nighttime spill hours are 1800–0500.
- **Summer Spill Operations June 21 through August 31:** Spill operations will continue from spring at 30% 24 hours per day vs. 45 kcfs day/Gas Cap night until July 13 at 0500 hours, then 45 kcfs day/Gas Cap night through August 31. (Corps 2017, E-12)

At Ice Harbor Dam, these alternating treatment requirements result in a jagged turbine flow pattern, as seen in Figure 2-3.



45 kcfs day/gas cap night

Alternating treatments every two days between 30% 24 hrs and 45 kcfs day/gas cap night

Figure 2-3. Flow Partitioning in Ice Harbor Dam from Example 2012 Dataset

2.2.10 Force Spill

Force spill may also be termed involuntary spill or lack of turbine spill. Force spill conditions occur when there is not enough powerhouse capacity to pass outflows, which most often occurs between April and August. Irrespective of other spill types, force spill is induced by the combination of effects from total outflow and powerhouse availability. Increased total outflows will increase force spill. Increased powerhouse availability will decrease force spill. In the example plot below, outflows are high enough to induce force spill at Lower Granite, beyond spill required for fish (Figure 2-4).

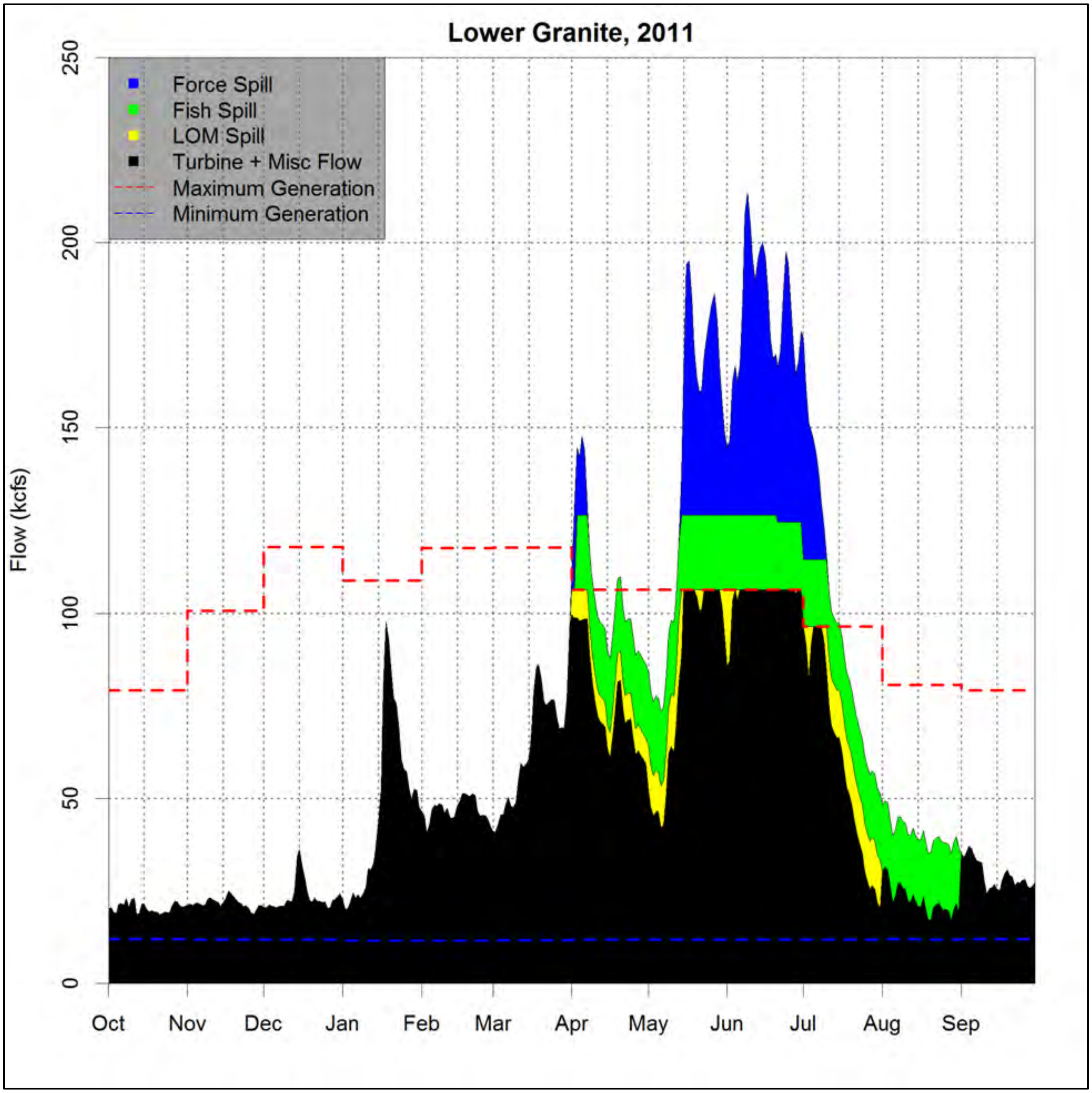


Figure 2-4. Example Force Spill Conditions at Lower Granite Dam in 2011

2.3 METHODOLOGY

Flow through each project is partitioned into multiple different components, based upon computation method (Table 2-5). The following section provides equations and descriptions for how the Corps spill tool parses flows into the various categories.

Table 2-5. Flow Categories Used in the Spill Allocation Process

Bulk Category	Category Name	Computation Method
Spill (QS_{Total})	Force (QS_{forced})	Computed as difference between total outflow and all other flow categories
	Lack of Market (LOM), (QS_{LOM})	Allocated to projects sequentially on spill priority list if there is available flow
	Fish (QS_{fish})	Fish operation parameters, limited by total outflow and minimum generation
	Fish Attraction ($QS_{attraction}$)	Constant value
	Powerhouse Bypass Flow ($Q_{PH\ Bypass}$)	Constant value
Lockage, Leakage, Sluiceway, Fish Ladder, etc.	Miscellaneous (Q_{misc})	Constant value
Powerhouse	Turbine (QT)	Limited by minimum and maximum generation; adjusted as needed to accommodate LOM and fish spill

2.3.1 Initialization of Flows

The fish passage spill requirements in any given alternative are known, along with project power generation characteristics. The first step in the spill allocation process is to compute the Infinite Market Case from the ResSim total flow. This case parses the total flow into fish passage spill and spill due to lack of turbine capacity without regard to market considerations (i.e., it assumes an unlimited demand or market depth) and there is no LOM spill computed.

A required fish spill ($QS_{fish,required}$) is computed from a lookup table that defines the project's spill criterion for a given time window. Note that the fish spill may be a percentage of the outflow, constant outflow, or contingent upon another project's outflow. The amount of spill for fish may be limited if inflows are insufficient to meet both the required fish passage spill and minimum turbine flow requirements such that,

$$\boldsymbol{QS_{fish} = minimum\begin{cases} QS_{fish,required} \\ QO - QT_{min} - Q_{misc} - Q_{Ph\ Bypass} \end{cases}} \quad \text{Equation 5}$$

where,

QT_{min} = minimum powerhouse flow, assumed constant for each project (kcfs)

QO = total outflow (kcfs)

Q_{misc} = miscellaneous flow: lockage, leakage, sluiceway, fish ladder, etc., derived from lookup table (kcfs)

$Q_{PH\ Bypass}$ = powerhouse surface bypass flow, derived from lookup table (kcfs)

Since the spill allocation does not change the reservoir operation, both total outflow (*QO*) and forebay elevation are known. Therefore $h/_{k}$ can be computed as a function of powerhouse efficiency and project head (i.e., the height difference between the forebay and tailwater). Additional information on the computation of the $h/_{k}$ term is provided in Section 2.2.3.

After calculating fish spill, the residual flow must be checked against the maximum generation limit. For purposes of this document, spill due to lack of *turbine* capacity is termed QS_{forced}.

$$\boldsymbol{QS_{forced} = maximum \begin{cases} QO - QS_{fish} - QS_{attraction} - Q_{misc} - QT_{max} - \ Q_{Ph\ Bypass} \\ 0 \end{cases}}$$

Equation 6

where,

QT_{max} = maximum turbine flow (kcfs)

QT_{max} = $Q_{PH\ Capacity,} * A$

$Q_{PH\ Capacity}$ = turbine generation capacity, determined by powerhouse rating curves

A = turbine availability factor, $0 \leq A \leq 1$, from lookup table (unitless fraction)

$QS_{attraction}$ = attraction spill, derived from a lookup table (kcfs)

Turbine flow (*QT*) may then be computed as:

$$\boldsymbol{QT = QO - QS_{Total} - Q_{misc} - \ Q_{Ph\ Bypass}} \qquad \text{Equation 7}$$

where,

QS_{Total} = total spill flow (kcfs)

= $QS_{fish} + QS_{attraction} + QS_{forced}$

The daily spill flows are first computed at each project assuming an Infinite Market Limit (i.e., there is no LOM spill). The next step is to compute LOM spill and adjust other flows as needed.

2.3.2 Allocating Lack of Market Spill

LOM data is currently supplied on a monthly basis in MW from Bonneville's AURORA (EPIS 2018) model results. Realistically, LOM generation is a daily or hourly phenomenon. So, the monthly LOM is modulated to a daily basis using the system flows. See Section 4.2 for more details. For each day, the total LOM generation is sequentially allocated to individual projects using a spill priority list.

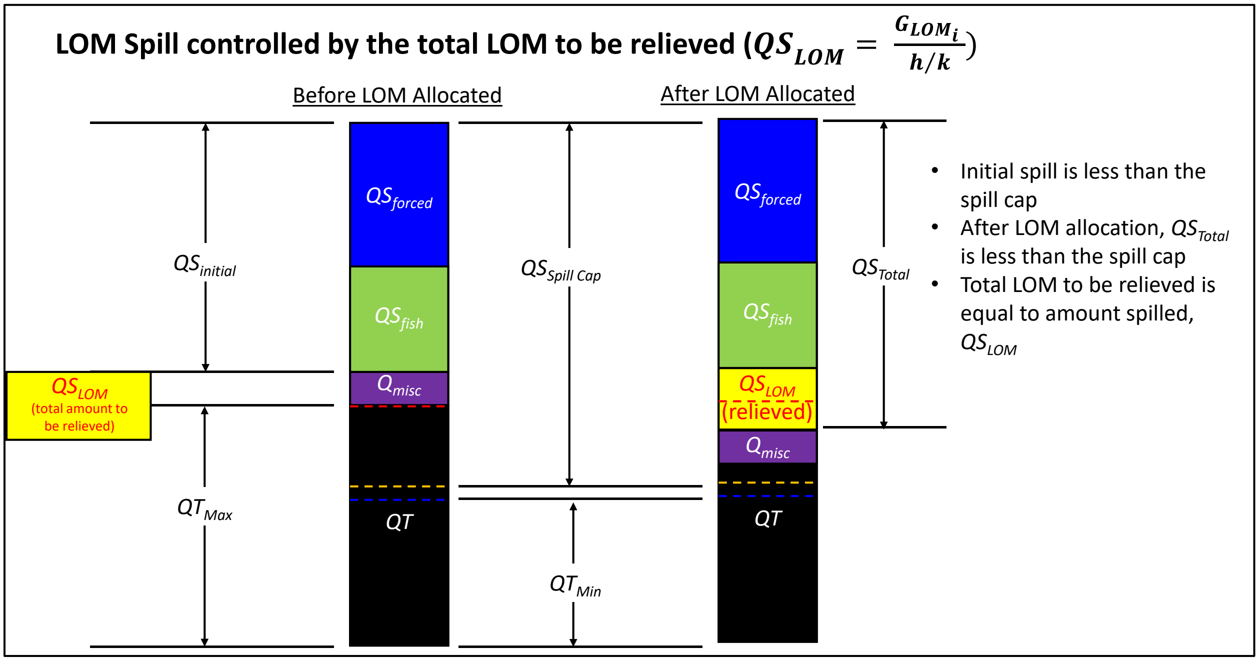
A project will relieve some fraction or all of the LOM spill if there is allocable spill available. In this case, the initial spill ($QS_{initial}$) includes spill for fish passage, force spill, and any LOM spill computed in prior advancements of the spill priority list. Equation 8 checks how much LOM spill can be allocated by accounting for the spill cap and minimum generation requirements. The term $\frac{G_{LOM_i}}{h/k}$ is all of the remaining LOM spill that needs to be allocated. The term $QS_{Spill\ Cap} - QS_{initial}$ is the allocable spill that is available for LOM spill up to the spill cap. Lastly, $QO - QS_{initial} - Q_{misc} - QT_{min}$ is the amount of spill that meets the minimum generation requirement. Any of these three terms may control the allocated LOM spill, so the minimum of these values is taken in Equation 8. The three scenarios where LOM spill is controlled by (1) total LOM spill, (2) spill cap, and (3) minimum generation are shown in Figure 2-5, Figure 2-6, and Figure 2-7, respectively. A fourth scenario where no LOM spill is relieved is shown in Figure 2-8.

$$\boldsymbol{QS_{LOM}} = \boldsymbol{minimum}\begin{cases} \dfrac{\boldsymbol{G_{LOM_i}}}{\boldsymbol{h/k}} & ;all\ of\ the\ lack\ of\ market\ spill \\ \boldsymbol{QS_{Spill\ Cap} - QS_{initial}} & ;spill\ up\ to\ the\ spill\ cap \\ \boldsymbol{QO - QS_{initial} - Q_{misc} - QT_{min} - Q_{Ph\ Bypass}} & ;meet\ minimum\ generation \end{cases}$$

Equation 8

where,

$QS_{Spill\ Cap}$ = spill cap from spill priority list for current priority order



- Initial spill is less than the spill cap
- After LOM allocation, QS_{Total} is less than the spill cap
- Total LOM to be relieved is equal to amount spilled, QS_{LOM}

Figure 2-5. Lack of Market Spill Controlled by the Total Lack of Market to be Relieved

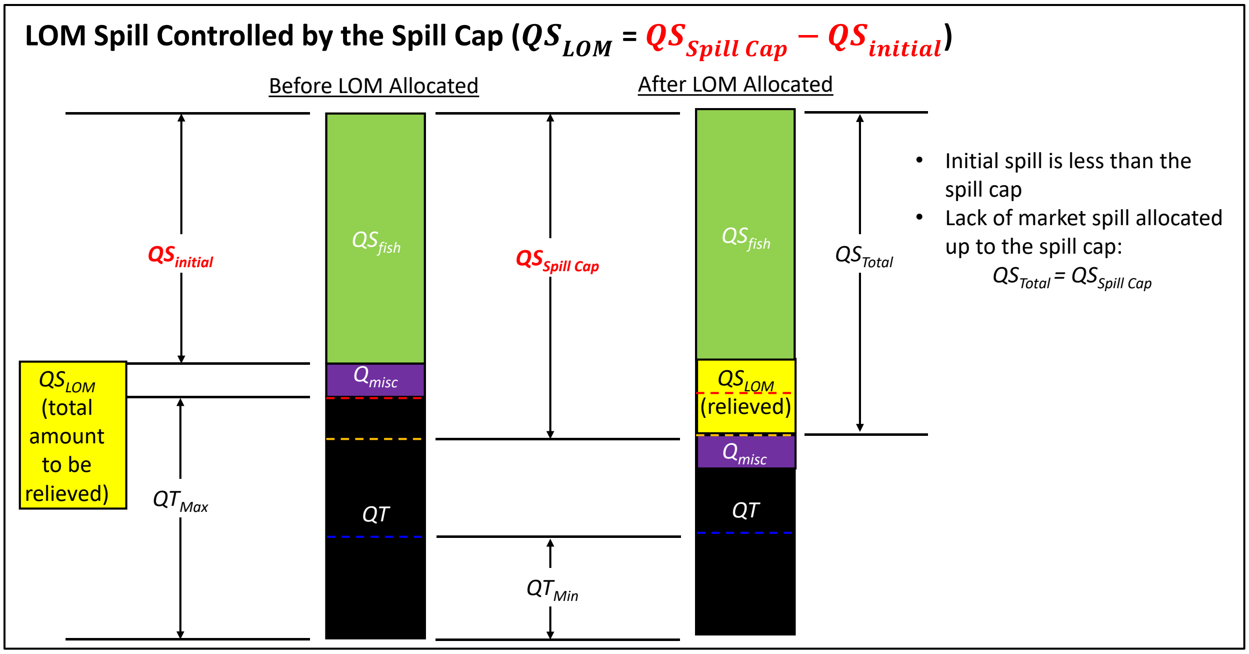


Figure 2-6. Lack of Market Spill Controlled by the Spill Cap

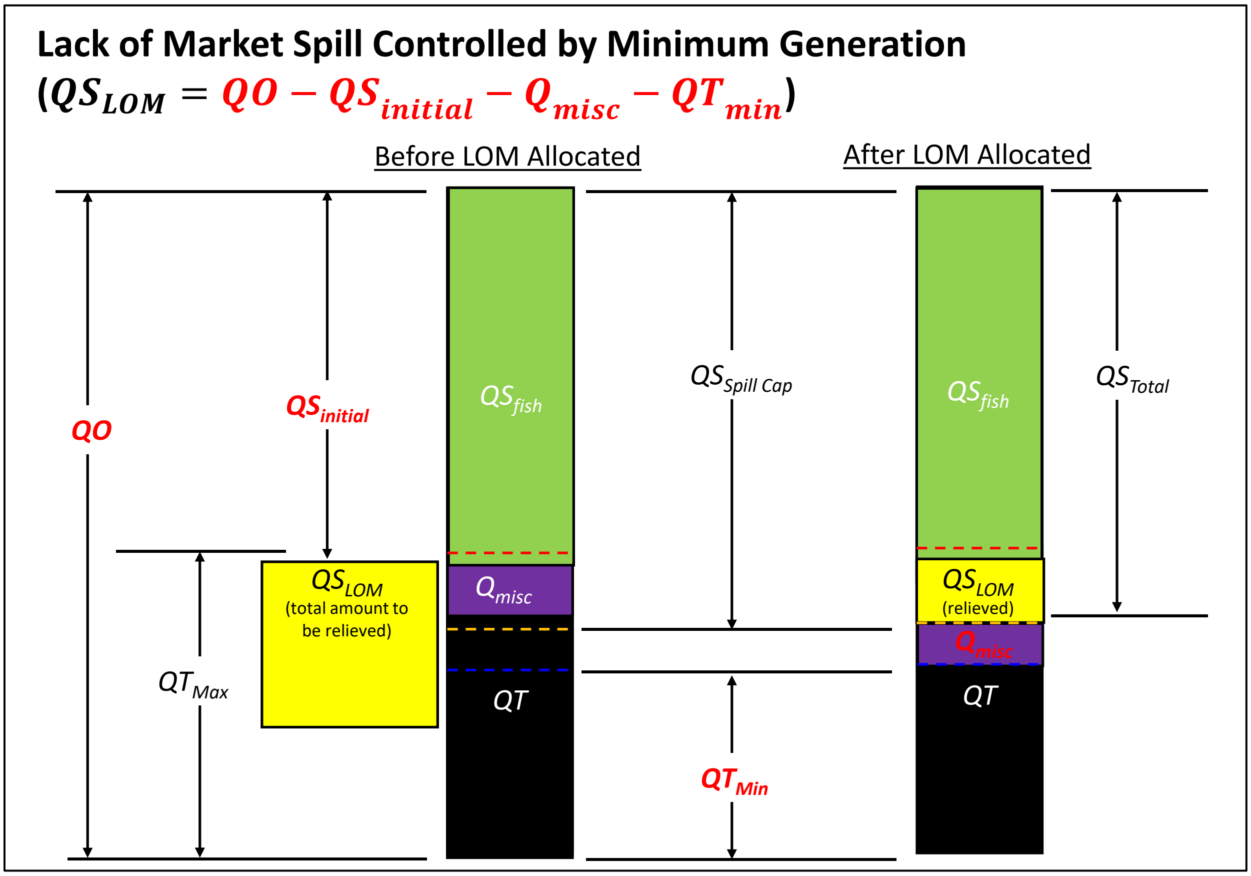


Figure 2-7. Lack of Market Spill Controlled by Minimum Generation Requirements

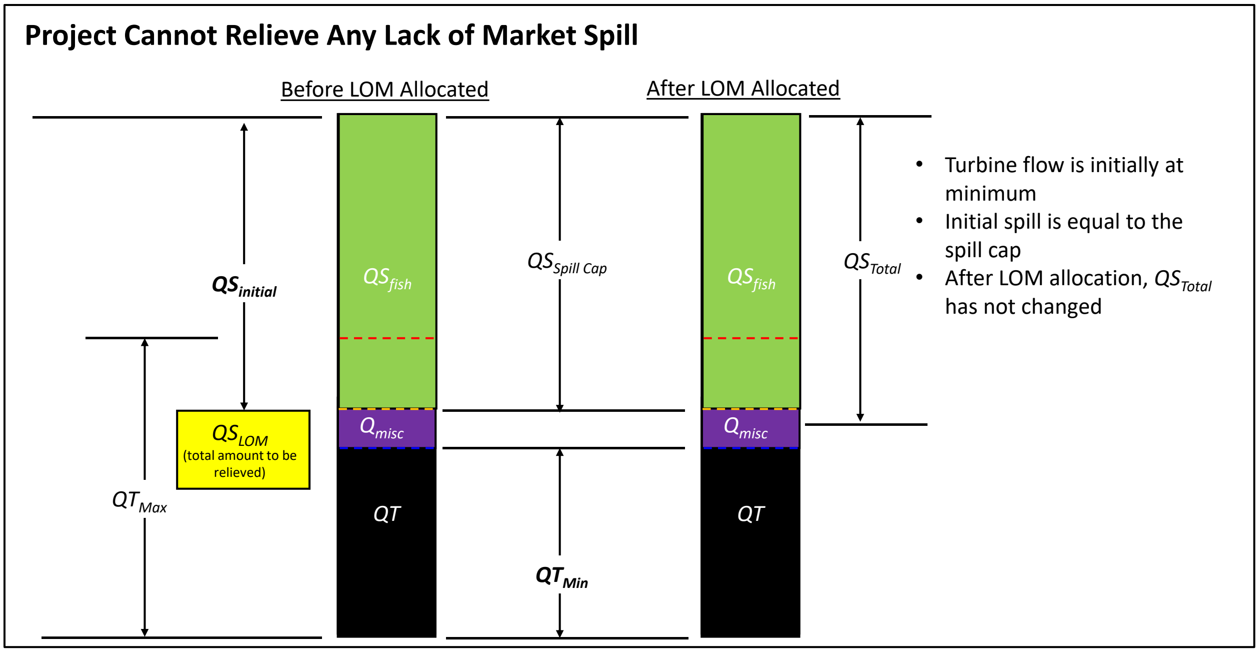


Figure 2-8. No Lack of Market Spill Relieved

In the scenarios where not all of the LOM spill is relieved (i.e., every scenario except where all of the LOM spill is allocated), the LOM term is updated:

$$G_{LOM_{i+1}} = G_{LOM_i} - QS_{LOM}(h/k) \qquad \text{Equation 9}$$

The new LOM generation, $G_{LOM_{i+1}}$, is then used to allocate LOM spill to the next project on the spill priority list, repeating the evaluation in Equation 8. This approach provides an allocation of LOM spill to derive total spill, using the total flow time series from ResSim, while approximating the hydro generation capability derived in the power impact analysis. The shape of ResSim flows does not include the power operation of load factoring within hours, days, and weeks and how that operation affects spill.

2.3.3 h/k

The term *h/k* is used to define the generation capacity per unit of flow, typically in units of MW and kcfs, respectively:

$$h/_k = eh\left(\frac{1}{11.815}\frac{MW}{ft\cdot kcfs}\right) \qquad \text{Equation 10}$$

where,

$h/_k$ = generation per unit flow (MW/kcfs)
e = efficiency (unitless fraction)
h = head (feet)

$= h_{HW} - h_{TW} - h_{Loss}$

h_{Loss} = hydraulic losses in dam (ft)

h_{HW} = headwater elevation from ResSim (ft)

h_{TW} = tailwater elevation from ResSim (ft)

Assumptions:

h_{Loss} = 0 ft for all projects

Equation 10 is simply a rearranged form of the power equation. In ResSim, outputs are available for both *e* and *h* on a daily basis. Using the above formula, the MW generation per kcfs of flow is computed for each day. The *h/k* values are then used to convert between power generation and flow.

CHAPTER 3 - SPILL ANALYSIS APPROACH

3.1 ALTERNATIVES ANALYSIS

The intent of this document is to present results so that impact teams can focus on relevant areas of change. Changes in spill at projects are made in comparison to the No Action Alternative, and typically referenced as averages over time periods, not specific water years. Flow changes may also be described quantitatively or qualitatively as increasing or decreasing relative to the No Action Alternative, with figures for visual reference.

3.1.1 Alternative Measures Directly Affecting Spill

Table 3-1 shows all of the measures affecting spill in each alternative and notes the specific spill metric being altered by the measure. Measures that affect the total outflow from projects are not noted here. Measures that affect fish spill typically have the largest impact on total spill.

Table 3-1. Columbia River System Operations Measures Affecting Spill

CRSO Measure	MO1	MO2	MO3	MO4	PA	Spill Metric Being Affected
Construct JDA/MCN/IHR powerhouse surface passage routes		X				Other Spill
Construct MCN/IHR powerhouse surface passage routes	X					Other Spill
Construct MCN powerhouse surface passage routes			X	X		Other Spill
Construct additional powerhouse surface passage routes to meet system-wide PITPH target				X		Other Spill
Upgrade spillway weirs to Adjustable Spillway Weirs (ASWs)	X	X	X		X	Minimum Spill
No installation of fish screens						Availability
No installation of fish screens at Ice Harbor, McNary and John Day projects		X			X	Availability
No installation of fish screens at McNary project			X			Availability
Install new "fish-friendly" and high-efficiency/capacity turbines at John Day	X	X	X	X	X	Availability
Addition of spillway weir notch gate inserts				X		Fish Spill
Remove earthen embankments and adjacent structures, as required, at each LSR dam			X			Spill Priority List, Projects Removed from Compute
Flex spill operation to 125% TDG					X	
Use spill through existing surface passage structures for steelhead				X		Fish Spill
Conduct spill test to evaluate latent mortality hypothesis	X					Fish Spill
Low powerhouse encounter rate (PITPH) during spring emigration period				X		Waiver Spill Caps and Fish Spill

CRSO Measure	MO1	MO2	MO3	MO4	PA	Spill Metric Being Affected
Modify summer juvenile fish passage spill operations	X					Fish Spill
Reduce the duration of summer juvenile fish passage spill			X			Fish Spill
Allow contingency reserves to be carried within juvenile fish passage spill	X	X	X	X	X	Availability
Limit fish passage spill to 110 percent total dissolved gas (TDG)		X				Waiver Spill Caps and Fish Spill
Modify spring juvenile fish passage spill by applying results of performance std testing			X			Fish Spill
Operational constraints for ongoing Grand Coulee maintenance of power plants	X	X	X	X	X	Availability
Operate turbines across their full range of capacity year-round		X	X	X		Availability
Operate turbines within and above 1% peak efficiency only			X	X	X	Availability
Zero Generation Operations may occur on the Lower Snake River projects November – February*		X			X	Availability

Note: ASW = adjustable spillway weir; MO1 = Multiple Objective Alternative 1; MO3 = Multiple Objective Alternative 3; MO4 = Multiple Objective Alternative 4; PA = Preferred Alternative; PH = Powerhouse; PITPH = Powerhouse Encounter Rate.

1/ Changed in errata.

3.1.2 Lines of Evidence Used to Determine Causes of Change in Spill

There are multiple possible reasons why an alternative measure would cause spill at a project to be different from spill in the No Action Alternative. Changes to the fish spill operations (e.g., modifying fish spill at Bonneville Dam from 100 kcfs to 220 kcfs) or spill caps (e.g., limiting spill to 110 percent TDG instead of 115 percent) produce the most obvious and direct effects on spill. Additionally, increased total outflow at a project, as a result of reservoir operation changes, will increase total spill during force spill conditions. Modifying total outflow at an upstream project like Grand Coulee will change outflow at all downstream projects. Spill changes caused by availability and LOM differences are less obvious to detect. Changes to availability will adjust the powerhouse capacity, which in turn will produce different spill during force spill conditions (Figure 3-1).

Increased LOM will increase the amount of spill systemwide. However, the projects where LOM spill will occur depends upon the capacity of each project to uptake LOM (i.e., the difference between the current spill cap and total spill). LOM flow’s contribution to a project’s flow changes are determined by looking at the magnitude of LOM flow relative to that of total spill flow.

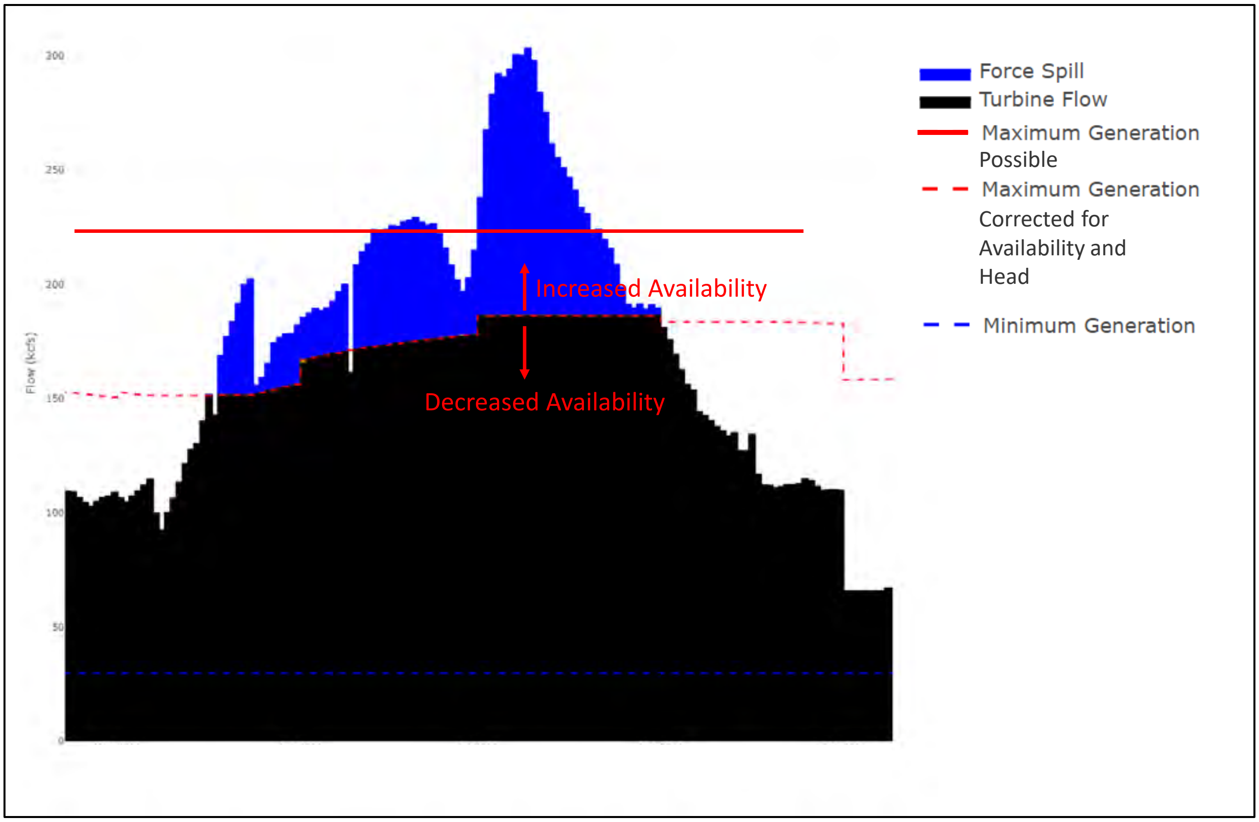


Figure 3-1. Example Flow Hydrograph Demonstrating How Availability Affects Force Spill

3.1.3 Multiple Objective Alternative 1 Spill Operations and Plots

MO1 is unique in the way that spill was modeled; it is the only alternative where there are variations in spill operations between years. Spill operations are classified as either test or base spill. Base spill has similar spill operation to the No Action Alternative, while test spill is typically a higher spill target. This spill operation is also termed “50/50 block design” in the detailed alternative descriptions. Fish spill operations change each year, alternating between starting with test or base spill. Mid-season, on May 11, operations change from base/test spill to test/base spill. The timing of the start and end times of fish spill operations also change between the lower Snake and lower Columbia projects. The time windows of fish spill operations for MO1 are defined below, with alternate end dates provided for each project on the lower Snake River:

Lower Snake

- April 3 to May 11: Base/Test Spill
- May 12 to June 19: Test/Base Spill
- June 20 to August * Summer Spill
    - * LWG ends August 18; LGS ends August 21; LMN and IHR end August 6

Lower Columbia

- April 10 to May 11: Base/Test Spill
- May 12 to June 19: Test/Base Spill
- June 20 to August 31: Summer Spill

Displaying results on a daily average basis does not adequately capture the base and test spill operations. So, additional plots are provided in Sections 4.8 through 4.15 for displaying the separated base and test spill operations in MO1, averaged daily over the extended period of record (i.e., water years 2008 through 2016). The MO1 analysis was first conducted on the base and test spill operations separately, with the same base/test operation occurring for the entire early April through to June 9 spill block period and repeating each year. The results were then spliced together to create spill operations that alternate each year. The separate base and test spill plots (e.g., Figure 4-2are derived from the separate base and test analyses. The separated spill operations plots are not representative of actual MO1 operations in a given year, but provide context for the extent to which test and base operations change from the No Action Alternative. The combined project plots for each alternative (e.g., Figure 4-1) show MO1 results from the spliced spill operations.

Tables are provided with the separate test and base spill operations used at each project. Spill cap tables that do distinguish between test or base operations have the same spill cap applied to both operations.

3.2 CAVEATS AND DISCLAIMERS RELATED TO SPILL MODELING

3.2.1 Impact of Runoff Volume on Spill

The response of spill to a given alternative will be contingent upon the type of water year examined (i.e., high, average, or low runoff volume). This analysis does not assess the impacts of runoff volume on spill between alternatives. However, some generalizations can be made about changes in spill with respect to runoff volume and/or flow rates. Average flow conditions (i.e., flow that is both sufficient to meet turbine generation, and not drastically exceed the maximum powerhouse capacity) will be most sensitive to measures in alternatives with respect to spill. During low water years, it is more likely that minimum generation requirements will limit both fish passage spill and the amount of LOM spill that can be allocated at a project. Also, during a high water year, the effects of an alternative’s variation in LOM and fish passage spill will be damped by force spill conditions. Therefore, during an average water year, alterations to fish passage spill and LOM conditions will be more impactful.

3.2.2 80-Year and 9-Year Dataset Comparability

Two different datasets were derived from each alternative analysis: an 80 year (period of record, water years 1929 to 2008) and a 9 year (extended, water years 2009 to 2016). These periods contained different water years with different flows, and therefore result in different results with respect to spill. The 9-year dataset was created to provide input flows to water quality analysis; the reduced size of the dataset, and more recent years for analysis facilitate better quality control. However, general trends in the datasets are the same with respect to differences from the No Action Alternative, and any conclusions derived from the 9-year dataset about fish passage spill are equally applicable to the 80-year dataset. Differences in the average total outflow between the datasets does cause some differences in spill at the non-fish passage projects and during winter months. The monthly average spill proportion does not differ by more than 5 percent between the 9-year and 80-year datasets, with the exception of Dworshak. Outflows from Dworshak are more sensitive to spill because the flows are much lower relative to the lower Snake and lower Columbia projects. Changes in spill of several kcfs can shift the proportion of spill at Dworshak by a large amount (i.e., change in average spill of 1 kcfs is more impactful at Dworshak than it would be on spill passage projects).

3.2.3 Multiple Objective Alternative 2 Modified Spill Priority List

One of the primary objectives of the MO2 measures is to provide an adequate, efficient, economical, and reliable power supply. To meet this objective, the spill priority list was modified to decrease the amount of LOM spill allocated to the lower Snake River projects. This was accomplished by rearranging the order of the spill priority list in April through August, so that LOM spill is first allocated to the lower Columbia projects. The April through August project order for the first priority level is: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, Dworshak, then Chief Joseph. An example of the July spill priority list for MO2 is provided in Table 3-2. As described in Section 2.2.2, the spill priority list advances in 1 percent TDG increments between priority levels, which deviates from the spill priority list used by Bonneville modeling and current, real-time operations.

Table 3-2. Multiple Objective Alternative 2, July Spill Priority List

Project	TDG (%)	Spill Cap (kcfs)	Spill Cap (% of Total Outflow)	Priority Level	Spill Priority Number
BON	110	2		1	1
TDA	110	19		1	2
JDA	110	19		1	3
MCN	110	1		1	4
IHR	110	7		1	5
LMN	110	6		1	6
LGS	110	6		1	7
LWG	110	7		1	8
DWR	110	4	30	1	9
CHJ	105	6		1	10
BON	115	49		2	11
TDA	115	73		2	12
JDA	115	78		2	13
MCN	115	83		2	14
IHR	115	12		2	15
LMN	115	10		2	16

3.2.4 Multiple Objective Alternative 3 Modified Spill Priority List

The spill priority list needed to be modified in MO3 to accommodate the absence of the lower Snake projects. This was done by simply removing the MO3 projects from the spill priority list, while also preserving the same TDG levels at all other projects. An example of the July spill priority list for MO3 is provided in Table 3-3. As described in Section 2.2.2, the spill priority list advances in 1 percent TDG increments between priority levels, which deviates from the spill priority list used by Bonneville modeling and current, real-time operations.

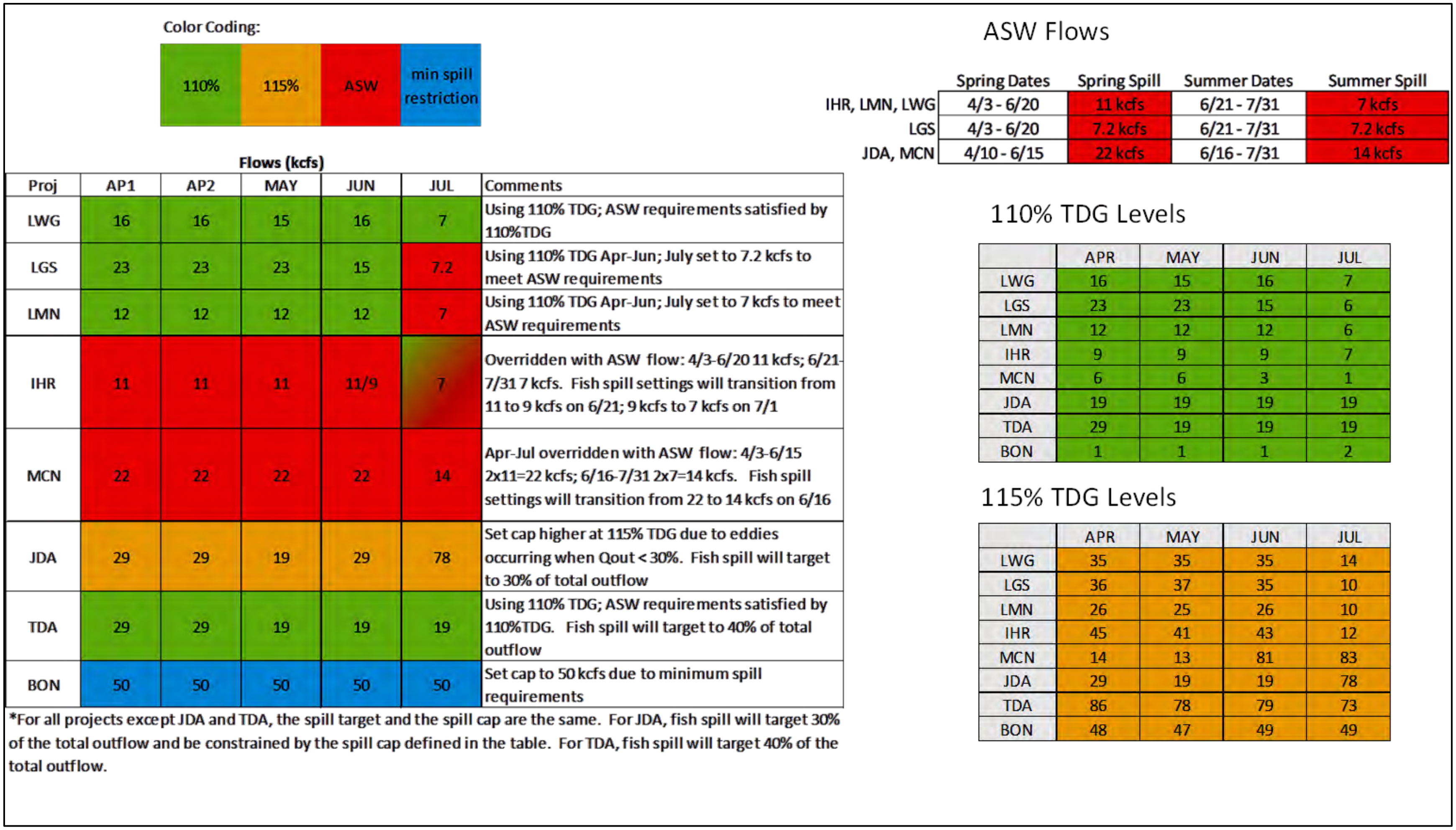
Table 3-3. Multiple Objective Alternative 3, July Spill Priority List

Project	TDG (%)	Spill Cap (kcfs)	Spill Cap (% of Total Outflow)	Priority Level	Spill Priority Number
MCN	110	1		1	1
JDA	110	19		1	2
TDA	110	19		1	3
BON	110	2		1	4
CHJ	105	6		1	5
DWR	110	4	30	1	6
MCN	111	3		2	7
JDA	111	19		2	8
TDA	111	25		2	9
BON	111	3		2	10
CHJ	106	9		2	11
MCN	112	4		3	12
JDA	112	19		3	13
TDA	112	33		3	14
BON	112	17		3	15
CHJ	107	11		3	16
MCN	113	5		4	17

3.2.5 Multiple Objective Alternative 2 Spill Cap Adjustments

The 110 percent TDG fish spill requirements in MO2 were much lower than other alternatives, necessitating an increase in the spill caps to meet the adjustable spillway weir (ASW) flows defined in the Modify Bonneville Ladder Serpentine Weir measure. This is needed because a minimum flow must be met at the adjustable spillway weirs, or else spill would need to be diverted through a different spill bay. Through deliberation, Bonneville and the Corps decided that meeting the ASW flow was preferable overusing a non-ASW spill bay, and the spill caps were increased to meet the minimum ASW flow.

Additional adjustments to spill caps were needed at Bonneville and John Day Dams. At Bonneville Dam, the minimum spill requirement of 50 kcfs overrode the 110 percent TDG requirements of 1 to 2 kcfs. At John Day, dangerous eddies occur when outflow is less than 30 percent of the total outflow. So, the 110 percent TDG requirement at John Day was increased to the 115 percent TDG requirement for safety purposes. Figure 3-2below shows when the 110 percent TDG spill cap was used, and when it was overridden by another requirement like the 115 percent TDG at John Day, minimum spill restriction at Bonneville, or ASW minimum spill requirements.



Color Coding:

🟩	🟧	🟥	🟦
110%	115%	ASW	min spill restriction

Flows (kcfs)

Proj	AP1	AP2	MAY	JUN	JUL	Comments
LWG	16	16	15	16	7	Using 110% TDG; ASW requirements satisfied by 110%TDG
LGS	23	23	23	15	7.2	Using 110% TDG Apr-Jun; July set to 7.2 kcfs to meet ASW requirements
LMN	12	12	12	12	7	Using 110% TDG Apr-Jun; July set to 7 kcfs to meet ASW requirements
IHR	11	11	11	11/9	7	Overridden with ASW flow: 4/3-6/20 11 kcfs; 6/21-7/31 7 kcfs. Fish spill settings will transition from 11 to 9 kcfs on 6/21; 9 kcfs to 7 kcfs on 7/1
MCN	22	22	22	22	14	Apr-Jul overridden with ASW flow: 4/3-6/15 2x11=22 kcfs; 6/16-7/31 2x7=14 kcfs. Fish spill settings will transition from 22 to 14 kcfs on 6/16
JDA	29	29	19	29	78	Set cap higher at 115% TDG due to eddies occurring when Qout < 30%. Fish spill will target to 30% of total outflow
TDA	29	29	19	19	19	Using 110% TDG; ASW requirements satisfied by 110%TDG. Fish spill will target to 40% of total outflow
BON	50	50	50	50	50	Set cap to 50 kcfs due to minimum spill requirements

*For all projects except JDA and TDA, the spill target and the spill cap are the same. For JDA, fish spill will target 30% of the total outflow and be constrained by the spill cap defined in the table. For TDA, fish spill will target 40% of the total outflow.

ASW Flows

	Spring Dates	Spring Spill	Summer Dates	Summer Spill
IHR, LMN, LWG	4/3 - 6/20	11 kcfs	6/21 - 7/31	7 kcfs
LGS	4/3 - 6/20	7.2 kcfs	6/21 - 7/31	7.2 kcfs
JDA, MCN	4/10 - 6/15	22 kcfs	6/16 - 7/31	14 kcfs

110% TDG Levels

	APR	MAY	JUN	JUL
LWG	16	15	16	7
LGS	23	23	15	6
LMN	12	12	12	6
IHR	9	9	9	7
MCN	6	6	3	1
JDA	19	19	19	19
TDA	29	19	19	19
BON	1	1	1	2

115% TDG Levels

	APR	MAY	JUN	JUL
LWG	35	35	35	14
LGS	36	37	35	10
LMN	26	25	26	10
IHR	45	41	43	12
MCN	14	13	81	83
JDA	29	19	19	78
TDA	86	78	79	73
BON	48	47	49	49

Figure 3-2. Multiple Objective Alternative 2 Spill Cap Assignments

3.2.6 John Day Improved Fish Passage Turbines

The improved fish passage (IFP) turbines at John Day were modeled by altering the (powerhouse) availability calculations, based on projections of availability for the first 10 years after completed installation. Availability is the only spill modeling input that was altered to account for the IFP turbines at John Day. There are comingled effects of no longer having to install fish screens, and longer unit outages during planned maintenance. The impact of contingency reserves will also dampen effects to changes in availability. The maximum powerhouse flow capacity at John Day was assumed unchanged in modeling.

The final expected performance information for the new turbines will not be available until the completion of the specific design computational fluid dynamics (CFD) and biological scale modeling stage (the Corps' Engineer Research and Development Center) of the new turbine designs. The power capacity of the individual units in MW is not expected to change significantly. It is likely that a slight reduction in maximum turbine flow capability (i.e., hydraulic capacity) will result from higher efficiency turbines. The pressure criteria for juvenile fish passage will also encourage a slight reduction in hydraulic capacity. In the CRSO EIS modeling, because the specific information on the characteristics for the new turbines is not yet available, the decision was made to simply keep the maximum powerhouse capacity static for modeling purposes. Furthermore, while changes in hydraulic characteristics and efficiency are meaningful when examined in considering the effectiveness of various design options, these changes are dwarfed by the flow and generation changes from other measures in the alternatives and would not be discernable in CRSO modeling.

Changes to the powerhouse availability affect flow through the powerhouse. However, fish spill will impinge powerhouse flows up to the spill cap. Thus, increased availability won't affect fish spill. The availability will have an effect on spill during force spill condition because the powerhouse will have more or less flow capacity (Figure 3-3).

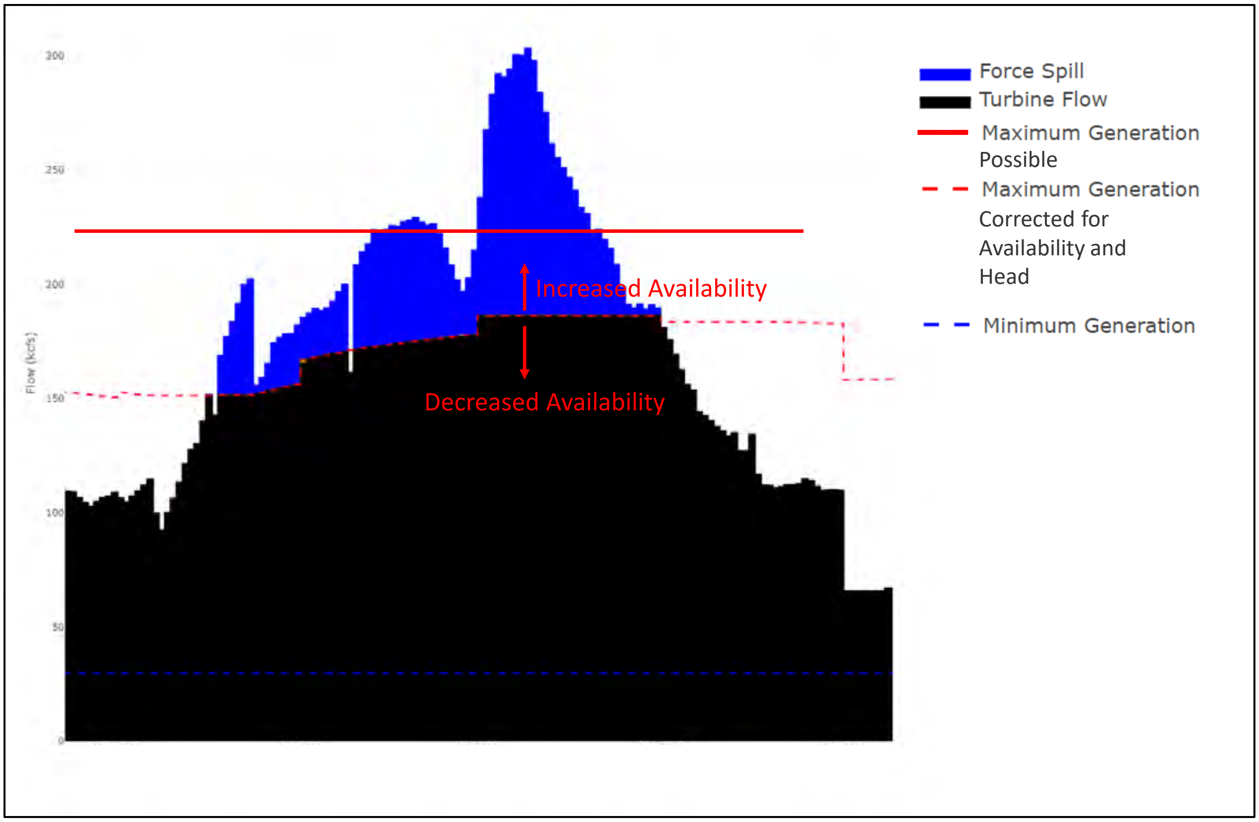


Figure 3-3. Example of Powerhouse Availability Influence on Force Spill

3.2.7 Spill Priority and Spill Table Differences, Bonneville and Corps Modeling

The spill priority list used in Corps spill modeling uses a different interval between levels than other efforts: projects advance 1 percent TDG between levels in the list used for Corps modeling (1 percent TDG list), 2 to 5 percent TDG between levels used by the Technical Management Team in real-time operations and Bonneville power modeling (5 percent TDG list). The choice was made by the Corps to reduce the increments of TDG between levels to adjust spill flows, and more evenly distribute the allocation of LOM spill to different projects. With the exception of MO3 and MO4, LOM values in the MOs are greater than observed LOM values because the power model assumes 2022 market conditions, which has on average less power demand due to increased usage of renewables. Less demand equates to more LOM spill. However, this estimate of future LOM spill is only available as a monthly average. Using the 5 percent TDG list, LOM spill on the lower Snake River is predominantly applied to Lower Granite Dam. Corps accommodated the monthly estimate of new LOM conditions by modifying the spill priority list, which resulted in LOM spill being more evenly distributed.

In addition to differences in the spill priority list used between Bonneville modeling (HydSim) and Corps modeling (ResSim), there is a difference in the spill tables used to equate TDG percentage to flows. These tables are used when a fish spill criteria is set by a TDG limit (e.g., 120 percent TDG), and within the spill priority list. HydSim modeling used spill tables with different TDG-to-spill relationships, established in December 2018. The final Corps spill modeling used spill tables developed in February 2019. The difference between the two tables is how to represent a spill level to achieve 120 percent TDG in the tailwater and 115 percent TDG in the forebays (i.e., 2018 gas cap spill). The December 2018 table is representative only of 120 percent TDG in the tailwater, while the February 2019 tables are a mixed representation of the spill required to achieve the dual constraint of 120 percent TDG in the tailwater and 115 percent TDG in the forebay. Table 3-4 below tabulates the maximum differences between the two spill tables by project and month in kcfs.

The result of using different spill tables and spill priority lists is a discontinuity in the way LOM spill is applied at projects between HydSim and Corps spill modeling. However, HydSim results only inform Corps spill modeling via LOM values and powerhouse availability (Table 2-2). The difference in spill tables and spill priority lists between Bonneville and Corps modeling is an acknowledged difference in modeling assumptions. Corps made the choice to use the February 2019 spill tables to better represent a 120 percent/115 percent gas cap spill operation and 1 percent TDG spill priority list to account for the monthly average LOM modeling in the assumed 2022 future market conditions modeled for the MOs.

Table 3-4. Maximum Differences in Spill between December 2018 and February 2019 Spill Tables (kcfs)

Project Group	Project Abbreviation	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Middle Columbia	GCL	0	0	0	0	0	0	0	0	0	0	0	0
	CHJ	4	4	4	4	4	4	4	4	4	4	4	4
Lower Snake	LWG	3	2	2	3	3	3	1	4	4	11	3	3
	LGS	4	4	4	4	4	4	8	13	5	25	18	4
	LMN	3	3	3	2	2	3	9	9	9	20	16	3
	IHR	3	2	2	3	2	3	2	2	3	33	3	3
Lower Columbia	MCN	4	11	12	12	12	12	86	87	12	14	4	4
	JDA	2	2	3	3	2	2	11	41	41	9	2	3
	TDA	4	4	4	4	4	4	4	4	4	4	4	4
	BON	4	4	4	4	4	4	4	4	4	4	4	4

3.2.8 Sub-Daily Spill Computation

The USACE spill allocation process treats requested fish flow on a given day as a whole, and doesn't pre-apply limitations due to minimum turbine flows or powerhouse capacity to operations before computing an average daily requested fish spill. For example, if a spill operation specifies spill as 72 kcfs for 16 hours, and 20 kcfs for 8 hours, the requested fish spill is computed as:

$$(72 \text{ kcfs})*(2/3) + (20 \text{ kcfs})*(1/3) = 54.7 \text{ kcfs}$$

Limitations due to minimum turbine flow and powerhouse capacity are then applied to the 54.7 kcfs. A post-analysis of USACE flex spill results in the Preferred Alternative showed a +/- 5 to 10 kcfs difference in spill is possible compared to the daily spill values if powerhouse flow limitations are applied to the performance and spill cap flows prior to deriving a daily requested fish spill (e.g., in the above equation, reduce 72 kcfs prior to computing daily spill if powerhouse minimum flow requirements aren't being satisfied). The post-analysis showed the USACE methods tends to overestimate spill during low flows and underestimate spill during low flows relative to a spill computation method that adjusts flows prior to computing a daily average. The USACE spill computation process is a simplification done for the sub-daily spill operation that does not assume that daily average flows are representative of hourly flows. Sub-daily spill operations are also present in the No Action Alternative and MO3, where these findings are likely also valid.

The choice was made to model daily operations because it is not appropriate to assume that average daily flows are representative of hourly flows. The figures below shows typical *observed* hourly outflow from McNary and Ice Harbor, where variations of up to 50 kcfs or more are normal throughout the day. These hourly variations, primarily caused by hydropower operations, are not captured in the ResSim results, and are therefore not captured in the spill analysis. Other fish passage projects show similar hourly flow changes throughout the day. Thus, the time step of the spill analysis should coincide with the time step used in ResSim (daily) and no assumptions should be made about hourly flows being equivalent to the average daily flows.

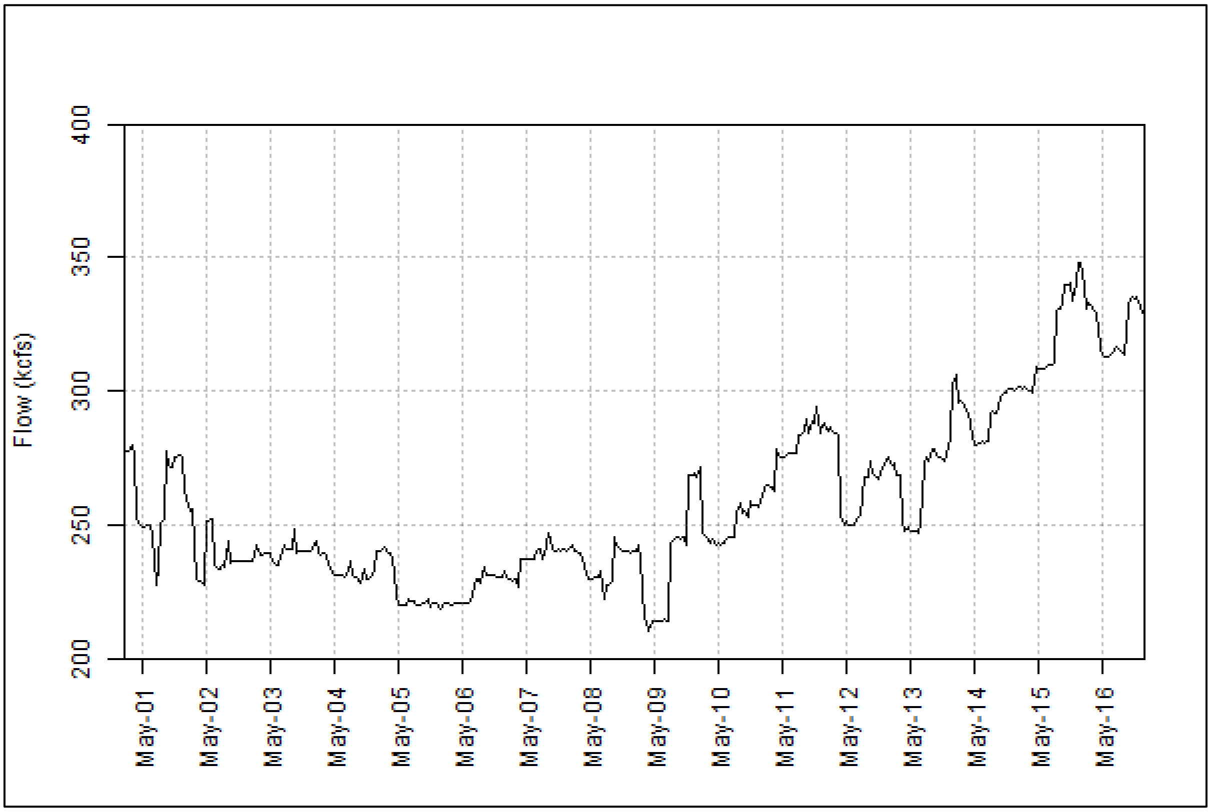


Figure 3-4. Observed McNary Hourly Outflow, 2019

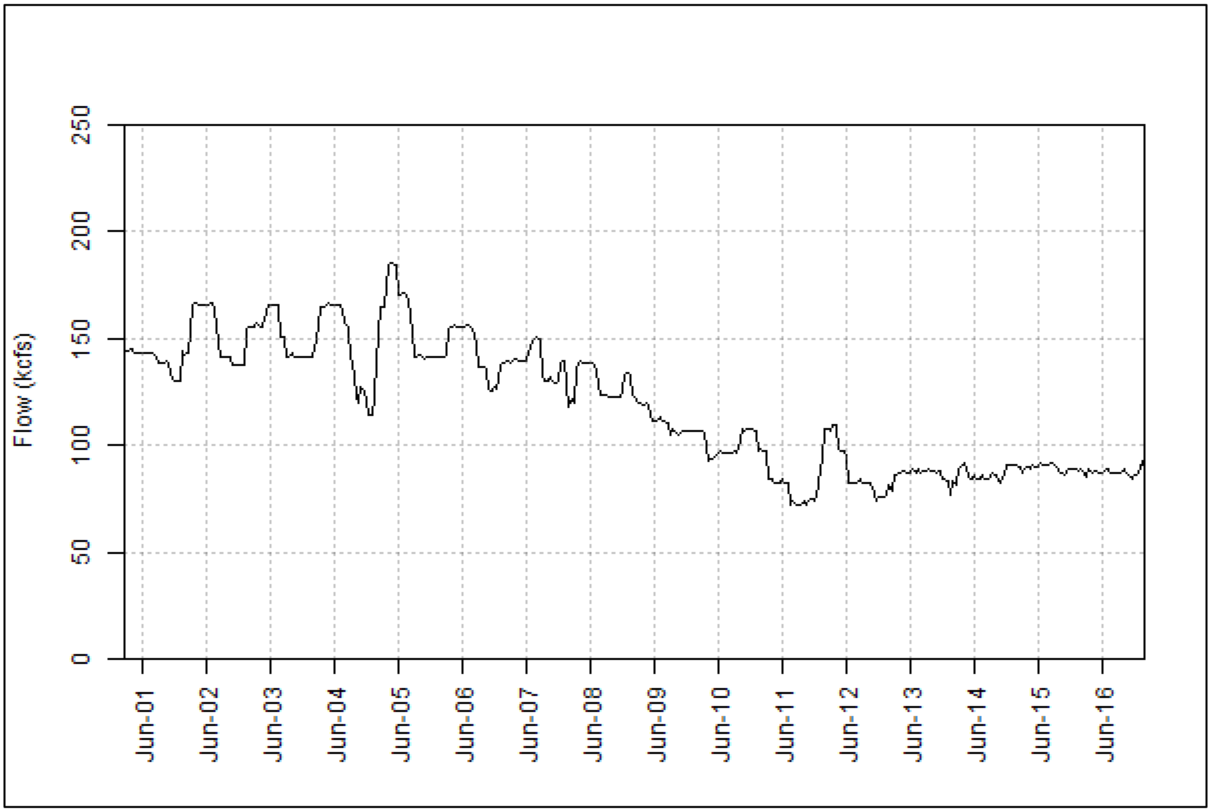


Figure 3-5. Observed Ice Harbor Hourly Outflow, 2019

3.2.9 Bonneville Spill Error in the Preferred Alternative

Late summer spill (August 15 to August 31) at Bonneville Dam in the Preferred Alternative was incorrectly modeled as 55 kcfs. The description of the preferred alternative noted that the 55 kcfs include 5 kcfs for the corner collected at Bonneville; the corner collector flows are already included in the miscellaneous flows and thus were doubly-counted. The actual late summer spill operation should have been modeled as 50 kcfs, resulting in 5 kcfs less spill than is shown in results. This error was not deemed significant enough to warrant re-running the PA spill analysis and subsequent water quality models.

3.2.10 No Action Alternative Lack of Market Error

In the final spill computation for the extended years No Action Alternative simulation, the LOM file used was outdated. The correct LOM data has slightly different LOM values. A post-analysis was conducted and the impacts to spill results were deemed negligible. Table 3-5 shows the average monthly differences in spill between the No Action Alternative simulation computed with the outdated and correct LOM data. The largest difference of 1.4 kcfs between the two runs occurs at The Dalles in March. The average total outflow at The Dalles in March is 176 kcfs, and the resultant error in spill with respect to total outflow is 0.8 percent. Error at all other projects and months is less than 1 percent (**Error! Reference source not found.**).

Table 3-5. Differences in Total Spill (kcfs) Between Final No Action Alternative and No Action Alternative Computed with Correct Lack of Market

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NOV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FEB	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAR	0.0	-1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AP1	0.0	-0.9	-0.2	0.0	0.0	-0.3	0.0	0.0	-0.5	-0.3	0.0	0.0	-0.1	-0.4	-0.4	0.0	0.0
AP2	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	-0.2	-0.4	-0.6	0.0	-0.1	0.0	-0.5	-0.7	0.0	0.0
MAY	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
JUN	0.0	0.0	0.2	0.0	0.1	0.1	0.1	0.3	0.3	0.0	0.0	0.1	0.1	0.2	0.2	0.0	0.0
JUL	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0
AG1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SEP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Orange = negative; green = positive. Opacity of color indicates magnitude.

CHAPTER 4 - ALTERNATIVES ANALYSIS

4.1 CHAPTER LAYOUT

This chapter reviews results from a generalized perspective by alternative, then project-by-project changes from the No Action Alternative with respect to spill. Each project will be described in a standard format with accompanying plots and tables. Summary hydrographs are provided of daily average flow partitioned into six separate categories, as described in Section 2.3. The fish spill operations, powerhouse availabilities, and spill caps are tabulated for each project. Spill caps are only tabulated during the fish passage season between March and August because they aren't applicable outside of that time range.

Projects may be referenced according to their river and geographic location as defined in Table 4-1. The lower Columbia and lower Snake projects are also termed "fish passage" projects. This chapter focuses on the fish passage projects but does provide information for all projects listed below. Spill at Libby Dam is very infrequent, so it is not included in monthly average spill tables. See the table in Libby Dam results section for a description of spill events at Libby Dam.

Table 4-1. Project Groupings, Repeated from Introduction Section

Acronym	Common Name	Project Group
BON	Bonneville	Lower Columbia
TDA	The Dalles	
JDA	John Day	
MCN	McNary	
IHR	Ice Harbor	Lower Snake
LMN	Lower Monumental	
LGS	Little Goose	
LWG	Lower Granite	
DWR	Dworshak	Dworshak
PRD	Priest Rapids	Middle Columbia
WAN	Wanapum	
RIS	Rock Island	
RRH	Rocky Reach	
WEL	Wells	
CHJ	Chief Joseph	
GCL	Grand Coulee	
HGH	Hungry Horse	Hungry Horse
LIB	Libby	Libby

4.1.1 Standard Result Metrics and Plots

Each alternative will initially be presented with a matrix containing average monthly total spill differences from No Action Alternative in kcfs. The months of April and August are both split mid-month to provide additional detail for those time periods. The difference matrix provides an overview and is color-coded to show projects that are most affected by changes in a given alternative.

Alternative results are presented using average daily hydrographs, where flows for a given day are averaged for the 9-year simulation (2008 to 2016). Additionally, the total average daily spill is plotted for each alternative, providing a general idea of the time of year alternatives increase or decrease spill relative to each other.

4.2 LACK OF MARKET

Table 4-2 defines the LOM conditions (average monthly megawatts) applied for each alternative. MO2 had the highest, and MO4 had the lowest LOM. This data was provided by Bonneville, using an assumed 2022 power market condition. Table 4-2 provides average values for comparative purposes; each water year had unique monthly average LOM values. As described in Section 2.2.8, monthly average LOM power values are modulated to daily values in proportion to the total system flow.

Table 4-2. Monthly Average Lack of Market (MW)

Alternative	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
NAA	0	1	0	3	23	74	189	287	373	91	2	1
MO1	0	0	1	2	17	63	161	254	449	94	1	1
MO2	0	2	0	5	16	54	292	664	719	225	8	0
MO3	0	1	0	0	5	17	49	48	132	63	3	0
MO4	0	1	0	2	18	2	30	35	120	28	0	1
PA	2	2	0	5	12	30	102	101	255	48	2	1

Note: NAA = No Action Alternative. For shading, opacity indicates magnitude.

4.3 NO ACTION ALTERNATIVE

Table 4-3 shows the total spill in the No Action Alternative for each project where spill data were derived.

Table 4-3. Monthly Average Total Spill, No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	1	0	1	2	5	5	0	0	0	0	0	0	0	0	0	0	0
NOV	1	0	1	2	4	5	0	0	0	0	0	0	0	0	0	0	0
DEC	1	0	0	2	3	4	0	0	0	0	0	0	0	0	0	0	0
JAN	5	1	0	7	3	7	0	0	0	1	0	0	0	0	0	0	0

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
FEB	9	4	0	15	5	11	0	0	0	1	1	0	0	0	0	0	0
MAR	10	13	0	16	4	7	0	0	0	0	0	0	0	0	0	1	0
AP1	67	46	31	69	4	11	1	0	7	5	0	46	27	22	22	5	1
AP2	111	92	70	103	25	31	13	1	13	9	1	52	33	27	27	3	2
MAY	135	111	91	142	36	54	18	9	21	18	11	49	35	34	34	1	0
JUN	153	122	98	170	46	59	31	28	28	23	13	53	37	37	37	2	0
JUL	118	90	73	119	45	52	34	26	24	21	18	34	19	16	21	2	0
AG1	91	61	45	77	24	25	22	9	10	0	0	20	14	9	15	1	0
AG2	87	54	39	68	15	13	10	8	9	0	0	18	14	8	14	1	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0	0	0	0	0

4.4 MULTIPLE OBJECTIVE ALTERNATIVE 1

With respect to spill, MO1 had the least difference from the No Action Alternative. The largest differences in spill occurred at the lower Snake River projects, John Day, and McNary. The spill operation on the lower Snake and lower Columbia projects alternates each year in MO1 (see Section3.1.3). Additional figures are provided in the project-by-project description of each alternative for the lower Columbia and lower Snake projects, showing both the test and base spill as average daily hydrographs. The May 11 transition date between base and test spill operations is also annotated. Table 4-4 shows the combined MO1 results that average both test and base spill conditions. Table 4-5 shows the difference between those MO1 results and the No Action Alternative.

Table 4-4. Monthly Average Total Spill, Multiple Objective Alternative 1 (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	1	0	1	3	5	6	0	0	0	0	0	0	0	0	0	0	0
NOV	1	0	1	1	4	5	0	0	0	0	0	0	0	0	0	0	0
DEC	1	0	0	3	3	6	0	0	0	0	0	0	0	0	0	0	0
JAN	5	1	0	6	3	6	0	0	0	1	0	0	0	0	0	0	0
FEB	8	3	0	14	5	10	0	0	0	1	1	0	0	0	0	0	0
MAR	10	11	0	13	4	7	0	0	0	1	0	0	0	0	0	1	0
AP1	65	44	38	71	4	9	1	0	6	4	0	35	25	24	25	5	1
AP2	114	89	86	118	24	27	12	1	12	7	0	45	30	30	30	3	1
MAY	132	104	96	149	32	48	17	5	17	12	4	50	32	34	35	1	0
JUN	154	118	101	177	48	61	32	30	29	25	12	49	36	38	40	2	0

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
JUL	112	86	72	123	43	49	31	23	22	17	13	22	18	16	21	3	0
AG1	86	58	50	78	24	25	22	9	10	0	0	3	5	8	12	1	0
AG2	81	50	43	64	15	13	10	8	9	0	0	0	0	3	2	0	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0	0	0	0	0

Table 4-5. Monthly Average Differences in Total Spill, Multiple Objective Alternative 1 minus No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	0.1	0.0	0.0	0.9	0.1	0.3	0.0	0.0	0.2	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
NOV	-0.1	0.0	0.0	-0.1	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEC	0.4	0.1	0.0	1.1	0.0	1.7	-0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAN	-0.2	-0.2	0.0	-1.1	-0.1	-1.6	0.0	0.0	0.0	-0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
FEB	-1.1	-1.1	0.0	-1.7	-0.3	-1.5	0.0	0.0	0.0	-0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
MAR	0.1	-1.8	-0.1	-3.1	0.1	0.3	0.0	0.0	0.0	0.3	0.3	-0.1	0.0	0.0	0.0	0.0	0.0
AP1	-1.9	-2.4	6.2	2.5	-0.1	-2.7	0.0	0.0	-1.1	-1.1	0.0	-10.9	-2.2	2.5	2.9	-0.1	-0.1
AP2	2.8	-2.4	16.3	14.5	-0.7	-3.4	-0.8	-0.6	-1.9	-2.0	-1.4	-7.2	-2.6	2.9	2.9	0.0	-0.5
MAY	-2.9	-6.9	4.9	6.5	-4.4	-6.5	-1.6	-3.7	-4.5	-5.9	-7.7	0.9	-3.6	0.2	1.7	0.0	0.0
JUN	1.0	-4.1	2.7	6.8	2.6	1.4	1.6	2.4	1.7	2.2	-0.3	-4.1	-1.0	1.7	2.5	0.3	0.0
JUL	-5.2	-3.9	-0.8	3.7	-2.4	-2.9	-2.2	-2.4	-2.1	-4.1	-5.0	-12.1	-0.6	0.3	-0.2	0.7	0.0
AG1	-4.9	-3.1	4.9	0.6	-0.1	-0.5	-0.6	-0.3	-0.1	-0.3	-0.1	-17.0	-9.6	-1.4	-3.2	-0.2	0.0
AG2	-6.2	-3.8	3.5	-3.8	0.0	-0.1	-0.4	-0.3	-0.1	-0.1	0.0	-17.8	-13.7	-5.7	-12.3	-0.3	0.0
SEP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0

Note: Positive values indicate MO1 has more spill than the No Action Alternative, negative values indicate MO1 has less spill.

4.5 MULTIPLE OBJECTIVE ALTERNATIVE 2

MO2 had the most LOM spill of any alternative. Because of the large amounts of LOM spill, the spill priority list was modified in MO2 to accommodate a decrease in spill on the lower Snake River (see Section 3.2.3 for further explanation). The fish spill operation in MO2 is a 110 percent TDG requirement, which is a reduced spill requirement from the No Action Alternative (Table 4-6 and Table 4-7).

Table 4-6. Monthly Average Total Spill, Multiple Objective Alternative 2 (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	1	0	1	0	5	6	0	0	0	0	0	0	0	0	0	0	0
NOV	1	0	1	2	4	5	0	0	0	0	0	0	0	0	0	0	0
DEC	2	0	0	4	3	8	0	0	0	1	0	0	0	0	0	0	0
JAN	5	1	0	8	4	7	0	0	0	1	1	0	0	0	0	0	0
FEB	7	3	0	11	5	8	0	0	0	1	1	0	0	0	0	0	0
MAR	10	10	0	16	4	7	0	0	0	1	0	0	0	0	0	0	0
AP1	39	36	16	32	4	9	1	0	6	2	0	11	9	13	15	4	0
AP2	68	52	30	53	25	27	12	1	12	4	0	19	15	25	18	4	1
MAY	94	75	34	90	33	49	18	8	20	11	6	36	23	32	25	1	0
JUN	119	90	59	124	49	62	33	31	30	23	16	41	28	29	29	1	0
JUL	80	47	66	57	44	51	32	24	23	18	16	13	10	10	10	2	0
AG1	4	1	1	8	24	25	22	9	10	0	0	0	0	0	0	1	0
AG2	2	1	1	1	15	13	10	8	9	0	0	0	0	0	0	1	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0	0	0	0	0

Table 4-7. Monthly Average Differences in Total Spill, Multiple Objective Alternative 2 minus No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	0.0	0.0	0.0	-1.4	0.1	0.3	0.0	0.0	0.1	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
NOV	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEC	0.9	0.0	0.0	2.6	0.0	3.7	-0.1	0.0	-0.1	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
JAN	0.5	0.3	0.0	0.7	0.2	-0.7	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.3	0.0
FEB	-2.3	-1.5	0.0	-4.0	-0.8	-3.1	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAR	-0.3	-3.3	-0.1	-0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.0	0.0	-0.6	0.0
AP1	-28.2	-10.6	-14.9	-37.1	-0.1	-2.3	0.0	0.0	-1.1	-2.7	0.0	-35.1	-18.3	-8.8	-7.5	-1.5	-0.3
AP2	-43.2	-39.4	-40.2	-50.4	-0.3	-3.6	-0.3	0.0	-1.6	-4.7	-1.1	-33.4	-18.2	-2.2	-9.3	0.5	-0.7
MAY	-41.1	-35.8	-57.2	-52.4	-3.0	-4.9	-0.3	-0.8	-1.2	-7.5	-5.2	-12.9	-12.6	-2.5	-8.6	0.3	-0.1
JUN	-33.4	-32.2	-39.7	-46.6	3.5	2.3	2.0	3.7	2.5	-0.1	3.4	-12.8	-8.9	-7.2	-8.1	-0.5	-0.3
JUL	-37.9	-42.7	-7.1	-61.8	-1.2	-1.3	-1.2	-1.3	-1.1	-3.0	-2.1	-20.9	-8.7	-5.8	-11.4	0.2	0.1
AG1	-87.1	-60.1	-43.8	-69.5	0.0	-0.4	-0.1	-0.1	-0.1	-0.3	0.0	-20.3	-14.4	-8.9	-15.1	0.0	0.0
AG2	-85.0	-53.3	-38.3	-67.4	0.0	-0.1	-0.2	-0.2	0.0	-0.1	0.0	-17.8	-13.7	-8.3	-14.5	0.0	0.0
SEP	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Positive values indicate MO2 has more spill than the No Action Alternative, negative values indicate MO2 has less spill.

4.6 MULTIPLE OBJECTIVE ALTERNATIVE 3

The lower Snake River dams are removed in MO3, requiring a modified spill priority list. From April through August, the spill priority list typically starts at Lower Granite, progresses down the lower Snake River, then continues from McNary to Bonneville Dam. With the lower Snake projects removed, the spill priority list in MO3 begins at McNary, as if the lower Snake projects were simply removed from the original list (see Section 3.2.4 for additional details). As a result, LOM spill is primarily allocated on the lower Columbia projects. The spring fish spill operation on the lower Columbia projects is a 120 percent TDG spill requirement (Table 4-8 and Table 4-9).

Table 4-8. Monthly Average Total Spill, Multiple Objective Alternative 3 (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN
OCT	1	0	1	0	5	6	0	0	0	0	0	0	0
NOV	1	0	1	2	4	5	0	0	0	0	0	0	0
DEC	1	0	0	3	3	5	0	0	0	1	0	0	0
JAN	4	0	0	6	3	5	0	0	0	1	1	0	0
FEB	8	1	0	14	6	10	0	0	0	2	2	0	0
MAR	10	3	0	13	4	7	0	0	0	1	0	1	0
AP1	62	51	53	70	4	7	1	0	6	2	0	5	1
AP2	121	128	129	141	24	26	12	0	10	4	0	3	1
MAY	134	139	140	167	31	47	16	4	14	9	6	0	0
JUN	148	126	117	169	48	60	33	29	25	23	17	1	0
JUL	109	84	70	109	43	49	31	23	22	18	16	2	0
AG1	2	0	0	9	24	25	22	9	10	0	0	1	0
AG2	0	0	0	1	15	13	10	8	9	0	0	1	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0

Table 4-9. Monthly Average Differences in Total Spill, Multiple Objective Alternative 3 minus No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN
OCT	-0.1	0.0	0.0	-1.3	0.1	0.3	0.0	0.0	0.2	0.5	0.5	0.0	0.0
NOV	0.0	0.0	0.0	0.7	0.0	0.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0
DEC	0.5	0.0	0.0	1.1	0.0	1.7	-0.1	0.0	0.0	0.8	0.1	0.0	0.0
JAN	-0.4	-0.4	0.0	-1.3	-0.1	-2.1	0.0	0.0	0.0	0.2	0.3	0.0	0.0
FEB	-0.9	-3.0	0.0	-1.2	0.1	-1.1	0.0	0.0	0.1	0.8	1.0	0.0	0.0
MAR	-0.1	-9.6	-0.3	-3.4	0.0	0.2	0.0	0.0	0.0	0.4	0.4	0.0	0.0
AP1	-5.2	4.9	21.8	1.7	-0.2	-4.2	0.0	0.0	-0.9	-3.3	0.0	-0.1	-0.1
AP2	9.7	36.2	58.7	37.6	-0.8	-4.9	-1.0	-1.2	-3.0	-5.2	-1.4	-0.2	-0.4
MAY	-1.6	28.4	49.5	24.7	-4.4	-7.3	-2.3	-5.5	-7.4	-9.4	-5.2	-0.6	0.0
JUN	-5.0	3.5	19.1	-1.3	2.4	0.6	2.0	1.6	-2.7	-0.4	4.3	-0.3	0.0

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN
JUL	-8.9	-5.8	-3.4	-10.1	-2.5	-2.9	-2.4	-2.5	-2.1	-3.9	-1.9	0.0	0.0
AG1	-89.0	-61.1	-44.6	-68.9	-0.1	-0.5	-0.7	-0.3	-0.1	-0.3	0.0	0.0	0.0
AG2	-86.9	-54.2	-39.3	-66.9	0.0	-0.1	-0.4	-0.4	-0.1	-0.1	0.0	0.0	0.0
SEP	-0.1	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Positive values indicate MO3 has more spill than the No Action Alternative, negative values indicate MO3 has less spill.

4.7 MULTIPLE OBJECTIVE ALTERNATIVE 4

MO4 has the highest spill operations on the fish passage projects of any alternative. Spill is higher in MO4 than the No Action Alternative at all of the fish passage projects (i.e., lower Columbia and lower Snake) throughout the fish passage season. The high spill also drastically reduces the LOM conditions. The MO4 spill criterion is set to 125 percent TDG, causing the fish passage projects to have powerhouse flows at or near minimum generation during a majority of the spill season, with some exceptions during high flows. The juvenile fish passage season is also extended from early April to March 1, producing much more spill in March on the lower Snake and lower Columbia. Also, because the fish passage projects are at a very high spill, there is little capacity for those projects to absorb LOM. Thus, in MO4 most of the LOM spill gets allocated to the middle Columbia projects. All of the lower Snake projects, John Day, and McNary have powerhouse bypass flow in MO4 from March 1 through August 31. The powerhouse bypass flows are not included in the monthly average total spill, and as a result the No Action Alternative spill is actually higher than MO4 spill in August (Table 4-10 and Table 4-11).

Table 4-10. Monthly Average Total Spill, Multiple Objective Alternative 4 (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	9	8	9	8	5	6	0	0	0	0	0	2	2	2	2	0	0
NOV	9	8	9	9	4	5	0	0	0	0	0	2	2	2	2	0	0
DEC	1	0	0	3	3	6	0	0	0	1	0	0	0	0	0	0	0
JAN	4	1	0	7	3	6	0	0	0	1	0	0	0	0	0	0	0
FEB	7	3	0	12	5	9	0	0	0	1	0	0	0	0	0	0	0
MAR	138	126	104	99	4	7	0	0	0	1	0	36	34	31	32	1	0
AP1	154	143	126	126	4	8	1	0	6	2	0	58	54	50	49	5	0
AP2	170	160	145	149	24	25	11	0	10	2	0	65	59	56	54	3	1
MAY	198	200	176	201	31	47	16	3	13	7	5	78	71	66	64	0	0
JUN	205	201	178	209	48	59	33	30	30	21	15	76	68	62	59	1	0
JUL	160	145	133	147	44	51	34	25	25	18	16	37	32	32	32	2	0
AG1	109	90	84	89	24	25	22	9	10	0	0	16	13	14	14	1	0
AG2	89	77	69	73	15	13	10	8	9	0	0	14	11	12	12	1	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0	0	0	0	0

Table 4-11. Monthly Average Differences in Total Spill, Multiple Objective Alternative 4 minus No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	7.9	7.9	7.9	6.4	0.0	0.3	0.0	0.0	0.1	0.4	0.4	2.0	2.0	2.0	2.0	0.0	0.0
NOV	7.7	8.1	8.0	7.1	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	0.0	0.0
DEC	0.4	0.0	0.0	1.1	0.0	1.8	-0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAN	-0.2	-0.2	0.0	-0.8	-0.1	-1.2	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FEB	-2.0	-0.9	0.0	-2.8	-0.7	-2.4	0.0	0.0	0.0	-0.5	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
MAR	128.0	113.2	103.7	83.0	0.0	0.2	0.0	0.0	0.0	0.1	0.2	35.6	33.8	30.7	32.1	0.0	0.0
AP1	87.4	96.1	95.0	57.4	-0.2	-3.7	-0.1	0.0	-1.1	-2.7	0.0	12.1	26.5	28.1	27.1	-0.1	-0.1
AP2	58.4	68.3	75.2	45.6	-0.9	-5.3	-1.3	-1.2	-3.2	-6.5	-1.4	13.1	26.3	28.7	27.1	-0.3	-0.8
MAY	62.7	88.8	85.6	58.7	-4.5	-7.6	-1.7	-5.6	-8.4	-11.5	-5.9	29.0	35.8	31.8	30.5	-0.7	0.0
JUN	52.5	78.7	79.5	39.1	1.9	0.2	2.3	2.0	1.8	-2.2	2.2	23.1	30.8	25.0	22.3	-0.6	-0.1
JUL	42.8	55.7	60.3	28.4	-1.3	-1.3	0.1	-0.8	0.3	-3.4	-2.3	2.7	13.3	16.3	10.9	-0.1	0.0
AG1	17.2	29.1	39.0	11.1	-0.1	-0.6	-0.4	-0.2	-0.1	-0.3	-0.1	-3.8	-1.4	4.8	-1.2	0.0	0.0
AG2	2.4	22.6	30.0	4.7	0.0	-0.2	-0.2	-0.2	0.0	-0.1	0.0	-4.0	-2.9	3.4	-2.6	0.0	0.0
SEP	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Positive values indicate MO4 has more spill than the No Action Alternative, negative values indicate MO4 has less spill.

4.8 PREFERRED ALTERNATIVE

The Preferred Alternative operations define a flex spill on all of the fish passage projects (i.e., lower Columbia and lower Snake). Starting in early April and ending in mid-June, spill on the fish passage projects will change on a daily basis between 125% TDG for 16 hours and a performance spill the remainder of the day. Performance spill is much lower than 125% TDG spill. The Preferred alternative includes an initial summer spill between mid-June and mid-August, which is similar to or lower than performance spill. A late summer, low-spill operation is also included from mid-August to late August.

With the exception of The Dalles and Bonneville, flex spill operations produce greater spill relative to the NAA during flex operations (April through mid-June) at fish passage projects. Initial summer (mid-June to mid-August) spill is typically slightly lower, and late summer (mid-August through August) spill is much lower in the PA.

Table 4-12. Monthly Average Total Spill, Preferred Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	1	0	1	0	5	6	0	0	0	0	0	0	0	0	0	0	0
NOV	1	0	1	2	4	5	0	0	0	0	0	0	0	0	0	0	0
DEC	1	0	0	1	3	4	0	0	0	0	0	0	0	0	0	0	0
JAN	5	1	0	8	3	8	0	0	0	2	1	0	0	0	0	0	0
FEB	10	2	0	16	6	12	0	0	0	2	1	0	0	0	0	0	0
MAR	11	6	0	18	4	7	0	0	0	1	0	0	0	0	0	1	0
AP1	65	37	48	76	4	9	1	0	6	3	0	52	46	42	40	5	1
AP2	128	91	115	159	25	29	12	1	11	7	0	65	57	51	47	3	2
MAY	143	111	126	192	34	50	17	5	17	11	7	75	66	59	54	1	0
JUN	151	122	118	187	50	62	34	31	27	25	16	62	53	49	46	1	0
JUL	108	84	73	122	43	50	32	24	23	17	15	18	17	15	20	2	0
AG1	87	60	50	83	24	25	22	9	10	0	0	9	14	9	15	1	0
AG2	55	39	20	20	15	13	10	8	9	0	0	8	7	7	7	1	0
SEP	1	0	1	0	5	5	0	0	0	0	0	0	0	0	0	0	0

Table 4-13. Monthly Average Differences in Total Spill, Preferred Alternative minus No Action Alternative (kcfs)

Month	BON	TDA	JDA	MCN	PRD	WAN	RIS	RRH	WEL	CHJ	GCL	IHR	LMN	LGS	LWG	DWR	HGH
OCT	0.4	0.0	0.0	-1.3	0.1	0.3	0.0	0.0	0.2	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
NOV	0.1	0.1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DEC	0.0	0.0	0.0	-0.2	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JAN	0.7	0.2	0.0	0.6	0.2	0.3	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
FEB	0.4	-1.9	0.0	0.4	0.3	0.4	0.0	0.0	0.1	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0
MAR	1.1	-7.4	-0.2	1.1	0.1	0.7	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
AP1	-1.8	-9.2	16.5	7.6	-0.1	-2.2	0.0	0.0	-1.1	-1.7	0.0	6.1	18.9	20.2	18.0	-0.2	0.0
AP2	16.9	-0.5	45.5	56.0	-0.3	-1.7	-0.3	-0.7	-2.1	-2.0	-1.1	12.3	23.7	24.2	20.2	-0.1	0.0
MAY	8.1	0.5	35.0	49.8	-2.4	-3.7	-1.2	-3.6	-4.4	-7.3	-4.5	26.0	30.3	25.0	20.2	-0.3	0.0
JUN	-1.9	-0.1	19.4	17.1	3.9	3.2	2.9	3.1	-0.3	2.0	3.7	8.9	16.1	12.6	8.9	-0.1	0.0
JUL	-9.5	-5.5	-0.2	3.0	-1.7	-1.9	-1.5	-1.7	-1.6	-4.1	-2.7	-15.9	-1.4	-0.5	-1.5	0.0	0.0
AG1	-4.0	-1.1	5.4	5.5	0.0	-0.2	0.0	0.0	0.0	-0.1	0.0	-11.1	-0.5	-0.1	-0.5	0.0	0.0
AG2	-32.1	-14.9	-19.4	-48.0	0.0	-0.1	-0.3	-0.2	0.0	-0.1	0.0	-9.8	-7.1	-1.5	-7.2	0.0	0.0
SEP	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Positive values indicate the Preferred Alternative has more spill than the No Action Alternative, negative values indicate the Preferred Alternative has less spill.

4.9 BONNEVILLE DAM

MO4 and MO2 had the greatest variation in total spill from No Action Alternative at Bonneville Dam; MO4 produced more spill, and MO2 produced less. MO1, MO3, and the PA had nearly the same amount of total average spill as the No Action Alternative, with the exception of MO3 in August; the summer spill season was adjusted to end on July 31 instead of August 31 in MO3 (Figure 4-1, Table 4-14, Table 4-15, and Table 4-16).

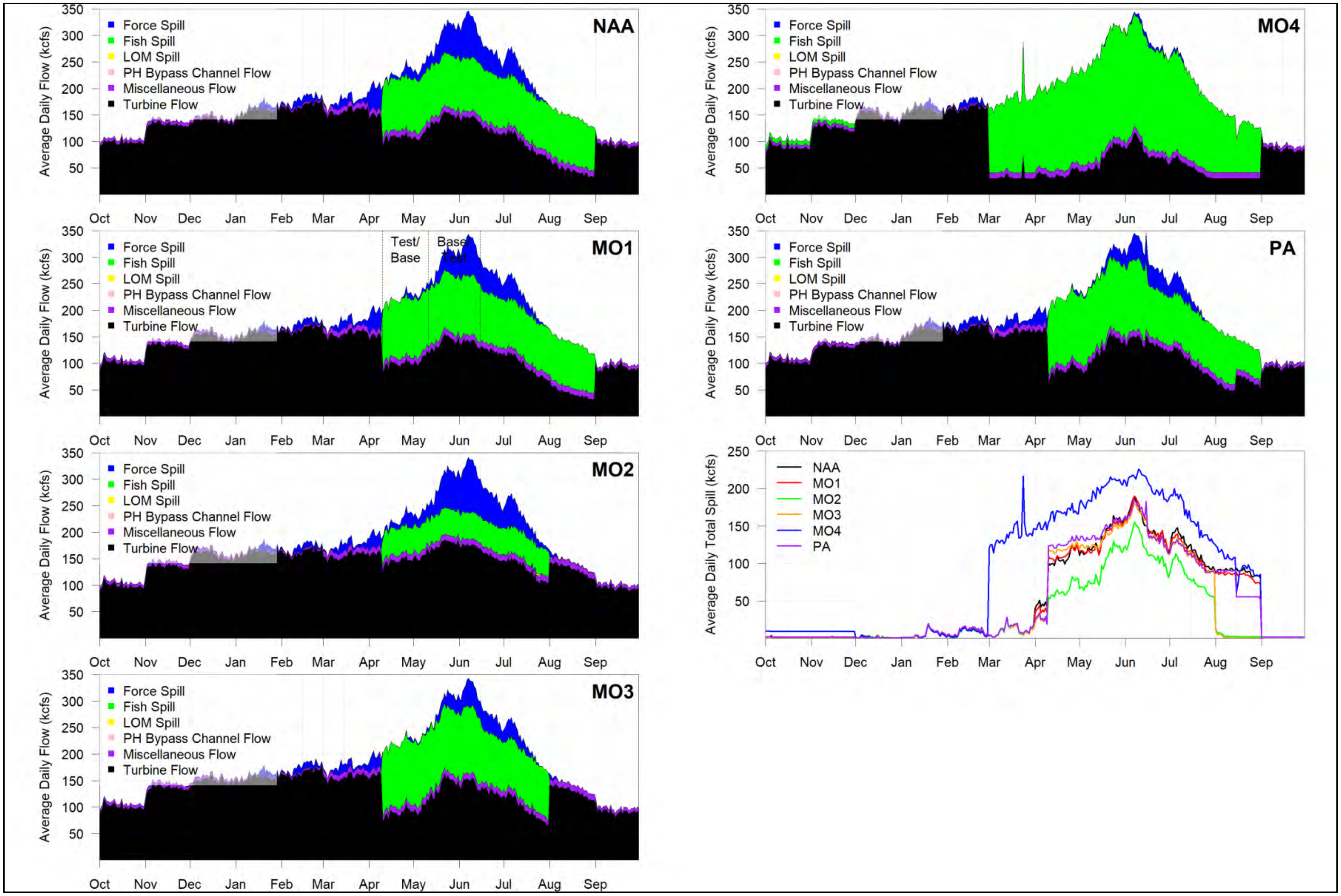


Figure 4-1. Bonneville Dam Partitioned Average Daily Outflow

Table 4-14. Bonneville Dam Fish Spill Configurations

Alternative	Start Date	End Date	Spill Operation
NAA	April 10	June 15	100 kcfs
NAA	June 16	August 31	Alternating between 85/121 kcfs day/night and 95 kcfs in two-day treatments
MO1 (Base)	April 10	June 15	100 kcfs
MO1 (Base)	June 16	August 31	95 kcfs
MO1 (Test)	April 10	June 15	122–126 kcfs (120%/115% TDG)
MO1 (Test)	June 16	August 31	95 kcfs
MO2	April 10	July 31	50 kcfs (Minimum limit of gate spill flow)
MO3	April 10	June 15	122–155 kcfs
MO3	June 16	July 31	Alternating between 85/121 kcfs day/night and 95 kcfs in two-day treatments
MO4	March 1	August 31	223–252 kcfs (125% gas cap)
MO4	October 1	November 30	8 kcfs (spillway weir notch)
PA	April 10	June 15	125% Daily Flex: 150 kcfs (spillway limitation) 16 hrs/100 kcfs 8 hrs
PA	June 16	August 14	95 kcfs
PA	August 15	August 31	55 kcfs

Table 4-15. Bonneville Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	59	68	71	72	72	69	58	58	60	57	58	62	62	62
MO1	59	68	71	72	72	69	60	60	62	59	59	63	63	62
MO2	69	68	71	72	72	69	67	67	69	66	67	71	71	72
MO3	69	68	71	72	72	69	67	67	69	66	67	71	71	72
MO4	69	68	71	72	72	69	67	67	69	66	67	71	71	72
PA	69	68	71	72	72	69	67	67	69	66	67	71	71	72

Table 4-16. Bonneville Dam Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	115	124	124	122	126	135	135	135
MO1 (YR1)	115	124	124	122	126	135	135	135
MO1 (YR2)	115	124	124	122	126	135	135	135
MO2	50	50	50	50	50	50	50	50
MO3	115	124	124	122	126	135	155	155
MO4	223	223	223	220	224	234	252	252
PA	223	223	223	220	224	135	155	155

4.9.1 Multiple Objective Alternative 1

The test and base spill operations did not drastically change the average daily spill at Bonneville Dam (Figure 4-2). During the fish passage season, the base spill operations are approximately 6 kcfs lower than No Action Alternative spill, and test spill operations are approximately 7.5 kcfs higher than the No Action Alternative. During summer spill (i.e., outside of the base/test spill operation time period), daily average spill in MO1 is approximately 4.5 kcfs lower than the No Action Alternative.

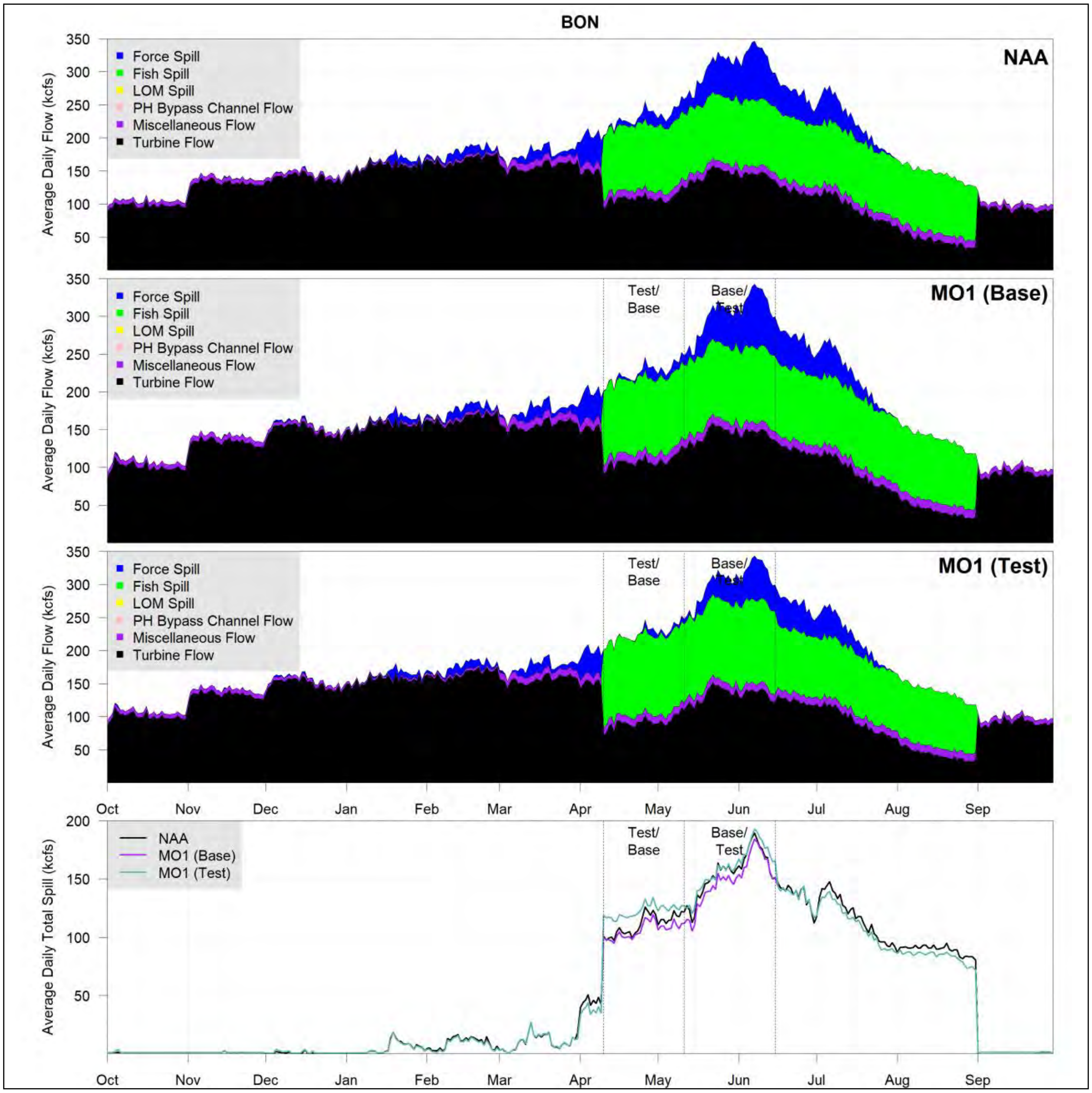


Figure 4-2. Bonneville Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.9.2 Multiple Objective Alternative 2

MO2 spill operations at Bonneville Dam occurs between April 10 and July 31 and is approximately 38 kcfs lower than spill in the No Action Alternative for that time period (MO2 average total spill is 92 kcfs, No Action Alternative average total spill is 130 kcfs). The change in spill is primarily due to the change in spill operations from 100 kcfs in the No Action Alternative, to 50 kcfs in MO2. During the MO2 spill operations, MO2 total outflow is approximately 4 kcfs lower than outflow in the No Action Alternative, and powerhouse availabilities are slightly increased. Decreased total outflows and increased powerhouse availabilities contribute to an average decrease in force spill of approximately 9 kcfs during the spill season.

4.9.3 Multiple Objective Alternative 3

MO3 spring spill operations (i.e., April 10 through June 15) of 122 to 125 kcfs are slightly higher than the 100 kcfs fish spill operations in the No Action Alternative. A maximum daily average difference of 19 kcfs occurs in early April.

4.9.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 10 and August 31, MO4 spill is approximately 44 kcfs higher (No Action Alternative spill is 121 kcfs, MO4 spill is 165 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 127 kcfs higher.

4.9.5 Preferred Alternative

PA flex spill operations at Bonneville Dam occurs between April 10 and June 15 and produces approximately 10 kcfs higher spill than in the No Action Alternative for that time period (PA total spill is 144 kcfs, NAA total spill is 134 kcfs). Spill for the remainder of the spill season is approximately 12 kcfs lower in the PA, due to a higher spill operation in the NAA (Table 4-14).

4.10 THE DALLES DAM

MO1 and the PA had the least impact on spill at The Dalles. However, all other alternatives produced a noticeable change. MO2 has less total spill, but also contained much more LOM spill. MO3 has more spill during the spring season (April 10 through June 15), where the fish operations require greater flows. MO4 has much higher spill than the No Action Alternative, similar to all other fish passage projects (Figure 4-3, Table 4-17, Table 4-18, and Table 4-19). PA spill was nearly the same as NAA spill (Figure 4-3).

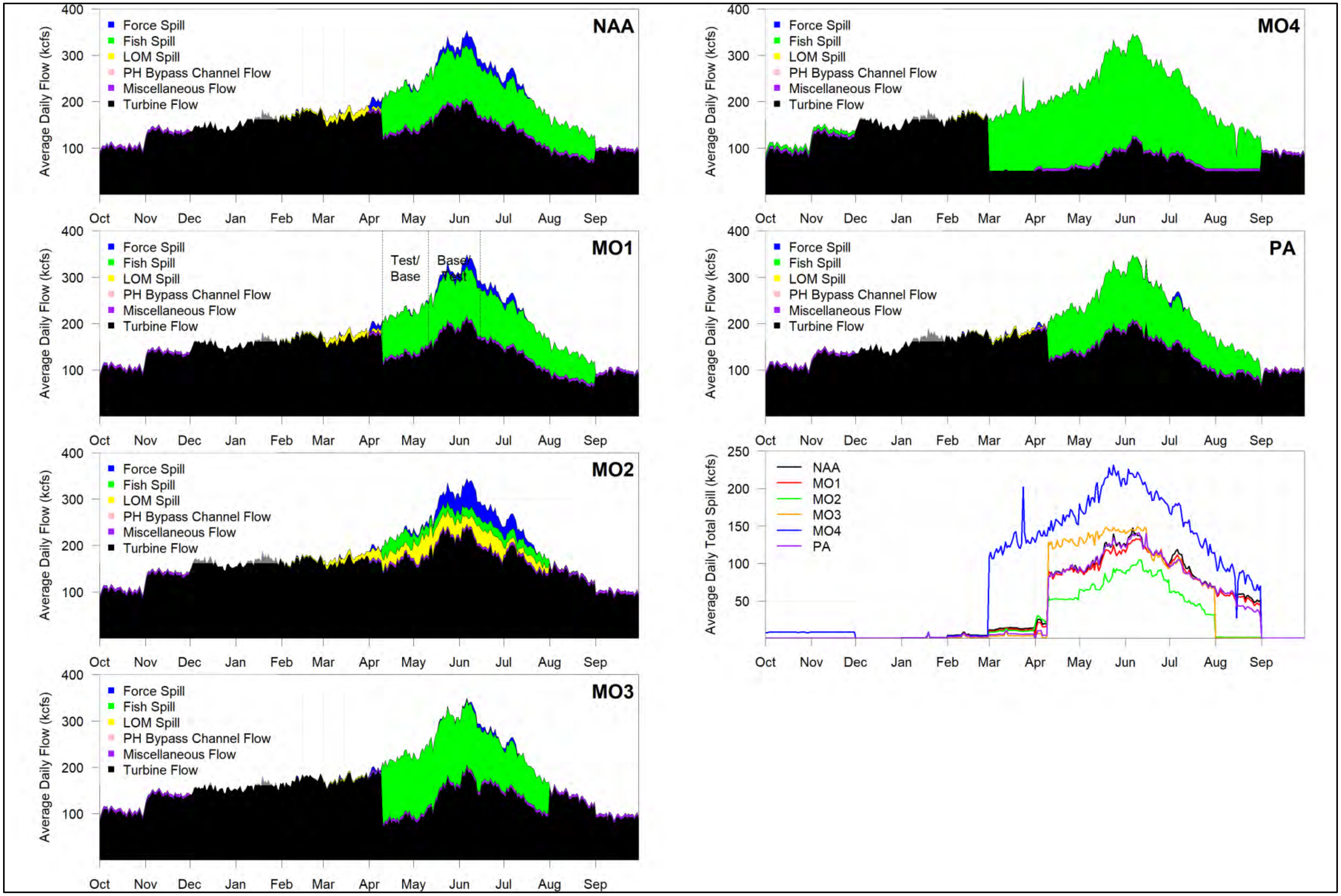


Figure 4-3. The Dalles Dam Partitioned Average Daily Outflow

973 **Table 4-17. The Dalles Dam Fish Spill Configuration**

Alternative	Start Date	End Date	Spill Operation
NAA	April 10	August 31	40% Total Outflow
MO1 (Base)	April 10	August 31	40% Total Outflow
MO1 (Test)	April 10	June 15	96 kcfs (120%/115% TDG)
MO1 (Test)	June 16	August 31	40% Total Outflow
MO2	April 10	July 31	40% Total Outflow (Limited by 110% TDG, 19–29 kcfs)
MO3	April 10	June 15	141–147 kcfs (120% TDG)
MO3	June 16	July 31	40% Total Outflow
MO4	March 1	August 31	229–246 kcfs (125% Gas Cap)
MO4	October 1	November 30	8 kcfs (Spillway Weir Notch)
PA	April 10	August 14	40% Total Outflow
PA	August 15	August 31	30% Total Outflow

974 **Table 4-18. The Dalles Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)**

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	60	77	79	84	77	76	61	61	63	62	61	60	60	67
MO1	60	77	79	84	77	76	65	65	68	67	65	63	63	67
MO2	74	77	79	84	77	76	75	75	77	76	75	74	74	82
MO3	74	77	79	84	77	76	75	75	77	76	75	74	74	82
MO4	74	77	79	84	77	76	75	75	77	76	75	74	74	82
PA	74	77	79	84	77	76	75	75	77	76	75	74	74	82

975 **Table 4-19. The Dalles Spill Caps (kcfs)**

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	100	125	125	125	125	125	125	125
MO1 (Base)	100	125	125	125	125	125	125	125
MO1 (Test)	100	96	96	96	96	125	125	125
MO2	63	29	29	19	19	19	22	22

Alternative	**MAR**	**AP1**	**AP2**	**MAY**	**JUN**	**JUL**	**AG1**	**AG2**
MO3	152	147	147	146	141	135	118	118
MO4	246	246	246	244	241	239	229	229
PA	246	246	246	244	241	125	125	125

976

4.10.1 Multiple Objective Alternative 1

The test and base spill operations did not have a large impact on spill at The Dalles because the base spill operation is 40 percent of total outflow, which can produce large amounts of spill. There are some periods of time in May and June where the base spill is higher on average than the test spill because the base spill has a higher requested fish spill resulting from the 40 percent total outflow operation. The result is that MO1 spill is on average approximately equal to spill in the No Action Alternative (Figure 4-4).

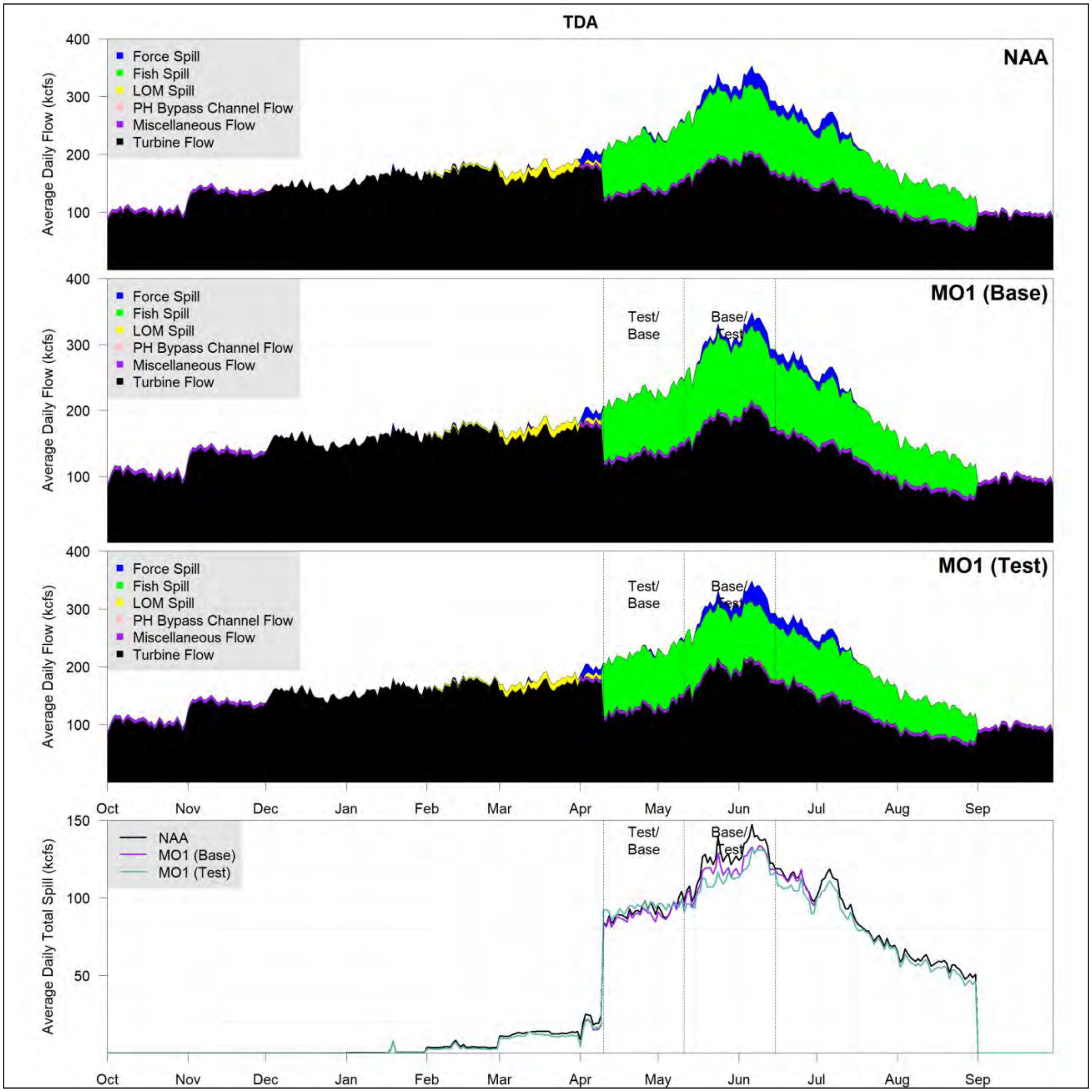


Figure 4-4. The Dalles Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.10.2 Multiple Objective Alternative 2

MO2 fish spill operations begin April 10 and end on July 31, which is one month prior to the end of the No Action fish spill operations. The average spill during MO2 spill operations is approximately 67 kcfs, while average spill in the No Action Alternative for the same time period is 104 kcfs. LOM spill and force spill conditions increase the total spill beyond the 19–29 kcfs spill caps (Figure 4-20) for MO2. From April 10 through July 31 in MO2, force spill and LOM spill contribute approximately 20 kcfs and 27 kcfs, respectively.

4.10.3 Multiple Objective Alternative 3

Spill operations in MO3 are only different from the No Action Alternative from April 10 through June 15, where the MO3 fish spill is between 141 and 147 kcfs (Table 4-21). The increased spill operations in MO3 produce an average spill difference from the No Action Alternative of approximately 27 kcfs during the April 10 through June 15 time period. During the summer operations in MO3 between June 16 and July 31, spill is approximately 5 kcfs lower in MO3. MO3 spill operations end July 31, one month prior to the No Action Alternative operations.

4.10.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 10 and August 31, MO4 spill is approximately 63 kcfs higher (No Action Alternative spill is 94 kcfs, MO4 spill is 157 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 113 kcfs higher. The MO4 spill operations also include 8 kcfs of spill from the spillway weir notch occurring throughout the months of October and November.

4.10.5 Preferred Alternative

Daily average PA spill for The Dalles is very similar to the NAA. Spring operations are both operating to 40% total outflow. The increased powerhouse availability in PA likely contributes the most to differences in spill; the PA has an average of approximately 6 kcfs less force spill than the NAA. Increased powerhouse availability can reduce the amount of force spill (see section 2.2.1). A 15 kcfs decrease in the PA spill operation is caused by transitions to 30% total outflow for the second half of August, while the NAA spill operation remains at 40% total outflow for that time period. Spill caps are much higher in the PA from March through June, which creates more instances where the fish spill impinges upon the maximum powerhouse capacity. However, the increased spill caps have a minimal impact when flows are high enough to induce force spill conditions.

4.11 JOHN DAY DAM

All alternatives showed some differences from the No Action Alternative at John Day. MO1 spill was greater than the No Action Alternative because of the test spill operations, and slightly increased summer spill operations. MO2 spill is decreased because spill caps are much lower. MO3 spring operations produce much higher spill due to the 120 percent TDG spill requirement, while summer spill operations are the same as the No Action Alternative. MO4 has 125 percent TDG requirements, which produce much higher spill than the No Action Alternative (Figure 4-5 and Table 4-22). PA spill was similar to MO3 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Figure 4-5).

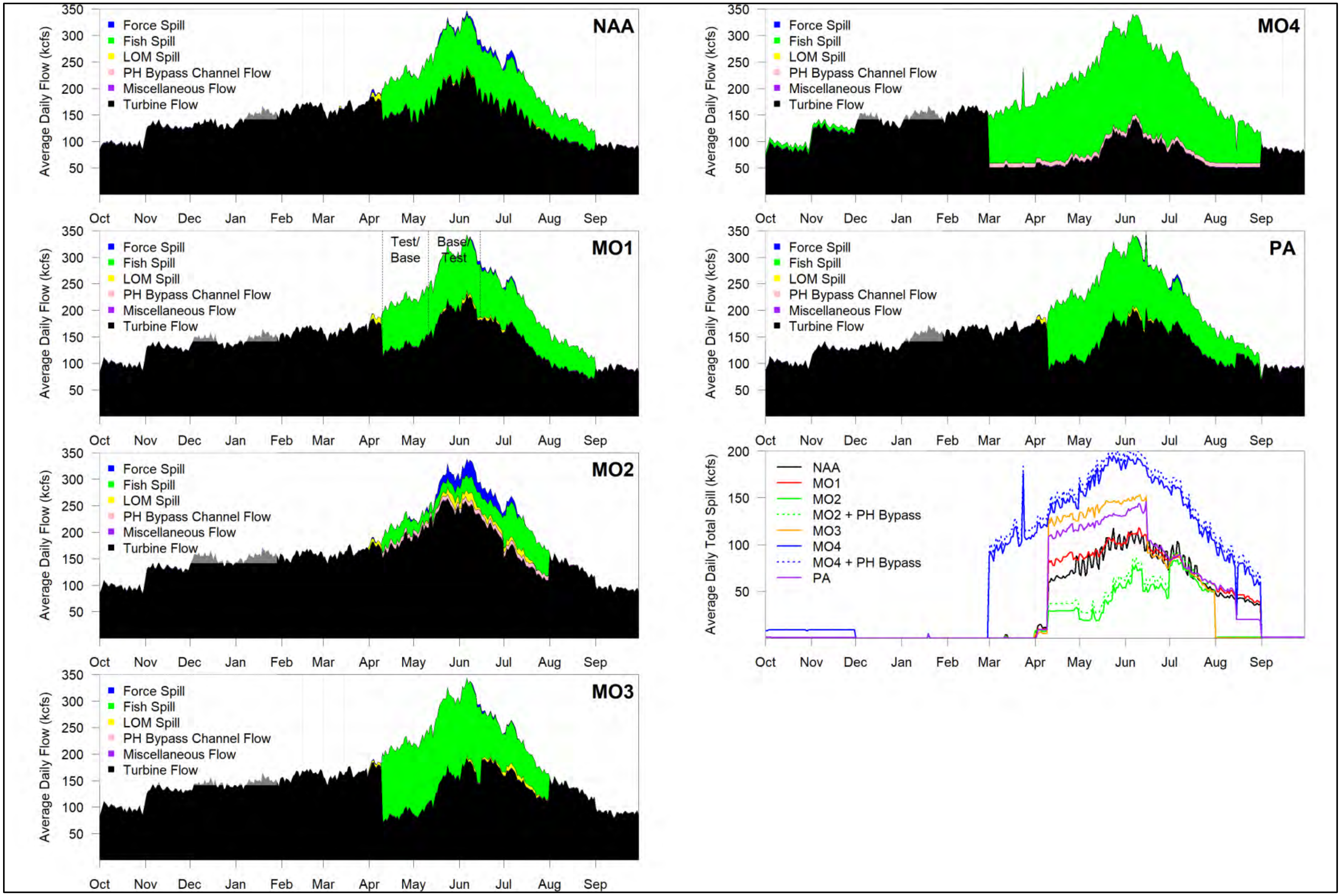


Figure 4-5. John Day Dam Partitioned Average Daily Outflow

1030 **Table 4-20. John Day Dam Fish Spill Configuration**

Alternative	Start Date	End Date	Spill Operation
NAA	April 10	April 26	30% Total Outflow
NAA	April 27	July 20	Alternating between 30% and 40% in two-day treatments
NAA	July 21	August 31	30% Total Outflow
MO1 (Base)	April 10	June 15	32% Total Outflow
MO1 (Base)	June 16	August 31	35% Total Outflow
MO1 (Test)	April 10	June 15	110 kcfs (120%/115% TDG)
MO1 (Test)	June 16	August 31	35% Total Outflow
MO2	April 10	July 31	30% Total Outflow (Limited by 115% TDG due to dangerous eddies when spill < 30% total outflow, 19–78 kcfs)
MO2	April 10	July 31	8 kcfs (Powerhouse Bypass)
MO3	April 10	June 15	147–155 kcfs (120% TDG)
MO3	June 16	July 31	30% Total Outflow
MO4	March 1	August 31	200–208 kcfs (125% Gas Cap)
MO4	March 1	August 31	8 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	8 kcfs (Spillway Weir Notch)
PA	April 10	June 15	120% Daily Flex: 146 kcfs 16 hrs/32% Total Outflow 8 hrs
PA	June 16	August 14	35% Total Outflow
PA	August 15	August 31	20 kcfs

1031 **Table 4-21. John Day Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)**

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	76	83	83	82	82	83	76	76	78	82	76	79	79	84
MO1	85	84	84	84	84	85	88	88	89	88	87	86	86	85
MO2	85	84	84	84	84	85	83	83	83	83	83	83	83	85
MO3	85	84	84	84	84	85	83	83	83	83	83	83	83	85
MO4	85	84	84	84	84	85	83	83	83	83	83	83	83	85
PA	85	84	84	84	84	85	83	83	83	83	83	83	83	85

Table 4-22. John Day Dam Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	110	110	110	110	110	110	110	110
MO1	110	110	110	110	110	110	110	110
MO2	34	29	29	19	29	78	19	19
MO3	129	148	148	147	147	150	155	155
MO4	201	201	201	200	200	203	208	208
PA	201	201	201	200	200	110	110	110

4.11.1 Multiple Objective Alternative 1

The test spill operation of 110 kcfs produced an average increase of 23 kcfs for the spring operations (April 10 through June 15). Summer operations in MO1 were approximately 1.5 kcfs greater than the No Action Alternative (June 16 through August 31), because the MO1 summer operation spill requirement is 35 percent, an increase from the 30 percent requirement in the No Action Alternative (Figure 4-6 and Table 4-20).

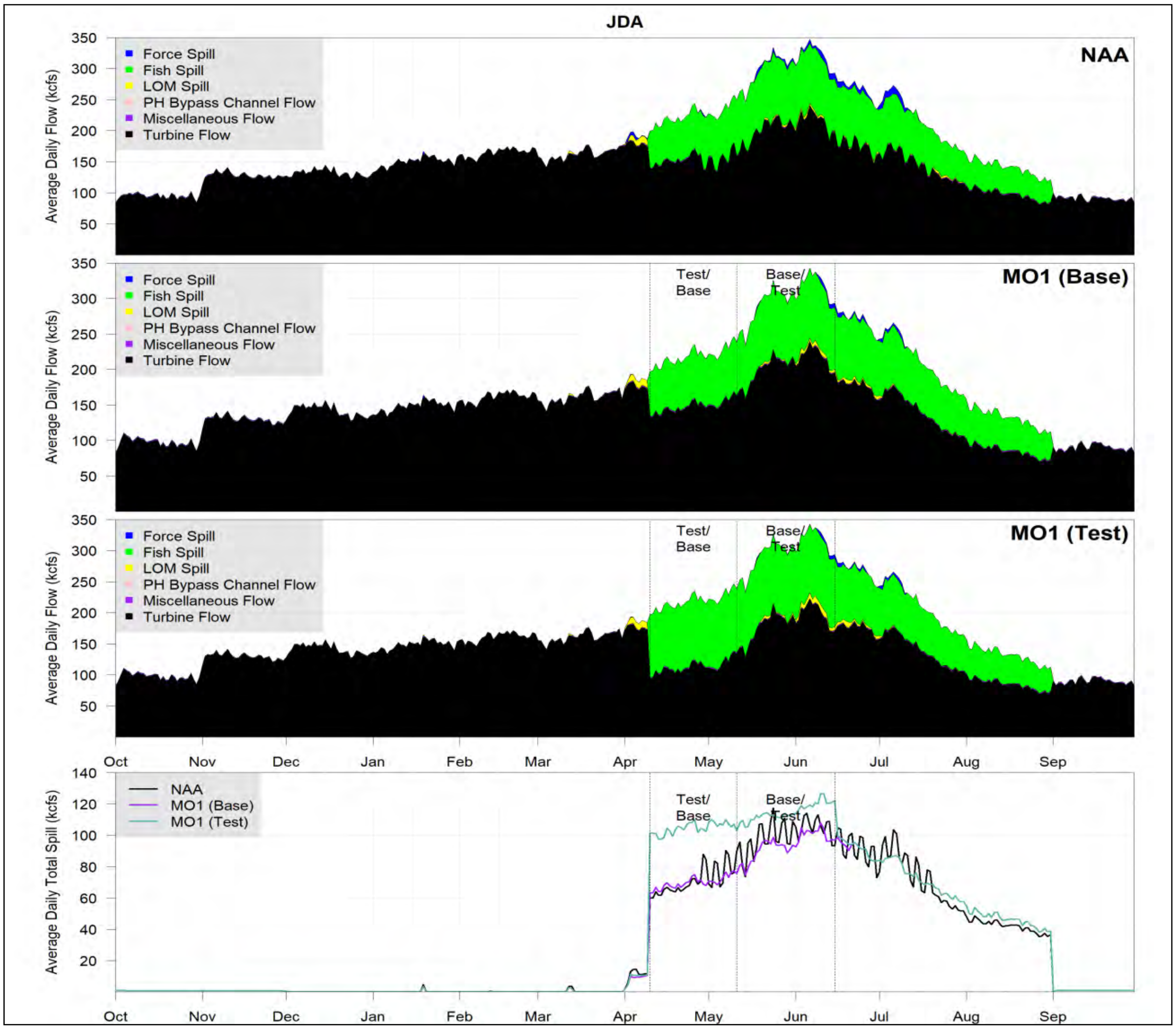


Figure 4-6. John Day Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.11.2 Multiple Objective Alternative 2

John Day Dam has a minimum spill requirement to prevent dangerous eddies from forming in the tailwater. The 110 percent TDG requirement in MO2 was superseded by the minimum spill requirement, and set to the 115 percent TDG requirements, i.e., 19 to 78 kcfs (Table 4-20). There is a shift in MO2 spill starting in July because the spill cap increases from 29 kcfs in June to 78 kcfs in July. From April 10 through June 30, MO2 spill is on average 46 kcfs lower than the No Action Alternative spill. In July, spring freshet flows are typically receding, and the 30 percent total outflow spill requirement is usually lower than the 78 kcfs spill cap (average total outflow is 213 kcfs, 30 percent of which is 71 kcfs). Thus, in July, the MO2 and No Action Alternative spill flows are much closer (MO2 spill is an average of 8 kcfs lower). MO2 spill operations end July 31, one month prior to the No Action Alternative operations. During spill operations, John Day has an additional flow of 8 kcfs used for the powerhouse bypass in MO2.

4.11.3 Multiple Objective Alternative 3

The MO3 fish spill operation is 120 percent TDG from April 10 through June 15, resulting in an average increase in spill of 52 kcfs over the No Action Alternative (MO3 spill is 138 kcfs, No Action Alternative spill is 87 kcfs) during the spring operations. Summer spill operations in MO3 are 30 percent of the total outflow, while summer operations in the No Action Alternative alternate between 30 and 40 percent of the total outflow in two-day treatments, then transition to only 30 percent of outflow on July 21. Summer spill in MO3 is approximately 3 kcfs lower because of the alternating treatment operations in the No Action Alternative (Table 4-20).

4.11.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 10 and August 31, MO4 spill is approximately 66 kcfs higher (No Action Alternative spill is 75 kcfs, MO4 spill is 141 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 104 kcfs higher.

4.11.5 Preferred Alternative

The flex spill operations from April 10 through June 15 at John Day produce approximately 38 kcfs more spill than the NAA (NAA spill is 87 kcfs, PA spill is 125 kcfs). Average initial summer spill from June 15 through mid-August are very similar between the PA and the NAA. However, the NAA operations have an alternating spill pattern, while the PA spill holds a constant 35% of total outflow. Transitional summer spill (August 15 to August 31) is reduced in the PA by approximately 20 kcfs due to a reduced spill criteria (Table 4-20).

4.12 MCNARY DAM

All alternatives showed some differences from the No Action Alternative at McNary. Powerhouse bypass flows (8 kcfs during fish passage spill) are present in all MOs, but not in the PA. MO2 spill is an average of 57 kcfs lower than the No Action Alternative. Including powerhouse bypass flows as spill, MO1, MO3, and MO4 have 14 kcfs, 19 kcfs, and 52 kcfs greater spill than the No Action Alternative during their respective spill passage time periods (Figure 4-7; Table 4-23, Table 4-24, and Table 4-25). PA spill was similar to MO4 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Figure 4-7).

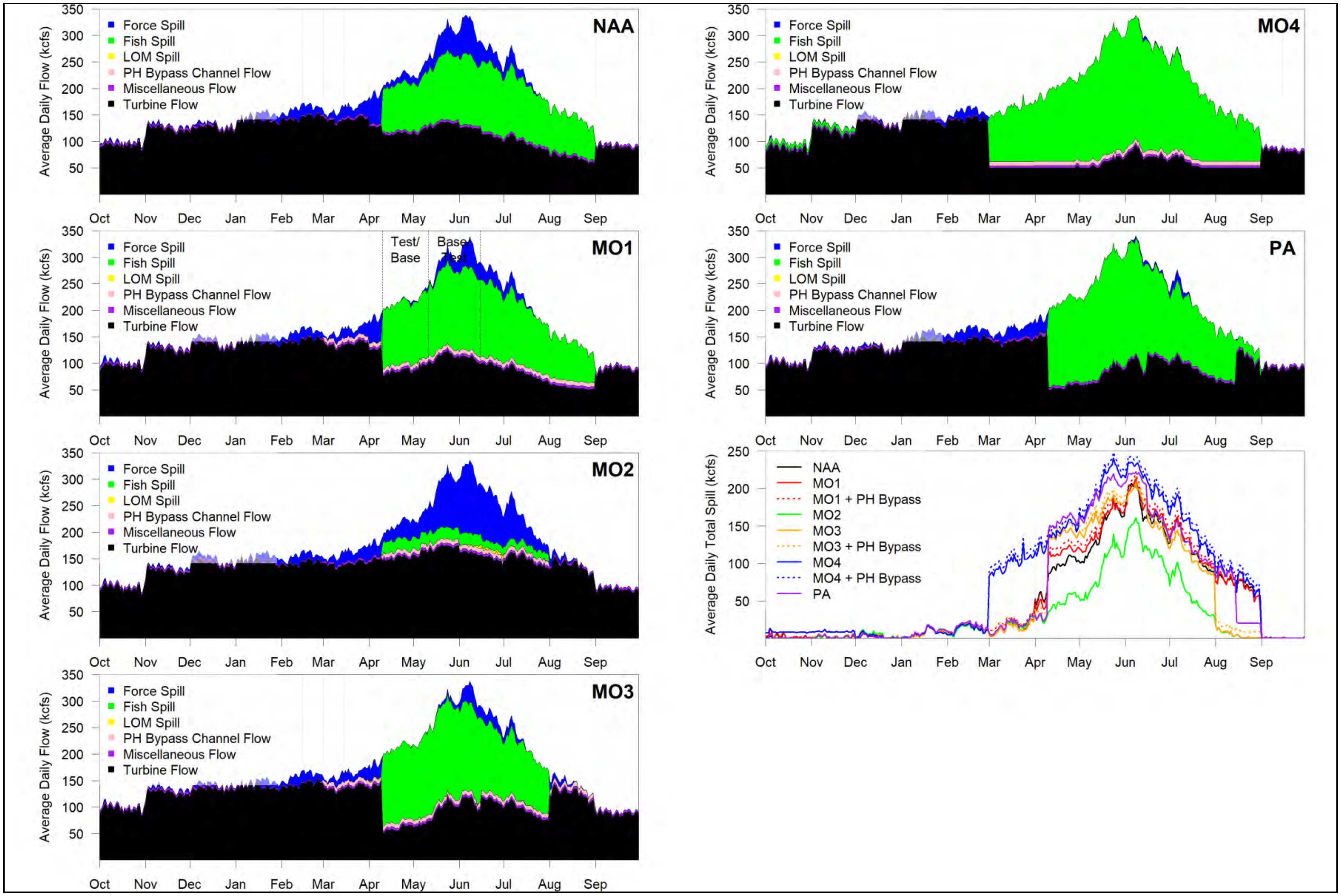


Figure 4-7. McNary Dam Partitioned Average Daily Outflow

Table 4-23. McNary Dam Fish Spill Configuration

Alternative	Start Date	End Date	Spill Operation
NAA	April 10	June 15	40% Total Outflow
NAA	June 16	August 31	50% Total Outflow
MO1 (Base)	March 1	August 31	8 kcfs (Powerhouse Bypass)
MO1 (Base)	April 10	June 15	48% Total Outflow
MO1 (Base)	June 16	August 31	57% Total Outflow
MO1 (Test)	March 1	August 31	8 kcfs (Powerhouse Bypass)
MO1 (Test)	April 10	June 15	164 kcfs (120%/115% TDG)
MO1 (Test)	June 16	August 31	57% Total Outflow
MO2	April 10	July 31	14–22 kcfs (ASW flows override 110% TDG)
MO2	April 10	July 31	8 kcfs (Powerhouse Bypass)
MO3	April 10	June 15	172–189 kcfs (120% TDG)
MO3	June 16	July 31	50% Total Outflow
MO3	March 1	August 31	8 kcfs (Powerhouse Bypass)
MO4	March 1	August 31	266–272 kcfs (125% TDG)
MO4	March 1	August 31	8 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	8 kcfs (Spillway Weir Notch)
PA	April 10	June 15	125% Daily Flex: 265 kcfs 16 hr/48% Total Outflow 8 hr
PA	June 16	August 14	57% Total Outflow
PA	August 15	August 31	20 kcfs

Table 4-24. McNary Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	48	64	68	71	71	71	59	59	60	55	60	59	59	50
MO1	48	64	69	71	71	71	60	60	60	56	60	59	59	50
MO2	62	64	69	71	71	71	76	76	76	71	76	75	75	65
MO3	62	64	69	71	71	71	71	71	71	65	71	70	70	65
MO4	62	64	69	71	71	71	76	76	76	71	76	75	75	65
PA	62	64	69	71	71	71	76	76	76	71	76	75	75	65

Table 4-25. McNary Dam Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	170	189	189	188	172	176	180	180
MO1 (Base)	170	189	189	188	172	176	180	180
MO1 (Test)	170	164	164	164	164	176	180	180
MO2	3	22	22	22	22	14	4	4
MO3	170	189	189	188	172	176	180	180
MO4	272	272	272	270	266	269	272	272
PA	272	272	272	270	266	176	180	180

4.12.1 Multiple Objective Alternative 1

Figure 4-8 shows McNary Dam for test and base spill operations, including flows from the powerhouse bypass flow (i.e., 8 kcfs March 1 through August 31). During the spring, test spill operations exceed average daily flows in No Action Alternative by up to 22 kcfs (excluding powerhouse bypass flows). Summer flows in MO1 are approximately 2.5 kcfs higher than the No Action Alternative (excluding powerhouse bypass flows).

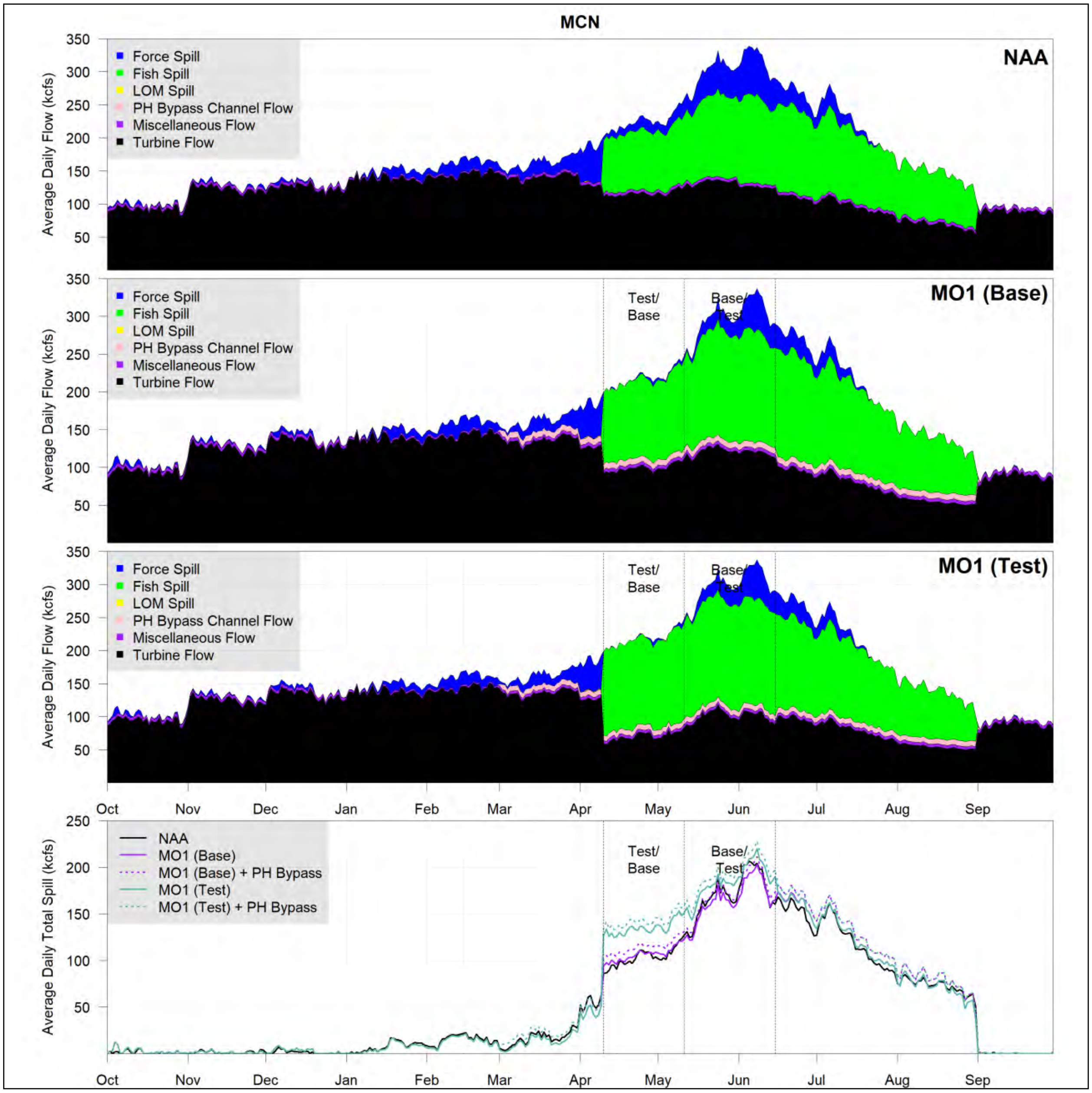


Figure 4-8. McNary Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.12.2 Multiple Objective Alternative 2

Per the Increase Juvenile Fish Transport measure, "all juvenile salmonids entering the fish bypasses at collector projects and at McNary" are to be collected and transported. The juvenile bypass at McNary in MO2 will have the same TDG contribution as a juvenile fish facility (i.e., none). Thus, the additional line noting the total spill plus powerhouse bypass flows is not included for the MO2 figure. Spill at McNary in MO2 includes 14 to 22 kcfs fish passage spill, and 8 kcfs for powerhouse bypass flows between April 10 and July 31. However, high flows in spring induce force spill conditions, causing MO2 spill to be approximately 82 kcfs on average during the April 10 to July 31 time period, 53 kcfs lower than spill in the No Action Alternative.

4.12.3 Multiple Objective Alternative 3

MO3 spill operations at McNary include 172 to 189 kcfs spill during spring (April 10 through June 15), 50 percent total outflow in the summer (June 16 through July 31), and 8 kcfs powerhouse bypass flows March 1 through August 31. MO3 spring spill is an average of 164 kcfs at McNary, approximately 25 kcfs higher than No Action Alternative spill during the same time period. Larger differences between the No Action Alternative and MO3 spill occur in early April. The average MO3 spring spill (164 kcfs) is lower than the 172 to 189 kcfs fish spill requirement because there are instances in low flow years where the spill is restricted to meet minimum generation requirements. Average summer spill, including powerhouse bypass flows, in MO3 is nearly the same as spill in the No Action Alternative.

4.12.4 Multiple Objective Alternative 4

MO4 spill between April 10 and August 31 is approximately 66 kcfs higher than the No Action Alternative spill operations, (No Action Alternative spill is 75 kcfs, MO4 spill is 141 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 83 kcfs higher (91 kcfs including powerhouse bypass flows).

4.12.5 Preferred Alternative

The flex spill operations from April 10 through June 15 at McNary produce approximately 47 kcfs more spill than the NAA (NAA spill is 139 kcfs, PA spill is 186 kcfs). Initial summer spill (June 15 through August 15) is approximately 5 kcfs higher in the PA due to the 57% total outflow operation (NAA operation is 50% total outflow), and late summer spill (August 15 through August 31) is 48 kcfs lower due to the 20 kcfs operation (NAA operation is still 50% total outflow).

4.13 ICE HARBOR DAM

Each alternative had somewhat unique spill operations at Ice Harbor. In the No Action Alternative, there is a two-day treatment spill operation between April 28 and July 13, producing abrupt changes in spill during that time period (Figure 4-9). In MO1, the base and test spring spill operations bracketed the daily spill rates in the No Action Alternative

(Figure 4-10). MO2 has the lowest spill rates at Ice Harbor but has the most LOM spill allocated; average spill flow during the MO2 spill season is 31 kcfs. MO3 results are not shown because Ice Harbor Dam is removed in that alternative. MO4 has an earlier start to spill operations than the No Action Alternative, and much higher spill rates. PA spill was similar to MO4 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Figure 4-9, Table 4-26, Table 4-27, and Table 4-28).

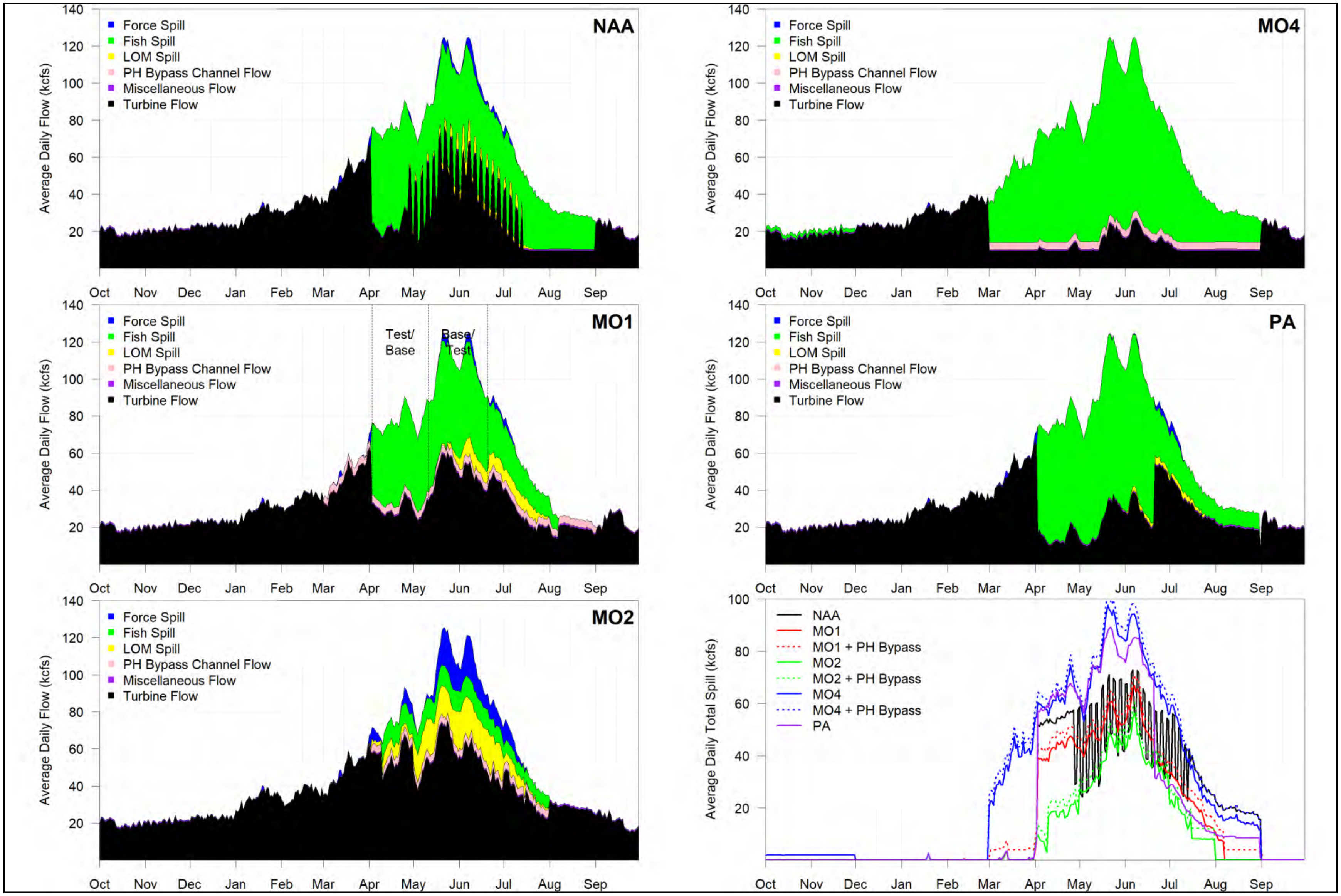


Figure 4-9. Ice Harbor Dam Partitioned Average Daily Outflow

Table 4-26. Ice Harbor Dam Fish Spill Configuration

Alternative	Start Date	End Date	Spill Operation
NAA	April 3	April 27	45 kcfs day/gas cap night
NAA	April 28	July 13	Alternating between 45 kcfs day/gas cap night and 30% total outflow in two-day treatments
NAA	July 14	August 31	45 kcfs day/gas cap night
MO1 (Base)	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO1 (Base)	April 3	August 6	30% Total Outflow
MO1 (Test)	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO1 (Test)	April 3	June 20	86 kcfs (120%/115% TDG)
MO1 (Test)	June 21	August 6	30% Total Outflow
MO2	April 3	July 31	7 –11 kcfs (ASW flows override 110% TDG)
MO2	April 3	July 31	4 kcfs (Powerhouse Bypass)
MO4	March 1	August 31	118–129 kcfs (125% TDG)
MO4	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	2 kcfs (Spillway Weir Notch)
PA	April 03	June 20	125% Daily Flex: 119 kcfs 16 hr/30% Total Outflow 8 hr
PA	June 21	August 14	30% Total Outflow
PA	August 15	August 31	8.5 kcfs

Table 4-27. Ice Harbor Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	72	74	83	72	84	82	87	87	87	87	66	72	72	78
MO1	72	74	83	72	84	82	83	83	84	84	66	69	69	78
MO2	77	74	83	72	84	82	83	83	83	85	62	69	69	84
MO3	81	79	87	76	88	85	87	87	87	87	66	72	72	87
MO4	77	74	83	72	84	82	84	84	85	85	62	69	69	84
PA	77	74	83	72	84	82	83	83	83	85	62	69	69	84

Table 4-28. Ice Harbor Dam Spill caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	70	94	94	88	90	97	101	101
MO1 (Base)	70	94	94	88	90	97	101	101
MO1 (Test)	70	86	86	86	86	97	101	101
MO2	17	11	11	11	11	7	7	7
MO4	125	125	125	118	120	129	133	133
PA	125	125	125	118	120	97	101	101

4.13.1 Multiple Objective Alternative 1

Figure 4-10 shows test and base spill operations in MO1 at Ice Harbor, including powerhouse bypass flows (i.e., 4 kcfs March 1through August 31). Test spill operations are higher than No Action Alternative during the spring. During the two-day treatment operations in the No Action

Alternative, MO1 test spill operations fluctuate between approximately 2 kcfs and 44 kcfs higher than No Action Alternative, with a mean increase of 23 kcfs. MO1 base spill operations produce spill rates lower than or equal to the No Action Alternative. There are some instances where the No Action Alternative and base spill operations in MO1 are nearly equal because both alternatives have a spill requirement of 30 percent total outflow. However, on average, base spill operations are 10 kcfs lower than spill in the No Action Alternative.

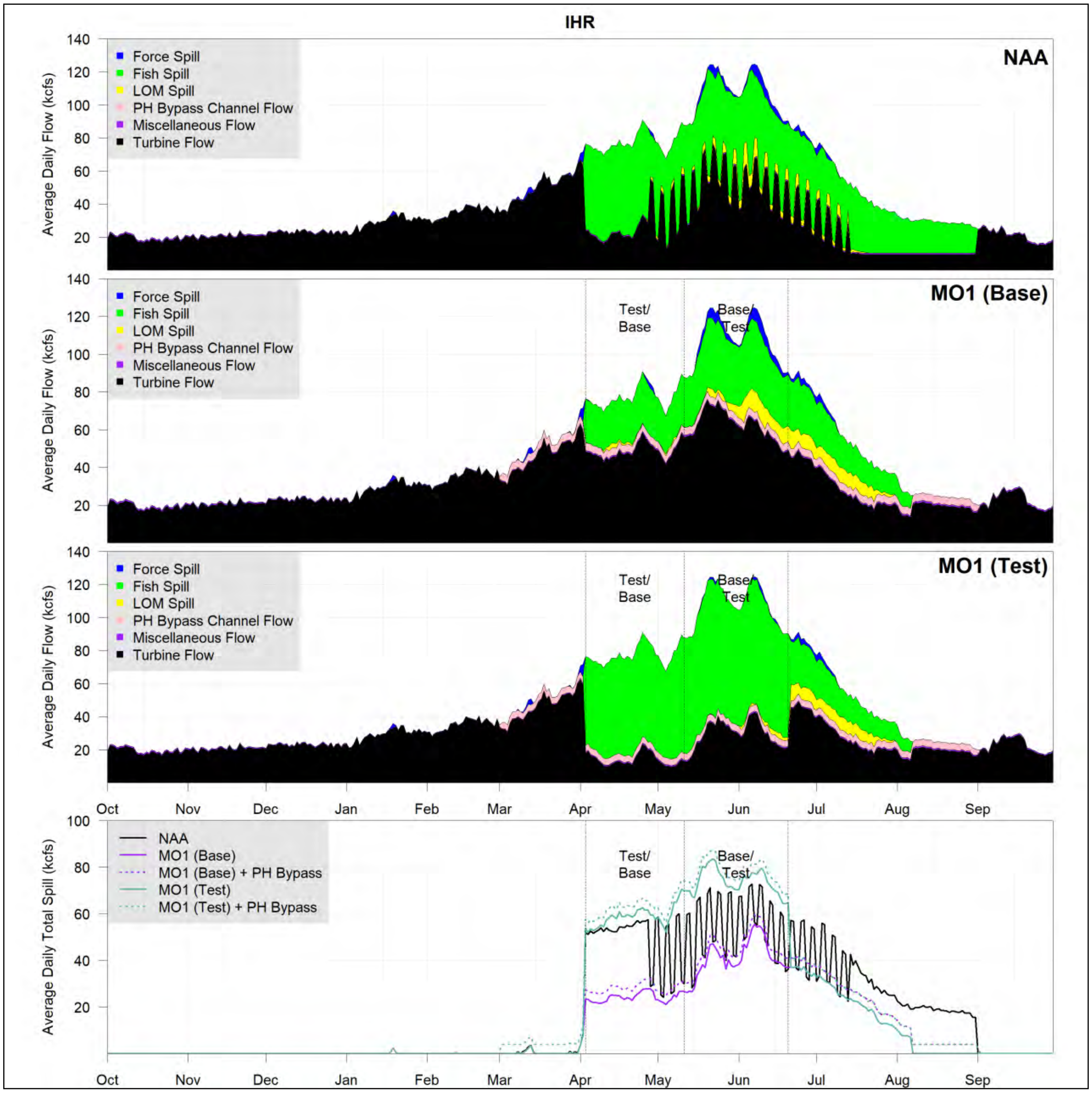


Figure 4-10. Ice Harbor Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.13.2 Multiple Objective Alternative 2

MO2 spill operations at Ice Harbor occur from April 3 to July 31 and include 7 to 11 kcfs fish spill and 4 kcfs powerhouse bypass flow. Average spill in MO2 is 27 kcfs (31 kcfs including powerhouse bypass flows) between April 3 and July 31, approximately 21 kcfs lower than the No Action Alternative average spill during the same time period. MO2 spring spill is higher than the fish spill requirement of 7 to 11 kcfs due to spill contributions by LOM (11 kcfs average) and force spill (7 kcfs average).

4.13.3 Multiple Objective Alternative 3

Ice Harbor Dam is removed in MO3.

4.13.4 Multiple Objective Alternative 4

MO4 spill is approximately 12 kcfs higher than No Action Alternative spill between April 3 and August 31 (No Action Alternative spill is 41 kcfs, MO4 spill is 53 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 36 kcfs higher (40 kcfs including powerhouse bypass flows).

4.13.5 Preferred Alternative

Ice Harbor flex spill operations from April 3 to June 20 produced spill approximately 19 kcfs greater than the NAA during that time period (NAA spill was 52 kcfs, PA spill was 71 kcfs). During initial summer spill operation, PA spill is approximately 14 kcfs lower than the NAA, and approximately 10 kcfs lower than the NAA due a lower spill requirements (Table 4-26).

4.14 LOWER MONUMENTAL DAM

Spill results in MO2 and MO4 have the greatest difference from the No Action Alternative. MO1 spill is only slightly lower than the No Action Alternative in spring. MO2 results have much lower spill, and a shorter spill season. MO4 has both much more spill and an earlier start to spring spill (Figure 4-11). MO3 results are not shown because Lower Monumental Dam is removed in that alternative. PA spill was similar to MO4 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Table 4-29, Table 4-30, and Table 4-31).

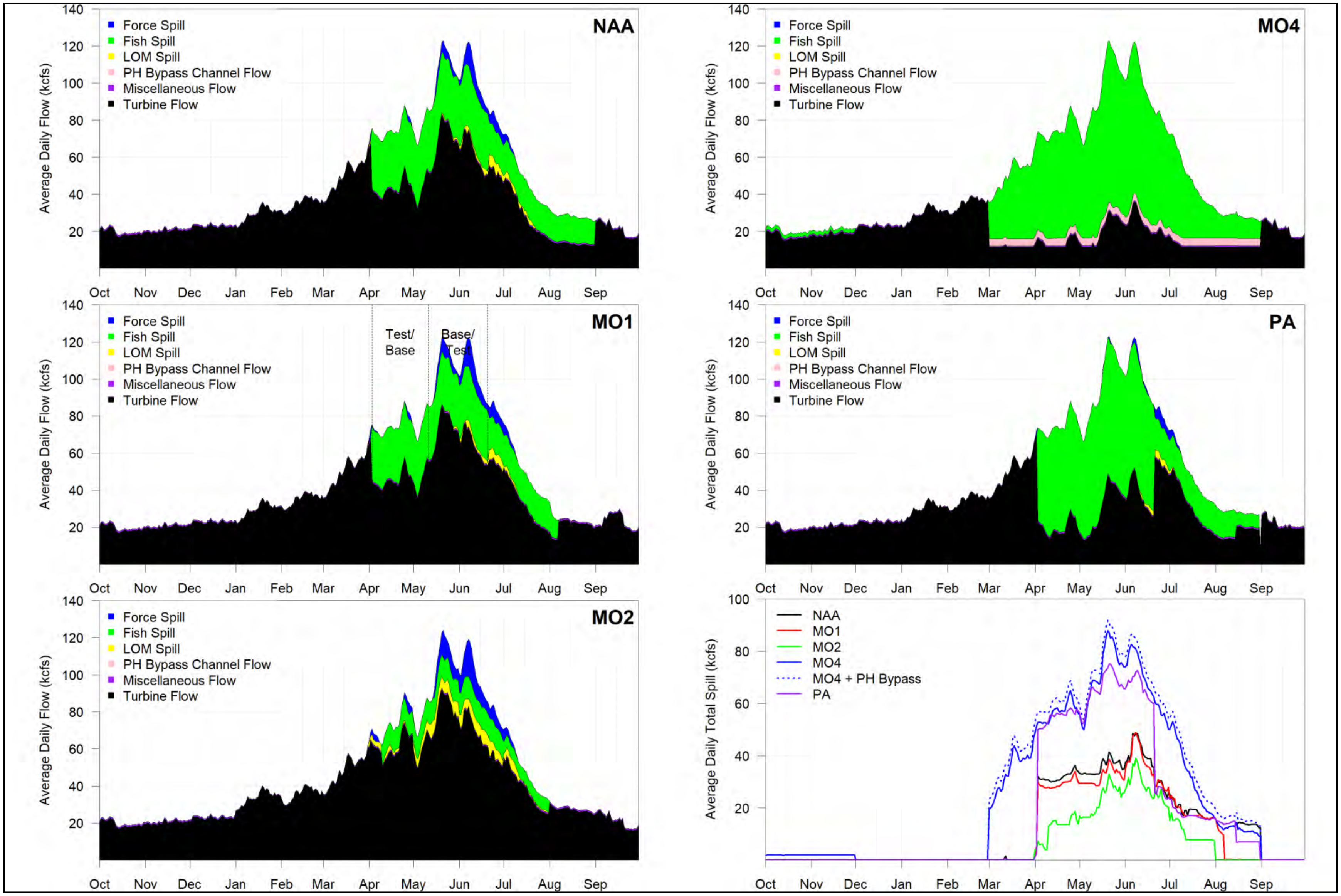


Figure 4-11. Lower Monumental Dam Partitioned Average Daily Outflow

Table 4-29. Lower Monumental Dam Fish Spill Configuration

Alternative	Start Date	End Date	Spill Operation
NAA	April 3	June 20	33 kcfs (Waiver Gas Cap)
NAA	June 21	August 31	17 kcfs
MO1 (Base)	April 3	June 20	26 kcfs
MO1 (Base)	June 21	August 6	17 kcfs
MO1 (Test)	April 3	June 20	33 kcfs (120%/115% TDG)
MO1 (Test)	June 21	August 6	17 kcfs
MO2	April 3	July 31	7–12 kcfs (110% TDG, ASW flows override in July)
MO4	March 1	August 31	99–104 kcfs (125% TDG)
MO4	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	2 kcfs (Spillway Weir Notch)
PA	April 03	June 20	125% Daily Flex: 98 kcfs 16 hr/30 kcfs 8 hr
PA	June 21	August 14	17 kcfs
PA	August 15	August 31	7 kcfs

Table 4-30. Lower Monumental Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	61	75	85	86	85	83	84	84	83	75	73	67	67	60
MO1	61	75	85	86	86	83	80	80	80	72	69	64	64	60
MO2	68	75	85	86	86	83	85	85	84	76	74	68	68	67
MO3	67	74	83	84	84	81	84	84	83	75	73	67	67	67
MO4	68	75	85	86	86	83	86	86	86	77	74	69	69	67
PA	68	75	85	86	86	83	85	85	84	76	74	68	68	67

Table 4-31. Lower Monumental Dam Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	25	33	33	33	33	33	33	33
MO1 (Base)	25	26	26	25	26	33	33	33
MO1 (Test)	25	33	33	33	33	33	33	33
MO2	17	12	12	12	12	7	6	6
MO4	101	101	101	99	99	104	108	108
PA	101	101	101	99	99	33	33	33

4.14.1 Multiple Objective Alternative 1

Test spill operations in MO1 have the same spill requirements as the No Action Alternative (33 kcfs, April 3 through June 15). Base spill spring operations have a lower spill requirement of 26 kcfs, resulting in an average difference of approximately 5.5 kcfs decrease in spill from the No Action Alternative (Figure 4-12).

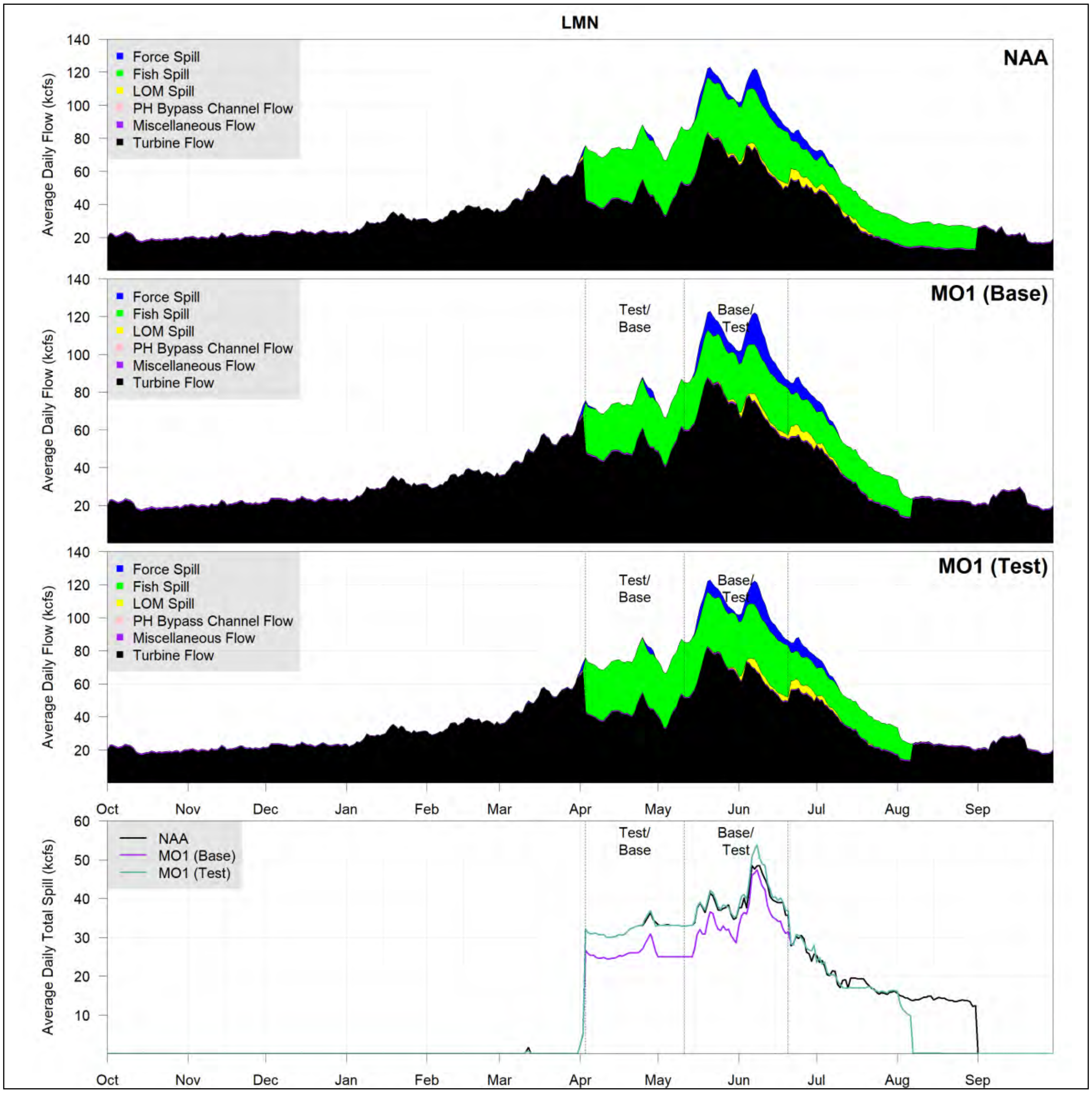


Figure 4-12. Lower Monumental Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.14.2 Multiple Objective Alternative 2

Spill operations at Lower Monumental Dam in MO2 only include a fish spill requirement of 7 to 12 kcfs between April 3 and July 31. Average total spill in MO2 during the fish operations is approximately 18 kcfs, 12 kcfs lower than spill in the No Action Alternative. LOM and force spill conditions contribute an average of 4 kcfs and 4 kcfs, respectively, during the fish passage season.

4.14.3 Multiple Objective Alternative 3

Lower Monumental Dam is removed in MO3.

4.14.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 3 and August 31, MO4 spill is approximately 20 kcfs higher (No Action Alternative spill is 27 kcfs, MO4 spill is 47 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 34 kcfs higher (38 kcfs including powerhouse bypass flows).

4.14.5 Preferred Alternative

Lower Monumental flex spill operations from April 3 to June 20 produced spill approximately 19 kcfs greater than the NAA during that time period (NAA spill was 52 kcfs, PA spill was 71 kcfs). PA spill is approximately 1 kcfs lower during initial summer spill operation, and approximately 7 kcfs lower in late summer spill due to lower spill requirements (Table 4-29).

4.15 LITTLE GOOSE DAM

Spill in MO1 and MO2 did not vary from the No Action Alternative at Little Goose Dam as much as at other projects. MO2 spill is marginally lower than the No Action Alternative's throughout the spill season, with most of the difference occurring in summer. Similar to other projects, MO4 spill is much greater than spill in the No Action Alternative and starts earlier in the year. MO3 results are not shown because Little Goose Dam is removed in that alternative. PA spill was similar to MO4 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Figure 4-13, Table 4-32, Table 4-33, and Table 4-34).

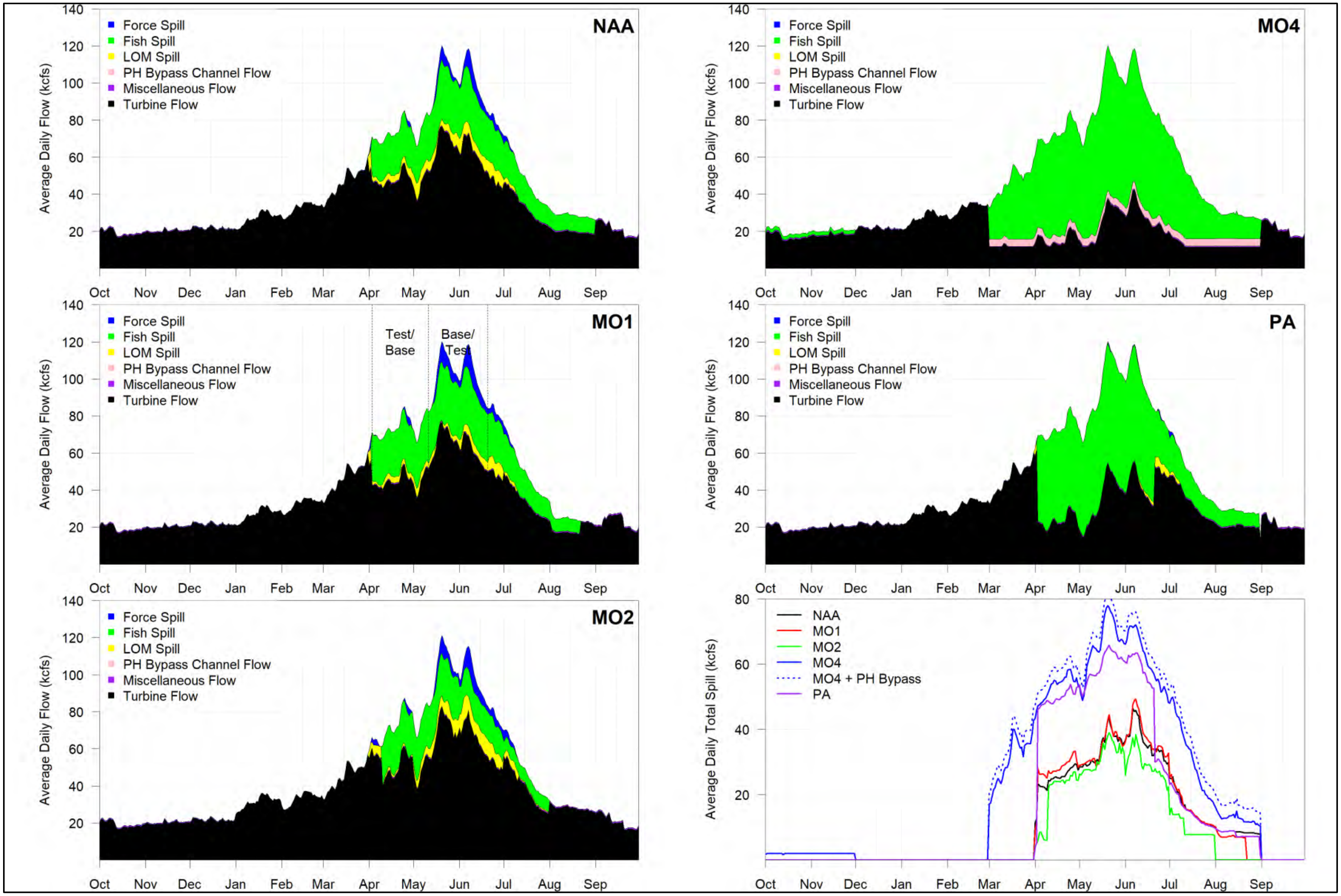


Figure 4-13. Little Goose Dam Partitioned Average Daily Outflow

Table 4-32. Little Goose Dam Fish Spill Configuration

Alternative	Start Date	End Date	Spill Operation
NAA	April 3	August 31	30% Total Outflow
MO1 (Base)	April 3	August 21	30% Total Outflow
MO1 (Test)	April 3	June 20	30 kcfs (120%/115% TDG)
MO1 (Test)	June 21	August 21	30% Total Outflow
MO2	April 3	July 31	7.2–23 kcfs (110% TDG, ASW flows override in July)
MO4	March 1	August 31	82–83 kcfs (125% TDG)
MO4	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	2 kcfs (Spillway Weir Notch)
PA	April 03	June 20	125% Daily Flex: 79 kcfs 16 hr/30% Total Outflow 8 hr
PA	June 21	August 14	30% Total Outflow
PA	August 15	August 31	7.2 kcfs (overridden by ASW req.)

Table 4-33. Little Goose Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	59	80	76	83	82	81	74	74	73	73	66	62	62	61
MO1	59	80	76	83	82	81	70	70	69	70	63	59	59	61
MO2	73	80	76	83	82	81	81	81	80	82	73	69	69	75
MO4	73	80	76	83	82	81	83	83	82	82	73	69	69	75
PA	73	80	76	83	82	81	81	81	80	82	73	69	69	75

Table 4-34. Little Goose Dam Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	35	36	36	37	35	31	32	32
MO1	35	36	36	37	35	31	32	32
MO2	23	23	23	23	15	7.2	7	7
MO4	82	82	82	82	82	83	83	83
PA	82	82	82	82	82	31	32	32

4.15.1 Multiple Objective Alternative 1

The base spill operations in MO1 produce nearly the same amount of spill as the No Action Alternative because both have the same fish spill operations (i.e., 30 percent total outflow). MO1 base spill and No Action Alternative spill are not exactly the same because the No Action Alternative has approximately 1.3 kcfs more LOM spill throughout the MO1 base/test spill operations (i.e., April 3 through June 20). MO1 test spill operations produced higher average daily spill than the No Action Alternative, with average difference of approximately 2 kcfs during the test/base spill operations. MO1 summer spill results are nearly the same as the No

Action Alternative and end on August 21, which is earlier than the No Action Alternative August 31 cutoff (Figure 4-14).

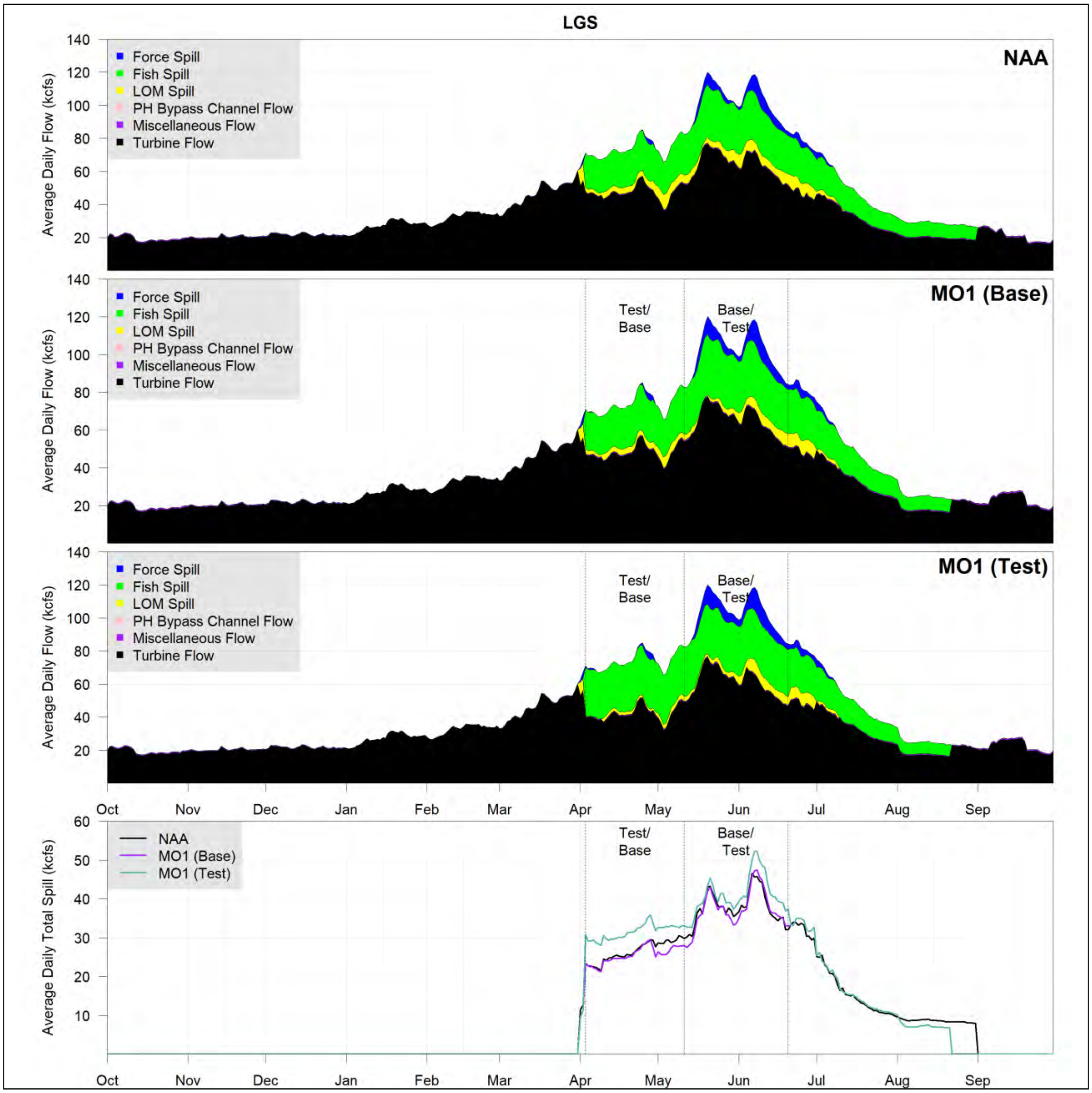


Figure 4-14. Little Goose Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.15.2 Multiple Objective Alternative 2

MO2 spill operations at Little Goose Dam only include fish spill of 7.2 to 23 kcfs between April 3 and July 31. Average total spill in MO2 during the fish operations is approximately 23 kcfs, 5 kcfs lower than spill in the No Action Alternative. The average MO2 spill in late July is 7.2 kcfs, equal to the fish spill requirement for that time period because there is almost no contribution to spill from LOM or force spill during the receding limb of the spring freshet.

4.15.3 Multiple Objective Alternative 3

Little Goose Dam is removed in MO3.

4.15.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 10 and August 31, MO4 spill is approximately 21 kcfs higher (No Action Alternative spill is 24 kcfs, MO4 spill is 45 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 31 kcfs higher (35 kcfs including powerhouse bypass flows).

4.15.5 Preferred Alternative

Little Goose flex spill operations from April 3 to June 20 produced spill approximately 24 kcfs greater than the NAA during that time period (NAA spill was 32 kcfs, PA spill was 56 kcfs). PA spill is nearly the same as the NAA because the spill operation in both alternatives is 30% total outflow for the time period (June 21 to August 14). In late summer PA spill is approximately 1 kcfs lower due to lower spill requirements (Table 4-32).

4.16 LOWER GRANITE DAM

Both MO2 and MO4 spill results at Lower Granite Dam varied from spill in the No Action Alternative. MO1 spill results were very similar to No Action Alternative spill, except in August where MO1 spill is lower. MO2 spill is decreased from No Action Alternative spill and ends earlier. MO4 spill is much higher than No Action Alternative spill and starts earlier. MO3 results are not shown because Lower Granite Dam is removed in that alternative. PA spill was similar to MO4 during the beginning of spill season, but more similar to NAA spill after flex spill ends in mid-June (Figure 4-15, Table 4-35, Table 4-36, and Table 4-37).

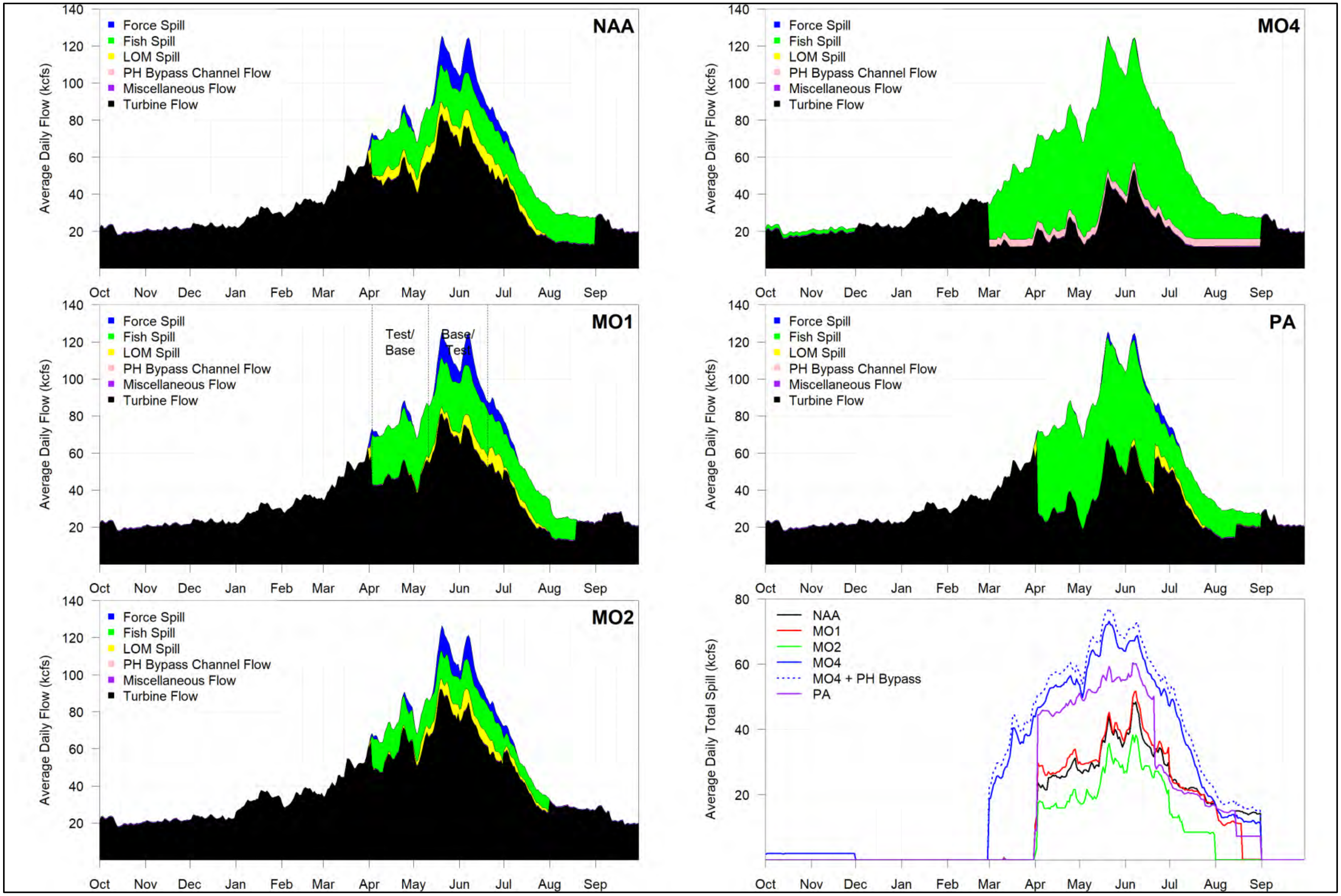


Figure 4-15. Lower Granite Dam Partitioned Average Daily Outflow

Table 4-35. Lower Granite Dam Fish Spill Configuration

Alternative	Start Date	End Date	Spill Operation
NAA	April 3	June 20	20 kcfs
NAA	June 21	August 31	18 kcfs
MO1 (Base)	April 3	June 20	20 kcfs
MO1 (Base)	June 21	August 18	18 kcfs
MO1 (Test)	April 3	June 20	35 kcfs (120%/115% TDG)
MO1 (Test)	June 21	August 18	18 kcfs
MO2	April 3	July 31	7–16 kcfs (110% TDG)
MO4	March 1	August 31	73–74 kcfs (125% TDG)
MO4	March 1	August 31	4 kcfs (Powerhouse Bypass)
MO4	October 1	November 30	2 kcfs (Spillway Weir Notch)
PA	April 03	June 20	125% Daily Flex: 72 kcfs 16 hr/20 kcfs 8 hr
PA	June 21	August 14	18 kcfs
PA	August 15	August 31	7 kcfs

Table 4-36. Lower Granite Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	55	70	82	76	82	82	74	74	74	74	67	56	56	55
MO1	55	70	82	76	82	83	70	70	71	72	64	53	53	55
MO2	70	70	82	76	82	83	83	83	83	85	76	63	63	69
MO4	70	70	82	76	82	83	85	85	85	85	76	63	63	69
PA	70	70	82	76	82	83	83	83	83	85	76	63	63	69

Table 4-37. Lower Granite Spill Caps (kcfs)

Alternative	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2
NAA	35	35	35	35	35	27	23	23
MO1 (YR1)	35	35	35	35	35	27	23	23
MO1 (YR2)	35	35	35	35	35	27	23	23
MO2	20	16	16	15	16	7	11	11
MO4	74	74	74	74	74	73	75	75
PA	74	74	74	74	74	27	23	23

4.16.1 Multiple Objective Alternative 1

Similar to Little Goose, the MO1 base spill operations are the same as the No Action Alternative spill operations: 20 kcfs for MO1. Thus, the minor differences between No Action Alternative and MO1 base spill (+/- 3 kcfs) are induced by a combination of differences in total outflow, LOM spill, and powerhouse availability. The fish spill requirements for MO1 test spill operation is 35 kcfs. Force spill conditions and LOM spill increased total average spill during MO1 test spill to 39 kcfs on average during the test spill period. The average spill in the No Action Alternative at Lower Granite from April 3 through June 20 is 32 kcfs due to LOM (adding 6 kcfs) and force spill (adding 6 kcfs) contributing to the 20 kcfs of required fish spill. Thus, the average difference in spill between MO1 test operations and the No Action Alternative is 7 kcfs (Figure 4-16).

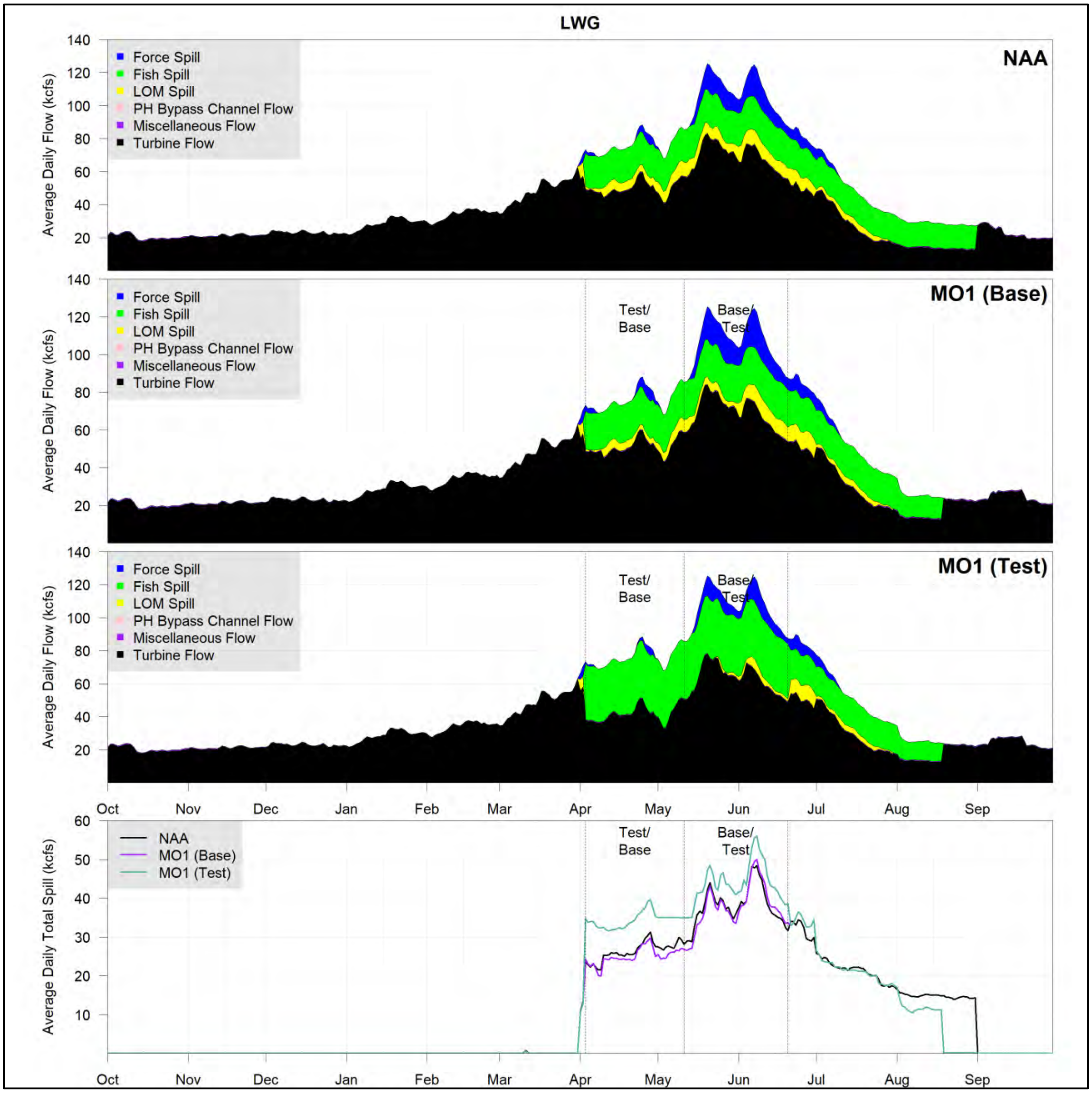


Figure 4-16. Lower Granite Dam Base and Test Spill Operations in Multiple Objective Alternative 1

Note: Plot details in Section 3.1.3.

4.16.2 Multiple Objective Alternative 2

MO2 spill operations at Lower Granite only include fish spill of 7 to 16 kcfs between April 3 and July 31. Average total spill in MO2 during the fish operations is approximately 20 kcfs, 9 kcfs lower than spill in the No Action Alternative. The average MO2 spill in late July is 7 kcfs, equal to the fish spill requirement for that time period because there is typically no contribution to spill from LOM or force spill during the receding limb of the spring freshet.

4.16.3 Multiple Objective Alternative 3

Lower Granite Dam is removed in MO3.

4.16.4 Multiple Objective Alternative 4

During the No Action Alternative spill operations between April 3 and August 31, MO4 spill is approximately 18 kcfs higher (No Action Alternative spill is 26 kcfs, MO4 spill is 44 kcfs). In March, where there are no spill operations in the No Action Alternative, only the occasional force spill, MO4 spill is 32 kcfs higher (36 kcfs including powerhouse bypass flows).

4.16.5 Preferred Alternative

Lower Granite flex spill operations from April 3 to June 20 produced spill approximately 19 kcfs greater than the NAA during that time period (NAA spill was 2 kcfs, PA spill was 20 kcfs). PA spill is nearly the same as the NAA because the spill operation in both alternatives is 18 kcfs for the time period (June 21 to August 14). In late summer PA spill is approximately 7 kcfs lower due to a lower spill requirement of 7 kcfs (Table 4-32).

4.17 DWORSHAK DAM

There are no fish spill operations at Dworshak Dam. Also, the powerhouse availabilities did not change between alternatives (Table 4-38). So, changes in spill at Dworshak are induced only by LOM spill and total outflow. Spill at Dworshak typically has a double peak pattern throughout the year, with a large peak in April, and another smaller peak in June and August (Figure 4-17). Starting in July, the No Action Alternative, MO3, MO4, and Preferred Alternative spill at Dworshak is almost identical, which makes the lines difficult to distinguish in Figure 4-17.

Table 4-38. Dworshak Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
All Alternatives	82	97	68	85	98	98	98	98	98	98	98	98	98	85

MO1 average daily spill in April is nearly the same as spill in the No Action Alternative (+/- 0.25 kcfs). Higher June and July outflows in MO1 increase spill relative to the No Action Alternative during those months by approximately 0.5 kcfs. Lower August outflows in MO1 decrease spill relative to the No Action Alternative by approximately 0.2 kcfs.

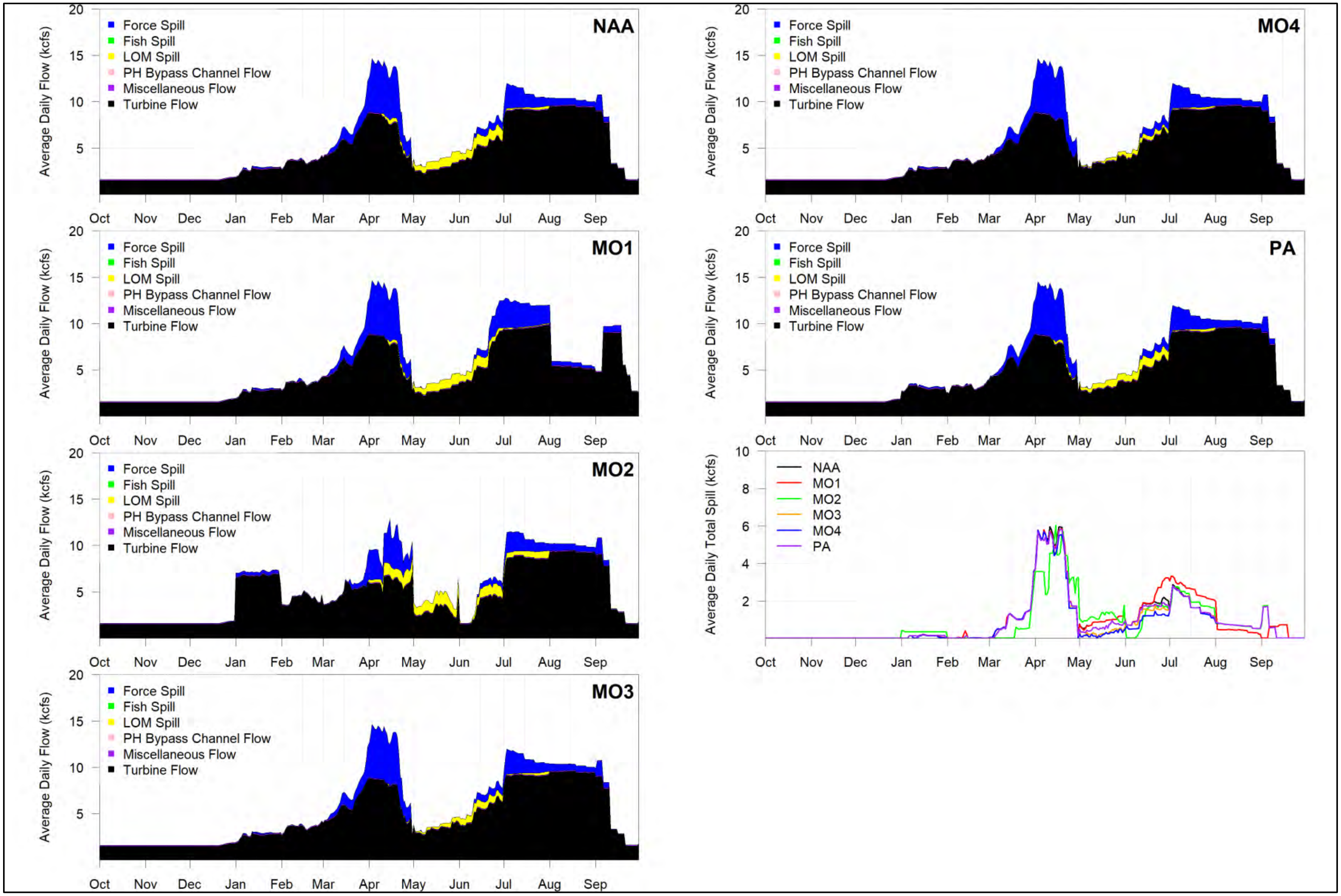
From June 1 through August, MO2 and No Action Alternative total average spill rates are approximately 1.3 kcfs and 1.4 kcfs, respectively, with a maximum difference of up to 1.3 kcfs.

The average January spill in MO2 is also approximately 0.4 kcfs higher than the No Action Alternative due to increase total outflows

MO3 and No Action Alternative spill rates are very similar. MO3 spill is 0.25 kcfs lower than the average No Action Alternative spill in June. In late April during peak spill, MO3 daily average spill is lower than No Action Alternative spill by at most 0.5 kcfs due to higher LOM spill in the No Action Alternative.

MO4 and No Action Alternative spill rates are also very similar. MO4 spill is 0.6 kcfs lower than the average No Action Alternative spill in May through June. In late April during peak spill, MO4 daily average spill is lower than No Action Alternative spill by at most 0.5 kcfs due to higher LOM spill in the No Action Alternative.

PA spill rates are nearly identical to those in the No Action Alternative. The maximum difference between PA and NAA spill on any given day is 0.5 kcfs, where NAA is slightly higher because there is greater magnitude of lack of market spill (Table 4-2).



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1348 **Figure 4-17. Dworshak Dam Partitioned Average Daily Outflow**

4.18 MIDDLE COLUMBIA PROJECTS

In this section, summary hydrographs are provided for each project on the middle Columbia River, followed by a brief discussion about spill changes. Spill at the middle Columbia projects did not vary greatly between the MOs, No Action Alternative, and Preferred Alternatiuve. Measures only modified the LOM, total outflow, and some projects' powerhouse availabilities. Grand Coulee and Chief Joseph are the only projects on the middle Columbia that had different powerhouse availabilities in the MOs, as documented in their respective results subsections. Powerhouse availability factors for all other middle Columbia projects are tabulated below (Table 4-39).

Outflow at Grand Coulee controls flows at all other projects on the middle Columbia. Thus, spill at all middle Columbia projects is influenced by outflow from Grand Coulee. Changes in spill induced by total outflow (i.e., force spill conditions) on the middle Columbia can be traced to operations at Grand Coulee that modified timing and/or magnitude of releases. Most of the LOM spill on the middle Columbia projects is typically allocated at Chief Joseph and/or Wells. Thus, spill rates at Chief Joseph and Wells are more influenced by MOs LOM than other projects on the middle Columbia (Figure 4-18 through Figure 4-24).

Table 4-39. Non-Federal Middle Columbia Dam Powerhouse Availabilities for All Alternatives (percent of maximum powerhouse capacity)

Project	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
Priest Rapids	100	100	100	93	90	96	100	100	100	100	100	100	99	90
Wanapum	90	90	90	90	90	90	90	90	90	99	100	91	90	90
Rock Island	88	88	90	96	88	88	88	88	88	89	88	96	96	92
Rocky Reach	90	90	90	90	90	90	90	90	90	84	90	90	90	90
Wells	87	92	92	92	92	92	92	92	100	100	100	92	92	82

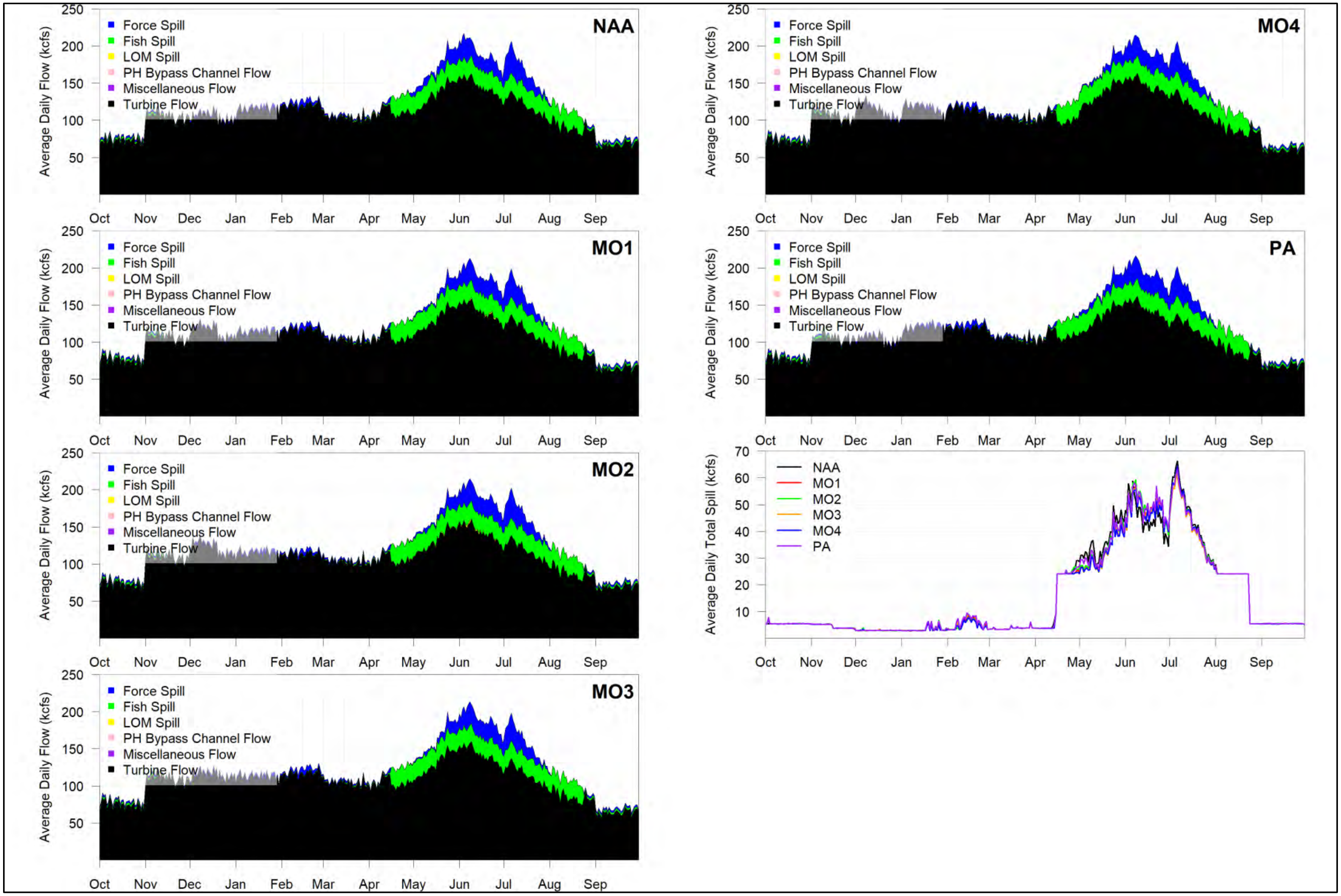
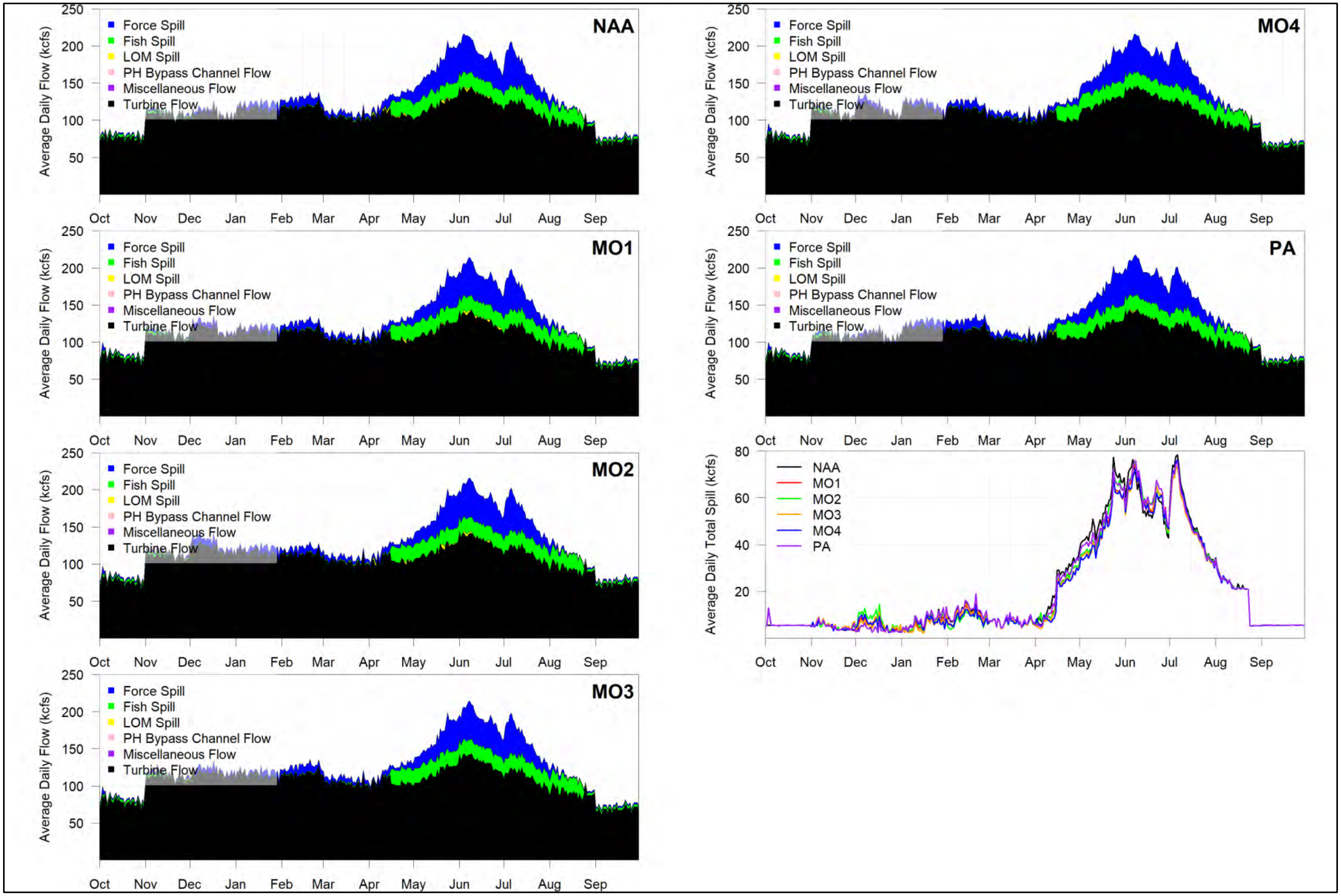


Figure 4-18. Priest Rapids Dam Partitioned Average Daily Outflow



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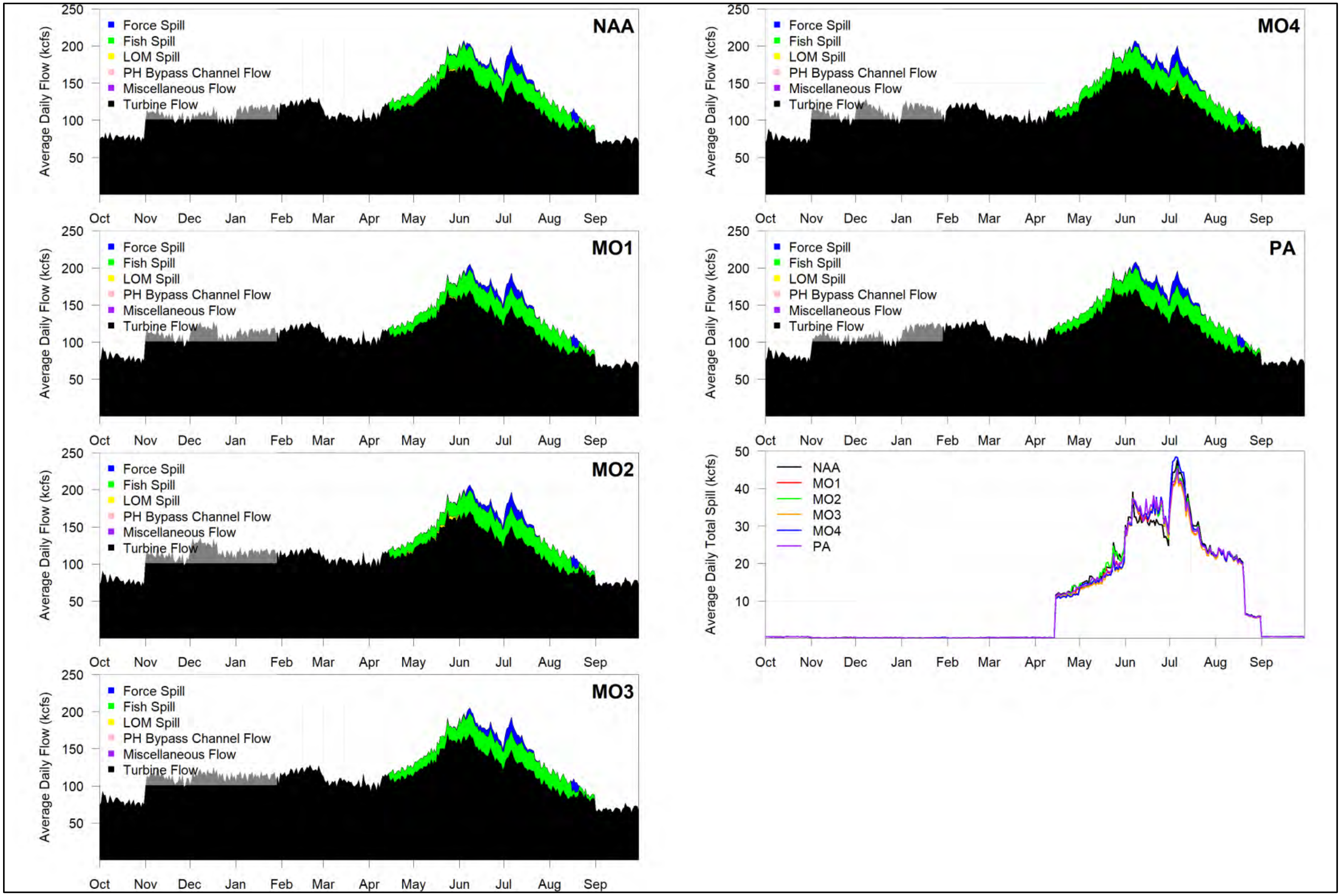
1371 **Figure 4-19. Wanapum Dam Partitioned Average Daily Outflow**



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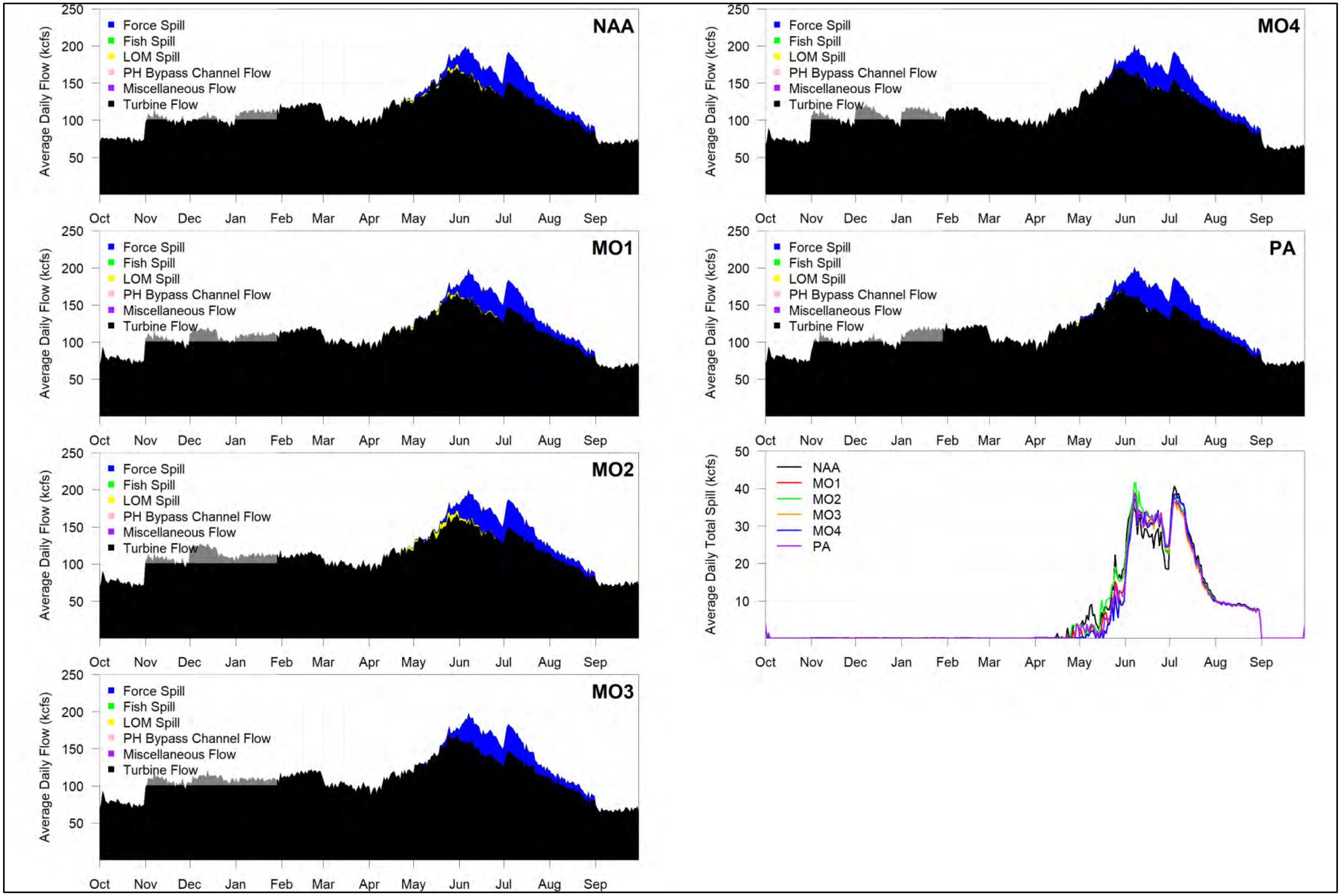
1373 **Figure 4-20. Rock Island Dam Partitioned Average Daily Outflow**



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1375 **Figure 4-21. Rocky Reach Dam Partitioned Average Daily Outflow**

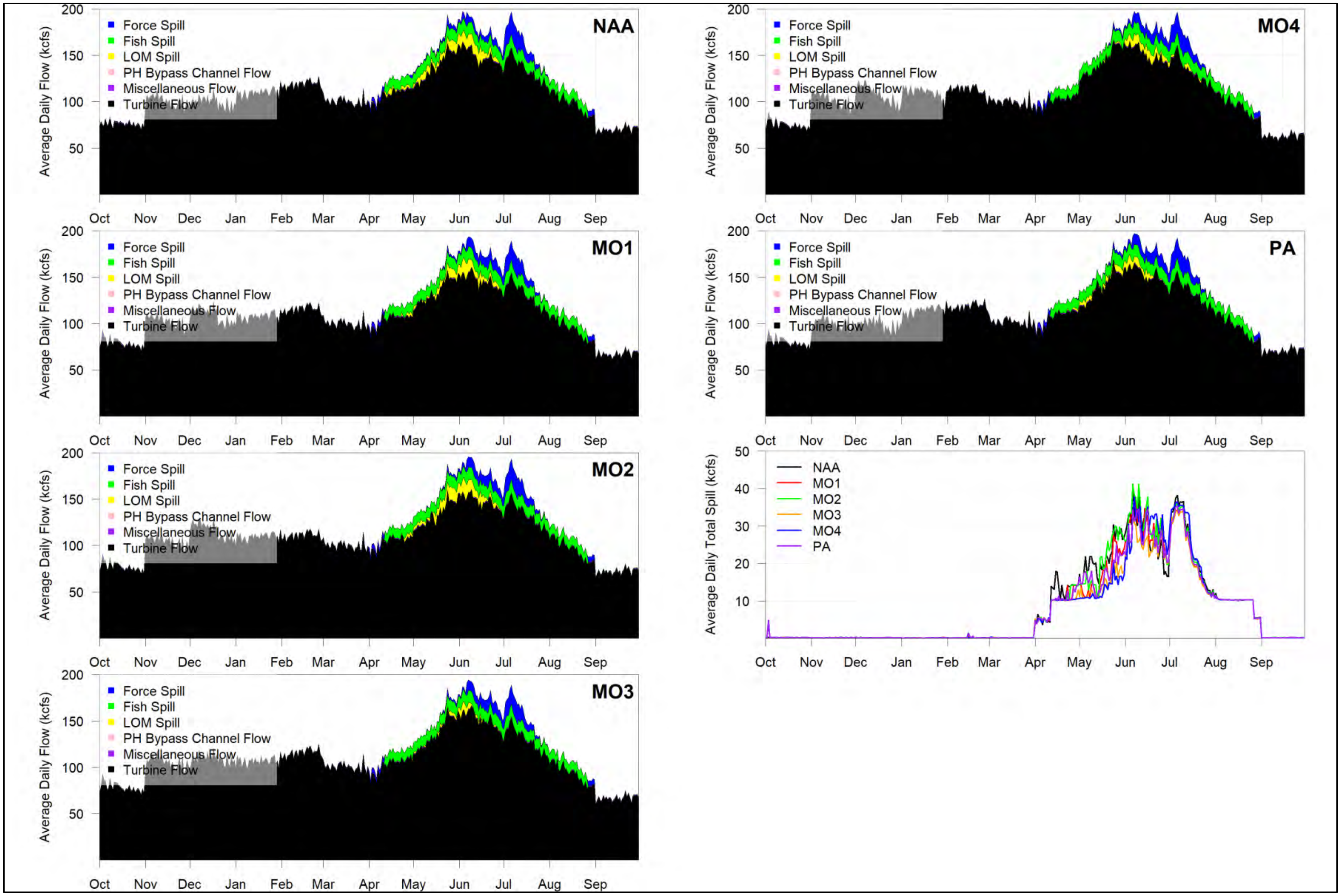


Figure 4-22. Wells Dam Partitioned Average Daily Outflow

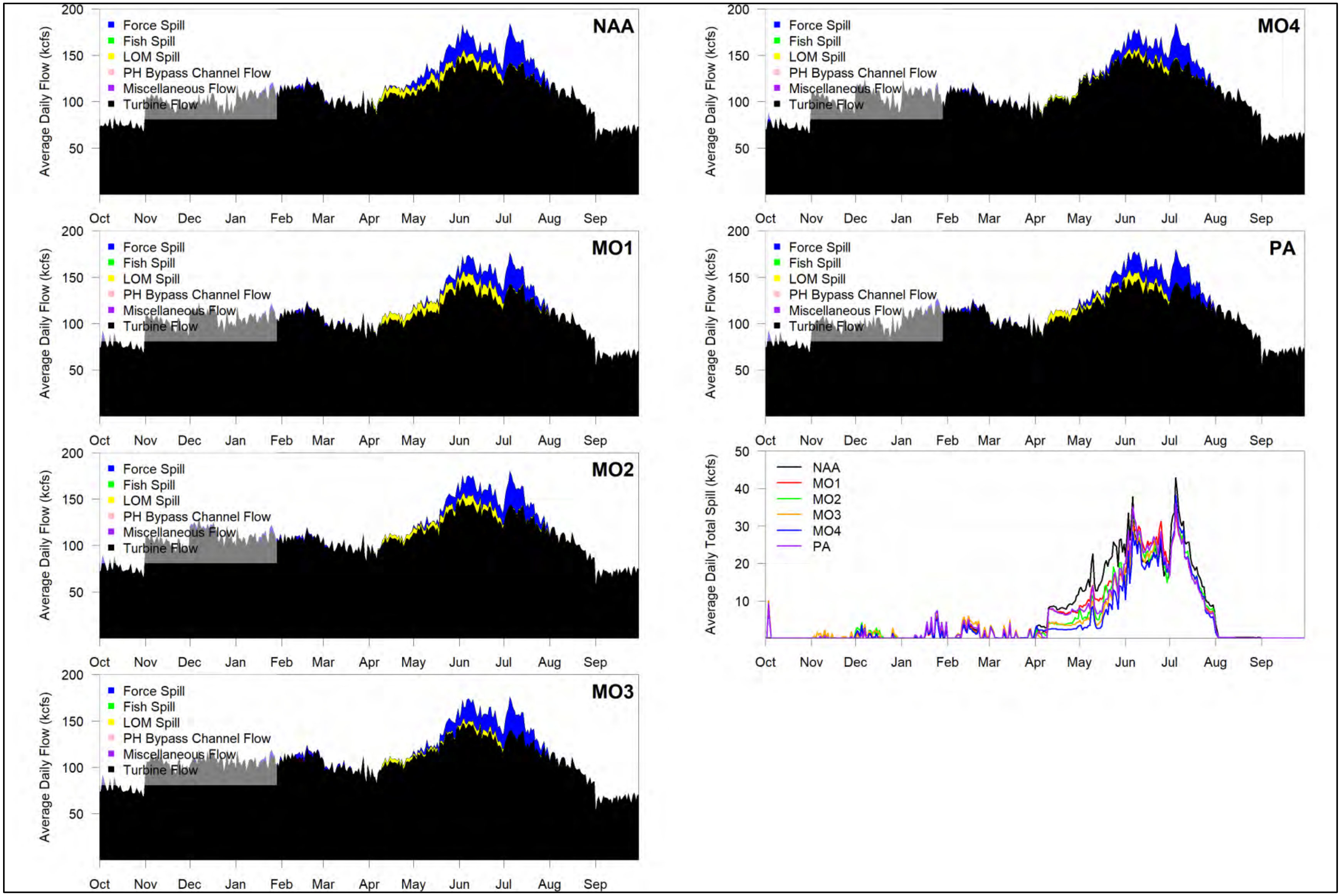
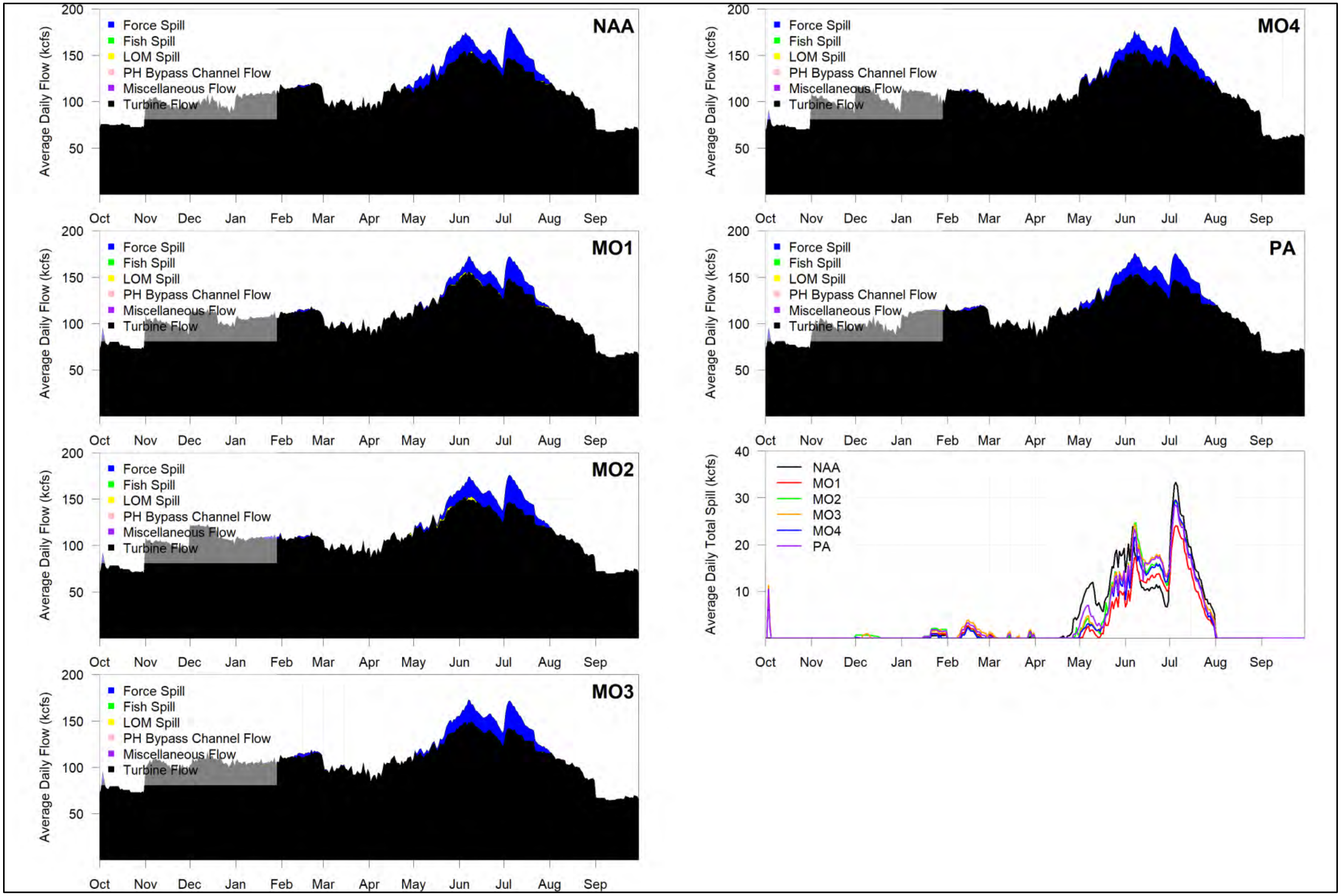


Figure 4-23. Chief Joseph Dam Partitioned Average Daily Outflow



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1381 **Figure 4-24. Grand Coulee Dam Partitioned Average Daily Outflow**

4.18.1 Priest Rapids Dam

Fish spill operations at Priest Rapids are unchanged among all MOs and the No Action Alternative, and are tabulated below (Table 4-40):

Table 4-40. Priest Rapids Dam Spill Operations in All Alternatives

Start Date	End Date	Spill Operation
April 16	August 23	24 kcfs
August 24	November 15	2.8 kcfs
November 16	November 30	1.8 kcfs
December 1	December 31	0.2 kcfs
January 1	January 31	0.2 kcfs
February 1	March 15	1.1 kcfs
March 16	April 15	1.8 kcfs

Powerhouse availabilities are also unchanged among alternatives, and changes in total spill are induced solely by changes in total outflow. Spill caps are fixed at 40 kcfs throughout the year. Average daily differences in spill between the No Action Alternative, MOs, and PA varied by at most 8 kcfs on any given day. The primary fish spill operations at Priest Rapids are 24 kcfs, occurring between April 16 and August 23. During that time period, total spill increases above the 24 kcfs requirement due to force spill conditions. Average spill for all alternatives from April 16 to August 23 is between 38 and 40 kcfs, with maximum spill rate between 61 and 66 kcfs.

4.18.2 Wanapum Dam

Fish spill operations at Wanapum Dam are unchanged among all alternatives, and are tabulated below (Table 4-41):

Table 4-41. Wanapum Dam Spill Operations in All Alternatives

Start Date	End Date	Spill Operation
April 16	August 23	20 kcfs
August 24	November 15	3.4 kcfs
November 16	November 30	1.7 kcfs
December 1	December 31	0.8 kcfs
January 1	January 31	0.8 kcfs
February 1	March 15	1.2 kcfs
March 16	April 15	1.7 kcfs

Powerhouse availabilities are also unchanged among alternatives, and changes in total spill are induced solely by changes in total outflow. Spill caps are fixed at 50 kcfs throughout the year. Differences in spill between the No Action Alternative, MOs, and PA varied by at most 11 kcfs on any given day. The primary fish spill operations are 20 kcfs, occurring between April 16 and August 23. During that time period, total spill increases above the 20 kcfs requirement due to force spill conditions. Average spill for all alternatives from April 16 to August 23 is between 48 and 51 kcfs, with maximum spill rate between 73 and 78 kcfs.

4.18.3 Rock Island Dam

Fish spill operations at Rock Island Dam are unchanged among all alternatives, and are tabulated below (Table 4-42):

Table 4-42. Rock Island Dam Spill Operations in All Alternatives

Start Date	End Date	Spill Operation
April 15	April 30	9.3% Total Outflow
May 1	May 31	10% Total Outflow
June 1	June 30	18% Total Outflow
July 1	August 15	20% Total Outflow
August 16	August 31	6.3% Total Outflow

Powerhouse availabilities are also unchanged among alternatives, and changes in total spill are induced solely by changes in total outflow. Spill caps are fixed at 30 kcfs throughout the year. Differences in spill between the No Action Alternative, MOs, and PA varied by at most 11 kcfs on any given day. Spill season operations are a function of total outflow between 6.3% and 20%, occurring between April 16 and August 31. During that time period, increases above the spill requirement occur due to force spill conditions. Average spill for all alternatives from April 16 to August 23 is between 48 and 51 kcfs, with maximum spill rate between 44 and 49 kcfs.

4.18.4 Rocky Reach Dam

Rocky Reach does not have spill operations in any alternative. All spill is induced by either LOM or force spill conditions. Spill at Rocky Reach typically occurs in May through September, peaking in June or early July. The average spill in May through September is approximately 14 kcfs, and the maximum spill is 40 kcfs. The average daily spill at Rocky Reach varies among alternatives by at most 11 kcfs.

4.18.5 Wells Dam

The fish spill at Wells Dam is unique because it is proportionate to the outflow at Chief Joseph. Between April 12 and August 26, spill is 6.5 percent of Wells project outflow if Chief Joseph outflow is greater than 140 kcfs. Otherwise, spill at Wells is 10.2 kcfs. Spill caps are a constant 45 kcfs throughout the year. Spill operations at Wells occur in April through August (Table 4-43). The average daily spill during this time period is approximately 20 kcfs, and maximum spill is 41 kcfs. Average daily spill at Wells varies among alternatives by at most 14 kcfs on any given day. MO4 spill is the lowest because MO4 has the least LOM contribution to spill at Wells. No Action Alternative and MO2 spill at Wells are relatively higher due to more LOM spill. Most of the differences in spill between alternatives occurs in April and May. Table 4-44 shows the partitioned force, LOM, and total spill at Chief Joseph, averaged from April 1 through May 31.

Table 4-43. Wells Dam Spill Operations in All Alternatives

Start Date	End Date	Spill Operation
April 12	August 26	If Chief Joseph Total Outflow greater than 140 kcfs, 6.5% total outflow. Otherwise, 10.2 kcfs.

Table 4-44. Wells Dam Average Spill Metrics from April 1 through May 31

Alternative	Force Spill (kcfs)	LOM Spill (kcfs)	Fish Spill (kcfs)	Total Spill (kcfs)
NAA	2.2	4.6	9.0	15.8
MO1	1.4	2.7	9.0	13.1
MO2	1.4	4.9	9.0	15.3
MO3	1.4	0.9	9.0	11.3
MO4	1.4	0.4	9.0	10.8
PA	1.6	2.4	9.1	13.0

4.18.6 Chief Joseph Dam

Chief Joseph Dam does not have any fish spill operations, but powerhouse availability does change slightly among alternatives. Availabilities are impacted by the requirement to hold reserves at the project. As the objectives allow reserves to be held outside of 1 percent or turbines at the fish passage projects can use wider operating ranges, the net effect is frequently higher availability at Chief Joseph and Grand Coulee (lower reserve requirement). Changes in spill are induced by the combined effects of changes to powerhouse availability, total outflow, and LOM spill. As previously stated, spill rates at Chief Joseph are more influenced by LOM conditions than other projects on the middle Columbia. In real-time operations, spill at Chief Joseph is preferable over spill at Grand Coulee; this preference was maintained in modeling via the spill priority list (see Section 2.2.2 for more details). Spill at Chief Joseph typically occurs from April through July, peaking in early July. Most of the deviation in spill among alternatives occurs in April and May (Figure 4-23). Table 4-45 and Table 4-46 show the partitioned force, LOM, and total spill at Chief Joseph, averaged from April 1 through May 31. In all alternatives, the average Chief Joseph spill between June and July is 19 to 22 kcfs.

Table 4-45. Chief Joseph Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	68	68	68	69	76	74	74	74	77	81	84	84	84	74
MO1	68	68	68	69	76	72	79	79	83	86	87	86	86	75
MO2	68	68	68	69	76	74	78	78	80	85	87	86	86	74
MO3	65	65	65	66	72	71	75	75	77	82	85	85	85	72
MO4	68	68	68	69	76	74	77	77	80	85	87	86	86	74
PA	68	68	68	69	76	74	78	78	80	85	87	86	86	74

Table 4-46. Chief Joseph Dam Average Spill Metrics from April 1 through May 31

Alternative	Force Spill (kcfs)	LOM Spill (kcfs)	Total Spill (kcfs)
NAA	6.5	6.0	12.5
MO1	2.0	7.0	9.0
MO2	3.0	4.0	7.0
MO3	3.5	2.5	6.0
MO4	2.5	2.0	4.5
PA	3.6	4.5	8.1

4.18.7 Grand Coulee Dam

Flows at Grand Coulee typically get high enough to induce force spill between May and July. There are two general routes to spill water past Grand Coulee, the regulating outlets on the face of the dam (40 total, 2 rows of 20) or over the 11 drum gates. If the forebay elevation is above 1,266 feet (NGVD29), Reclamation releases the water evenly across the 11 spillway gates. If water is released through the outlets, when the pool elevation is below 1,266 feet, then it is released evenly through the upper and lower gates. An over/under spill pattern for the outlets is used to minimize TDG generation.

The powerhouse availability integrates the Grand Coulee Maintenance Operation measure, which reduces the overall powerhouse availability, but other factors in each alternative further impact this value including reserve obligations, operating range conditions, and the ability to hold reserves above 1 percent on any number of projects. Because availabilities are impacted by the requirement to hold reserves at the project, as the objectives allow reserves to be held outside of 1 percent or turbines elsewhere can use wider generator or reservoir operating ranges, the net effect is frequently higher availability at Chief Joseph and Grand Coulee (lower reserve requirement) even with increased maintenance for Grand Coulee in alternatives.

Variations in the powerhouse availability and total outflow drive differences in spill rates between the No Action Alternative, MOs, and the Preferred Alternative. Powerhouse availability for each month and alternative are compiled in Table 4-47. LOM spill at Grand Coulee is rare, but can contribute to total spill. Table 4-48 shows various spill metrics and total spill averaged for the months of May through July, when a majority of spill occurs at Grand Coulee. The No Action Alternative has the most spill in May and July, primarily due to higher total outflows. MO3 and the PA have higher spill in June because the powerhouse availability is lower than other alternatives, limiting the amount of flow that can be passed through the powerhouse. MO1 and MO2 have the most LOM spill at Grand Coulee because the alternatives have high LOM conditions; however MO1 LOM values are comparable to the No Action Alternative (Table 4-48). The test spill operations in MO1 limit the amount of LOM the lower Snake and lower Columbia can absorb, increasing the LOM spill at other projects like Grand Coulee.

Table 4-47. Grand Coulee Dam Powerhouse Availabilities (percent of maximum powerhouse capacity)

Alternative	OCT	NOV	DEC	JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL	AG1	AG2	SEP
NAA	54	55	55	55	60	59	59	59	61	65	67	67	67	60
MO1	53	53	53	53	58	56	62	62	64	69	71	70	70	58
MO2	53	53	53	53	58	57	60	60	62	65	68	67	67	58
MO3	50	50	50	51	56	54	58	58	60	63	66	65	65	55
MO4	53	53	53	53	58	57	60	60	61	65	68	67	67	58
PA	68	67	67	58	53	53	53	53	58	57	60	60	62	65

Table 4-48. Grand Coulee Average Spill Metrics for May, June, and July

Month	Alternative	Force Spill (kcfs)	LOM Spill (kcfs)	Total Outflow (kcfs)	Powerhouse Availability (%)	Total Spill (kcfs)
May	NAA	11.2	0.1	138.8	61.0	11.3
	MO1	3.4	0.2	130.8	64.0	3.6
	MO2	5.3	0.9	133.0	62.0	6.2
	MO3	6.2	0.0	129.8	60.0	6.2
	MO4	5.4	0.0	135.4	61.0	5.4
	PA	6.8	0.0	135.9	58.0	6.8
June	NAA	12.4	0.2	157.3	65.0	12.6
	MO1	11.4	0.8	156.4	69.0	12.2
	MO2	15.1	0.6	158.6	65.0	15.7
	MO3	16.9	0.0	157.1	63.0	16.9
	MO4	14.8	0.0	161.5	65.0	14.8
	PA	16.2	0.1	160.8	57.0	16.3
July	NAA	17.8	0.2	151.1	67.0	18.0
	MO1	12.8	0.2	144.9	71.0	13.0
	MO2	15.9	0.1	148.5	68.0	16.0
	MO3	16.0	0.1	144.3	66.0	16.1
	MO4	15.7	0.0	149.5	68.0	15.7
	PA	15.3	0.1	148.1	60.0	15.3

4.19 HUNGRY HORSE DAM

Spill at Hungry Horse Dam typically occurs twice a year: from early April to early May, and from mid-June to mid-July. Spill modeling for Hungry Horse was conducted with an assumed, fixed maximum powerhouse flow capacity of 9 kcfs. Thus, any changes to spill are solely caused by changes in total outflow. Table 4-49 shows the average and maximum spill at Hungry Horse for the two main time periods when spill occurs.

1491 **Table 4-49. Hungry Horse Spill**

	Average Total Outflow (kcfs)						Average Spill (kcfs)						Max Spill (kcfs)					
Time Period	**NAA**	**MO1**	**MO2**	**MO3**	**MO4**	**PA**	**NAA**	**MO1**	**MO2**	**MO3**	**MO4**	**PA**	**NAA**	**MO1**	**MO2**	**MO3**	**MO4**	**PA**
4/1 - 5/15	6.9	6.5	5.8	6.6	6.4	6.9	0.9	0.7	0.5	0.7	0.5	0.9	2.9	2.3	1.6	2.6	1.9	2.8
6/15 - 7/15	6.1	6.0	5.0	6.0	6.0	6.0	0.8	0.7	0.6	0.8	0.7	0.8	1.5	1.5	1.4	1.5	1.5	1.5

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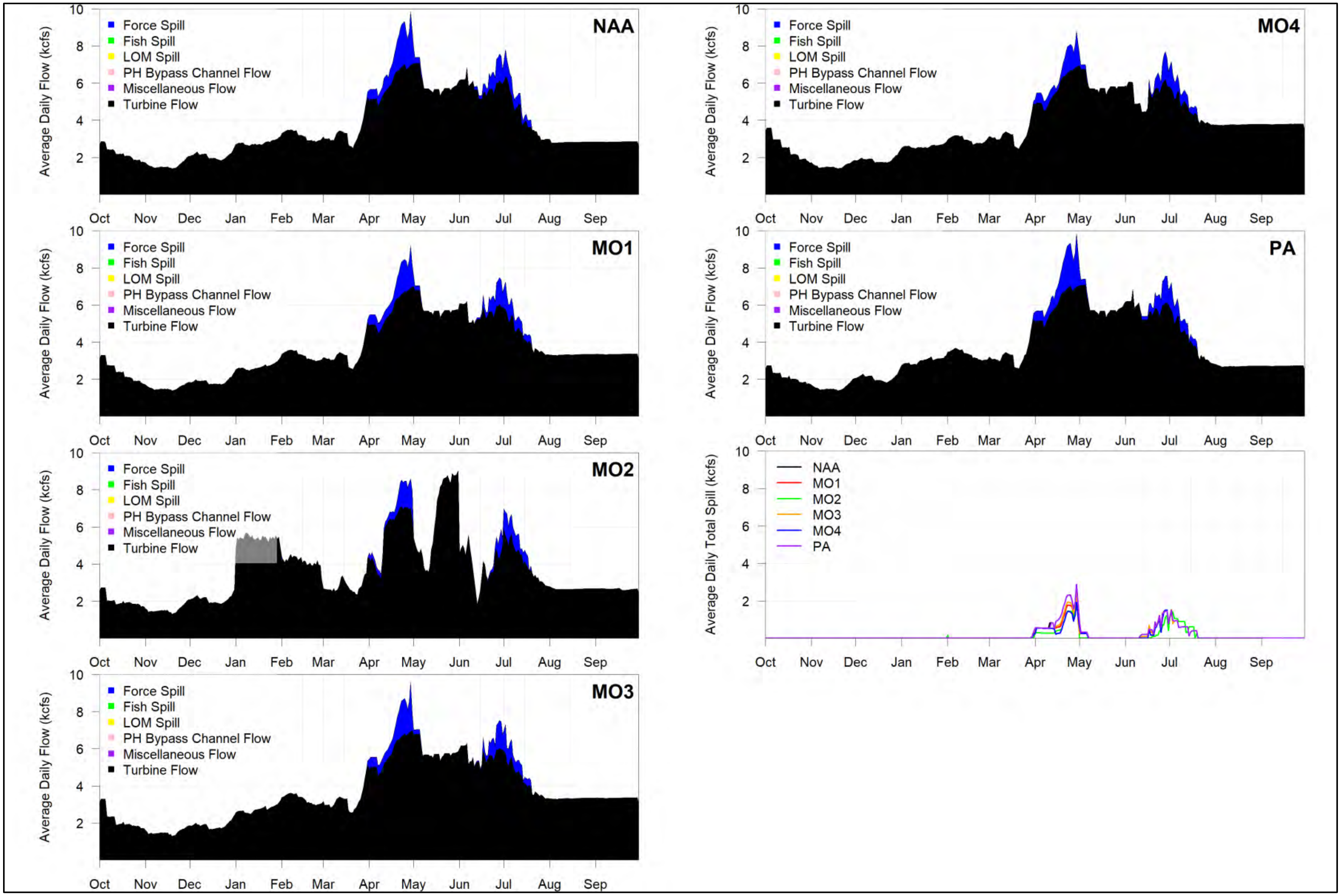
The powerhouse flow capacity limitation at Hungry Horse is imposed by an assumed power transmission limitation: there are four total units at the Hungry Horse project, but only three may be used at any given time. In any given year additional outages can occur due to North American Electric Reliability and Western Electricity Coordinating Council requirements, which may limit the ability to pass water through the power plant and in some cases may result in additional spill. Additionally, Reclamation is planning a Hungry Horse Power Plant Modernization and Overhaul Project (Reclamation 2018). This overhaul would take place over four years, currently scheduled to start in 2020 or 2021. During one of the four years, maintenance would require outages for one year in the power plant, limiting the power plant to two units available for one year, reducing the hydraulic capacity to approximately 6 kcfs. This could result in additional spill in this one year, and the maximum TDG anticipated from the overhaul study was 120 percent. In most years the reduced hydraulic capacity would not result in significantly more spill and would not result in higher TDG than presented in this analysis. As spill typically occurs during the spring when water temperatures are cool, a substantial increase in spill is required to raise TDG above 115 percent. During this period the resident fish have typically migrated out of South Fork Flathead River. Additionally, any elevated TDG is diluted when flowing into the mainstem Flathead River (Figure 4-25).



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1511 **Figure 4-25. Hungry Horse Dam Partitioned Average Daily Outflow**

4.20 LIBBY DAM

Libby Dam spill results were derived from ResSim assuming all project maintenance can be moved out of the spring period. Libby Dam has no fish passage spill, nor is LOM spill applied. Additionally, spill events occur very rarely. To facilitate review, Libby spill results are tabulated for both the 80-year and extended-year datasets instead of presented as daily averages. The NAA had the least number of spill events, but spill rates in the 2012 event were much higher than the other MOs (Table 4-50).

Table 4-50. Libby Spill Events

	Max Spill Rate (kcfs)						**Number of Days Spill Occurred**					
Year	**MO1**	**MO2**	**MO3**	**MO4**	**NAA**	**PA**	**MO1**	**MO2**	**MO3**	**MO4**	**NAA**	**PA**
1934	0.4	0.8	0.8	0.4	0.0	1.6	3	4	4	3	0	9
1948	0.0	0.0	0.0	0.0	0.0	0.6	0	0	0	0	0	5
1950	0.0	0.0	0.0	0.0	0.0	4.5	0	0	0	0	0	2
1951	2.9	2.9	2.9	2.9	0.0	2.7	9	9	9	9	0	11
1954	6.7	6.7	6.7	6.7	0.0	3.6	8	8	8	8	0	8
1956	0.0	0.0	0.0	0.0	0.0	1.6	0	0	0	0	0	6
1961	0.0	0.5	0.5	0.0	3.7	0.0	0	9	9	0	5	0
1972	7.3	7.0	7.0	7.3	0.1	4.4	10	8	8	10	2	9
1980	0.0	0.0	0.0	0.0	0.0	4.7	0	0	0	0	0	1
1991	4.5	4.5	4.5	4.5	0.0	2.2	9	9	9	9	0	9
1994	4.9	0.0	0.0	3.2	0.0	0.0	8	0	0	6	0	0
1996	0.0	0.0	0.0	0.0	0.0	0.7	0	0	0	0	0	1
1997	0.0	0.0	0.0	0.0	0.0	2.8	0	0	0	0	0	10
1998	1.7	0.0	0.0	2.2	3.9	0.0	10	0	0	10	3	0
2011	2.0	2.0	2.0	1.6	0.0	2.0	1	1	1	1	0	1
2012	12.7	10.4	10.4	26.3	36.2	6.8	52	51	51	35	51	52
2014	0.0	0.0	0.0	4.6	0.0	1.1	0	0	0	12	0	1
Total Spill Events							**9**	**8**	**8**	**10**	**4**	**14**

CHAPTER 5 - REFERENCES

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Draft Columbia River System Operations
Environmental Impact Statement

Appendix B, Part 3
Columbia River System HEC-WAT and HEC-RESSIM Model Documentation

EXECUTIVE SUMMARY

PURPOSE OF TECHNICAL APPENDIX B, PART 3

This technical appendix documents the Columbia River System hydroregulation modeling approach, executed using Watershed Analysis Tool and Reservoir System Simulation software from the U.S. Army Corps of Engineers Hydrologic Engineering Center. This technical appendix has been prepared as documentation for the Columbia River System Operations Environmental Impact Statement.

ORGANIZATION OF APPENDIX B, PART 3

After background information is provided in Chapters 1 and 2, the approach to reservoir modeling for the Columbia River System is described in Chapter 3. A description of reservoir operations along with relevant details of the implementation is provided in Chapter 4. A brief statement regarding the incorporation of the Yakima and Upper Snake Basins is provided in Chapter 5. Chapter 6 summarizes the vertical datum shift used at the projects, and Chapter 7 contains the references. Annex A contains the Multiple Objective Alternative modeling sheets and the Preferred Alternative modeling sheet.

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ACRONYMS AND ABBREVIATIONS

AR	atmospheric river
Arrow	Arrow Lakes/Hugh Keenleyside
BiOp	biological opinion
Bonneville	Bonneville Power Administration
CCP	common computation point
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRD	Columbia River Datum
CRSO	Columbia River System Operations
CRT	Columbia River Treaty
ECC	energy content curve
EIS	Environmental Impact Statement
FCOP	flood control operating plan
FCRC	flood control refill curve
FERC	Federal Energy Regulatory Commission
FRM	flood risk management
HEC	Hydrologic Engineering Center
HEC-FIA	HEC Flood Impact Analysis
HEC-RAS	HEC River Analysis System
HEC-ResSim	HEC Reservoir System Simulation
HEC-WAT	HEC Watershed Analysis Tool
ICF	Initial Controlled Flow
kaf	thousand acre-feet
kcfs	thousand cubic feet per second
Maf	million acre-feet
MO	Multiple Objective Alternative
MOP	minimum operating pool
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NPUA	Non-Power Uses Agreement
NTSA	Non-Treaty Storage Agreement
PGE	Portland General Electric
PUD	public utility district
Reclamation	Bureau of Reclamation
RES	Reservoir System Simulation
SKQ	Seli’š Ksanka Qlispe’
SRD	storage reservation diagram

SSARR	Streamflow Synthesis and Reservoir Regulation
SynRes	Synthetic Reservoir Operation
TDG	total dissolved gas
TSR	Treaty Storage Regulation
URC	upper rule curve
USFWS	U.S. Fish and Wildlife Service
VarQ	variable discharge storage regulation procedure
VDL	variable draft limit

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CHAPTER 1 - INTRODUCTION

This technical appendix documents the Columbia River System hydroregulation modeling approach, executed using Watershed Analysis Tool (HEC-WAT) and Reservoir System Simulation (HEC-ResSim) software from the U.S. Army Corps of Engineers Hydrologic Engineering Center. This technical appendix has been prepared as documentation for the Columbia River System Operations (CRSO) Environmental Impact Statement (EIS). The U.S. Army Corps of Engineers (Corps), the Bureau of Reclamation (Reclamation), and Bonneville Power Administration (Bonneville), as Federal co-lead agencies, are preparing the CRSO EIS to assess and update their long-term strategy for the operation and configuration of the multi-purpose system.

CHAPTER 2 - PURPOSE OF TECHNICAL APPENDIX

This appendix describes the hydroregulation modeling approach used to characterize physical water conditions (river flows, reservoir releases and elevations) in the Columbia River System, and to inform subsequent modeling and/or impact analyses that are dependent on physical water conditions. An automated, rules-based modeling approach is employed to reflect operations at multiple projects in the Columbia River Basin. The Columbia River Watershed System is shown in Figure 2-1.

For the CRSO EIS, contemplated changes to dam operation and/or configuration are limited to the 14 Federal dams as described in the EIS main report. To appropriately reflect the complexity of the Columbia River System, the hydroregulation modeling described in this appendix does include operations at more than those 14 Federal dams. This is necessary to provide a more complete description of the modeling process but should not be taken to imply that operations/configurations at the non-CRSO projects are modified from their current operations in the modeling for CRSO alternatives.

Figure 2-1. Columbia River Watershed System

CHAPTER 3 - RESERVOIR MODELING APPROACH

The Columbia River and many of its tributaries are managed for multiple purposes including hydropower, flood risk management (FRM), ecosystem function, irrigation, recreation, water supply, and navigation. In practice, various types of hydroregulation modeling are performed by modelers, in support of short-term and long-term decision making. Short-term model applications often involve user-specified "hand regulation" to override general rules, which is appropriate when a high amount of real-time information is available to the modeler. In contrast, long-term planning studies benefit from a rules-based hydroregulation modeling approach, as described this appendix. The rules-based approach consistently applies operational rules that govern over a wide range of hydrologic conditions. Many years of observed and synthetic data are run through the model to determine the range of expected results from a particular alternative.

3.1 MODEL DEVELOPMENT HISTORY

Historically, the Corps and Bonneville completed operational planning studies through use of two computer models, AUTOREG for flood risk management, and HYDSIM for power modeling (which incorporates flood risk management). AUTOREG was used by the Corps until about 2012 to complete studies of systemwide flood risk management operations of the system's dams and reservoirs (herein referred to as projects) on a daily timestep. HYDSIM is used by Bonneville to complete studies of system wide hydropower operations and operates on a quasi-monthly timestep. The HYDSIM model for the Columbia River Basin is discussed in the Hydroregulation Appendix (Appendix I).

Over the past decade, the Corps has developed modeling tools to more accurately portray physical water characteristics and associated impacts in the Columbia River Basin. Today, a suite of computer models, including the HEC River Analysis System (HEC-RAS), HEC-ResSim, HEC Flood Impact Analysis (HEC-FIA), and other sub-components[1] can be computed using HEC-WAT. The HEC-WAT framework orchestrates the building, editing, and running of a series of models to help perform water resources studies. This suite of models allows the Corps to evaluate uncertainties using Monte Carlo inputs, sampling hydrology and forecasting for thousands of events. Automation of the various models within the HEC-WAT framework allows for a variety of metrics to be produced, providing quantitative information for various assessments (Corps 2017a).

The HEC-WAT model sequence used for CRSO evaluations is referred to as the Columbia River System Model (CRS Model). It simulates spring flood risk management operations, winter flood risk management operations, ecosystem operations including those described in biological opinions (BiOps), and a variety of other operations that represent the multi-purpose nature of the reservoir system. Its ability to simulate multi-purpose operations makes it well-suited for simulation of the CRSO EIS alternatives. The CRS Model is used to simulate flows and reservoir

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[1] Other sub-components include the upper rule curve (URC) and energy content curve (ECC) plug-ins for HEC-WAT.

levels at various locations for a wide range of hydrologic conditions throughout the basin. Water surface elevations at non-reservoir locations in the basin are developed external to the CRS Model using methods described in a separate section of this H&H Appendix (Appendix B, Part 6 – Flow-Stage Relationship).

3.2 GENERAL MODEL DESCRIPTION

The CRS Model represents multi-purpose operations at various dams in the Columbia River Basin. The model is composed of a set of different models and plug-ins that are run in sequence (contained within the HEC-WAT modeling framework) to mimic the multi-purpose operations within the Columbia River Basin. The modeling sequence is detailed below and shown in Figure 3-1. There are three steps in the process, and each step contains two submodels. As described in the third step, the regulation for certain parts of the basin can be held constant. All CRSO alternatives evaluated using the CRS Model hold constant the operation of Mica, Arrow, and Duncan dams (in Canada) to match operations in the No Action Alternative.

The CRS Model follows this process:

Step 1. Run the upper rule curve (URC)[2] model to develop initial estimates of minimum reservoir drafts for the evacuation period; then run the ResSim Flood0 model to determine operations based solely on the upper rule curve guidance.

Through the URC model (in the upper left elliptical box in Figure 3-1), initial estimates of reservoir URC drafts are generated, which describe the maximum allowable elevation for a reservoir during its evacuation period to meet system flood risk management requirements. Also, refill targets based on local and system forecasts and constraints are estimated. The operational focus of the HEC-ResSim model, the box labeled “HEC-ResSim URC Ops” (also known as the Flood0 model), is to follow the system flood risk management guidance with reservoirs simply running to their URCs.

Step 2. Coordinated Canadian Columbia River Treaty (CRT) hydropower operations are then calculated within the constraints of flood risk. As part of this process (see the large middle box in Figure 3-1), the energy content curve (ECC)[3] generator develops rule curves for Canadian projects that meet project refill requirements serving as input to the “Base Canadian Operations” HEC-ResSim model (also known as the power model) and CRT and supplemental power operations at Canadian reservoirs.[4]

Step 3. As a third step (see the right-most large box in Figure 3-1), the draft requirement for Grand Coulee is estimated based on the total available upstream space. The model

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[2] The URC Program is a plug-in within the WAT which automates its execution and manages the flow of data between the URC and other programs. For more information on the URCs, see Section 4.2.4.

[3] The ECC Program navigates input objectives and constraints to determine the desired pool elevation and storage for each project to best meet system hydropower requirements. The ECC plug-in within the WAT manages the ECC program’s input/output and execution and calls the ECC itself along with pre- and post-processing executables developed by Bonneville. Further information is provided in the Hydroregulation Appendix (Appendix I).

[4] Information on Canadian operations as they relate the CRSO EIS is in Chapter 2 of the main EIS report.

simulates a final Columbia River System operation (draft and refill based on local and system flood risk requirements) using final storage requirements, with the addition of ecosystem and winter FRM operations. The final HEC-ResSim model ("Daily Final Regulation," also known as the Flood1 model) depicts the multi-purpose system operation on a daily timestep. For the CRSO Multiple Objective Alternatives (MOs), the project operations at Mica, Arrow, and Duncan dams (in Canada) were set to match the No Action Alternative because those dams should not change in response to a change to operations at U.S. projects.

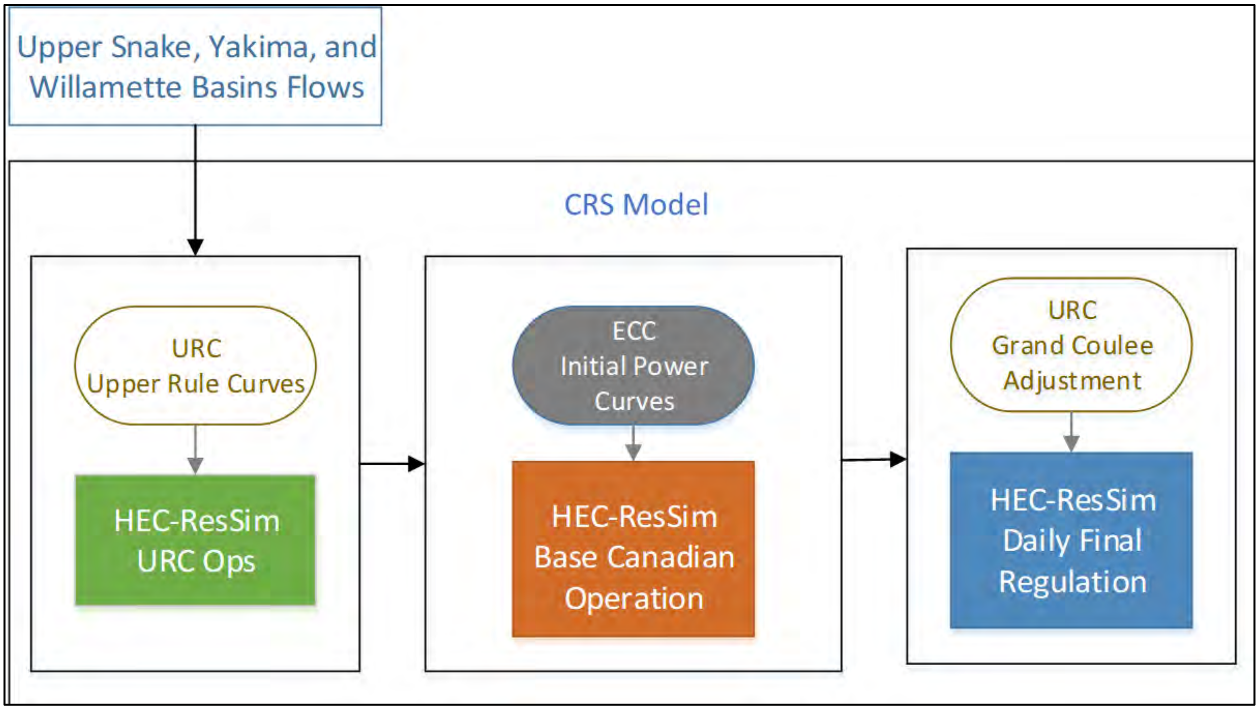

Figure 3-1. Columbia River System Model Program Order

Inputs to the CRS Model include the Yakima, upper Snake, and Willamette River Basin flows. For CRSO evaluations (which do not contemplate changes to dams in those basins), existing hydrologic datasets are used. Flows from these basins are used as input to the CRS Model as shown in Figure 3-1. The remainder of this section describes how the key structural components of an HEC-ResSim model (such as dams/reservoirs, stream centerlines, and common computations points) are established.

3.3 MODEL OBJECTIVES AND ASSUMPTIONS

The CRS Model was designed to meet the following objectives:

- Represent multi-purpose operations of dams in the system, including local flood storage and refill operations, Columbia River System flood storage and refill operations, and operations that are described in BiOps.

- Represent an interpretation of current Columbia River hydropower operations under the CRT and incorporate the effects of power drafts in Canadian reservoirs on FRM.
- Include and be able to model year-round detailed operations of all major Columbia River Basin projects that affect water levels at reservoirs and river reaches in the system. Flows from the upper Snake River, Yakima, and Willamette River Basins are input as inflow hydrographs from existing hydrologic datasets.
- Function efficiently in a Monte Carlo framework, allowing Monte Carlo simulation of the system's reservoir operations with varying water supply forecasts and synthetic hydrographs that represent extreme events.
- Provide output in a daily timestep format, which is useful in estimating a variety of impacts associated with water conditions (reservoir elevations and river flows) in the basin.

The models and tools described in this document allow for a comprehensive approach in evaluating the Columbia River System, where all key variables, parameters, and components are subject to probabilistic analysis. The approach is in compliance with analytical requirements set forth in two key engineer regulations of the Corps: Engineer Regulation 1105-2-100, Planning Guidance Notebook (Corps 2000a) and Engineer Regulation 1105-2-101, Risk Assessment for Flood Risk Management Studies (Corps 2017b).

The CRS Model is designed for study use to represent rule-based reservoir operations. All rules in the model are explicitly defined and do not include the range of decisions that might be made in real time, which rely on information that may not be available to the model. These decisions also include a level of subjectivity (i.e., human decisions) that cannot inherently be replicated by a model or can only be approximated using assumptions.

A description of reservoir operations is provided in Section 4.

3.4 MODEL INPUTS

A list of all the major input datasets used for the CRS Model is included below.

3.4.1 List of Projects Included

The CRS Model includes projects that were included in the Corps' AUTOREG model, as well as additional projects that have the potential to substantially affect system operations (reservoir levels and river flows) based on storage availability and/or concurrence of peak flows with peak flows on the Columbia River. Table 3-1 indicates how each project is included in the model. "Run-of-river" indicates that the project pool has little to no fluctuation during the year.

Table 3-1. Summary of Modeled Projects

Dam Name	River Name	River Mile	Owner	United States or Canada	CRS Model	Run-of-River in CRS Model
Albeni Falls	Pend Oreille	89.2	Corps	United States	X	–
American Falls	Snake	723.9	Reclamation	United States	Input (Snake)	–
Anderson Ranch	South Fork Boise	38.9	Reclamation	United States	Input (Snake)	–
Arrow Lakes/Hugh Keenleyside[1/]	Columbia	783.3	BC Hydro	Canada	X	–
Arrow Rock	Boise R.	78.9	Reclamation	United States	Input (Snake)	–
Bonneville	Columbia	145.5	Corps	United States	X	X
Boundary	Pend Oreille	16.4	Seattle City Light	United States	X	X
Box Canyon	Pend Oreille	33.2	Pend Oreille PUD	United States	X	X
Brilliant	Kootenai(y)	1.8	Columbia Power Corp. & Columbia Basin Trust	Canada	X	X
Brownlee	Snake River	284.7	Idaho Power Company	United States	X	–
Bumping Lake	Bumping	16.4	Reclamation	United States	Input (Yakima)	–
Cabinet Gorge	Clark Fork	15	Avista	United States	X	X
Cascade	North Fork Payette	41.1	Reclamation	United States	Input (Snake)	–
Chelan	Chelan	4.3	Chelan County PUD	United States	X	X
Chief Joseph Dam	Columbia	545.3	Corps	United States	X	X
Cle Elum	Cle Elum	7.9	Reclamation	United States	Input (Yakima)	–
Corra Linn	Kootenai(y)	16.1	FortisBC	Canada	X	X
Deadwood	Deadwood	23.7	Reclamation	United States	Input (Yakima)	–
Duncan	Duncan	45.1	BC Hydro	Canada	X	–
Dworshak	North Fork	1.9	Corps	United States	X	–
Grand Coulee	Columbia	596.5	Reclamation	United States	X	–
Hells Canyon	Snake	247.8	Idaho Power Company	United States	X	X
Hungry Horse	South Fork Flathead	5.3	Reclamation	United States	X	–
Ice Harbor	Snake	9.3	Corps	United States	X	X
Jackson Lake	Snake	1,009.7	Reclamation	United States	Input (Snake)	–
John Day	Columbia	216.6	Corps	United States	X	–
Kachess	Kachess	1.6	Reclamation	United States	Input (Yakima)	–

Dam Name	River Name	River Mile	Owner	United States or Canada	CRS Model	Run-of-River in CRS Model
Keechelus	Yakima	217.5	Reclamation	United States	Input (Yakima)	–
Kootenay Canal	Kootenai(y)	14	BC Hydro	Canada	X	X
Libby	Kootenai(y)	219.9	Corps	United States	X	–
Little Falls	Spokane	32.3	Avista Corp.	United States	X	X
Little Goose	Snake	69.7	Corps	United States	X	X
Long Lake Dam/ Lake	Spokane	37.1	Avista Corp.	United States	X	X
Lower Bonnington	Kootenai(y)	14	FortisBC	Canada	X	X
Lower Granite	Snake	106.8	Corps	United States	X	X
Lower Monumental	Snake	40.9	Corps	United States	X	X
Lucky Peak	Boise	67.2	Corps	United States	Input (Snake)	–
McNary	Columbia	291.2	Corps	United States	X	X
Mica	Columbia	1,009.4	BC Hydro	Canada	X	–
Monroe Street	Spokane	77.5	Avista Corp.	United States	X	X
Nine Mile	Spokane	61.3	Avista Corp.	United States	X	X
Noxon Rapids	Clark Fork	34.5	Avista Corp.	United States	X	X
Owyhee	Owyhee	29.6	Reclamation	United States	Input (Snake)	–
Oxbow	Snake	272.8	Idaho Power Company	United States	X	X
Palisades	Snake	907.9	Reclamation	United States	Input (Snake)	–
Pelton	Deschutes	102.4	Confederated Tribes of Warm Springs and PGE	United States	X	X
Pelton Reregulating	Deschutes	100	Confederated Tribes of Warm Springs and PGE	United States	X	X
Post Falls – Lake	Spokane	105.3	Avista	United States	X	–
Priest Lake	Priest River	44.5	State of Idaho	United States	X	X
Priest Rapids	Columbia	397	Grant County PUD	United States	X	X
Revelstoke	Columbia	929.8	BC Hydro	Canada	X	X
Rock Island	Columbia	453.6	Chelan County PUD	United States	X	X
Rocky Reach	Columbia	473.9	Chelan County PUD	United States	X	X
Round Butte	Deschutes	110.2	Confederated Tribes of Warm Springs and PGE	United States	X	–
Seven Mile	Pend Oreille	6.4	BC Hydro	Canada	X	X

Dam Name	River Name	River Mile	Owner	United States or Canada	CRS Model	Run-of-River in CRS Model
SKQ/Flathead Lake	Flathead	73.8	SKQ	United States	X	–
Slocan	Kootenai(y)	13	FortisBC	Canada	X	X
The Dalles	Columbia	192	Corps	United States	X	X
Thompson Falls	Clark Fork	71.1	Northwestern Energy	United States	X	X
Tieton	Tieton	21.8	Reclamation	United States	Input (Yakima)	–
Upper Bonnington	Kootenai(y)	14.7	FortisBC	Canada	X	X
Upper Falls	Spokane	78	Avista Corp.	United States	X	X
Wanapum	Columbia	415.3	Grant County PUD	United States	X	X
Waneta	Pend Oreille	0.6	BC Hydro	Canada	X	X

Note: PGE = Portland General Electric; PUD = public utility district; SKQ = Seli'š Ksanka Qlispe'.

1/ Arrow Lakes/Hugh Keenleyside is referred to as "Arrow" in the remainder of this document.

3.4.2 Project Representation

Projects may be represented within HEC-ResSim with the following information:

- Physical Data:
  - Pool definition: elevation versus storage table (area as needed)
  - Dam definition: dam height and length
  - Outlet capacity curve (elevation versus maximum discharge rating table) for power plant, spillway, and other outlet structures
  - Tailwater rating curves at certain dams
  - Head loss (as needed)
  - Power plant data (outlet, capacity, efficiency, etc.)
  - Leakage and lockage at certain dams
- Operational Data:
  - Maximum, normal or target, and minimum operating pool (MOP) elevations
  - Minimum and maximum release constraints, downstream release target rules, system rules, etc.

These data and operational requirements were obtained from Water Control Manuals, system FRM documents, historical models used for hydroregulation and power studies, and any other sources available such as memoranda, surveys, or conversation with dam tenders, and have been verified by Corps Northwestern Division Columbia Basin Water Management personnel. Depending on the scenario to be evaluated with the model, operational data and/or rules can be modified to represent changes to dam operations. Examples include changes to target pool elevations, minimum and maximum releases, and downstream release target rules.

3.4.3 Stream Centerline

The stream centerline defined within an HEC-ResSim model is primarily used to dictate the reservoir connectivity; its length and physical location are not used in computations. The stream centerline is however important when models are run within the HEC-WAT framework because it is the backbone to which all HEC-WAT components are related. For the CRS Model, the stream centerline is generally defined using the National Hydrographic Dataset developed by the U.S. Geological Survey, with some exceptions.

3.4.4 Routing Method

HEC-ResSim computes travel time between reservoirs using hydrologic, as opposed to hydraulic, routing methods. Hydrologic routing methods are based on approximations of the continuity equation with assumed relationship between storage, inflow, and outflow within a reach. Hydraulic routing methods, on the other hand, combine the continuity equation with additional, physically based relationships, which describe the actual physics of the movement of the water (such as the momentum equation).

Historically, the Streamflow Synthesis and Reservoir Regulation (SSARR) hydrologic routing method has been used in reservoir modeling of the Columbia River Basin for water management studies. The SSARR routing method is used within the SSARR model, which was developed to provide mathematical hydrologic simulations for systems analysis as required for the planning, design, and operation of water control works. The SSARR model was further developed for operational river forecasting and river management activities. As a general purpose mathematical model of a river system, the SSARR model was a useful tool for streamflow and runoff forecasting, for long-term studies of the hydrology of a river system, and for studies of reservoir regulation. The SSARR model has been applied by various agencies, organizations, and universities on numerous river systems in the United States and abroad. Detailed information about the SSARR hydrologic routing method can be found in the SSARR User Manual (Corps 1991).

In the CRS Model, the routing parameters were determined by one of two methods:

- Computing them according to the SSARR routing equation, or
- Using values from historically used models (SSARR with the AUTOREG interface), which have been fine-tuned over decades of basinwide reservoir regulation studies

3.4.5 Junctions and Common Computation Points

Junctions in ResSim are points at which routing reaches begin and end, and they are also the points at which local inflows are allowed to enter the system. The junctions in ResSim coincide with common computation points (CCPs) in HEC-WAT. In the CRS Model, CCPs dictate locations in the HEC-WAT watershed where boundary conditions are defined, or where hydrologic data is available or shared across different models.

3.4.6 Streamflows

The CRS Model can use streamflow data from a variety of sources, including the 2010 Level Modified Streamflows dataset (1928 to 2008), Extended Observed Streamflows (2009 to 2016), and the 26 synthetic hydrologic events that were developed to increase the diversity of large-scale flood events not represented in the historical period of record.

The 2010 Level Modified Streamflows dataset (Bonneville 2011) is used routinely in Columbia River Basin studies and was cooperatively developed by Bonneville, the Corps, and Reclamation to represent semi-unregulated daily historic streamflow with irrigation withdrawals adjusted to 2010 levels for the period from 1928 through 2008. This dataset and other inflow datasets are described in Parts 4 and 5 of this H&H Appendix (Appendix B).

Inflows to the Columbia River from the Willamette River are computed separately using a model developed by the Corps, Portland District, and are included in the CRS Model as fixed hydrographs by water year.

3.4.7 Water Supply Forecasts

Modeled reservoir draft requirements and certain other operations in the CRS Model are governed by seasonal water supply forecasts. The locations and seasonal periods for these water supply forecasts are described in Section 4.2.2. Details on the methods used to develop the water supply forecast dataset are provided in a separate section of this H&H Appendix (Appendix B, Part 4 – Hydrologic Data Development). The CRSO EIS also uses hydrology from years 2009 to 2016 in a variety of evaluations associated with the EIS alternatives. For these recent years (2009 to 2016), the CRS Model uses the actual issued seasonal water supply forecasts for each location.

3.4.8 Initial Reservoir Conditions

For model runs using the 2010 Level Modified Streamflows dataset without forecast uncertainty or the extended observed flows, the reservoir elevations are initialized using a historic average or target elevation for the end of an ideal water year, depending on the site. Reservoir elevation and storage carry over between water years so if a reservoir is unable to hit the September 30 target, this will affect the next water year.

In the Monte Carlo compute, each water year simulated is independent of the previous or next year. At Grand Coulee, Libby, and Hungry Horse, a need was identified to represent the effects of missing the end of water year draft target, as this may compromise refill in the following year. To simulate this, a probability distribution for the end of water year elevation is created from the 80-year period of record computes. The probability distribution is then sampled in the Monte Carlo compute by the ResSim model, thereby capturing the variability in reservoir contents carried over from one year to the next.

CRSO simulations for each alternative employed Monte Carlo sampling to capture the effect of seasonal forecast variability.

CHAPTER 4 - DESCRIPTION AND IMPLEMENTATION OF RESERVOIR OPERATIONS

4.1 GENERAL DESCRIPTION

This section presents an overview of year-round reservoir operations for the No Action Alternative as modeled in the CRS Model. The CRS Model includes multiple reservoir simulation models developed using the HEC-ResSim Reservoir System Simulation software package, along with several other submodels, within the HEC-WAT environment.

HEC-ResSim will determine a release at each project to move the pool elevation toward the specified guide curve elevation for that project. This determination is made at each timestep. The ability of HEC-ResSim to achieve the elevation on the guide curve at each timestep is limited by the following factors:

- Inflow into the project
- Physical constraints of the project
- Operating rules

Project operations and constraints in an HEC-ResSim model are specified project by project in an operation set. Each operation set contains a specification of the operating zones of the reservoir and the set of rules per operating zone that constrain releases. For run-of-river projects, elevation zones were set, but no other operations were specified in the CRS Model. In other words, releases at run-of-river projects are determined strictly by attempting to maintain reservoir elevation at the top of the guide curve, subject only to physical constraints.

4.2 OPERATIONS RELATED TO FLOOD RISK MANAGEMENT

The Pacific Northwest has two principal flood seasons. November through March is the rain-produced flood period. These floods occur most frequently on streams west of the Cascade Range. May through July is the snowmelt flood period. East of the Cascades, snowmelt floods dominate the runoff pattern for the Columbia River Basin. FRM involves drawing down reservoirs to provide an adequate amount of space to store runoff, and filling reservoir space in a manner to minimize downstream damages. FRM operations include system FRM goals for the lower Columbia River, and local FRM goals in the vicinity of individual projects. Often, if FRM goals for the lower Columbia River are met, they will be met at other potential flood damage areas in the basin.

Seasonal volume runoff forecasts (also called water supply forecasts) are used to determine reservoir storage requirements for several FRM projects. These projects have storage reservation diagrams (SRDs), which, based on runoff volume forecast, specify the amount of space to be made available by the beginning of the refill period. The principles of Columbia River risk management regulation are contained in the Columbia River Treaty Flood Control Operating Plan (FCOP) (Corps Northwestern Division for the U.S. Entity 2003). The SRDs used to model Canadian projects (Mica, Arrow, and Duncan) are available in the FCOP; the SRDs used to model U.S. projects are available at the public website of the Corps' Northwestern Division (Corps 2019).

4.2.1 System Seasonal Flood Risk Management Operations

Yearly FRM operation involves two seasonal periods: the storage reservoir evacuation period (normally the low water period from October through March) and the reservoir refill period (normally the high-flow period from May through July). Either evacuation or refill of reservoir storage may occur during April depending on runoff conditions.

4.2.1.1 Flood Storage Evacuation Period

In the winter months, reservoirs are drafted in accordance with their SRDs to provide storage for the spring runoff. Storage requirements are primarily based on forecasts of spring/summer volume runoff. Early evacuation of reservoirs is required for the possibility of an early spring runoff that would preclude more reservoir draft. In order to ensure drawdown in an orderly manner with consideration of project operating limits, it is necessary to initiate evacuation of most reservoirs by either December 1 or January 1. The period used for forecasting varies by reservoir, as shown in Table 4-1. The pattern and timing of the draft is described in each reservoir's SRD. Differences in timing of the draft are due to the elevation of the contributing areas in each watershed. Lower elevation watersheds and those located farther south typically have an earlier completion of spring runoff.

Table 4-1. Reservoir Forecast Periods

Dam	Forecast Used for Evacuation (Period, Location)
Mica	April–August, The Dalles
Arrow	April–August, The Dalles
Duncan	April–August, Duncan
Libby	April–August, Libby
Grand Coulee	April–August, The Dalles
Hungry Horse	May–September, Hungry Horse
Dworshak	April–July, Dworshak
Brownlee	April–August, The Dalles April–July, Brownlee (regulated)

4.2.1.2 Flood Storage Refill Period

Refill is initiated to (1) meet the system FRM objective represented by the managed flow objective for the lower Columbia River as measured at The Dalles, (2) ensure water is available for fall and winter power needs, or (3) provide water for other non-power needs.

Day-to-day regulation in the refill period under current operations is accomplished by first establishing a managed flow objective at The Dalles (the Initial Controlled Flow, or ICF) using the methodologies described in the FCOP.

The ICF date is defined as the date that the unregulated mean daily discharge is forecast to first exceed the controlled flow objective at The Dalles. The Flood Storage Refill Period for each project commences a certain number of days prior to the ICF date (Table 4-2) in the CRS Model, with certain project-specific details provided later in this appendix.

Table 4-2. Commencement of Flood Storage Refill Period

Project	Days Before ICF Date that Refill Operations Can Be Initiated
Mica	5
Libby	10
Duncan	10
Hungry Horse	10
Dworshak	1
Arrow	2
Flathead Lake	0
Noxon Rapids	0
Lake Pend Oreille	0
Grand Coulee	1
Brownlee	1
John Day	0

During the refill period, the upstream reservoirs operate as a system to meet the objective flow at The Dalles (called the Controlled Flow). The first controlled flow of the runoff season is called the Initial Controlled Flow, or ICF.

It should be noted that a reliable forecast window of unregulated streamflow does not extend beyond 10 days; in an effort to maintain a high likelihood of complete refill in years with moderate to low runoff volume, refill during real-time operations may begin before unregulated flows are forecasted to exceed controlled flow objectives at The Dalles. In modeled operations, a low-flow procedure was implemented to guide refill when The Dalles water supply forecast is below 80 million acre-feet (Maf).

Flood control refill curves (FCRCs) also provide a guide initiating refill and establishing refill rates at individual reservoirs in certain circumstances. FCRCs are described in Section 4.2.7.1.

4.2.2 Local Flood Risk Management

Projects are also operated for local FRM. Within the CRSO study area, there are local FRM objectives at Spalding, Idaho, and the community of Ahsahka, Idaho (below Dworshak), Bonners Ferry, Idaho (below Libby), and Columbia Falls, Montana (below Hungry Horse). The objective at all these locations is to avoid exceeding a certain flow (or stage) at which major flood damage occurs.

4.2.2.1 Bonners Ferry

The stage at Bonners Ferry is limited to 64 feet (elevation of 1,764 feet National Geodetic Vertical Datum of 1929 [NGVD29]; 1,767.9 feet North American Vertical Datum of 1988 [NAVD88]). The operation for Bonners Ferry must account for the influence of the releases from Libby, the intervening local flow, and backwater effects from Kootenay Lake. The stage at Bonners Ferry is dependent on the flow at Bonners Ferry, as well as the Kootenay Lake stage downstream of Queens Bay, British Columbia. To account for this, HEC-ResSim incorporates a multi-parameter rating to limit the release from Libby. The release from Libby is subject to its full pool elevation of 2,459 feet NGVD29 (2,462.9 feet NAVD88) not being exceeded.

4.2.2.2 Spalding

The maximum flow limit at Spalding is 105,000 cubic feet per second (cfs). In the HEC-ResSim model, release values from Dworshak are incrementally tested in decreasing 500-cfs values (from a maximum of 25,000 cfs to a minimum of 1,600 cfs) until the simulated flow at Spalding falls below the desired maximum flow value. The release from Dworshak is subject to its full pool elevation of 1,600 feet NGVD29 (1,603.3 feet NAVD88) not being exceeded.

The 25,000 cfs limit at Dworshak is for FRM at Ahsahka, Idaho, located about 1.3 miles downstream of the dam.

4.2.2.3 Columbia Falls

Maximum releases from Hungry Horse are set based on the elevation of Flathead Lake, which defines the maximum flow at Columbia Falls. The maximum flow at Columbia Falls is calculated in the HEC-ResSim model as follows:

- If Flathead Lake elevation ≥ 2,892 feet NGVD29 (2,895.6 feet NAVD88), the maximum flow at Columbia Falls is 44,100 cfs.
- If Flathead Lake elevation < 2,892 feet NGVD29 (2,895.6 feet NAVD88) and ≥ 2,891.5 feet NGVD29 (2,895.1 feet NAVD88), the maximum flow at Columbia Falls is based on the elevation of Flathead Lake based on the following equation, which is meant to serve as a smooth transition between the upper and lower maximum flow limits:
    - 51,100 cfs – ((Flathead Lake elevation – 2,895.1 feet) * (7,000))
    - Note that the flow can range from 51,100 cfs at elevation 2,891.5 feet NGVD29 (2,895.1 feet NAVD88) to 47,600 cfs at elevations just below 2,892 feet NGVD29 (2,895.6 feet NAVD88)
- If Flathead Lake elevation is less than 2,891.5 feet NGVD29 (2,895.1 feet NAVD88), the maximum flow at Columbia Falls is 51,100 cfs.

The pool elevation at Hungry Horse can override the maximum flow values that are based on the Flathead Lake elevation. Once the elevation at Hungry Horse is within 2 feet of the full pool elevation of 3,560 feet NGVD29 (3,563.9 feet NAVD88), the maximum flow at Columbia Falls is 51,100 cfs.

The release from Hungry Horse is subject to a minimum release of 300 cfs while operating to flood stage at Columbia Falls, and is also subject to not exceeding its full pool elevation.

4.2.3 Winter Floods

The Portland, Oregon, and Vancouver, Washington, area can be flooded during both winter (November to March) and late spring. Large winter flood events in the Pacific Northwest are caused by atmospheric rivers (ARs). ARs are enhanced water vapor plumes in the atmosphere sourced from tropical latitudes and transported by extratropical cyclones. ARs last only a few days but deliver a substantial amount of precipitation and warm temperatures over their duration. High rainfall rates during these events, often augmented by low-elevation snowmelt, can cause flooding. Flood stage categories for the Columbia River at the Vancouver gage are established by the National Weather Service.[5] There are six recorded events where the river exceeded major flood stage (25 feet) by more than 2 feet. Two of these events occurred during the winter: 27.7 feet (29.5 feet NGVD29; 33.0 feet NAVD88) on December 25, 1964, and 27.2 feet (29.0 feet NGVD29; 32.5 feet NAVD88) on February 9, 1996.

Most of the Columbia River System storage is well upstream of the Portland and Vancouver area, and a majority of the heavy AR rainfall occurs in the drainage basin below major storage projects. However, the Columbia River Basin can offer some storage to reduce flood impacts to Portland and Vancouver. During the largest ARs, there is often a substantial amount of rainfall that lands east of the Cascades and into the lower Snake River Basin. During the winter event in February 1996, the projects on the Columbia River System provided support to the lower reaches through regulation over the week of the storm. This operation consisted of 12 large projects in the basin, including a pre-event drafting and storage in the 4 projects on the lower Columbia River and storage at Mica and Arrow to limit Arrow outflows to the natural lake outflow.

In the HEC-ResSim model, Columbia River Basin systemwide winter FRM operations are implemented in a tiered framework; each operational tier is determined by the severity of forecasted stage at the Vancouver gage. This mimics real-time operations, where operators use a forecast developed by the National Weather Service Northwest River Forecast Center. The River Forecast Center produces a 10-day forecast of streamflow; however, operational decisions for short-duration winter events typically only rely on forecasts within a 5-day window due to high uncertainty and lower skill in the 5- to 10-day range. The model uses a method to generate a 5-day forecasted stage similar to that product.

The modeled forecast routine uses a regression-based method of estimating stage from the inflow from the Willamette River and Columbia River mainstem. To estimate the 5-day

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[5] The datum at the Vancouver station is 1.82 feet (a stage reading of 0 is 1.82 feet above sea level, or more specifically NGVD29).

forecasted regulated flow out of Bonneville Dam for this calculation, a simplified representation of regulation in the Columbia River System is used. This simple projection of Bonneville Dam outflow and known quantities for the other inputs of the Vancouver stage estimation method are used for the forecasts of Vancouver stage. Generic operating rules are used for regulation from the headwaters down to Bonneville Dam. The projection of operations and regulated flow occurs for the length of the forecast window and the starting pool elevations at all projects are the previous day's elevation. The operations at the most upstream reservoir are modeled for the whole forecast horizon, then the flows are routed downstream to the next reservoir to adjust the flows. This process is carried through until flows are routed all the way down to Bonneville Dam. This method allows for the use of short-term forecast inflows when projecting reservoir operations and downstream flows. The use of forecasted inflows with error is not currently implemented—the future inflows are assumed to be known with perfect foresight. Incorporating short-term forecast error could have a large influence of operations at headwater projects. However, this has less of an influence on the flows out of Bonneville Dam because much of the system's operations of large storage projects are based on the spring FRM objectives, which are less affected by short-term forecasts.

The simplified model projection simulates all reservoirs, ensuring that the forecasted flows are realistic and incorporate the at-site project limits. The following reservoirs are used in forecasting the Vancouver stage in the model: Mica, Arrow, Duncan, Libby, Corra Linn, Hungry Horse, SKQ, Albeni Falls, Grand Coulee, Brownlee, and Dworshak.

The severity of forecasted events is described using different levels, called tiers. The 1- to 5-day forecast of Vancouver stage is used to determine the event tier level. Table 4-3 lists the tier levels and corresponding Vancouver stage triggers. The modeled Vancouver stage is used to determine the Operations Status, which is either Status 1 (Pre-Event), Status 2 (Near Peak), or Status 3 (Recession).

Table 4-3. Flood Severity Tiers and Operational Response (Status) Based on Vancouver Stage

	Vancouver Stage			
Tier	**Tier Trigger (forecast)**	**Status 1 Pre-Event (current, ft CRD)**	**Status 2 Near Peak (current, ft CRD)**	**Status 3 Recession (current, ft CRD)**
Tier 1	≥16, <17	<16	≥16	≤15
Tier 2	≥17, <20	<17	≥17	≤16
Tier 3	≥20	<20	≥20	≤17

Note: CRD = Columbia River Datum.

The tier of the forecasted event determines which projects will operate for FRM. For a Tier 1 event, lower Columbia River projects including Bonneville Dam, John Day, McNary, and The Dalles operate for winter FRM. During Tier 2 events, Grand Coulee, Albeni Falls, and Dworshak are added. During the most severe events, Tier 3, projects in the upper basin are added to the FRM operations: Libby Dam, Hungry Horse, SKQ, Arrow, and Duncan (Table 4-4). FRM operations are divided into three categories that are referred to as statuses in the model nomenclature. The first status (Status 1) is pre-event, where the river is forecasted to exceed flood stage within the 5-day forecast window and the current stage is still below flood stage. In

Status 1, some of the projects will draft to create flood storage. The second status (Status 2) is near the peak of the event, and active projects store water. The final status (Status 3) occurs after the flood peak has occurred, flow is receding, and the projects draft to their normal operating elevations. The ranges of Vancouver stage that define each of these statuses are listed in Table 4-4. The following sections summarize the specific operations for each of the projects with winter FRM operations.

Table 4-4. Projects with Winter Flood Risk Management Operations for Event Tiers 1 to 3

Tier	Projects with FRM Operations
1	Bonneville Dam, The Dalles, John Day, McNary
2	Tier 1, Grand Coulee, Albeni Falls, Dworshak
3	Tiers 1 and 2, Libby, Hungry Horse, SKQ, Arrow, Duncan

4.2.3.1 Lower Columbia River Dams

The Tier 1 projects operate for winter FRM in all tier level events. During Status 1, pre-event, these projects draft to their respective minimum pool elevations. The draft is constrained to keep the stage at Vancouver at or below 16 feet CRD. During Status 2, these projects fill available storage, distributing the fill evenly over the number of days where Vancouver stage is projected to be in the Status 2 range. Once Status 3 is triggered these projects draft the water stored during the event that is above the normal operating pool over the course of 7 days. This modeled operation provides a total of 921 thousand acre-feet (kaf) of flood storage space (John Day, 534 kaf; Bonneville Dam, 149 kaf; McNary, 185 kaf; The Dalles, 53 kaf).

4.2.3.2 Grand Coulee

Grand Coulee operates for winter FRM during Tier 2 and 3 events when there is space available. During Status 1, the project passes inflow until 3 days before Status 2. Next, during the 3 days prior to and during Status 2, the project fills the storage space available (to full pool), distributed evenly over this period. This impounds water during the peak of the flood to mitigate for flooding on the Columbia River mainstem. Once Status 3 is initiated, the project drafts the water stored during the event that is above the spring FRM requirement. The post-event draft is constrained by the variable maximum draft rates specified for the project. The travel time from Grand Coulee to Vancouver is approximately 1 to 1.5 days.

4.2.3.3 Albeni Falls

Albeni Falls operates for winter FRM during Tier 2 and 3 events. During Status 1, the project passes inflow. During Status 2, when inflow is less than 50,000 cfs, the project releases 10,000 cfs. If inflow is greater than 50,000 cfs, outflow is equal to the maximum release of the powerhouse (17,000 to 27,000 cfs). Once Status 3 is triggered, the project drafts the water stored during the event that is above the spring FRM requirement. This draft is constrained by the physical limits of the river channel between the lake and the dam. The travel time from Albeni Falls to Grand Coulee is approximately 1 day.

4.2.3.4 Dworshak

Dworshak operates for winter FRM during Tier 2 and 3 events. This project does not have winter FRM operations during Status 1 because the travel time is too long to ensure evacuated storage can pass through the system before the winter storm. During Status 2, the project limits outflows to the minimum outflow requirement. Once Status 3 is triggered, the project drafts the water stored during the event that is above the spring FRM requirement at the maximum allowable outflow rate. The travel time from Dworshak to Vancouver is approximately 1 to 2 days.

4.2.3.5 Libby

Libby operates for winter FRM during Tier 3 events. During Status 1 and 2, release is limited to 4,000 cfs (minimum flow). Once Status 3 is initiated, the water stored during the event that is above the spring FRM requirement is drafted. This draft is limited by ramping rates and the maximum capacity of the powerhouse (12,000 to 28,000 cfs).

4.2.3.6 Hungry Horse

Hungry Horse operates for winter FRM during Tier 3 events. During Status 1 and 2, release is limited to the maximum of at-site minimum release or the Columbia Falls minimum. Once Status 3 is initiated, the water stored during the event that is above the spring FRM requirement is drafted evenly over the course of 7 days.

4.2.3.7 Seli'š Ksanka Qlispe'

SKQ operates for winter FRM during Tier 3 events. During Status 1 and 2, release is limited to the minimum of powerhouse capacity (13,500 cfs) and inflow. Once Status 3 is initiated, the water stored during the event that is above the spring FRM requirement is drafted. This draft is limited by the physical constraints of the channel between the dam and the upstream lake.

4.2.3.8 Arrow

Arrow operates for winter FRM during Tier 3 events. If Vancouver stage is projected to be over 20 feet in the next 3 days, the project attempts to reduce releases to inflow. A ramping rate of 15,000 cfs per day is applied, and releases are not permitted to drop below a minimum flow of 15,000 cfs. This ramp down in releases continues through Status 2. Once Status 3 is triggered, the project drafts the water stored during the event that is above the spring FRM requirement over the course of 7 days.

4.2.3.9 Duncan

Duncan operates for winter FRM during Tier 3 events. If Vancouver stage is projected to be over 20 feet in the next 3 days, the project releases the maximum of inflow and the minimum release (100 cfs). This release logic continues through Status 2. Once Status 3 is triggered, the project drafts the water stored during the event over the course of 3 days.

4.2.3.10 Willamette

Regulation of the Willamette system is simulated external to the CRS Model. A timeseries of regulated flow at Willamette Falls is used as a boundary condition, and the CRS Model has no knowledge of the internal states (reservoir pool conditions or flows) beyond the Willamette inflow at Willamette Falls just upstream of Portland. Running the Willamette Model concurrently with the CRS Model was determined to not be necessary as the operations are not a function of seasonal water supply forecasts which can be varied in the Monte Carlo compute mode.

Each winter the projects are drafted to the minimum conservation pool until the spring when it is time to refill for the conservation season. Each Willamette project operates for local flood control on its own tributaries and all projects work together to provide Willamette River system flood protection at three mainstem control points. During flood events, the dams regulate to bankfull and local flood stage, partially filling while releasing minimum flows. Generally, storage is released after the event has peaked. Project outflows follow a hierarchical order, with each project having its own ramping rate for both increasing and decreasing flows. The operational objectives are to draft to minimum levels after an event, however there are times when that is not possible (e.g., consecutive storms). Given the nature of how the Willamette system projects operate, projects are already pre-drafted for a flood event as much as they are able. There are special circumstances where a project may be required to release more than minimum outflow during a flood event to avoid overfilling. If the combination of pool elevation and project inflow requires special regulation curves, then project outflows will be larger than minimums, even during a flood event. Following special regulation curves is a higher priority than controlling for bankfull or flood stage at downstream control points.

4.2.4 Upper Rule Curve Operations

To prepare for capturing spring runoff in the Columbia River System, reservoir space requirements for FRM projects are governed by a URC at each project. The URC is the guide curve that describes the maximum elevation required of a given reservoir during its evacuation and refill period to meet system FRM requirements. It is one of many guide curves that dictate the actual operations of a project.

Mica, Arrow, Duncan, Libby, Hungry Horse, Brownlee, and Dworshak are operated to each individual project’s URC during the drawdown season. The URCs are developed from individual project or system projected forecast runoff for a specified period, such as April to August and April to July. The forecast runoff volume and the project SRD are used to determine the amount of space that is required at each project to meet system or local FRM objectives. This calculation is computed at the start of every month when a new official water supply forecast is available. During the refill season each project is operated to assist in local and system FRM. In addition, each project is operated to refill by project-specific dates.

The Grand Coulee URCs are determined from the Grand Coulee SRD based upon an adjusted water supply forecast for The Dalles. The adjusted The Dalles water supply forecast is computed as the unregulated April to August volumetric flow forecast minus an upstream storage correction. The upstream storage correction is defined as the sum of the space projected to be available at the start of the flood control refill period for eleven reservoirs upstream of The Dalles. The reservoirs include Mica, Libby, Duncan Hungry Horse, Dworshak, Arrow, Flathead Lake, Noxon, Lake Pend Oreille, Brownlee, and John Day. For each reservoir, the space projected to be available is limited to a defined reservoir specific maximum value or the amount that can be physically stored based upon forecasted inflows to that reservoir. Through this method, the Grand Coulee URCs are adjusted to account for the operations of the 11 upstream reservoirs.

Also, during the month of April, Grand Coulee will prioritize targeting the April 30 target URC elevation over the April 10 and 15 elevations if draft rate limits apply.

The URC utility program is responsible for generating the URCs that represent the maximum pool elevation for each of the reservoirs in the Columbia River Basin that participate in system FRM and whose draft shape is defined by an SRD and a local or system runoff volume forecast (Table 4-5). The URC program operation is independent of HEC-ResSim.

Table 4-5. Columbia Flood Model – Complex Operations Summary

Operation	Description	Affected or Participating Projects							
		Mica	Arrow	Duncan	Libby	Hungry Horse	Dworshak	Brownlee	Grand Coulee
URC Operation	Specification and modification of the URCs at the system flood storage projects to account for potential On Call or other FRM operation.	X	X	X	X	X	X	X	X
System Flood Risk Management and ICF Operation	Determination of and operation for the ICF at The Dalles. Includes automated refill.	X	X	X	X	X	X	X	X
SynRes	"Synthetic Reservoir" operation of Arrow and Grand Coulee.		X						X
Variable discharge storage regulation procedure (VarQ)	An alternate system FRM operation to improve the likelihood of refill and potentially provide more in-stream flow during and after the refill season.				X	X			

Note: ICF Operation, SynRes, and VarQ are described in later sections of this document.

To generate the URC for a project, the program reads files specifying the project elevation-storage diagrams, the project SRD, and the forecasted runoff or snow cover. The SRD table lists the end-of-month space below full pool required for a range of runoff forecasts. The SRD specification is flexible and can accommodate multiple forecast parameters (e.g., runoff at two different locations), tables for standard, local, and On Call URCs, and a table of refill percentages by date.

For each given date in the SRD or refill table, the program determines a draft based on the forecasted seasonal runoff. The program interprets the water supply forecast for each output date in the SRD file. The resulting draft for the given input forecast is calculated by linear interpolation of the draft values specified for that date and forecast value. Generally, data is returned only for dates in the SRD table, but the program can output daily drafts, interpolated between each SRD date. This is required when the Grand Coulee adjustment is used.

Additional tables are also specified for local FRM requirements as a storage reservation diagram, or an On Call SRD for CRT FRM operations. If On Call operations are triggered, the On Call SRD table is used instead of the given SRD. If a local SRD is given, the draft value returned is the maximum value of the SRD (or On Call) and the local SRD tables.

4.2.5 Seasonal Guide Curve Operation

There are several projects in the CRS Model that are operated to seasonal guide curves. These projects are Albeni Falls, SKQ, Corra Linn, and Brownlee. Ice Harbor, Lower Monumental, Little Goose, and Lower Granite have seasonal guide curves, but these are not in place for FRM but, instead, are in place for fish passage operations. Seasonal guide curve operations require the projects to achieve a predetermined draft regardless of runoff forecasts. Some of the guide curve operations come directly from Water Control Manuals, while other ones are a blend of an approximation of real-time operations and guidelines.

4.2.5.1 Albeni Falls Guide Curve

The guide curve for Albeni Falls incorporates Kokanee salmon (*Oncorhynchus nerka*) spawning limitations into the curve. From November 15 to 30, the lake is stabilized for Kokanee salmon spawning. In December, a minimum control elevation is established to protect Kokanee salmon spawning and egg incubation while a holding period is implemented in the January to March time period.

4.2.5.2 Brownlee Guide Curve

Brownlee operations are guided by both its URC (depending on The Dalles and Brownlee forecasts) and ecosystem operations (reflected in the Federal Energy Regulatory Commission [FERC] license and incorporated in its guide curve). In the summer and fall, the model operates to a series of targets as defined in the FERC license, then transitions to maintaining steady flows for spawning in the middle of winter. In February, the model transitions smoothly from the steady flow operation for spawning to higher flows if required to meet the URC target at the end of each month until June.

4.2.5.3 Corra Linn Guide Curve

The guide curve for Corra Linn Dam represents the drawdown for Kootenay Lake called for in the 1938 International Joint Commission Order on Kootenay Lake. The guide curve is followed unless the outflow required by the guide curve exceeds the hydraulic capacity at Grohman Narrows.

4.2.5.4 John Day Guide Curve

The guide curve at John Day represents average operations with a 1.5-foot minimum irrigation pool range from April 10 through September 30. The real-time operations will have more variability as they are highly dependent on power operations.

4.2.5.5 Lower Snake River Dam Guide Curves

The guide curves for the lower Snake River Projects reflect the MOP plus 1-foot rule for each project and passing the September Dworshak flow augmentation through the projects.

4.2.5.6 Seli'š Ksanka Qlispe' Guide Curve

The guide curve at SKQ represents the FRM elevations that are included in the 1962 memorandum of understanding, as amended, between the Corps and the former dam owner (Montana Power Company) that is a part of the FERC license for this project.

4.2.6 Variable Discharge Storage Regulation Procedure Operation at Libby and Hungry Horse

Libby Dam and Hungry Horse Dam operate to an FRM strategy called VarQ, which stands for variable discharge storage regulation procedure.[6] The VarQ SRDs for Libby and Hungry Horse guide the evacuation of space for FRM and are available on the public website of the Corps' Northwestern Division (Corps 2019). A full description of the VarQ operation is in each project's water control manual. The following bullets provide a brief overview of the implementation of the VarQ procedure in the CRS Model:

- Required space is a function of the April-to-August runoff forecast at Libby and the May-to-September forecast at Hungry Horse.
- Following evacuation, FRM space is maintained until the initiation of refill. Refill is initiated approximately 10 days prior to when streamflow forecasts of unregulated flow are projected to exceed the ICF at The Dalles, or when the reservoir elevation intersects the FCRC, whichever comes first.
    - While refill can be triggered at Hungry Horse 10 days before the ICF date, this criterion is generally overridden, and refill starts on May 1 in almost all of the years.
- At the initiation of refill, if inflows are less than the VarQ outflow, inflow is passed until inflow rises to the VarQ level. The VarQ outflow is determined using the charts and storage

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[6] Q is engineering shorthand for flow or discharge.

correction methods described in each project's water control manual. VarQ outflows are updated after both the new May and June runoff forecasts are developed.

4.2.7 Refill Operations

The following paragraphs describe the modeling of refill operations. A modeling approach for the refill season (called the Automated Refill algorithm) is applied in the CRS Model. This algorithm uses a combination of remaining forecast of inflow, target date of refill, and storage available in the reservoirs to develop a strategy for release that will provide desired system FRM, to produce reasonable and realistic refill shapes and to prevent undesirably large flows at full storage which often occur when refill for a reservoir is reached before peak inflow has occurred.

4.2.7.1 Flood Control Refill Curves

The purpose of reducing the expected seasonal runoff volume is to mitigate a situation where the net inflow volume was over forecasted and refill cannot be achieved because the anticipated (expected) volume did not materialize, thus creating a refill volume shortfall.

FCRCs help guide the refill of reservoirs during the refill period to minimize the likelihood of flood control regulation adversely affecting refill. Individual project refill can commence prior to the date of the ICF at The Dalles if the reservoir is at or below its FCRC. These curves define the lower limit of reservoir drawdown that can be filled with a 95 percent confidence. Their derivation is based on what is labeled as the “95 percent confidence volume runoff forecast.”

The 95 percent forecast is computing by reducing the expected seasonal runoff volume by the product of cross validation standard error and the statistical correction factor. For example, the 95 percent forecast for Libby is computed by reducing the expected seasonal runoff by 1.68 times the cross validation standard error (from t-distribution with an alpha of 0.95).

The FCRC is then developed through daily computations. The actual or forecasted inflow (forecasted inflow adjusted as described above) for each day is accumulated and then subtracted from the inflow forecast to obtain the residual forecast remaining for the rest of the forecast period. The minimum daily outflow volume for the remainder of the forecast period is accumulated each day. The volume available for refill is then the difference in inflow and outflow remaining for the forecast period. The allowable storage contents for each day are then computed by subtracting the volume available for refill from the gross storage at the project. This storage is then converted to an elevation to obtain the FCRC.

4.2.7.2 Specific Reservoir Refill Operations

Modeling of refill operations in ResSim relies on several assumptions and modeling techniques whose purpose is to mimic real-time operations. In general, Brownlee, Duncan, and Mica Reservoirs tend to refill based on their guide curves and expected Treaty Storage Regulation

(TSR)[7] flows (applicable to Duncan and Mica). Dworshak's and Hungry Horse's refills are guided by their refill operations for FRM and/or ecosystem support flows. Libby and Hungry Horse take into account VarQ flows when refilling. Arrow refills based on the power operation and is operated in tandem with Grand Coulee to control flows at The Dalles as needed.

4.2.7.3 Dworshak Refill

The refill rule at Dworshak is active from March through August. Refill occurs between 1 day before the ICF date and June 30 each year. The estimated refill flow, which is set as a maximum, minimum, or specified release depending on where the pool elevation is compared to the URC, is updated on a weekly basis each month. In cases where the inflow to Dworshak is less than the calculated refill flow, the release is set equal to the inflow so as not to draw down the pool. The inflow for Dworshak is estimated following the Automated Refill procedure. Refill at the projects also follows the table interpolation procedure and the top-off procedure.[8]

The target fill date is adjusted after June 15 to limit flows to powerhouse capacity by July 10 or total dissolved gas (TDG) limit if that is not possible. Refill is triggered based on the ICF date or intersection of the URC with the FCRC, whichever comes first.

4.2.7.4 Seli'š Ksanka Qlispe' Refill

During water years with large spring runoff volumes, refill of SKQ is delayed based on the volume of forecasted runoff at Hungry Horse that has not flowed into the system yet (remaining runoff). Hungry Horse remaining runoff is used as an indicator of streamflow volume and timing for SKQ. High remaining runoff indicates years with high inflows and also years where a large volume of inflow is experienced late in the melt season. On June 1 the model uses the remaining runoff volume to set the date of full refill. If remaining runoff is less than 1,100 kaf, the date targeted to be full remains at June 15. For remaining runoff greater than 1,500 kaf on June 1, the date targeted to be full by is delayed to June 30. When June 1 remaining runoff is between 1,100 and 1,500 kaf, the refill date is linearly interpolated between June 15 and June 30.

4.2.7.5 Grand Coulee Refill

In April, operations will target the April 10 Objective elevation value using the March water supply forecast, and then target the April 30 Objective elevation, prioritizing the April 30 Objective elevation over the April 10 elevation if draft rate limits apply. In May, if the forecast increases from April to May, Grand Coulee will draft up to the draft rate limit to try to reach the new value from the SRD if refill has not started already. From May through June, Grand Coulee simply targets a straight line to an end-of-June value.

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[7] The TSR modeling step is described in the Hydroregulation Appendix (Appendix I).

[8] The top-off procedure is described in Section 4.2.7.5 of this Appendix.

For the end-of-June target, the CRS Model includes operation for the Lake Roosevelt Incremental Storage Release Project. Based on input from real-time operators, Grand Coulee targets either 1,286.5 feet NGVD29 (1,290.4 feet NAVD88) or 1,286 feet NGVD29 (1,289.9 feet NAVD88), based on whether the forecast predicts a non-drought year (greater than 60 Maf forecasted volume) or a drought year, respectively. In cases where the 5-day average flow at The Dalles is greater than 500 thousand cubic feet per second (kcfs), Grand Coulee will target 1,282 feet NGVD29 (1,285.9 feet NAVD88) to reserve space for the end of refill season.

In July, the model fills 25 percent of the remaining storage to fill each day to reach close to 1,290 feet NGVD29 (1,290.9 feet NAVD88) on July 7.

As part of the technique for determining the project release, a table is developed of trial project releases ranging from minimum to maximum release as one parameter. The other table parameter, beginning storage, results from summing each day's forecast inflow minus trial outflow from the current date to the target fill date to determine filled space and subtracting it from full pool storage. The release is determined by interpolating from the table of outflow versus beginning storage using the parameter of current storage, thereby calculating a straight-line pattern of refill so that Grand Coulee, given perfect forecast and no other limiting factors on the outflow, would just refill on the refill date. Since forecast inflows are not perfect, the process is repeated to adjust the release daily.

Before refilling, the Grand Coulee pool elevation is only allowed to decrease, and it is limited to its lowest level achieved to maintain the storage space in the reservoir. Release is not allowed to drop below inflow unless such a release would violate the maximum release limits or the release from Grand Coulee would force the flow at The Dalles to rise above the ICF, in which case some inflow is stored in the reservoir. If the ICF is less than 400 kcfs, then flows at The Dalles are allowed to rise above the ICF up to 400 kcfs.)

Grand Coulee's refill is generally divided into two periods. The first part of refill ends when the reservoir is a week from full. Different logic determines the release during the first part of refill and the top-off. The scripted refill rule computes releases from April through August.

- The release is calculated as the outflow that would cause the reservoir to just fill on its target date assuming the forecasted inflows for that date.
- When the reservoir storage would reach or exceed full pool within 7 days at the current refill rate, a top-off algorithm is triggered. When the pool elevation reaches this point, the maximum release may be changed so that one-third of the remaining storage space will be filled each day for a smooth transition.

In larger runoff situations, the adjusted forecast inflow hydrograph may exceed the hydropower capacity on the desired date to have the reservoir refilled. This situation would result in undesirable spill of inflows greater than powerhouse capacity. In this situation, the refill algorithm determines the number of days until adjusted forecast inflows drop below the powerhouse flow capacity. The algorithm uses the volume under the adjusted forecast inflow hydrograph from the current date to the date when inflows will drop below hydropower capacity. The new volume is then used in determining the refill release to be made by the project. This technique delays refill by determining a slightly larger release, such that when the reservoir is filled, all releases can pass through the powerhouse.

Coordinated refill between Grand Coulee and Arrow (Synthetic Reservoir Operation [SynRes], see Section 4.2.7.8) only governs the operations when Grand Coulee sends a signal for Arrow that it is needed. If that is not the case, Grand Coulee computes its refill releases, and Arrow follows target TSR outflows and other objectives determined by the model.

4.2.7.6 Arrow Refill

In general, Arrow refills based on a combination of Automated Refill, TSR flows or flows derived from other Canadian operations (such as non-power uses agreements), and SynRes. If operating for SynRes as signaled by Grand Coulee, Arrow makes a release decision every day to follow Chart 6 of the FCOP. Otherwise, the release is adjusted weekly. In the Automated Refill procedure, Arrow does not use the 95 percent confidence volume forecast adjustment, so there is no difference between the first half of refill and the second half of refill.

4.2.7.7 Final Fill Dates

Table 4-6 is a list of the final refill dates for the major storage projects in the CRS Model. It should be noted that not all reservoirs will actually fill in any given year.

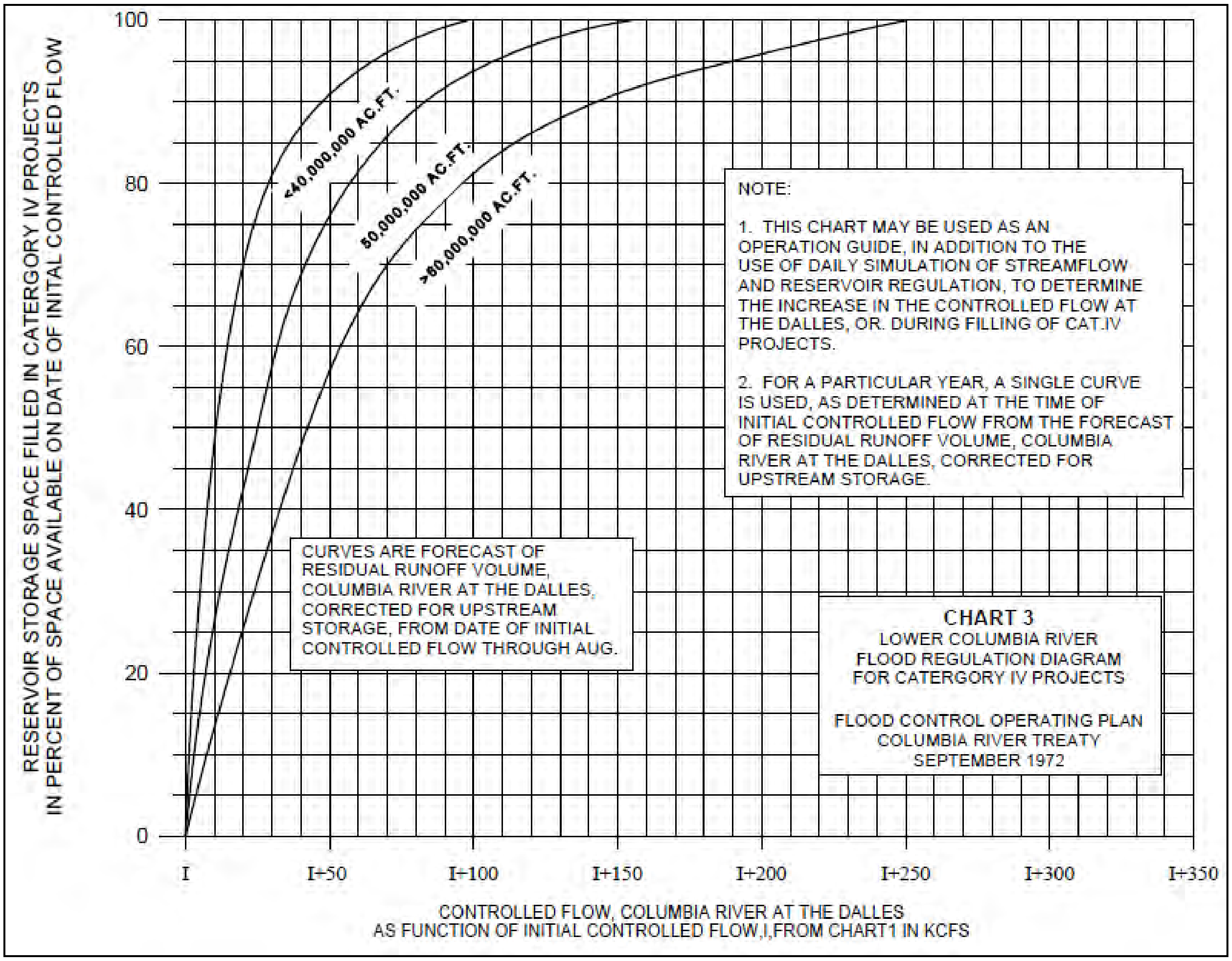
Table 4-6. Final Refill Date for Individual Projects

	Mica	**Libby**	**Duncan**	**Hungry Horse**	**Dworshak**	**Arrow Lakes**	**SKQ**	**Noxon Rapids**	**Albeni Falls**	**Grand Coulee**	**Brownlee**	**John Day**
Date	7/31	7/31	7/31	6/30	6/30	7/31	6/30	6/30	6/30	7/7	6/30	6/30

4.2.7.8 Synthetic Reservoir Operations – Arrow and Grand Coulee

Coordinated refill between Grand Coulee and Arrow is accomplished by SynRes. In the CRS Model, SynRes governs the operations when Grand Coulee sends a signal for Arrow that it is needed.

During the refill period, SynRes has Arrow and Grand Coulee refill at proportional rates to control flow at The Dalles. This concept of refilling at proportional rates while targeting a controlled flow at The Dalles is described in the FCOP. The proportional fill of each reservoir is guided by use of Charts 3 and 6 in the FCOP (Figure 4-1 and Figure 4-2). In the CRS Model, Chart 6 (Figure 4-2) is implemented as the SynRes operation.



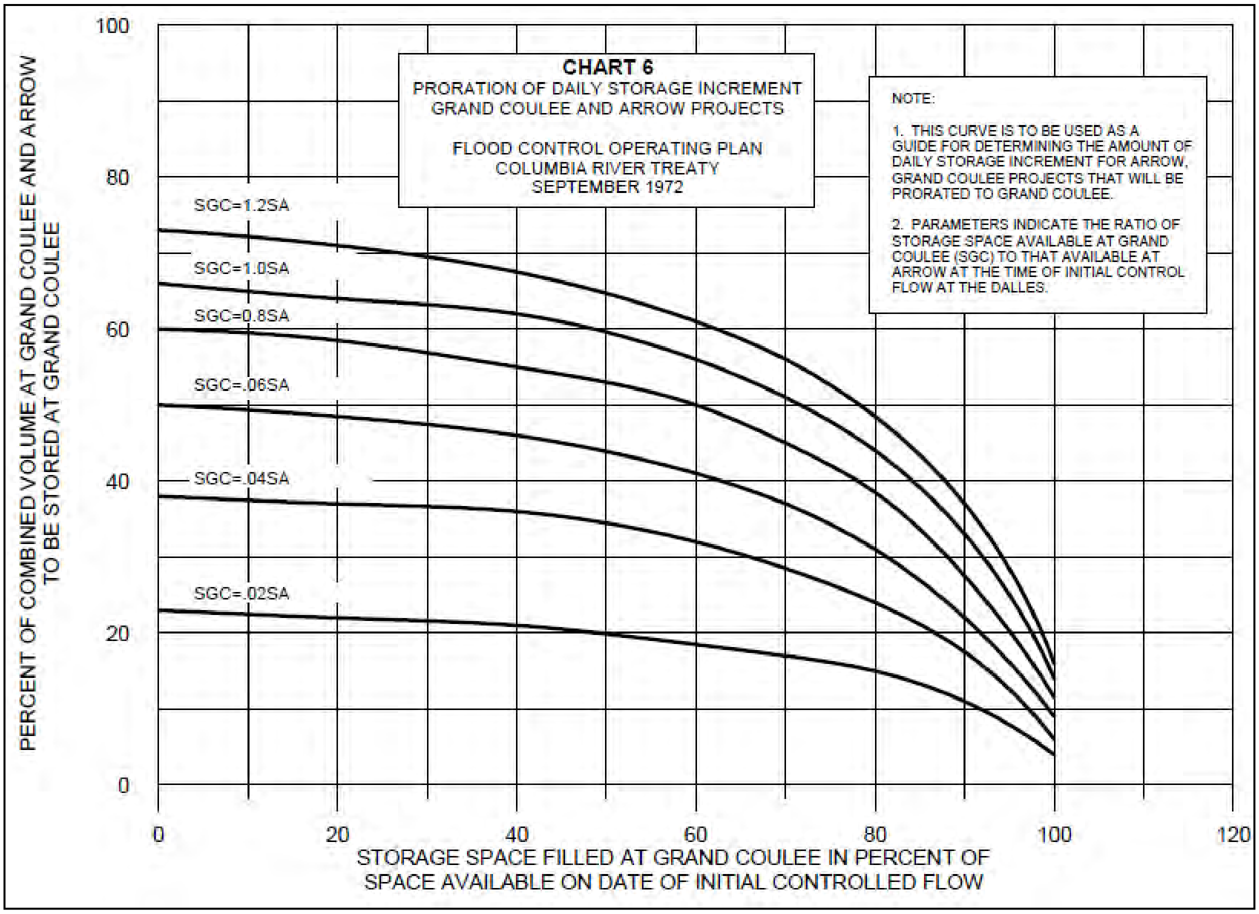
NOTE:

1. THIS CHART MAY BE USED AS AN OPERATION GUIDE, IN ADDITION TO THE USE OF DAILY SIMULATION OF STREAMFLOW AND RESERVOIR REGULATION, TO DETERMINE THE INCREASE IN THE CONTROLLED FLOW AT THE DALLES, OR. DURING FILLING OF CAT.IV PROJECTS.

2. FOR A PARTICULAR YEAR, A SINGLE CURVE IS USED, AS DETERMINED AT THE TIME OF INITIAL CONTROLLED FLOW FROM THE FORECAST OF RESIDUAL RUNOFF VOLUME, COLUMBIA RIVER AT THE DALLES, CORRECTED FOR UPSTREAM STORAGE.

Figure 4-1. Controlled Flow at The Dalles

Source: Flood Control Operating Plan, Chart 3 (Corps Northwestern Division for the U.S. Entity 2003)



NOTE:

1. THIS CURVE IS TO BE USED AS A GUIDE FOR DETERMINING THE AMOUNT OF DAILY STORAGE INCREMENT FOR ARROW, GRAND COULEE PROJECTS THAT WILL BE PRORATED TO GRAND COULEE.

2. PARAMETERS INDICATE THE RATIO OF STORAGE SPACE AVAILABLE AT GRAND COULEE (SGC) TO THAT AVAILABLE AT ARROW AT THE TIME OF INITIAL CONTROL FLOW AT THE DALLES.

Figure 4-2. Grand Coulee and Arrow Refill

Source: Flood Control Operating Plan, Chart 6 (Corps Northwestern Division for the U.S. Entity 2003)

4.2.7.9 Low Flow Refill Operations

In order to ensure that refill does not start too late during low-flow years (defined as years with an ICF less than or equal to 325 kcfs and an official April-to-August The Dalles forecast less than or equal to 80 Maf), the ICF date is set as no later than May 11. The reservoirs refill with typical days before ICF as shown in Table 4-2. Refill is allowed to start earlier than May 11 if the normal ICF date calculations justify it. In years that do not meet the criteria of a low-flow year, the refill date is set as no later than June 10.

4.2.8 Shift Operations (Dworshak and Grand Coulee)

System FRM space can be temporarily shifted, if possible, from Dworshak and Brownlee to Grand Coulee until April 15 with the volume used for flow augmentation by April 30 (transferring the space requirements back to Dworshak and Brownlee). The temporary system flood control transfer can be performed at Dworshak if the April to July forecast predicts a runoff of 3.0 Maf or less and if space is available at Grand Coulee. At Brownlee, the temporary transfer of system FRM space to Grand Coulee is subject to the availability of space at Grand

Coulee. The shifted FRM space requirements are shifted back to Dworshak and Brownlee by April 30 and Grand Coulee's space requirement reverts back to the non-shifted amount.

Shifts from Brownlee to Grand Coulee are not normally executed during in-season operations because there is generally not enough space after performing a shift from Dworshak to Grand Coulee; therefore, the Brownlee shift has not been incorporated in the CRS Model. Dworshak implements a partial shift, allowing the reservoir to reduce outflow in order to fill into the shifted space but not forcing it to follow the higher shifted elevation. On April 15, Dworshak begins to make releases to return to the un-shifted elevation. Grand Coulee operates to the full amount of potential shift, which is deeper than the un-shifted elevation. The potential FRM shift that is calculated and issued each month is limited to the operation of Grand Coulee above elevation 1,232.0 feet NGVD29 (1,235.9 feet NAVD88) at the end of March 15 and April 15. In addition, Grand Coulee can only accept a shift if it does not require an operation that exceeds the project's maximum draft rate limits. Between April 15 and April 30, flows are adjusted once every 5 days until the project returns its shifted elevation to the URC elevation on April 30.

4.2.9 Lower Granite Hinge Pool

Lower Granite Reservoir can create substantial backwater effects as far upstream as Spalding when the pool is at high levels. To reduce these backwater effects, an operation known as "hinge pool" is used. Under the hinge pool operation, when inflows to the reservoir exceed certain levels, the release from Lower Granite is increased to lower the pool elevation, preventing flooding upstream from backwater effects. A 3-day average forecast inflow is used to determine if the hinge pool operation is necessary. The water control manual for Lower Granite allows for a maximum drawdown of 0.5 feet/hour, so the pool can be drawn down to the required level in 1 day. The maximum pool elevations in the hinge pool operation are shown in Table 4-7.

Table 4-7. Lower Granite Hinge Pool Maximum Elevations

When Inflow Exceeds	Maximum Pool Elevation (feet NGVD29 [NAVD88])	Applicable Dates
50,000 cfs	738 (741.4)	July 15–December 14
	737 (740.4)	December 15–March 14
	737.7 (741.1)	March 15–July 14
120,000 cfs[1/]	734 (737.4)	All year
300,000 cfs	725 (728.4)	All year
420,000 cfs	724 (727.4)	All year

1/ In real-time operations, when inflow exceeds 120,000 cfs and is forecast to increase 5 percent over 24 hours. In modeled operations which use a daily timestep, 120,000 cfs is used.

4.3 OPERATIONS RELATED TO PHYSICAL CHARACTERISTICS OR LIMITATIONS

Many reservoir operations are related to physical characteristics or limitations of a project or the channel upstream or downstream of the project. For example, minimum pool or flow requirements are specified for several projects and are included in project Water Control Manuals. Physical characteristics or limitations are described in this section.

4.3.1 Head Loss

The CRS Model provides output for lake levels at the projects modeled. For projects with a channel restriction upstream of the dam, a head loss equation is used. Examples of this include Corra Linn Dam and Albeni Falls Dam.

4.3.2 Channel Restrictions and Backwater Limitations

The release at Arrow Dam is influenced by its pool elevation and Kootenay River flow. At high Kootenay River flows and low Arrow pool elevation, Arrow's outlet capacity is limited. Releases from Albeni Falls are limited by Lake Pend Oreille's natural restriction upstream of the project. Releases from Corra Linn are limited by the Grohman Narrows restriction upstream of the project. Post Falls releases are limited due to a channel restriction downstream of Lake Coeur d'Alene. The model has specific rules to limit the outflow from the projects on existing rating curves.

4.3.3 Minimum Outflow Requirements

Many projects have specific minimum outflows that may exist for multiple reasons, including safety concerns, navigation goals, ecosystem goals, etc. Table 4-8 is a list of the minimum flow requirements for projects in the CRS Model.

Table 4-8. Minimum Outflows in the CRS Model

Project	Minimum Outflow (cfs)
Albeni Falls	4,000
Arrow	5,000
Bonneville	70,000
Brownlee	The minimum outflows are set as 6,500 cfs[1/] downstream of Hells Canyon (Johnson Bar) and at 13,000 cfs at Lime Point (confluence of Salmon and Snake Rivers).
Chelan	50
Corra Linn	5,000
Duncan	100
Dworshak	Minimum outflow is 1,600 cfs. In May to June, for high forecast years (April–July values above 2.4 Maf), minimum flow is 2,400 cfs, which is the minimum flow value used for FCRC calculations.
Grand Coulee	30,000; additional release to support Vernita Bar and chum flows and supporting minimum flows downstream of Bonneville Dam.
Hungry Horse	300 for local flooding, hydropower, and emergencies, plus minimum flow requirements for bull trout dependent on forecast (both downstream and at Columbia Falls, see Section 4.7.5).

Project	Minimum Outflow (cfs)
Libby	4,000 plus minimum flow requirements for bull trout dependent on forecast.
McNary	Minimum flow of 50,000 cfs from March to November, 12,500 cfs otherwise.
Post Falls	300 or inflow, whichever is less.
SKQ	Releases vary from 3,200 cfs from August to April to 12,700 cfs in May to July.

1/ While 5,000 cfs is listed in the Water Control Manual, 6,500 cfs was agreed to in a memo with Idaho Power with regards to navigation for the system operations model. A minimum flow of 5,000 cfs is allowed in emergencies.

More details on minimum flows releases from Grand Coulee Dam are included in the following sections.

4.3.3.1 Grand Coulee Minimum Flow

In the CRS Model, Grand Coulee is subjected to a minimum daily average flow of 30,000 cfs at times. This requirement can be increased due to several requirements.

As stated in the Priest Rapids FERC License (FERC 2008), Article 45, Priest Rapids needs to maintain a required 36,000 cfs minimum flow to provide cooling water for a downstream generating plant (to avoid impacts to the operation of the former Hanford Works of the Atomic Energy Commission). Since Priest Rapids is a run-of-river project, Grand Coulee assists Priest Rapids in meeting this requirement.

The Vernita Bar flow requirement includes a 36,000 cfs minimum release from May through November.

From December to May, the minimum release from Grand Coulee is equal to 68 percent of the maximum monthly Wanapum flow that occurred in October and November.

4.3.3.2 Grand Coulee Minimum Bonneville Flow

Per the Bonneville Dam Water Control Manual (Corps 2014), the minimum flows downstream of the dam vary depending on the previous week’s average inflow. If average inflows are greater than 125 kcfs, then minimum flow is 100 kcfs if river flow can support this, but no less than 80 kcfs (instantaneous). If inflows are less than 125 kcfs, the minimum flow is set at 80 percent of the previous weekly average flows, but no less than 70 kcfs (instantaneous). As Bonneville Dam is a run-of-river project, Grand Coulee assists Bonneville Dam in meeting this requirement, especially during periods of low flow.

4.3.4 Minimum Operating Pool

The four lower Snake River projects operate to a minimum operating pool range. Table 4-9 summarizes the ranges for the projects, as well as the elevation modeled in the CRS Model.

Table 4-9. Minimum Pool Levels

Project	Minimum Pool (feet NGVD29)
Lower Granite Dam	- Normal operating range 733.0 to 738.0 feet - 1-foot MOP range (733.0 to 734.0 feet) from April 3 to August 31 - Modeled elevation 733.5 feet April 3 to August 31
Little Goose Dam	- Normal operating range 633.0 to 638.0 feet - 1-foot MOP range (633.0 to -634.0 feet) from April 3 to August 31 - Modeled elevation 633.5 feet from April 3 to August 31
Lower Monumental Dam	- Normal operating range 537.0 to 540.0 feet - 1-foot MOP range (537.0 to 538.0 feet) from April 3 to August 31 - Modeled elevation 537.5 feet from April 3 to August 31
Ice Harbor Dam	- Normal operating range 437.0 to 440.0 feet - 1-foot MOP range (437.0 to 438.0 feet) from April 3 to August 31 - Modeled elevation 437.5 feet from April 3 to August 31

4.3.5 Maximum Release (Dworshak)

Dworshak operates for a maximum release of 25,000 cfs to minimize damages at the confluence with the Clearwater downstream. Additionally, operations limit the flow at the downstream location of Spalding to 105,000 cfs. In real-time operations, there is also a ramping rate for life-and-safety operations that is not modeled as it occurs on an hourly basis and has no restriction at the daily timestep.

4.3.6 Special Discharge Regulation Schedule (Libby)

During large floods, normal FRM operations may result in premature filling of Libby Reservoir. A special discharge regulation schedule defines discharge requirements to best use the remaining storage below full pool. The values are included in the Libby Water Control Manual as Plate 7-1 (Corps 2012). In the CRS Model, this discharge regulation schedule is implemented using a series of Emergency Spillway Release Diagram curves, which determine a minimum discharge from Libby based on the reservoir elevation and inflow.

4.3.7 Grand Coulee Maximum Draft Rate Limit

In order to minimize bank instability during draft, Grand Coulee follows the rules given in Table 4-10.

Table 4-10. Grand Coulee Modeling Assumptions for Maximum Draft Rate Limits

Pool Elevation (feet NGVD29 [NAVD88])	Maximum Draft Rate (feet/day)
1,260 to 1,290 (1,263.9 to 1,293.9)	1.5
1,240 to 1,260 (1,243.9 to 1,263.9)	1.3
Below 1,240 (below 1,243.9)	1.0

Note: Actual Maximum Draft Rate Limits are 1.5 feet per day at all elevations.

4.4 OPERATIONS RELATED TO REAL-TIME REGULATION AND BEST PRACTICES

4.4.1 Limit Spill/Final Fill at Libby, Hungry Horse, Dworshak

During the final days of refilling a reservoir, when elevations are close to full pool, best management practices dictate adjusting releases to limit spill, if possible. Limiting spill is important to help reduce TDG levels. Releases from the reservoirs (in particular, Libby, Hungry Horse, and Dworshak) are usually increased as the pools begin to approach their full levels. For Libby and Hungry Horse, minimum releases for this purpose are triggered when the reservoir reaches a certain percentage of draft (80 percent full in this case).

In the case of Libby reservoir, spilling is also avoided during draft season (i.e., from the beginning of water year to start of refill). Therefore, during this time, flows are limited to powerhouse capacity as called for in the VarQ Operating Procedure for Libby.

4.4.2 Smooth Operations Below Guide Curve

In real-time operations, projects attempt to follow their guide curves within the constraints of all other operational requirements. Transitions between operations are generally smooth, with flow changes from one day to the next within reasonable boundaries. The model contains logic to mimic the generally smooth changes found in real-time operations as a result of additional basin knowledge and short-term flow forecasts.

These operations are included in the model to complement the anticipatory draft operations at Libby, Hungry Horse, and Dworshak (Section 4.4.4)

4.4.3 Limit Decreasing Flows and Spring Flow Transition at Hungry Horse

In real-time operations at Hungry Horse, the reservoir is operated to avoid abrupt reductions in discharge as the operation is transitioning from minimum flow to VarQ flow. This is done in the model except during periods of high flow. Reservoir operators also generally attempt to smooth flows between April and May by increasing releases after April 10 using estimates of May VarQ flows. This type of operation may result in the reservoir being 5 to 10 feet below the April 30 flood control elevation. This operation shifts some of the flow from May into April, but the total discharge volume remains in the spring migration period.

The CRS Model limits decreasing flows by requiring a steady flow over a 5-day period prior to implementing a reduction in releases.

4.4.4 Anticipatory Draft (Libby, Dworshak, and Hungry Horse)

The purpose of the anticipatory draft at Libby, Dworshak, and Hungry Horse dams is to allow a more gradual draft from the end of one month to the next based on either forecast or guide curves. This is accomplished by anticipating the next month’s forecast (typically done by producing an early-bird forecast with preliminary values as inputs to the next month’s forecast) and beginning to draft at the rate required to meet the next month’s end-of-month target (and mid-month targets where applicable). This only applies during the last 10 days of the previous month. These operations are needed during winter and early spring months (November through April). This generally improves the operation when the forecast is rising—it avoids having to increase releases rapidly in the next month to support a deeper draft target. This operation may draw down the reservoir below the current month's FRM target, but it will not permit shallower drafts than the following month's FRM target. This also helps to reflect real-time operations that reduce the need for spill to meet FRM targets. Dworshak releases are allowed to go above powerhouse capacity (up to a TDG cap) if, within the short-term forecast window, the next month's drafts are anticipated to be high.

4.4.5 Full Pool Buffer at Hungry Horse

At Hungry Horse, the refill reservoir elevation is generally targeted to be within 1 foot from full at all times when the project is not actively controlling for FRM at Columbia Falls. The target storage is set to full pool volume when actively controlling for FRM at Columbia Falls. The computations involving projected inflows and the target reservoir elevation result in a minimum release being specified when the project approaches full pool.

4.4.6 October, November, and December Operations at Libby

In October, Libby generally targets a constant flow release of 4,600 cfs (unless full pool is exceeded, causing the release to be increased to match inflow). The reservoir elevation is also targeted to be at 2,435 feet NGVD29 (2,438.9 feet NAVD88) at the end of November and at its URC elevation at the end of December. Minimum flows are specified to comply with these requirements.

4.5 POWER OPERATIONS

The Columbia River Basin is managed for multiple purposes, including hydropower. Limited modeling related to hydropower is performed with the CRS Model. The main model used for hydropower studies is Bonneville's HYDSIM model. HYDSIM is a hydroregulation model that simulates the month-to-month operation of the Pacific Northwest Hydropower System. The HYDSIM model for the Columbia River Basin is discussed in the Hydroregulation Appendix (Appendix I).

4.6 CANADIAN OPERATIONS NOT FOR POWER OR FLOOD RISK MANAGEMENT

In addition to operations at Canadian reservoirs for FRM and hydropower, the final operations at Canadian projects are influenced by a number of agreements. Two of these, the Non-Power Uses Agreement (NPUA) and the Non-Treaty Storage Agreement (NTSA), provide for water stored at Canadian dams to be released for ecosystem purposes. These operations are briefly described below.

4.6.1 Non-Power Uses Agreement

Since 1984, the annual Detailed Operating Plan has provided for supplemental operating agreements within each operating year as opportunities arise for mutual benefits. The NPUA is typically established annually by the U.S. and Canadian Entities. Under this agreement, a change in operations of the Canadian projects provides ecological benefits for both the United States and Canada. Since the agreement is made for the operating year (August to July), the water account from these operations must return to zero by July 31. There are three main components to the NPUA:

- Flow augmentation
- Mountain whitefish (*Prosopium williamsoni*) support
- Rainbow trout (*Oncorhynchus mykiss*) support

The flow augmentation water gets stored in the winter (typically from December to March) and released in the spring and summer to support salmon outmigration. Typically, 1 Maf is set to be stored in Mica reservoir by mid-April and released May through July. There are also options to store the water at Arrow if water is stored in December and not released in February or March. The shaped outflow releases from Arrow Reservoir support the protection of mountain whitefish in winter and rainbow trout in the spring.

4.6.2 Non-Treaty Storage

The NTSA is a water regulation agreement between BC Hydro and Bonneville that governs the use of 5 Maf of Kinbasket Reservoir storage not already covered by the CRT. NTSA operations impact discharges from the Kinbasket, Revelstoke, and Arrow Reservoirs as well as downstream U.S. hydroelectric projects. (Kinbasket Reservoir is the name of the reservoir behind Mica Dam.)

The most recent NTSA was signed in April 2012 and will expire in September 2024. As the NTSA is an enabling agreement, neither party is obligated to manage to a strict set of rules, but rather maintains the flexibility to use the additional storage to meet their power and nonpower management objectives. Most aspects of the NTSA are driven by economics (power prices), and so are not implemented in the CRS Model. However, the one aspect of the NTSA that is not directly tied to economics is the dry year release strategy, which provides 0.5 Maf in the lowest 20th percentile of water years. This aspect of the NTSA is implemented in the CRS Model. The 20th percentile is defined as a seasonal water supply of at 72.5 Maf at The Dalles based on the 2010 Level Modified Streamflows dataset.

4.7 U.S. ECOSYSTEM OPERATIONS

Ecosystem or water quality–related operations include:

- Variable draft limits (VDLs)
- TDG considerations

- Hanford Reach Agreement (Vernita Bar) operations
- Chum (*Oncorhynchus keta*) elevations objectives
- Priest Rapids and McNary flow objectives
- Juvenile spill flows
- MOP

The timing of multiple operations at the main CRSO storage projects is shown in Figure 4-3.

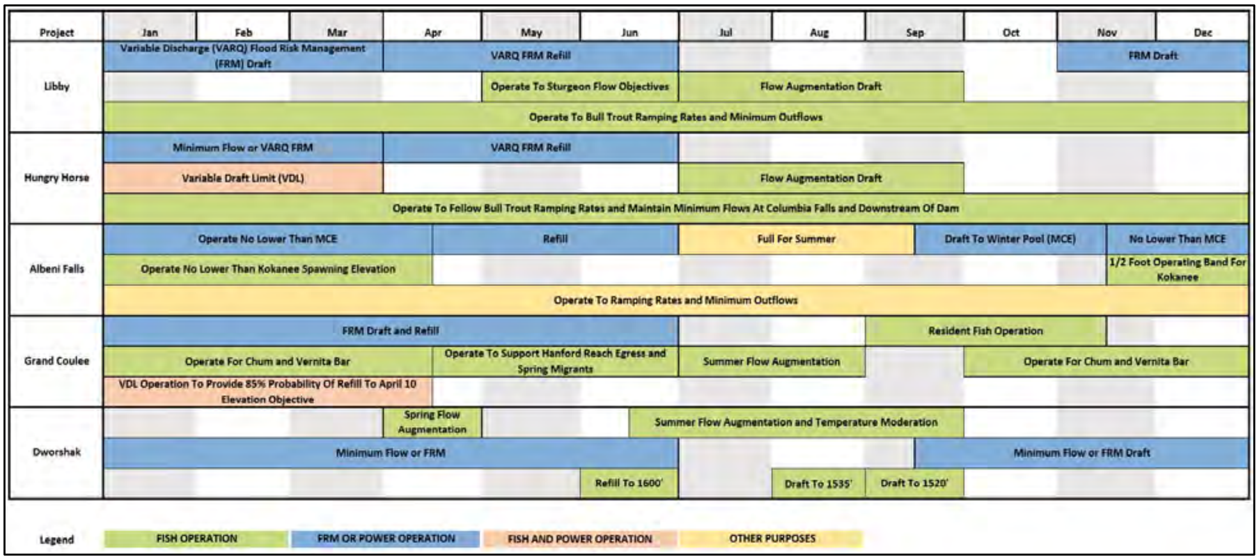


Figure 4-3. Seasonal Operations at Major Columbia River System Storage Dams

4.7.1 Vernita Bar Minimum Flow

In 2004, the mid-Columbia public utility districts, Bonneville, National Oceanic and Atmospheric Administration, Washington Department of Fish and Wildlife, and the Confederated Tribes of the Colville Reservation signed the Hanford Reach Fall Chinook Protection Program Agreement. The purpose of this agreement is the protection of fall Chinook salmon in the Hanford Reach of the Columbia River by providing minimum flows to meet biological objectives. Project operations specified in the Hanford Reach Fall Chinook Protection Program Agreement cover the spawning, pre-hatch, post-hatch, emergence, and rearing periods. In the CRS Model, Vernita Bar operations are modeled as release requirements from Grand Coulee as follows:

- From June to November, the minimum release is 36,000 cfs.
- From December to May, 68 percent of the October to November Wanapum maximum flow is compared to 70,000 cfs. The lower of those two values is set to the minimum flow subject to the minimum flow being at least 50,000 cfs.

The Wanapum minimum flow is estimated using a maximum of the monthly average flow of October or November and rounded to the nearest 5,000 cfs value. Releases are computed so that Grand Coulee pool elevation does not drop below the minimum VDL requirements and minimum pool.

4.7.2 Variable Draft Limits at Grand Coulee and Hungry Horse

VDLs are period-by-period draft limits at Grand Coulee and Hungry Horse from January through March. These are planned limits to Firm Energy Load Carrying Capability generation to protect the ability to refill Grand Coulee and Hungry Horse to their April 10 elevation objectives with an 85 percent and 75 percent confidence, respectively. While VDLs are calculated at both Grand Coulee and Hungry Horse, the pool elevation at Hungry Horse is typically drafted well below these limits to meet the minimum flow at Columbia Falls.

The VDLs are based on the April 10 elevation objective, which is calculated from the forecasted FRM elevations and statistical inflow volumes at Grand Coulee and Hungry Horse. The final official April 10 elevation objective is based on the URC’s computed using the Water Supply Forecast issued in March.

In general, the purpose of the VDLs are prescribed power flexibility in the form of lower limits for secondary energy power generation. The VDLs limit winter drafts to ensure adequate water for spring and summer flows. As such, the VDL is not an objective elevation but a limit to power flexibility.

The VDLs for Grand Coulee are computed on January 1, February 1, and March 1 as follows:

$$VDL_{Volume} = April\ 10_{Volume} - (Inflow - Outflow)$$

$$VDL_{Volume} = April\ 10_{Volume} - 85\%\ Inflow + PRD_{Objective} - GCL/PRD_{Incremental}$$

Where:

April 10$_{Volume}$ is the content at April 10 elevation based on the forecast

85% Inflow is the 85% probable inflow volume at Grand Coulee adjusted for Banks Lake pumping

PRD$_{Objective}$ is the volume to meet Priest Rapids flow objectives

GCL/PRD$_{Incremental}$ is the incremental flow volume between Grand Coulee and Priest Rapids dams

The absolute minimum VDLs are in Table 4-11.

Table 4-11. Grand Coulee Minimum Variable Draft Limits

Month	Minimum VDL (feet NGVD29 [NAVD88])
January	1,260 (1,263.9)
February	1,250 (1,253.9)
March	1,240 (1,243.9)

4.7.3 Chum Spawning and Incubation

Operations in support of chum spawning and incubation below Bonneville Dam are included in the CRS Model. The modeled operations cannot replicate the actual process used in real time operations, where the Technical Management Team[9] process is used to determine operations. Instead, the CRS Model uses a reasonable empirical approach for the chum operation.

Because Bonneville Dam is a run-of-river project with minimal storage capacity, Grand Coulee Dam drafts to support this operation within the constraints of the VDL. However, the reservoir's water surface elevation is allowed to reach as much as 10 feet below VDL as long as it does not go below the minimum VDL, which varies each month. The tailwater elevation below Bonneville Dam depends not only on the discharge from Bonneville Dam, but also discharge from the Willamette River.

An empirical equation relates the desired chum flow to maintain a set Bonneville Dam tailwater elevation and the Willamette flow at Salem:

$$Flow_{chum} = 38.83 + 2.23TW_{Bon}{}^{1.5} - 0.32Flow_{WillSalem}$$

Where:

$Flow_{chum}$ is the Bonneville outflow needed

TW_{Bon} is the desired tailwater elevation downstream of Bonneville Dam

$Flow_{WillSalem}$ is the Willamette River flow at Salem

Given a desired tailwater elevation and the predicted Willamette flow in Salem, it is possible to determine the target flow from Bonneville Dam.

4.7.4 Rate of Release Change (Libby and Hungry Horse)

Changes in the rate of release for Libby and Hungry Horse are constrained in the CRS Model. Maximum daily ramping rates used in the CRS Model for Libby are specified in Table 4-12. Maximum daily ramping rates used in the CRS Model for Hungry Horse are specified in Table 4-13. The ramping rates can be overridden by higher priority rules such as FRM and to avoid overfilling the reservoir.

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[9] The Technical Management Team is an inter-agency technical group responsible for making recommendations on dam and reservoir operations.

Table 4-12. Libby Ramping Rates

Flow Range (cfs)	Summer (May 1–September 30)		Winter (October 1–April 30)	
	Daily Maximum Ramp-up Rate (cfs/day)	Daily Maximum Ramp-down Rate (cfs/day)	Daily Maximum Ramp-up Rate (cfs/day)	Daily Maximum Ramp-down Rate (cfs/day)
4,000–6,000	5,000	500	5,000	1,000
6,000–9,000	5,000	1,000	5,000	2,500
9,000–16,000	10,000	2,000	10,000	5,000
>16,000	10,000	5,000	10,000	5,000

Source: U.S. Fish and Wildlife Service (USFWS) (2006)

Table 4-13. Hungry Horse Ramping Rates

Flow at Columbia Falls (cfs)	Daily Maximum Ramp-up Rate (cfs/day)	Daily Maximum Ramp-down Rate (cfs/day)
3,200–6,000	1,800	600
6,000–8,000	1,800	1,000
8,000–10,000	3,600	2,000
10,000–12,000	No limit	2,000
>12,000	No limit	5,000

Source: USFWS (2006)

4.7.5 Bull Trout

Minimum flow requirements for bull trout (*Salvelinus confluentus*) at Libby and Hungry Horse are incorporated in the CRS Model. The minimum release for bull trout at Libby is 6,000 cfs from May 15 through September 30. In addition, limits for days between July 1 (or completion of sturgeon pulse) and August 31 are shown in Table 4-14.

Table 4-14. Summer Minimum Flows for Bull Trout at Libby

May April-August Forecast at Libby (Maf)	Minimum Release for Bull Trout (cfs)
< 4.8	6,000
< 6.0	7,000
< 6.7	8,000
> 6.7	9,000

Minimum flows at Hungry Horse and Columbia Falls are dependent on the forecast. Releases are determined based on a minimum flow of 3,200 to 3,500 cfs at Columbia Falls and 400 to 900 cfs in the South Fork Flathead River (normal minimum flows from the Water Control Manual). The flows are shown in Table 4-15. The flows used are interpolated for forecasted values falling between the values shown in the table.

Table 4-15. Summer Minimum Flows for Bull Trout at Hungry Horse

April-to-August Forecast (kaf)	Minimum release (cfs)	Minimum flow at Columbia Falls (cfs)
≤ 1,190	400	3,200
≥ 1,790	900	3,500

4.7.6 Sturgeon (Libby Dam)

As called for in the 2006 USFWS BiOp (USFWS 2006), certain augmentation volumes are provided from Libby Dam to facilitate Kootenai River white sturgeon spawning and recruitment during the spring. The augmentation volumes should be met between May and July of each year. The volume of augmentation water varies based on the April through August forecast that is developed in May, as shown in Table 4-16. The volumes used are interpolated for forecasted values falling between the values shown in the table.

Table 4-16. Sturgeon Augmentation Volumes at Libby

April-to-August Forecast (Maf) developed in May	Sturgeon Volume (Maf)
0.0	0.00
≤ 4.8	0.00
4.8	0.80
5.4	0.80
6.4	1.12
6.9	1.20
8.5	1.20
≥ 8.9	1.60

Operations at Libby in the CRS Model are defined so that releases meet the augmentation volumes for the season. Operations vary based on the forecast, antecedent flow, powerhouse capacity, and summer flow. The target elevation for Libby Reservoir at the end of July is 5 feet from full (2,454 feet NGVD29; 2,457.9 feet NAVD88).

4.7.7 Summer Draft

4.7.7.1 Grand Coulee and Hungry Horse

The 2008/2014/2019 National Oceanic and Atmospheric Administration BiOp designates the summer migration period in the Columbia River at McNary Dam as July 1 through August 31. During this period, the minimum flow objective at McNary Dam is 200,000 cfs.

Reclamation designates Grand Coulee Dam and Hungry Horse Dam as projects that contribute to the Federal Columbia River Power System goal of using available storage to increase the probability of meeting a summer flow objective at McNary of 200,000 cfs in the months of July and August (Corps, Bonneville, and Reclamation 2015).

The following goals are applied to Grand Coulee:

- Draft to support salmon flow objectives during July and August with summer draft limit of 1,278 feet NGVD29 (1,281.9 feet NAVD88) to 1,280 feet NGVD29 (1,283.9 feet NAVD88) by August 31 based on the water supply forecast. For a forecast at The Dalles equal to or greater than 92 Maf, the draft limit is 1,280 feet NGVD29 (1,283.9 feet NAVD88). For a forecast at The Dalles less than 92 Maf, the draft limit is 1,278 feet NGVD29 (1,281.9 feet NAVD88). The lower water years benefit more from higher flow augmentation.
- Reduce pumping into Banks Lake and allow Banks Lake to operate up to 5 feet from full pool (full pool is elevation 1,570 feet) during August to help meet salmon flow objectives when needed. This operation is not modeled in HEC-ResSim since it would have a fairly minor effect on total project outflow.

The Columbia River Water Management Plan criteria—also known as the Lake Roosevelt Incremental Storage Release Project—reduces the target elevations by 1.0 foot in non-drought years (forecast greater than 60 Maf) and by 1.8 feet in drought years (forecast less than or equal to 60 Maf).

After summer flow augmentation, Lake Roosevelt is filled for resident fish purposes and to prepare for winter operations. In September, the minimum elevation at the end of the month for Grand Coulee is 1,283 feet NGVD29 (1,286.9 feet NAVD88). However, operational flexibility exists during the period, so the elevation target varies depending on a relationship that was derived using The Dalles TSR flow and unregulated flow.

The following goals are applied to Hungry Horse:

- Draft during July through September to a draft limit of 3,550 feet NGVD29 (3,553.9 feet NAVD88) (10 feet from full) by September 30, except in the driest 20th percentile of water conditions, limit draft to 3,540 feet NGVD29 (3,543.9 feet NAVD88) (20 feet from full) when needed to meet lower Columbia River flow augmentation objectives. If project fails to refill 20 feet from full, release inflows or operate to meet minimum flows through the summer months.
- Provide even or gradually declining flows during summer months.

4.7.7.2 Libby

During the months of July through September, Libby Dam is operated to augment flows for juvenile salmon outmigration in the Columbia River and to help meet local resident fish needs. The drafting of Libby Dam is as follows:

- Draft to 10 feet from full (2,449 feet NGVD29; 2,452.9 feet NAVD88) by the end of September, unless in the lowest 20th percentile water years (equal to a The Dalles May April-to-August forecast value of 71.8 Maf), then draft to 20 feet from full (2,439 feet NGVD29; 2,442.9 feet NAVD88) by the end of September.

- Target 2.5 feet above the end of September values by the end of August.
- If the project fails to refill, then release inflow or operate to meet minimum bull trout flows through the summer months.

4.7.7.3 Dworshak

Summer flow augmentation is provided from Dworshak to moderate river temperatures (improved water quality) and increasing water velocities in the lower Snake River. In real time reservoir operations, the summer temperature moderation and flow augmentation releases from Dworshak are shaped with the intent to maintain water temperatures at the Lower Granite tailrace fixed monitoring site at or below 68°F (20°C). As the CRS Model lacks the required meteorological inputs, this operation is modeled as a set of mid-season draft targets, producing flows that are generally in the range of those created by the summer flow augmentation.

The determination of the starting date for summer draft is as follows:

- Start summer draft if the date is between June 16 and June 30, Lower Granite flow is less than 30 kcfs, and the Dworshak pool has filled (full pool elevation is 1,600 feet NGVD29 [1,603.3 feet NAVD88]).
- Start summer draft between July 1 and July 10 when Lower Granite flow is less than 55 kcfs.
- Start summer draft no later than July 10.

At Dworshak in July, flows are allowed to be above powerhouse capacity but below the TDG cap. Also, flows are not allowed to increase to meet a target on a specific date but are allowed to meet that target shortly after the target date. Dworshak has a planned draft to elevation 1,535 feet NGVD29 (1,538.3 feet NAVD88) by the end of August and elevation 1,520 feet NGVD29 (1,523.3 feet NAVD88) by the end of September.

4.7.7.4 Brownlee

Operations at Brownlee reflect guidance in the FERC license, FRM, and fall Chinook salmon spawning flow. Summer flow augmentation is applied by targeting 2,059 feet NGVD29 (2,062.3 feet NAVD88) by August 7. Refill is targeted by June 30.

4.7.8 Flow Objectives

Flow objectives are intended to benefit salmon and steelhead migration on both the Snake River and the lower Columbia River. For Snake River salmon and steelhead, the seasonal average flow objectives (measured at Lower Granite) vary according to water volume forecasts and are as follows:

- 85 to 100 kcfs from April 3 to June 20
- 50 to 55 kcfs from June 21 to August 31

For the lower Columbia River, the seasonal flow objectives (measured at McNary) vary according to water volume forecasts and are as follows:

- 220 to 260 kcfs from April 10 to June 30
- 200 kcfs from July 1 to August 31

The flow objective at Lower Granite is supported by Dworshak, while the flow objective at McNary is supported by Grand Coulee and Dworshak. In reality, these objectives are managed on a weekly basis and are sometimes unachievable due to limited storage capability in the Columbia and Snake River systems. Meeting spring flow objectives becomes an issue in the lower water years when month-to-month reservoir operations coordination is essential. In addition, management of flow augmentation is also conditioned on deference to refill by June 30, subject to in-season considerations.

The Lower Granite and McNary flow objectives are not explicitly modeled in the CRS Model. The only objective explicitly modeled is the seasonal flow objective below Priest Rapids Dam from April 10 to May 15, which varies month to month.

4.7.9 Kokanee Spawning

To facilitate the spawning of Kokanee, Lake Pend Oreille is drafted to elevation 2,051.5 feet NGVD29 (2,055.4 feet NAVD88) by approximately mid-November and held through the end of spawning in late December. The lake is then operated between elevations 2,051 feet NGVD29 (2,054.9 feet NAVD88) and 2,056 feet NGVD29 (2,059.9 feet NAVD88). Section 7.04 in the 2000 Water Control Manual for Albeni Falls Dam contains guidance on the operation for Kokanee (Corps 2000b).

The modeling approach taken for Kokanee spawning is to set target pool levels using a rule curve.

4.7.10 Control for Total Dissolved Gas During Draft Season

Elevated TDG levels can be harmful to fish and other aquatic species. In addition to managing TDG levels during the fish passage season, special consideration is given to controlling TDG during the draft season at the headwater projects of Libby, Dworshak, and Hungry Horse. In general, the objective is to meet FRM targets at these storage projects without exceeding TDG limits, which can generally tolerate only small amounts of spill from these high-head dams. As the TDG is a function of atmospheric and in-river conditions, the flow at which the limit is exceeded is estimated in the CRS Model by a fixed value for a given reservoir outlet configuration. For Dworshak, the TDG limit is estimated as a function of flow.

4.7.11 Brownlee Spawning Flows

The flow requirements from Brownlee during the October through June time period are meant to benefit the fall Chinook salmon by providing stable flows during the spawning period and maintaining a minimum flow during incubation to prevent dewatering of redds.

The constant flows from October 10 to December 10 are determined to target a December 10 target elevation of 2,072 feet NGVD29 (2,075.3 feet NAVD88). This target is also considered operationally full for servicing winter load, which provides 5 feet of space below full pool to manage unexpected high winter inflows. End-of-month targets are developed for December, January, and February based on the minimum of the FERC license points, which are developed to address the component of the license application that deals with enhancement of environmental resources, and the URC.

4.8 OTHER OPERATIONS

4.8.1 Minimum Irrigation Pool at John Day

John Day does not go below the irrigation pool level between March 15 and November 15. The minimum irrigation pool is defined as 262.5 feet NGVD29 (265.7 feet NAVD88). During this time period, the maximum operating pool elevation is defined as 264 feet NGVD29 (267.2 feet NAVD88), defining an operating band of 1.5 feet.

4.8.2 Grand Coulee Drum Gate Maintenance

Drum gate maintenance at Grand Coulee is planned to occur during April and May annually and typically occurring between March 15 and May 15. The reservoir must be at or below elevation 1,255 feet NGVD29 (1,258.9 feet NAVD88) to accomplish this work, with an operating range typically between 1,250 feet NGVD29 (1,253.9 feet NAVD88) and 1,255 feet NGVD29 (1,258.9 feet NAVD88) during this time. Typically, the FRM elevations during this time of year provide the required elevations and sufficient time to accomplish this work. However, during dry years FRM operations will not draft Lake Roosevelt low enough for a long enough period of time to perform necessary maintenance on the drum gates. Drum gate maintenance may be deferred in some dry water years; however, drum gate maintenance must occur at a minimum one time in a 3-year period, two times in a 5-year period, and three times in a 7-year period. More details are available in the Water Management Plan (Corps, Bonneville, and Reclamation 2015). The drum gates are extremely important dam safety features and must be maintained at a satisfactory level.

In the CRS Model, drum gate maintenance is abandoned in the modeled operation and the pool allowed to rise above the maximum pool required for maintenance if needed to control downstream flow at The Dalles below 450,000 cfs. Historically, the drum gate maintenance has not had to be abandoned and peaks were managed using the available space. If the Drum Gate Maintenance operation is abandoned, it does not meet the criteria of a completed year.

In the CRS model, a “forced” drum gate maintenance year is one in which maintenance must occur to meet the 1 in 3, 2 in 5, and 3 in 7 requirements. A year is “forced” regardless of the value of the April 30 URC. Forced drum gate maintenance is modeled in the CRS Model.

4.8.3 John W. Keys III Pump-Generating Plant Pumping from Lake Roosevelt to Banks Lake

Most of the Columbia Basin Project is supplied with irrigation water based on the net pumping diversions at Grand Coulee. Irrigation water is pumped from Franklin D. Roosevelt Lake by the John W. Keys III Pump-Generating Plant. This plant has a total of 12 pumping units with 6 of these units having the ability to be reversed to produce hydropower. Columbia Basin Project Pumping (Banks Lake) data is submitted annually to the Pacific Northwest Coordination Agreement parties. Estimates of pumping are based on the Lake Roosevelt’s right to store water for irrigation and power. These estimates include the equivalent of 5 feet (65.5 thousand second-foot-days) of flow augmentation that occurs in August to support the 200 kcfs flow target at McNary along with the associated increase in pumping to return that 5 feet to Banks Lake. In the model, the pumping rate is not limited by the physical capacity of the pumps due to increased head that may occur when Grand Coulee’s draft is increased. The withdrawal is modeled as a ResSim diversion and leaves the system. Some returns are included in the input hydrology set downstream.

CHAPTER 5 - UPPER SNAKE AND YAKIMA RIVERS

The Yakima River Basin and the upper Snake River Basin are two of the larger tributaries of the Columbia River. Although they are out of scope for the CRSO effort, daily input from each of these basins is needed as input to the CRSO system model. Because these systems have a large irrigation component that drives summer reservoir operations, Reclamation traditionally simulates these basins. At the time of the CRSO modeling effort, Reclamation had developed only monthly models of these basins. So, the Corps developed two HEC-ResSim models to provide the needed data for this study.

The Corps developed a HEC-ResSim model of the Yakima River System to generate regulated outflow at the mouth, which is used as local inflow to the mainstem of the Columbia River. This model approximates current operations within the Yakima River System.

The Corps also developed a HEC-ResSim model of the upper Snake River Basin above the Brownlee project. This model was used to generate daily flows that were then adjusted using the monthly flows provided by Reclamation from the 2010 Level Modified Streamflows Study (Modified Flows). The Corps developed a hybrid model that would generate a daily timeseries using reservoir storage and flow targets from the Modified Flows datasets throughout the basin, except when FRM operations were active. The daily output at Brownlee was further scaled to ensure the monthly flow volumes match those in the Modified Flows dataset at that location. The values at the end and beginning of the month were smoothed to reduce large month-to-month changes in flow introduced by the monthly scaling.

Both datasets were used as input to the CRSO system model. The same input was used for all of the study alternatives.

CHAPTER 6 - VERTICAL DATUM SHIFT

Table 6-1 shows the datum adjustment from NGVD29 to NAVD88 for all dams and CCPs within the model. Datum conversion values were calculated using Corpscon6 (a coordinate conversion software developed by the Corps). The latitude and longitude of the point to be converted (e.g., top of dam) was obtained from the project's background information. If this information was not available, the midpoint of the dam was estimated using ArcGIS and aerial photography, and latitude and longitude values were extracted for use in Corpscon.

Table 6-1. Vertical Datum Adjustment

Dam or CCP Name	Datum Adjustment (feet)
Albeni Falls	3.9
American Falls	3.3
Anderson Ranch	3.4
Arrow	4.3
Arrowrock	3.4
Bonneville	3.3
Boundary	4.0
Box Canyon	4.0
Brilliant	4.2
Brownlee	3.3
Bumping Lake	3.9
Cabinet Gorge	3.9
Cascade	3.6
Chelan	3.9
Chief Joseph Dam	4.0
Cle Elum	3.9
Corra Linn	4.3
Deadwood	4.0
Duncan	4.3
Dworshak	3.3
Grand Coulee	3.9
Hells Canyon	3.6
Hungry Horse	3.9
Ice Harbor	3.4
Jackson Lake	4.3
John Day	3.2
Kachess	3.9
Keechelus	4.0
Kootenay Canal Projects	4.2
Libby	3.9
Little Falls	3.8
Little Goose	3.2
Long Lake Dam/Lake Spokane	3.8

Dam or CCP Name	Datum Adjustment (feet)
Lower Bonnington	4.2
Lower Granite	3.4
Lower Monumental	3.3
Lucky Peak	3.3
McNary	3.3
Mica	4.7
Monroe Street	3.8
Nine Mile	3.8
Noxon Rapids	3.9
Owyhee	3.3
Oxbow	3.4
Palisades	4.0
Pelton	3.6
Pelton ReReg	3.5
Post Falls – Lake Cœur d’Alene	3.8
Priest Lake	4.0
Priest Rapids	3.5
Revelstoke	4.5
Rock Island	3.7
Rocky Reach	3.8
Round Butte	3.6
Seven Mile	4.1
SKQ	3.6
Slocan	4.2
The Dalles	3.3
Thompson Falls	3.8
Tieton	3.8
Upper Bonnington	4.2
Upper Falls	3.8
Wanapum	3.5
Waneta	4.0
Wells	4.0

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CHAPTER 7 - REFERENCES

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ANNEX A

HEC-RESSIM Reservoir Operations Implementation of Alternatives

ANNEX A - HEC-RESSIM RESERVOIR OPERATIONS IMPLEMENTATION OF ALTERNATIVES

This annex contains the Multiple Objective Alternative (MO) modeling sheets for MO1, MO2, MO3, and MO4, as well as the Preferred Alternative. The sheets have been directly translated into this annex. Therefore, callouts to tables and figures are not made in the text of this annex.

COLUMBIA RIVER SYSTEM OPERATIONS MULTIPLE OBJECTIVE ALTERNATIVE 1 MODELING SHEET

Multiple Objective Alternative 1 Modeling Summary

Name:	MO1
CRSO Projects	Modified U.S. operations at multiple reservoirs
Flood Risk	Changes were made to the Grand Coulee and Libby upper rule curves (URCs) for flood risk management. Additionally, winter flood space was included at Grand Coulee. The changes in rule curves were designed with an intent to maintain the current level of flood risk.
Power	Some modifications to generation practices that were designed to increase hydropower generation efficiency.
Biological and Water Supply Objectives	Fully meet existing water supply obligations and provide for authorized additional regional water supply. Improve adult, juvenile, and resident fish migration, passage, rearing, and/or survival. Reduce greenhouse gas emissions in the Pacific Northwest.
Modeling System Configuration	Same as the No Action Alternative
Canadian Treaty Projects	Same as the No Action Alternative
Hydrologic Data Sets Used for Monte Carlo Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Deterministic Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Monte Carlo Evaluation	Same as the No Action Alternative

Note: CRSO = Columbia River System Operations; MO1 = Multiple Objective Alternative 1.

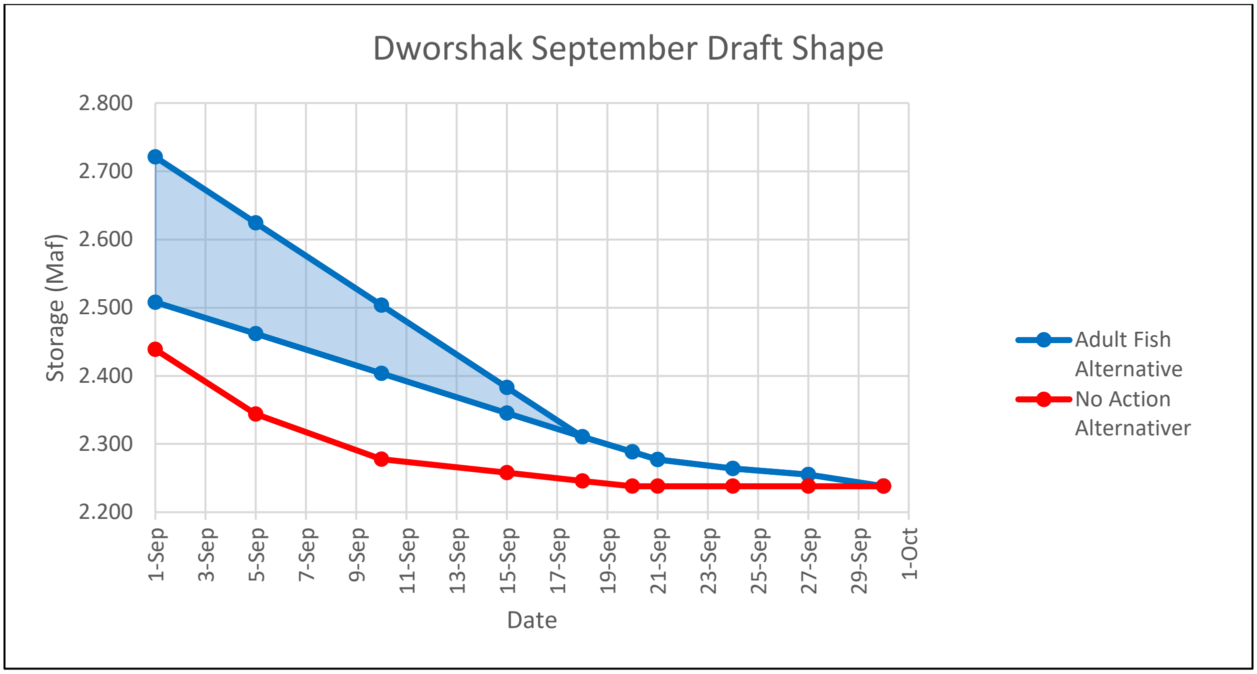
ResSim Assumptions (General)

- Fully incorporate all Adult Fish operations. A modification was applied to the end-of-August operations, where the attempt to stay at 3 thousand cubic feet per second (kcfs) through August was eliminated. Instead, end-of-August minimum elevations are met as often as possible.
- Fully incorporate all Water Supply operations.
- Fully incorporate all Water Management Flexibility.
- John Day change for Avian Predators described.
- Same modeling framework and operations as No Action Alternative everywhere else.
- Note: all elevations are in National Geodetic Vertical Datum of 1929 (NGVD29)

Dworshak Dam

- Begin summer draft sooner, on June 21 (instead of No Action's July 1). Delay draft until within one-half foot of full, or until July 5 (instead of No Action's July 10).
- Total dissolved gas (TDG) maximum, as referred to in this section regarding Dworshak, is based on an empirical equation from the Columbia Basin Research study of 1998. The maximum release varies based on maximum powerhouse capacity and percentage of spill, both which are dependent on current head at the project from the forebay water surface elevation.
- Once summer draft begins the project will target a release of full powerhouse to maximize cooling water until August 1.
    - Large water years: prior to August 1, releases are set to target 1,550 feet NGVD29 on August 1. Releases will be capped at the TDG maximum unless higher releases are needed to control overfilling.
    - Regular water years: prior to August 1, releases are set to target 1,555 feet NGVD29 on August 1. Releases will be capped at the TDG maximum unless higher releases are needed to control overfilling.
    - Large water years are defined as years with an April through July, April forecast greater than the 80th percentile.
- August 31 target draft elevation is a variable target with the intention of conserving water for the September draft: the maximum end-of-month target is 1,555 feet NGVD29 and minimum end-of-month target is 1,540 feet NGVD29. Releases are set to target the maximum target of 1,555 feet to save as much spare water as possible.
- September draft shape varies in the first half of the month based on the amount of carryover from the month August. The starting elevation for September 1 ranges from 1,540 feet to 1,555 feet and regardless of the starting elevation, all releases are set to target a draft elevation of 1,525.5 feet by September 18. From September 18 to the end of the

month, the draft shape is the same, regardless of the starting elevation at the first of the month, to taper releases to a target elevation of 1,520.0 feet by September 30. All releases in the month of September are limited to the TDG maximum. Water is released in larger amounts earlier in the month, as they have more value in the earlier part of the season. The tapering of releases in the second half the month are to conduct a transition of flow in the river back to a more natural regime as the reservoir goes to minimum discharge of 1.6 kcsf in the month of October. Shaping was done in units of storage volume (acre-feet), not draft elevation (feet), to better show the variable amount of water that is potentially carried over from September. Draft target elevations are shown in the table after the plot.



Note: Maf = million acre-feet.

September Draft Storage Target Tables

No Action Alternative		
Day of Month (September)	**Target Elevation (ft, NGVD29)**	**Target Storage (Maf)**
0	1,535.00	2.439
5	1,528.00	2.344
10	1,523.00	2.278
15	1,521.50	2.258
20	1,520.00	2.238
30	1,520.00	2.238

Adult Fish Alternative		
Day of Month (September)	**Target Elevation (ft, NGVD29)**	**Target Storage (Maf)**
0	Varies (1,540–1,555)	2.508–2.721
18	1,525.50	2.311
21	1,523.50	2.284
24	1,522.00	2.264
27	1,521.25	2.255
30	1,520.00	2.238

Hungry Horse Dam

September draft targets were updated to values that are interpolated from Hungry Horse forecasts.

Hungry Horse Forecast (Maf)	September Elevation Target (ft)
1.407	3,540
1.579	3,550

- In years where the flow augmentation draft is 10 feet, the end-of-September elevation is lowered by 4 feet. In years where the flow augmentation draft is 20 feet, the end-of-September elevation draft is lowered by 4.2 feet.
- The Columbia Falls minimum flows are increased by 493 cfs in July, August, and September to meet the water supply measure of delivering an additional 90 kaf at Hungry Horse Dam (Hungry Horse Additional Water Supply measure).
- All other operations are the same as the No Action Alternative.

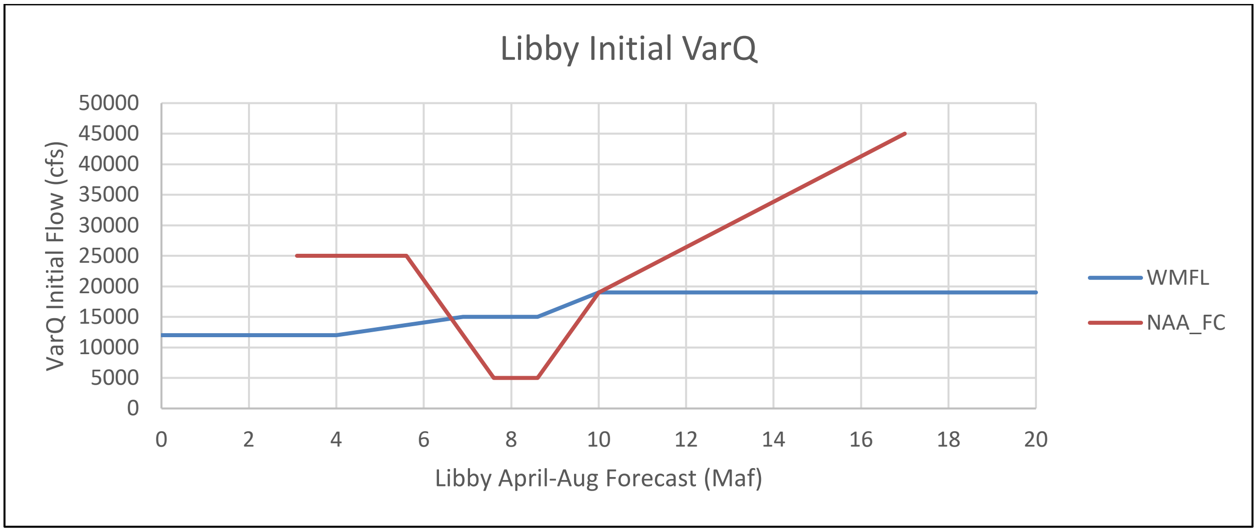
Libby Dam

September draft targets were updated to values that are interpolated from Libby forecasts. August targets are 2.5 feet higher than the interpolated values.

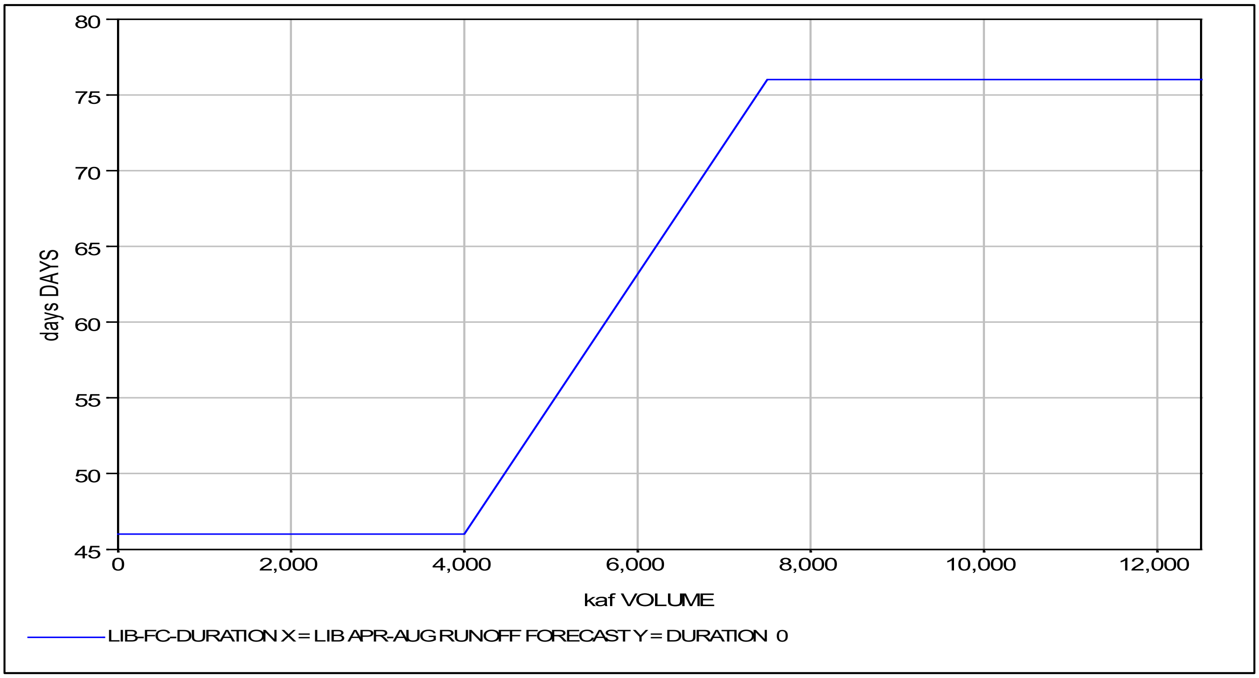
Libby Forecast (Maf)	September Elevation Target (ft)
4.66	2,439
5.01	2,449
6.78	2,449
7.33	2,454

- Modify Storage Reservation Diagram (SRD) and refill approach to operate for local interest in medium to low (<6.9 Maf Libby April to August forecast) water years. Eliminate variable end-of-December draft targets, replaced with fixed target at 2,420 feet.
- Modify refill procedures to improve chances of refill by accounting for future planned releases in variable discharge storage regulation procedure (VarQ) calculations.

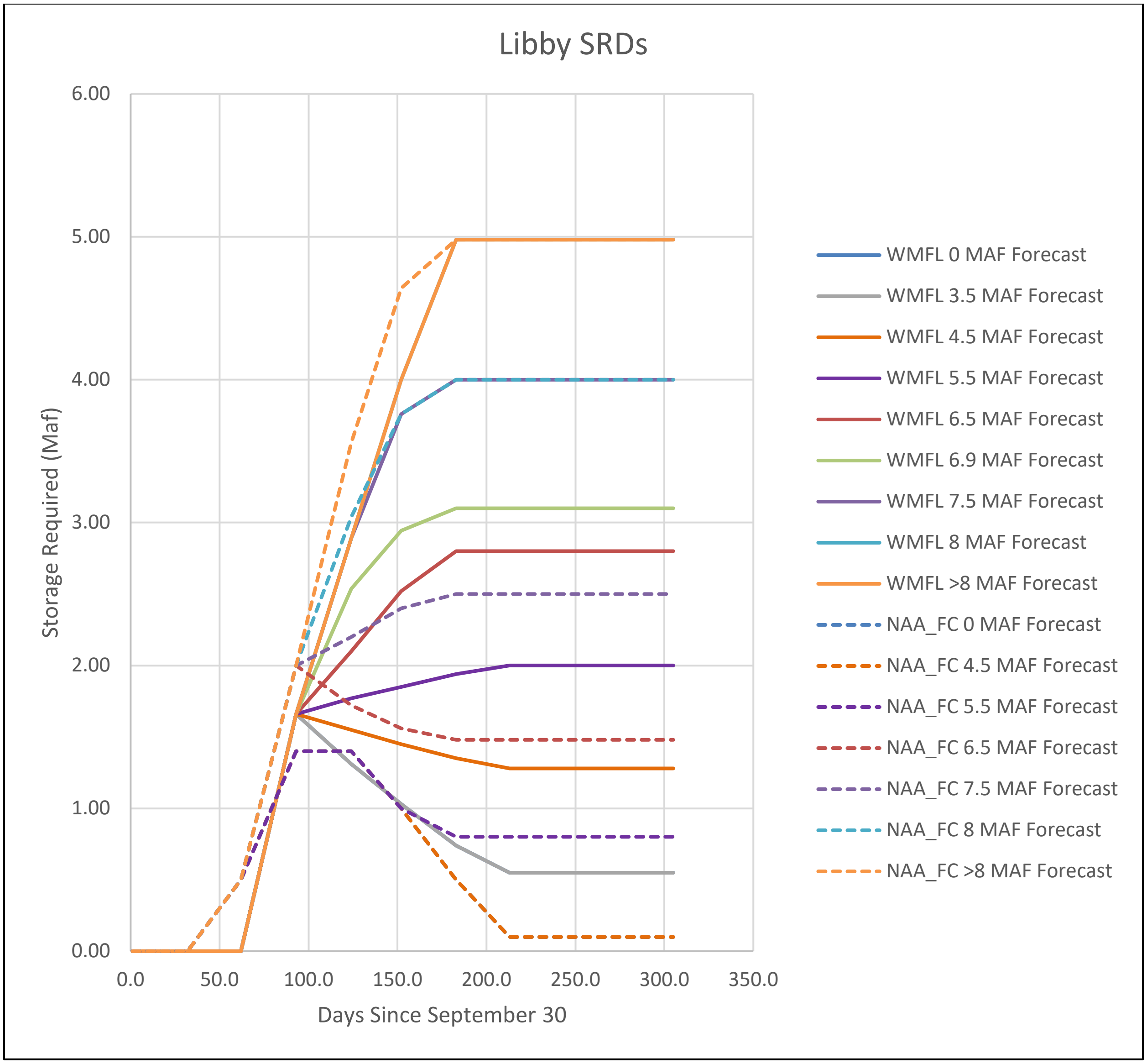
- Changes to VarQ code:
  - New initial VarQ numbers



  - Refill begins on May 1 if the Libby April to August forecast is less than 6.9 Maf.
  - Refill duration is the maximum of the system and local refill duration. Updated local duration expectations. NAA_FC expected local refill on July 31, but WMFL calculates refill duration in days since May 1 based on Libby's April to August forecasts:



    - SRDs are different in refill calculation. They operate to local flood control needs below 6.9 Maf and to system needs (same as NAA_FC by end of April) above 6.9 Maf.



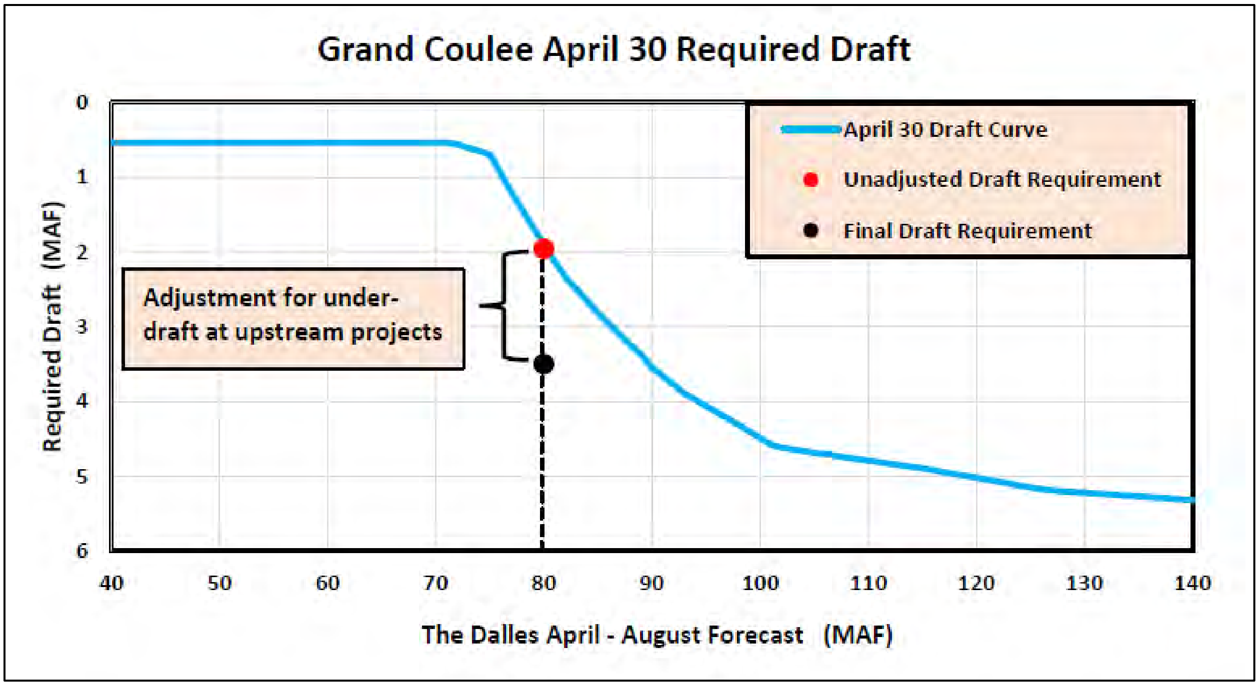
- A new adjustment for planned releases was added. Planned releases are currently just sturgeon pulse releases. This adjustment subtracts out an estimate of releases higher than VarQ that are likely to be required in the refill season. This is a new method.
- Previous release adjustment happens daily now.

Grand Coulee Dam

- A new method was implemented to adjust the URC for upstream storage space. Rather than adjusting The Dalles forecast to determine the URC requirements as with the current methodology, The Dalles forecast is used directly to determine the end-of-April draft requirement for Grand Coulee and requires a correction, in the form of a deeper draft target, when upstream storage reservoirs fail to achieve their required drafts for whatever reason. The Grand Coulee April 30 draft is based on four things:

- The Dalles water supply forecast
- Upstream storage reservoirs' required draft or draft that is manageable and dependable for system flood risk management (called a "base draft" in the modeling)
- The in-season draft (actual) of upstream reservoirs in relation to the base draft
- The relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (weighting curves for certain projects)

A two-step process is used to model this. First, a Grand Coulee unadjusted April 30 requirement is determined using the curve below and The Dalles water supply forecast. Second, an adjustment is made to the Grand Coulee April 30 required draft only if upstream storage projects have not been drafted to their base draft by April 30. If upstream projects are drafted equal to or deeper than their base draft, no adjustments are made. If upstream projects are shallower than their base draft, weighting factors are applied to each project's deviation from its base draft to compute an adjustment to Grand Coulee, which is then added to the Grand Coulee required draft target.



In addition, the "flat spot" was removed from the Grand Coulee SRD and replaced with a consistently increasing flood risk draft for all forecast ranges. The flat spot is a portion of the current SRD that targets a maximum draft point to 1,222.7 feet (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 Maf.

- The Grand Coulee draft rate used in planning (in the SRD) was decreased from 1 to 1.5 feet/day to 0.8 feet/day. This does not occur in the real-time operational drawdown limit, only in the SRD.
- Draft space was increased for winter flood space to require 650 thousand acre-feet (kaf) of space at Grand Coulee from the end of December through March. The following elevation targets were included for flood protection, though these targets were placed at a lower priority than chum operations, so these targets may not be met each year. The intent is to avoid Grand Coulee being overdrafted in the spring due to chum flow requirements that were inflated by meeting the winter flood requirements. The rule will allow violation of these winter flood requirements if meeting that requirement would increase the minimum chum flow.

DEC20_ELEV_TARGET = 1,282 feet NGVD29

DEC31_ELEV_TARGET = 1,282 feet NGVD29

- A constraint was placed on the available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee.

Lower Snake Dams

- The measure called for modified minimum operation pool (MOP) operations in the lower Snake River dams (MOP + 1.5 feet). This adjustment was ignored due to the inability of the model to fully reflect this measure; projects are modeled the same way as No Action Alternative. However, the No Action Alternative usually keeps these dams in the range of MOP + 1.0 feet.

John Day Dam

- Raise and maintain John Day Reservoir elevations between 263.5 and 265 feet (NGVD29) during the months of April and May. Flood risk management (FRM) operations determined by Vancouver stage are a constraint to this operation but may not be captured operationally in modeling for this measure.

Banks Lake Diversion

Columbia Basin Irrigation Project Pumping (Banks Lake) data: Current water withdrawals were modified to the amounts shown in the table below.

Month	Diversion Flow Rate (cfs)
January	32
February	227
March	2,282
April 1–15	10,458
April 16–30	11,343

Month	Diversion Flow Rate (cfs)
May	11,537
June	11,784
July	14,060
August 1–15	10,823
August 16–31	7,192
September	8,722
October	4,367
November	634
December	293

Diversion Below Chief Joseph

- A diversion was added just downstream of Chief Joseph Dam. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	3
May	19
June	42
July	50
August	34
September	7
October	2
November	0
December	0

Diversion at Flathead Lake

- A diversion was added at the upstream edge of Flathead Lake. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	
May	
June	
July	493
August	493

Month	Diversion Flow Rate (cfs)
September	494
October	
November	0
December	0

All Other Projects and Operations

- Same as the No Action Alternative operations.

COLUMBIA RIVER SYSTEM OPERATIONS MULTIPLE OBJECTIVE ALTERNATIVE 2 MODELING SHEET

Multiple Objective Alternative 2 Modeling Summary

Name:	Multiple Object Alternative 2 (MO2)
CRSO Projects	Modified U.S. operations at multiple reservoirs
Flood Risk	Changes were made to the Grand Coulee and Libby URCs for flood risk management. Additionally, winter flood space was included at Grand Coulee. The changes in rule curves were designed with an intent to maintain the current level of flood risk.
Power	Some modifications to generation practices that were designed to increase hydropower generation efficiency.
Biological and Water Supply Objectives	Fully meet existing water supply obligations, same as the No Action Alternative. Improve adult, juvenile, and resident fish migration, passage, rearing, and/or survival. Reduce greenhouse gas emissions in the Pacific Northwest.
Modeling System Configuration	Same as the No Action Alternative
Canadian Treaty Projects	Same as the No Action Alternative
Hydrologic Data Sets Used for Monte Carlo Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Deterministic Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Monte Carlo Evaluation	Same as the No Action Alternative

ResSim Assumptions (General)

- Fully incorporate all Water Management Flexibility operations.
- Incorporate some hydropower operations procedures.
    - Modify Libby and Hungry Horse ramping rates so they are less restrictive and operate solely for life, safety, and engineering reasons (Ramping Rates for Safety).
    - Draft Dworshak and Hungry Horse for hydropower.
- Implement Sliding Scale operations at Libby and Hungry Horse.
- Same modeling framework and operations as No Action Alternative everywhere else.
- Note: all elevations are in NGVD29

Hungry Horse Dam

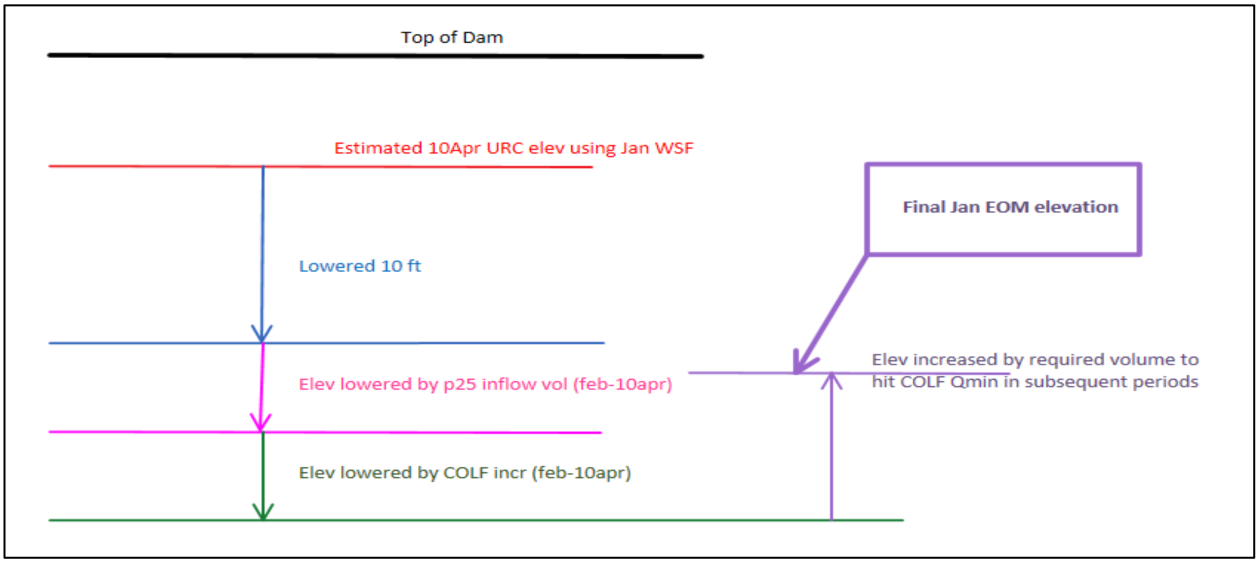
- Sliding scale: September draft targets were updated to values that are interpolated from Hungry Horse forecasts.

Hungry Horse Forecast (Maf)	September Elevation Target (ft)
1.407	3,540
1.579	3,550

- New Hungry Horse ramping rates

Flow Range (measured at Columbia Falls)	Ramp Up Unit Limit (daily max)
3,200–6,000 cfs	3,600 cfs/day
>6,000–8,000 cfs	3,600 cfs/day
>8,000–10,000 cfs	7,200 cfs/day
>10,000 cfs	No limit
Flow Range (measured at Columbia Falls)	**Ramp Down Unit Limit (daily max)**
3,200 – 6,000 cfs	1,200 cfs/day
>6,000–8,000 cfs	2,000 cfs/day
>8,000–12,000 cfs	4,000 cfs/day
>12,000 cfs	10,000 cfs/day

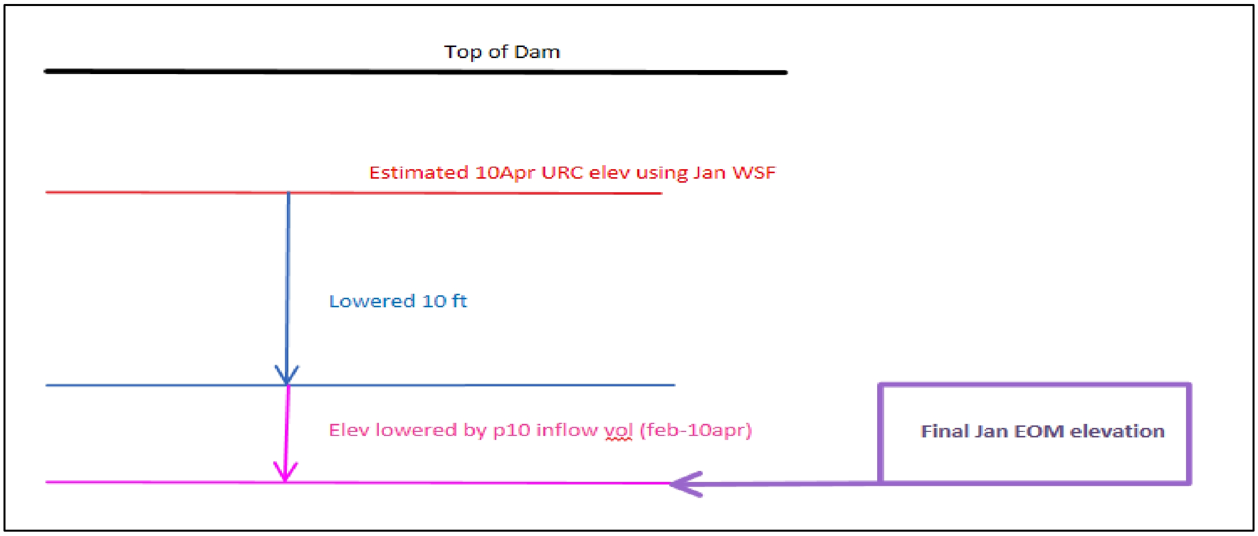
- Draft deeper for hydropower: Set April 10 target to 10 feet below the April 10 elevation objective; set January, February, and March lower limits to achieve a 90 percent probability of filling to the April 10 target. This was done by setting each individual month's target 10 feet below the current month's estimation of the April 10 elevation objective, lowered by the 25th percentile inflows volume between the current date and April 10 for subsequent months and a Columbia Falls incremental, then increased by the Columbia Falls minimum volume needed for subsequent months. Set April 15, April 30, and May 31 targets to 10 feet below URC. Maximum flow to reach these targets is the transmission limit of 9,000 cfs. An example of the January target elevation is depicted below, which is similar to the logic used for February and March targets.



- Minimum flow set to 900 cfs for hydropower.
- All other operations are the same as under the No Action Alternative.

Dworshak Dam

- Draft deeper for hydropower: Set April 10 target to 10 feet below the April 10 elevation objective; set January, February, and March lower limits to achieve a 90 percent probability of filling to the April 10 target. This was done by setting each individual month's target 10 feet below the April 10 elevation objective, lowered by the 10th percentile inflows volume between the current date and April 10. Set April 15, April 30, and May 31 targets to 10 feet below URC. Maximum flow to reach these targets is the hydropower capacity of 10,000 cfs. An example of the January target elevation is depicted below, which is similar to the logic used for February and March targets.

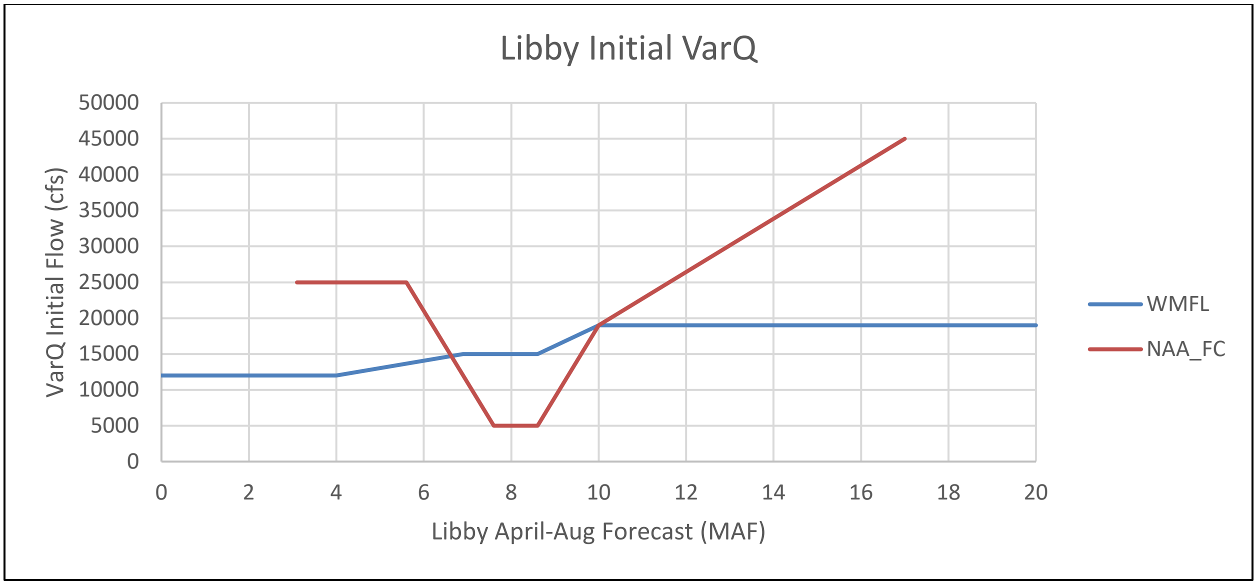


Libby Dam

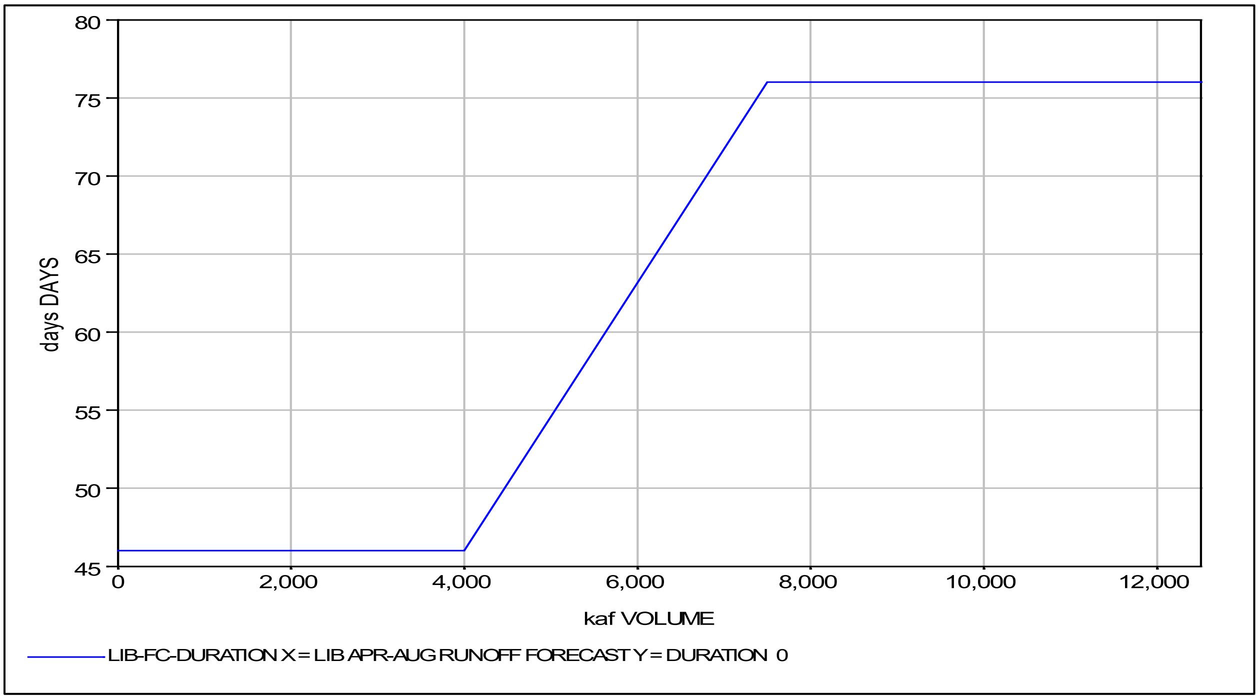
September draft targets were updated to values that are interpolated from Libby forecasts. August targets are 2.5 feet higher than the interpolated values.

Libby Forecast (Maf)	September Elevation Target (ft)
4.66	2,439
5.01	2,449
6.78	2,449
7.33	2,454

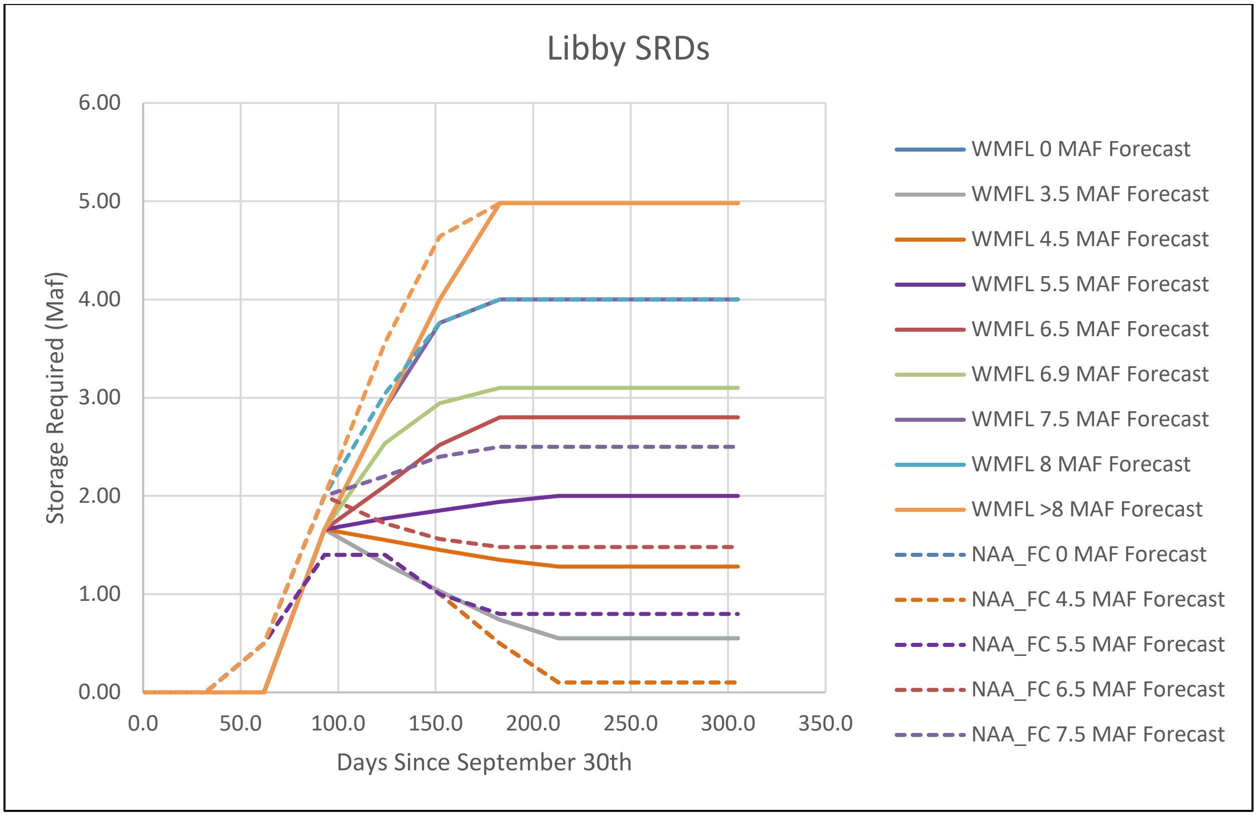
- Modify SRD and refill approach to operate for local interest in medium to low (<6.9 Maf Libby April to August forecast) water years. Eliminate variable end-of-December draft targets, replaced with a fixed target at 2,400 feet, 20 feet for hydropower draft.
- Modify refill procedures to improve chances of refill by accounting for future planned releases in VarQ calculations.
    - Changes to VarQ code:
        - New initial VarQ numbers



- Refill begins on May 1 if the Libby April to August forecast is less than 6.9 Maf.
- Refill duration is the maximum of the system and local refill duration. Updated local duration expectations. NAA_FC expected local refill on July 31, but WMFL calculates refill duration in days since May 1 based on Libby's April to August forecasts:



- SRDs are different in refill calculation. They operate to local flood control needs below 6.9 Maf and to system needs (same as NAA_FC by end of April) above 6.9 Maf.



  - A new adjustment for planned releases was added. Planned releases are currently just sturgeon pulse releases. This adjustment subtracts out an estimate of releases higher than VarQ that are likely to be required in the refill season. This is a new method.
  - Previous release adjustment happens daily now.

- New December 2,400 Libby draft target. New November draft target of 2,428 to moderate December flows.
- New Libby ramping rates (note that 1 unit = 5 kcfs):

Summer (May 1 to September 30)	
Flow Range	**Ramp Up or Unit Limit (daily max)**
4–9 kcfs	2 units[1/]
>9 kcfs	3 units
Flow Range	**Ramp Down or Unit Limit (daily max)**
4–6 kcfs	1 kcfs
6–9 kcfs	2 kcfs
9–16 kcfs	4 kcfs
> 16 kcfs	2 units

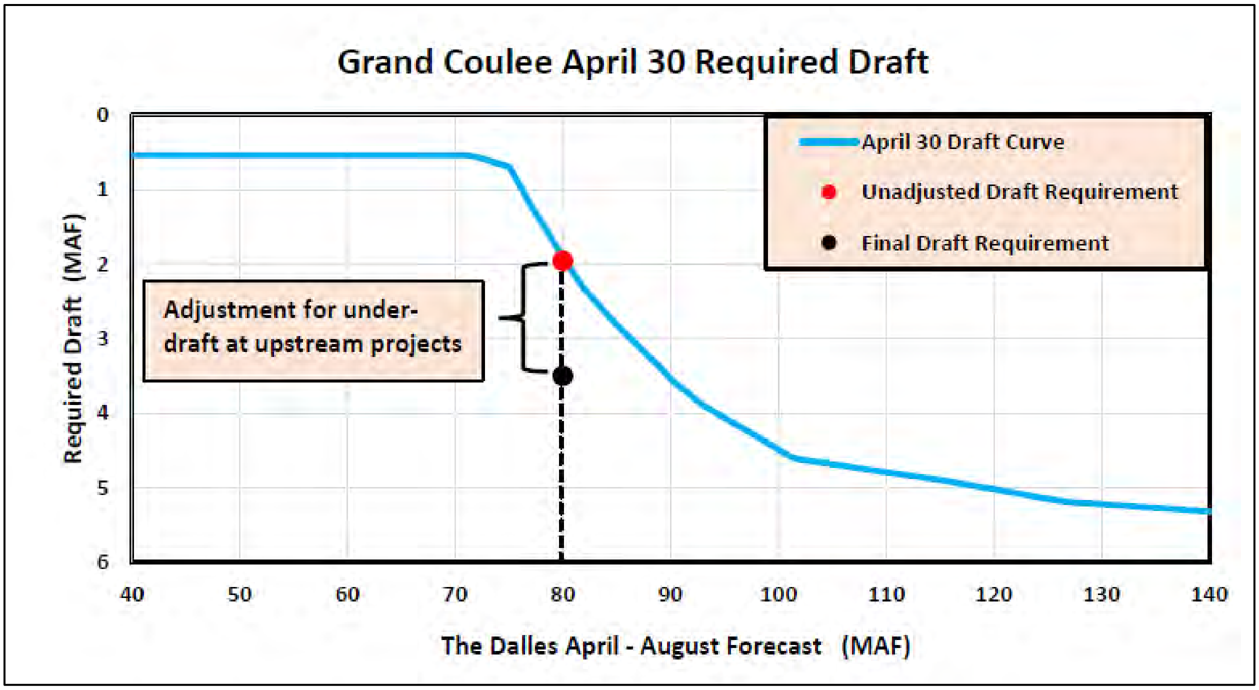
Winter (October 1 to April 30)	
Flow Range	**Ramp Up or Unit Limit (daily max)**
4–9 kcfs	2 units
> 9 kcfs	4 units
Flow Range	**Ramp Down or Unit Limit (daily max)**
4–6 kcfs	2 kcfs
6–9 kcfs	1 unit
9–16 kcfs	2 units
> 16 kcfs	2 units

1/ 1 unit = 5 kcfs

Grand Coulee Dam

- A new method was implemented to adjust the URC for upstream storage space. Rather than adjusting The Dalles forecast to determine the URC requirements as with the current methodology, The Dalles forecast is used directly to determine the end-of-April draft requirement for Grand Coulee and requires a correction, in the form of a deeper draft target, when upstream storage reservoirs fail to achieve their required drafts for whatever reason. The Grand Coulee April 30 draft is based on four things:
    - The Dalles water supply forecast
    - Upstream storage reservoirs' required draft or draft that is manageable and dependable for system flood risk management (called a "base draft" in the modeling)
    - The in-season draft (actual) of upstream reservoirs in relation to the base draft
    - The relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (weighting curves for certain projects)

A two-step process is used to model this. First, a Grand Coulee unadjusted April 30 requirement is determined using the curve below and The Dalles water supply forecast. Second, an adjustment is made to the Grand Coulee April 30 required draft only if upstream storage projects have not been drafted to their base draft by April 30. If upstream projects are drafted equal to or deeper than their base draft, no adjustments are made. If upstream projects are shallower than their base draft, weighting factors are applied to each project's deviation from its base draft to compute an adjustment to Grand Coulee, which is then added to the Grand Coulee required draft target.



In addition, the "flat spot" was removed from the Grand Coulee SRD and replaced with a consistently increasing flood risk draft for all forecast ranges. The flat spot is a portion of the current SRD that targets a maximum draft point to 1,222.7 feet (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 Maf..

- The Grand Coulee draft rate used in planning (in the SRD) was decreased from 1 to 1.5 feet/day to 0.8 feet/day. This does not occur in the real-time operational drawdown limit, only in the SRD.
- Draft deeper for hydropower:
  - September target minimum was changed to 1,277; October minimum target was changed to 1,283. As both month-end targets are a hydropower operation, the end elevations are variable depending on the year's market conditions. A similar method to No Action Alternative correlates Treaty Storage Regulation (TSR) flow at The Dalles (as a proxy for market strength) with how deep Grand Coulee should be drafted in a year. The new end-of-September and end-of-October elevations use the following relationships in MO2:

September		**October**	
TSR flow at The Dalles (cfs)	**End of month elevation (NGVD29)**	**TSR flow at The Dalles (cfs)**	**End of month elevation (NGVD29)**
0	1,277	0	1,283
83,500	1,277	73,000	1,283
88,000	1,278	75,000	1,283.2
95,000	1,280	81,000	1,284
98,000	1,281.5	86,000	1,285.8

September		**October**	
TSR flow at The Dalles (cfs)	**End of month elevation (NGVD29)**	**TSR flow at The Dalles (cfs)**	**End of month elevation (NGVD29)**
103,000	1,283.5	88,000	1,286.5
106,000	1,284	100,000	1,287.2
107,000	1,284.5	110,000	1,287.5
111,000	1,285.3	155,000	1,288
116,000	1,286.5	999,000	1,288
146,000	1,287.4		
161,000	1,288		
999,000	1,288		

  - The January and February variable draft limit minimum elevations were lowered by 10 feet.

- Draft space was increased for winter flood space to require 650 kaf of space at Grand Coulee from the end of December through March. The following elevation targets were included for flood protection, though these targets were placed at a lower priority than chum operations, so these targets may not be met each year. The intent is to avoid Grand Coulee being overdrafted in the spring due to chum flow requirements that were inflated by meeting the winter flood requirements. The rule will allow violation of these winter flood requirements if meeting that requirement would increase the minimum chum flow.

DEC20_ELEV_TARGET = 1,282 feet NGVD29

DEC31_ELEV_TARGET = 1,282 feet NGVD29

- A constraint was placed on the available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee.

Lower Snake River Projects

- In ResSim, the full hydropower flexibility could not be incorporated and so these operations were kept the same as No Action.

John Day Dam

- In ResSim, the full hydropower flexibility could not be incorporated and so these operations were kept the same as No Action.

All Other Projects and Operations

- Same as the No Action Alternative operations.

COLUMBIA RIVER SYSTEM OPERATIONS MULTIPLE OBJECTIVE ALTERNATIVE 3 MODELING SHEET

Multiple Objective Alternative 3 Modeling Summary

Name:	Multiple Object Alternative 3 (MO3)
CRSO Projects	Modified U.S. operations at multiple reservoirs
Flood Risk	Changes were made to the Grand Coulee and Libby URCs for flood risk management. The changes in rule curves were designed with an intent to maintain the current level of flood risk.
Power	Some modifications to generation practices that were designed to increase hydropower generation efficiency.
Biological and Water Supply Objectives	Fully meet existing water supply obligations and provide for authorized additional regional water supply. Improve adult, juvenile, and resident fish migration, passage, rearing, and/or survival. Reduce greenhouse gas emissions in the Pacific Northwest.
Modeling System Configuration	Same as the No Action Alternative
Canadian Treaty Projects	Same as the No Action Alternative
Hydrologic Data Sets Used for Monte Carlo Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Deterministic Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Monte Carlo Evaluation	Same as the No Action Alternative

ResSim Assumptions (General)

- Fully incorporate all Water Supply Alternative operations.
- Incorporate select Water Management Flexibility operations
    - Modify Grand Coulee water management flexibility operations to include flat spot procedures.
- Incorporate some hydropower operations procedures.
    - Modify Libby and Hungry Horse ramping rates so they are less restrictive and operate solely for life, safety, and engineering reasons (Ramping Rates for Safety).

- Implement Sliding Scale operations at Libby and Hungry Horse.
- Remove lower Snake River dams.
- Same modeling framework and operations as No Action Alternative everywhere else.
- Note: all elevations are in NGVD29

Hungry Horse Dam

September draft targets were updated to values that are interpolated from Hungry Horse forecasts.

Hungry Horse Forecast (Maf)	September Elevation Target (ft)
1.407	3,540
1.579	3,550

- For water supply, in years where the flow augmentation draft is 10 feet, the end-of-September elevation is lowered by 4 feet. In years where the flow augmentation draft is 20 feet, the end-of-September elevation draft is lowered by 4.2 feet.
- The Columbia Falls minimum flows are increased by 493 cfs in July, August, and September to meet the water supply measure at Hungry Horse Dam (Hungry Horse Additional Water Supply).
- New Hungry Horse ramping rates

Flow Range (measured at Columbia Falls)	Ramp Up Unit Limit (daily max)
3,200–6,000 cfs	3,600 cfs/day
>6,000–8,000 cfs	3,600 cfs/day
>8,000–10,000 cfs	7,200 cfs/day
>10,000 cfs	No limit
Flow Range (measured at Columbia Falls)	**Ramp Down Unit Limit (daily max)**
3,200–6,000 cfs	1,200 cfs/day
>6,000–8,000 cfs	2,000 cfs/day
>8,000–12,000 cfs	4,000 cfs/day
>12,000 cfs	10,000 cfs/day

- All other operations are the same as under the No Action Alternative.

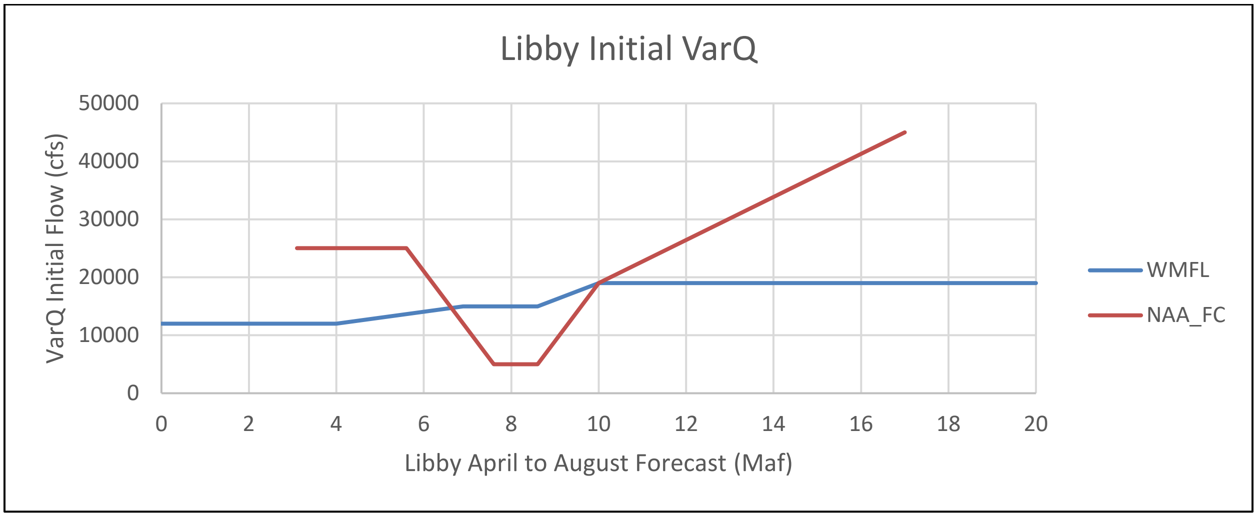
Libby Dam

- September draft targets were updated to values that are interpolated from Libby forecasts. August targets are 2.5 feet higher than the interpolated values.

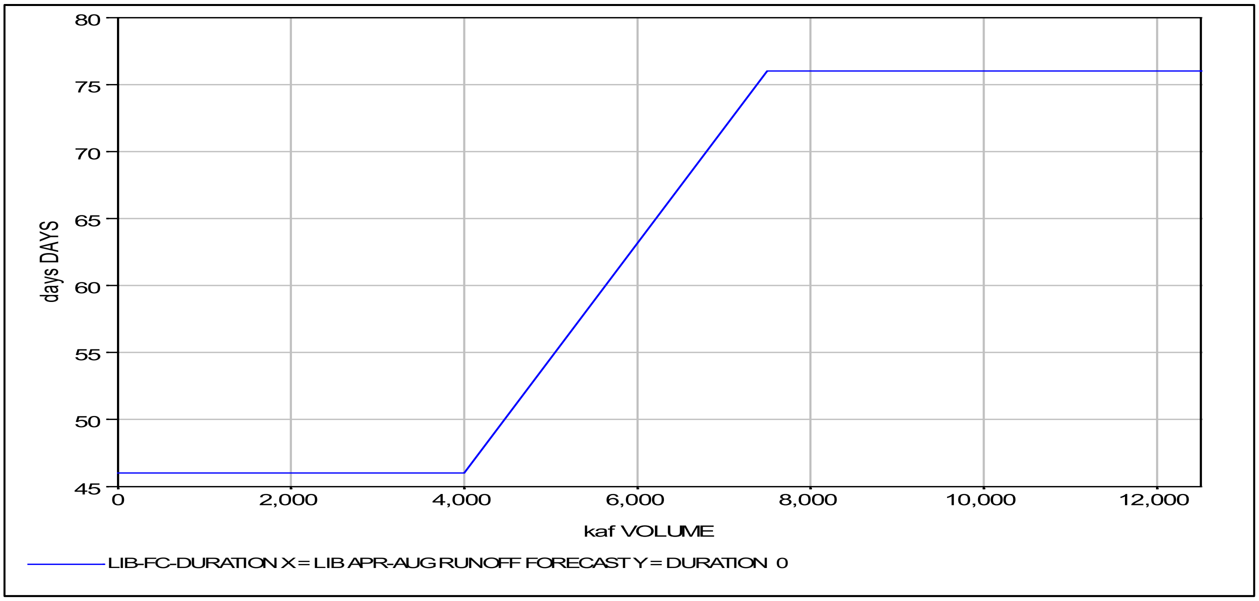
Libby Forecast (Maf)	September Elevation Target (ft)
4.66	2,439
5.01	2,449

Libby Forecast (Maf)	September Elevation Target (ft)
6.78	2,449
7.33	2,454

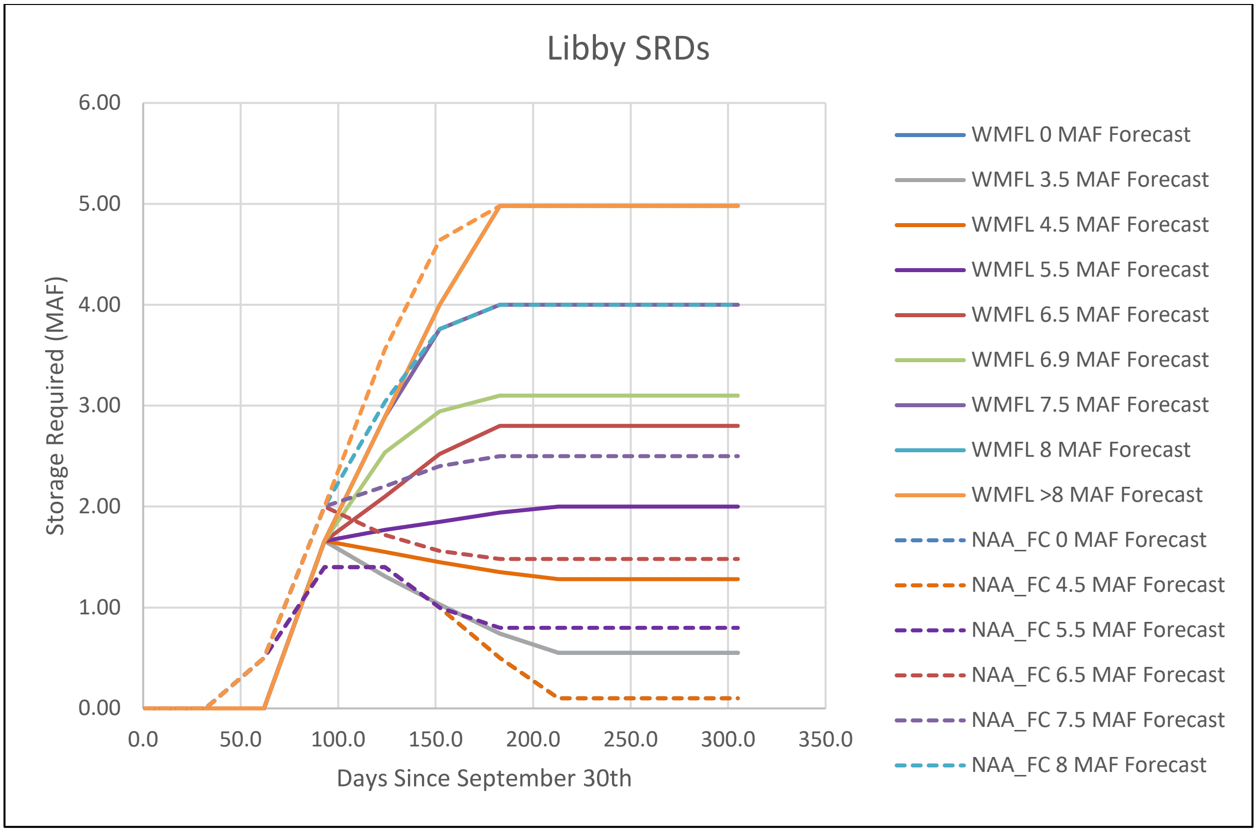
- Modify SRD and refill approach to operate for local interest in medium to low (<6.9 Maf Libby April to August forecast) water years. Eliminate variable end-of-December draft targets.
- New December 2,400-foot Libby draft target. New November draft target of 2,428 feet to moderate December flows.
- Modify refill procedures to improve chances of refill by accounting for future planned releases in VarQ calculations.
    - Changes to VarQ code:
        - New initial VarQ numbers



- Refill begins on May 1 if the Libby April to August forecast is less than 6.9 Maf.
- Refill duration is the maximum of the system and local refill duration. Updated local duration expectations. NAA_FC expected local refill is July 31, but WMFL calculates refill duration in days since May 1 based on Libby's April to August forecasts:



- SRDs are different in refill calculation. They operate to local flood control needs below 6.9 Maf and to system needs (same as NAA_FC by end of April) above 6.9 Maf.



- A new adjustment for planned releases was added. Planned releases are currently just sturgeon pulse releases. This adjustment subtracts out an estimate of releases higher than VarQ that are likely to be required in the refill season. This is a new method

  - Previous release adjustment happens daily now.

- New Libby ramping rates:

Summer (May 1 to September 30)	
Flow Range	**Ramp Up or Unit Limit (daily max)**
4–9 kcfs	2 units[1/]
>9 kcfs	3 units
Flow Range	Ramp Down or Unit Limit (daily max)
4–6 kcfs	1 kcfs
6–9 kcfs	2 kcfs
9–16 kcfs	4 kcfs
> 16 kcfs	2 units
Winter (October 1 to April 30)	
Flow Range	**Ramp Up or Unit Limit (daily max)**
4–9 kcfs	2 units
> 9 kcfs	4 units
Flow Range	Ramp Down or Unit Limit (daily max)
4–6 kcfs	2 kcfs
6–9 kcfs	1 unit
9–16 kcfs	2 units
> 16 kcfs	2 units

1/ 1 unit = 5 kcfs

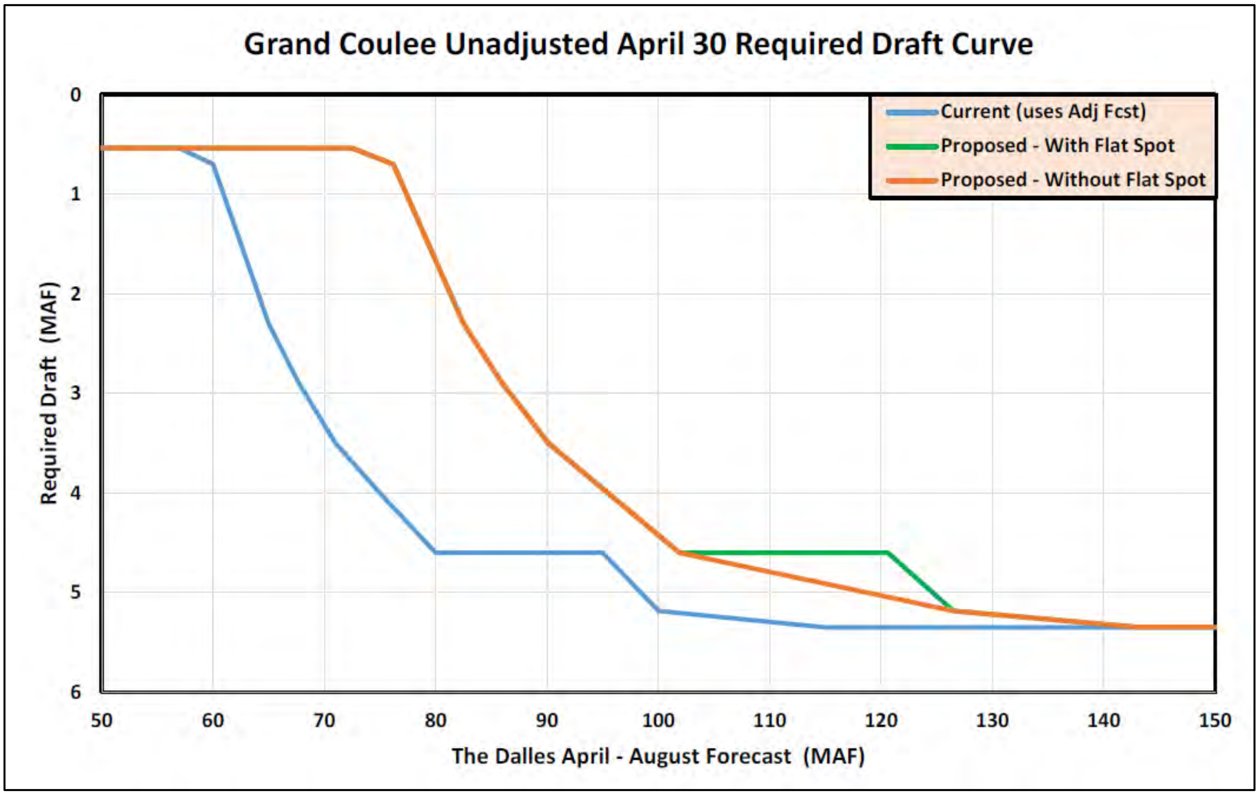
Grand Coulee Dam

- A new method was implemented to adjust the URC for upstream storage space. Rather than adjusting The Dalles forecast to determine the URC requirements as with the current methodology, The Dalles forecast is used directly to determine the end-of-April draft requirement for Grand Coulee and requires a correction, in the form of a deeper draft target, when upstream storage reservoirs fail to achieve their required drafts for whatever reason. The Grand Coulee April 30 draft is based on four things:
  - The Dalles water supply forecast
  - Upstream storage reservoirs’ required draft or draft that is manageable and dependable for system flood risk management (called a “base draft” in the modeling)
  - The in-season draft (actual) of upstream reservoirs in relation to the base draft

- The relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee (weighting curves for certain projects)

A two-step process is used to model this. First, a Grand Coulee unadjusted April 30 requirement is determined using the curve below and The Dalles water supply forecast. Second, an adjustment is made to the Grand Coulee April 30 required draft only if upstream storage projects have not been drafted to their base draft by April 30. If upstream projects are drafted equal to or deeper than their base draft, no adjustments are made. If upstream projects are shallower than their base draft, weighting factors are applied to each project's deviation from its base draft to compute an adjustment to Grand Coulee, which is then added to the Grand Coulee required draft target.

This alternative incorporates "flat spot" draft methodology, which changes the April 30 baseline draft curve from the orange line to the green line in the below graph. The flat spot is a portion of the current SRD that targets a maximum draft point to 1,222.7 feet (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 Maf (approximately 101 maf to 120.6 maf unadjusted The Dalles April to August forecast). With the flat spot draft methodology, no adjustments are made to the Grand Coulee draft requirement when The Dalles April to August forecast is between 101 maf and 120.6 maf even if upstream reservoirs are under-drafted.



- The Grand Coulee draft rate used in planning (in the SRD) was decreased from 1 to 1.5 feet/day to 0.8 feet/day. This does not occur in the real-time operational drawdown limit, only in the SRD.
- A constraint was placed on the available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee.

Lower Snake River Projects

- In ResSim, MO3 dam breach effects are estimating by turning these projects into "flow-through" dams, or dams that do not change pool elevations and release inflow.

Banks Lake Diversion

Columbia Basin Irrigation Project Pumping (Banks Lake) data: Current water withdrawals were modified to the amounts shown in the table below.

Month	Diversion Flow Rate (cfs)
January	32
February	227
March	2,282
April 1–15	10,458
April 16–30	11,343
May	11,537
June	11,784
July	14,060
August 1–15	10,823
August 16–31	7,192
September	8,722
October	4,367
November	634
December	293

Diversion Below Chief Joseph

- A diversion was added just downstream of Chief Joseph Dam. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	3
May	19
June	42

Month	Diversion Flow Rate (cfs)
July	50
August	34
September	7
October	2
November	0
December	0

Diversion at Flathead Lake

- A diversion was added at the upstream edge of Flathead Lake. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	
May	
June	
July	493
August	493
September	494
October	
November	0
December	0

All Other Projects and Operations

- Same as No Action Alternative operations.

COLUMBIA RIVER SYSTEM OPERATIONS MULTIPLE OBJECTIVE ALTERNATIVE 4 MODELING SHEET

Multiple Objective Alternative 4 Modeling Summary

Name:	Multiple Object Alternative 4 (MO4)
CRSO Projects	Modified U.S. operations at multiple reservoirs
Flood Risk	Changes were made to the Grand Coulee and Libby Dam URCs for flood risk management. Additionally, winter flood space was included at Grand Coulee Dam. The changes in rule curves were designed with an intent to maintain the current level of flood risk.

Power	Some modifications to generation and operation practices that were designed to increase hydropower generation efficiency.
Biological and Water Supply Objectives	Fully meet existing water supply obligations and provide for authorized additional regional water supply. Improve adult, juvenile, and resident fish migration, passage, rearing, and/or survival. Reduce greenhouse gas emissions in the Pacific Northwest.
Modeling System Configuration	Same as the No Action Alternative
Canadian Treaty Projects	Same as the No Action Alternative
Hydrologic Data Sets Used for Monte Carlo Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Deterministic Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Monte Carlo Evaluation	Same as the No Action Alternative

ResSim Assumptions (General)

- Fully incorporate all Water Supply Alternative operations.
- Fully incorporate all Water Management Flexibility operations.
- Operate Libby Dam to protect winter seeds by reducing Bonners Ferry winter stages to 1,753 feet when water supply forecast is below 6.9 Maf.
- Seasonally change lower Snake and lower Columbia reservoir elevations to improve fish operations.
- Strive to maintain 220 kcfs spring flows at McNary Dam.
- Same modeling framework and operations as No Action Alternative everywhere else.
- Note: all elevations are in NGVD 29

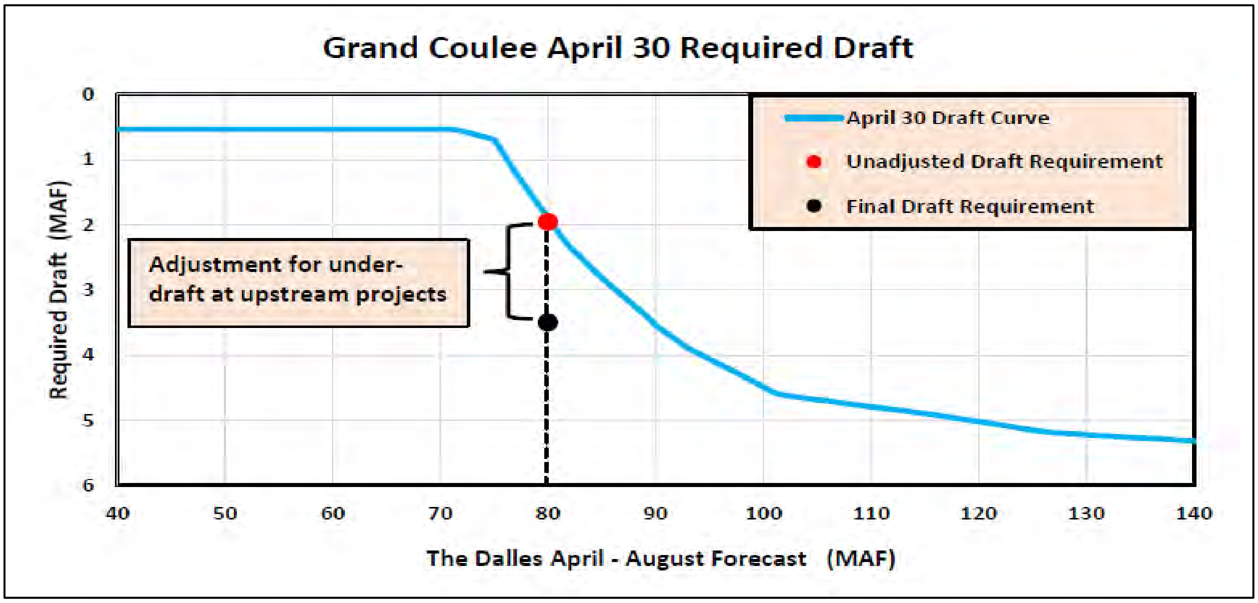
McNary Dam

- Juvenile fish operations were added to McNary Dam. The intent of this operation was to maintain a minimum flow of 220 kcfs at McNary Dam from May 1 through June 15 and a minimum flow of 200 kcfs between June 16 and August 1 in years when the April to August water supply forecast for The Dalles is less than 87.5 Maf. This was accomplished using Grand Coulee, Hungry Horse, Albeni Falls, and Libby Dams. A maximum volume of 2.0 Maf is used to augment outflows at McNary Dam while not exceeding maximum daily augmentation flow of 40 kcfs. After 2.0 Maf is used, the augmentation flows cease for the rest of the water year. Modeling at McNary Dam set a minimum outflow for juvenile fish between May 1 and August 1 that is triggered only when the May forecast at The Dalles is below 87.5 Maf and when less than 2.0 Maf of the augmentation flow has been provided.

Grand Coulee Dam

- A new method was implemented to adjust the URC for upstream storage space. Rather than adjusting The Dalles forecast to determine the URC requirements as with the current methodology, The Dalles forecast is used directly to determine the end-of-April draft requirement for Grand Coulee Dam and requires a correction, in the form of a deeper draft target, when upstream storage reservoirs fail to achieve their required drafts for whatever reason. The Grand Coulee Dam April 30 draft is based on four things:
    - The Dalles water supply forecast
    - Upstream storage reservoirs' required draft or draft that is manageable and dependable for system flood risk management (called a "base draft" in the modeling)
    - The in-season draft (actual) of upstream reservoirs in relation to the base draft
    - The relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee Dam (weighting curves for certain projects)

A two-step process is used to model this. First, a Grand Coulee Dam unadjusted April 30 requirement is determined using the curve below and The Dalles water supply forecast. Second, an adjustment is made to the Grand Coulee Dam April 30 required draft only if upstream storage projects have not been drafted to their base draft by April 30. If upstream projects are drafted equal to or deeper than their base draft, no adjustments are made. If upstream projects are shallower than their base draft, weighting factors are applied to each project's deviation from its base draft to compute an adjustment to Grand Coulee Dam, which is then added to the Grand Coulee Dam required draft target.



In addition, the "flat spot" was removed from the Grand Coulee Dam SRD and replaced with a consistently increasing flood risk draft for all forecast ranges. The flat spot is a portion of the current SRD that targets a maximum draft point to 1,222.7 feet (NGVD29) for adjusted The Dalles April to August seasonal volume forecasts between 80 and 95 Maf.

- The Grand Coulee Dam draft rate used in planning (in the SRD) was decreased from 1 to 1.5 feet/day to 0.8 feet/day. This does not occur in the real-time operational drawdown limit, only in the SRD.
- Draft space was increased for winter flood space to require 650 kaf of space at Grand Coulee from the end of December through March. The following elevation targets were included for flood protection, though these targets were placed at a lower priority than chum operations, so these targets may not be met each year by the December 21 target. The intent is to avoid Grand Coulee Dam being overdrafted in the spring due to chum flow requirements that were inflated by meeting the winter flood risk management requirements. The rule will allow violation of these winter flood risk management requirements if meeting that requirement would increase the minimum chum flow. It will meet the winter flood risk management requirement once it can do so without increasing the chum level.

  DEC20_ELEV_TARGET = 1,282 feet NGVD29

  DEC31_ELEV_TARGET = 1,282 feet NGVD29

- A constraint was placed on the available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam.
- Juvenile fish operations were added to Grand Coulee Dam that used its storage to provide all augmentation flows at McNary Dam, while the upstream projects "backfill" into Grand Coulee Dam storage. This simplified modeling, as accounting for travel time from the upstream reservoirs was unnecessary. This operation is in effect when the May-issued April to August water supply forecast at The Dalles is below average (87.5 Maf). Operations at Grand Coulee Dam both calculate a minimum release that provides the appropriate augmentation flow at McNary Dam and accounts for the amount of flow that has been released each day and how much total volume has been released to date. Accounting at Grand Coulee Dam entailed determining what the current flow augmentation target at McNary Dam is, and how much flow augmentation Grand Coulee Dam should be provided based on intervening inflows to McNary Dam. The flow augmentation for each day is limited based on how much flow augmentation volume has already been provided, as shown in the table below.

Augmentation Volume Provided (Maf)	**Max Daily Augmentation Flow (kcfs)**
0 - 1.75	40
1.75 - 1.98	20
1.98 - 2.0	10

Each day's flow augmentation volume was tracked by summing the current day's provided volume with the volume already provided to McNary Dam to ensure that the total volume provided to McNary Dam doesn't exceed 2.0 Maf. This running volume total is accessible by other rules at upstream dams. The project then releases a minimum outflow that will provide the necessary augmentation flow to McNary Dam.

Although all of the flow release for the augmentation flow at McNary Dam is provided by Grand Coulee Dam, it is ultimately only responsible for providing 37.3 percent (746 kaf at full augmentation) of the flow augmentation volume. This was accomplished by lowering the Grand Coulee refill targets for June 30, July 7, and August 31 by 37.3 percent of the total provided augmentation volume.

Because some upstream augmentation volume takes longer to reach Grand Coulee Dam, the July 7 target for Grand Coulee Dam includes the augmentation volume (that has accumulated up to that point) from Grand Coulee, Hungry Horse Dam, and Libby Dam. The August 31 elevation target is the typical No Action Alternative elevation lowered by the full Grand Coulee Dam augmentation volume for that year. The end-of-September target fills half of the augmentation volume from Grand Coulee Dam, and the end-of-October elevation is back on the typical target elevation.

Albeni Falls Dam

- Juvenile fish operations: Albeni Falls is responsible for providing 7.3 percent (145.2 kaf at full augmentation) of the flow augmentation volume. This was done by creating a new rule at Albeni Falls that lowers its June 30 refill target by this augmentation volume. The June 30 full-pool target decreased from 2,062.25 feet under the No Action Alternative to 2059.7 feet in MO4.

Hungry Horse Dam

- September draft targets were updated to values that are interpolated from Hungry Horse Dam forecasts.

Hungry Horse Dam Forecast (Maf)	September Elevation Target (ft)
1.407	3,540
1.579	3,550

- In years where the flow augmentation draft is 10 feet, the end-of-September elevation is lowered by 90 kaf (4 feet). In years where the flow augmentation draft is 20 feet, the end-of-September elevation draft is lowered by 90 kaf (4.2 feet).
- The Columbia Falls minimum flows are increased by 493 cfs in July, August, and September to meet the water supply measure of delivering an additional 90 kaf at Hungry Horse Dam.
- Juvenile fish operations: Hungry Horse Dam is responsible for providing 20.8 percent (416 kaf at full augmentation) of the flow augmentation volume. This was done by lowering the

refill target for June 30 (3,541.8 feet NGVD29 at full augmentation) and the summer draft targets for August 31 and September 30.

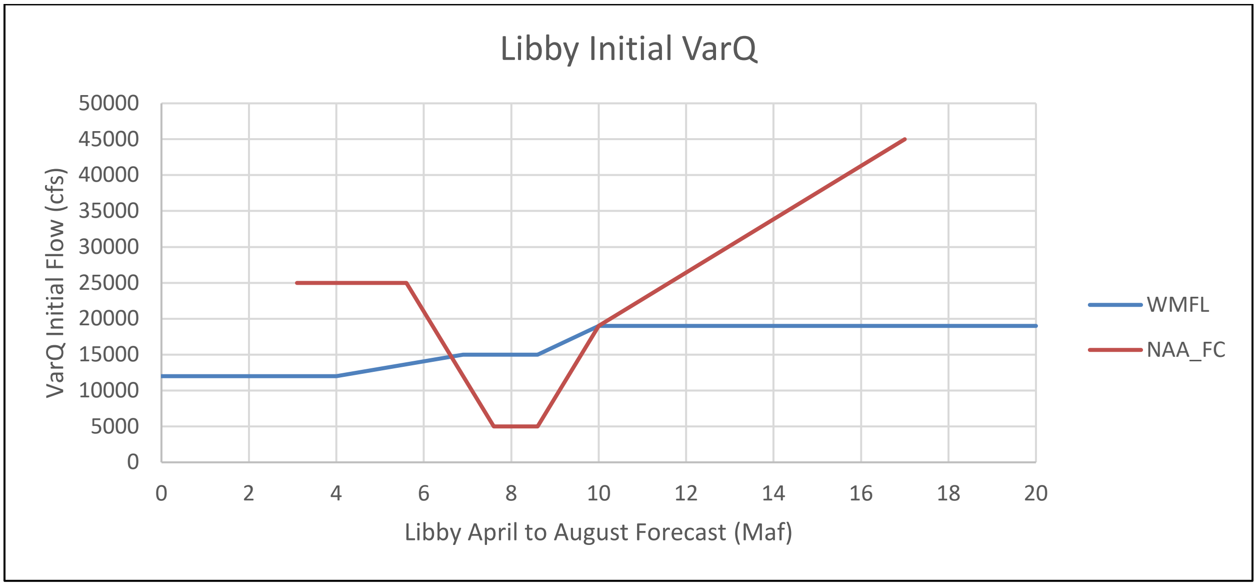
- All other operations are the same as under the No Action Alternative.

Libby Dam

- September draft targets were updated to values that are interpolated from Libby Dam forecasts. August targets are 2.5 feet higher than the interpolated values.

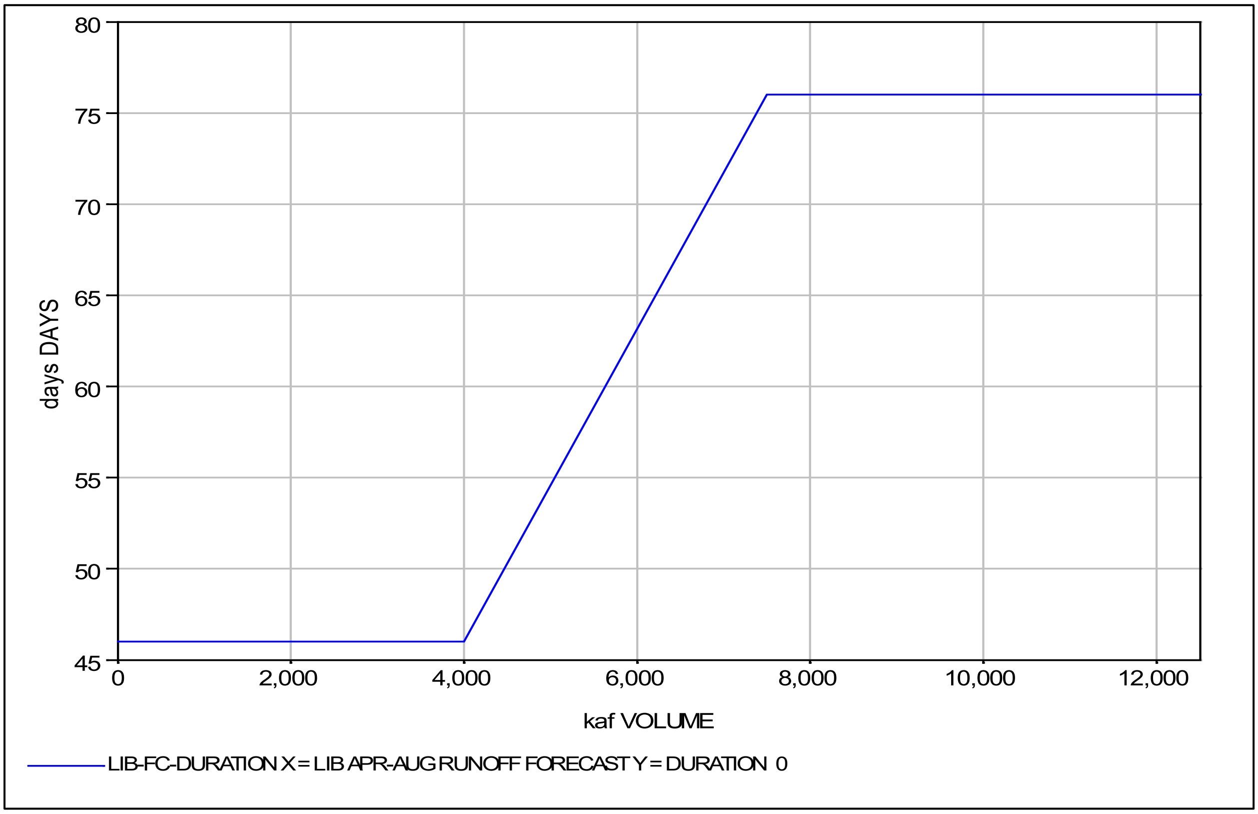
Libby Dam Forecast (Maf)	September Elevation Target (ft)
4.66	2,439
5.01	2,449
6.78	2,449
7.33	2,454

- Modify SRD and refill approach to operate for local interest in medium to low (<6.9 Maf Libby Dam April to August forecast) water years. Eliminate variable end-of-December draft targets, replaced with a fixed target at 2420 feet.
- Modify refill procedures to improve chances of refill by accounting for future planned releases in VarQ calculations.
    - Changes to VarQ code:
        - New initial VarQ numbers

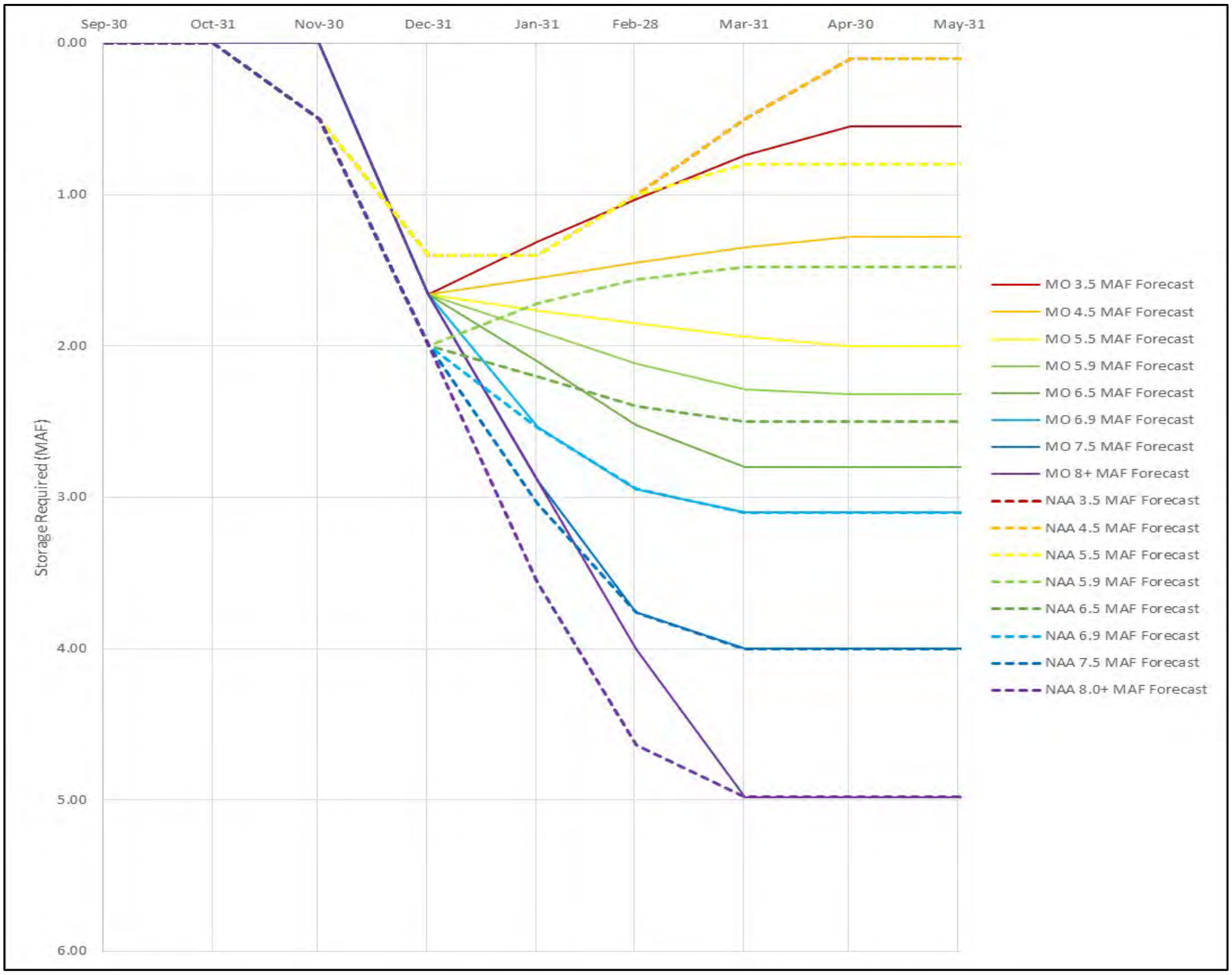


- Refill begins on May 1 if the Libby Dam April to August forecast is less than 6.9 Maf.
- Refill duration is the maximum of the system and local refill duration. Updated local duration expectations. NAA_FC expected local refill is July 31, but this measure

calculates refill duration in days since May 1 based on Libby Dam's April to August forecasts:



- SRDs are different in refill calculation. They operate to local flood control needs below 6.9 Maf and to system needs (same as NAA_FC by end of April) above 6.9 Maf.



  - A new adjustment for planned releases was added. Currently the planned releases include sturgeon pulse releases. This adjustment subtracts out an estimate of releases higher than VarQ that are likely to be required in the refill season. This is a new method.
  - Previous release adjustment happens daily now.

- 1,753-foot Bonners Ferry operations: Libby Dam operations were changed to attempt to meet at maximum stage at Bonners Ferry of 1,753 feet from November through March to aid in the survival of riparian vegetation downstream of Libby Dam. In January through March, the operations are toggled on/off based on the Libby April to August water supply forecast of 6.9 Maf. The modeling logic is as follows:
  - In November to December and from January to March, if the Libby Dam water supply forecast is lower than 6.9 Maf, a maximum outflow is determined based on Bonners Ferry stage
  - A minimum outflow is determined for Libby based on Bonners Ferry stage. If the expected stage is above 1,753 feet, the minimum release will be 9 kcfs. If not, the minimum release will be the same as the typical minimum release, which is 4 kcfs.

- Juvenile Fish operations: Libby is responsible for providing 34.7 percent (694 kaf at full augmentation) of the flow augmentation volume. This augmentation volume was provided by lowering Libby's refill and draft targets. The July 31 5 feet from full-pool target decreased from 2,454 feet in the No Action Alternative to 2,438.2 feet in MO4.

Lower Columbia River Projects

- Lower Columbia run-of-river reservoirs have reduced elevations to accelerate fish travel times within turbine efficiency ranges. Modified elevations are active March 25 through August 15. See old and new elevation targets below.

NGVD29 Elevations		
Reservoir	**ResSim NAA Operation (feet)**	**MO4 Errata (feet)**
Bonneville	76	72.25
The Dalles	158.1	155.75
John Day	263.25	261.75
McNary	338.7	337.5
Ice Harbor	437.5	**437.75**
Lower Monumental	537.5	**537.75**
Little Goose	633.5	**633.75**
Lower Granite	733.5	**733.75**

Lower Snake River Projects

- Lower Snake River run-of-river reservoirs have slightly increased elevations to allow for the fastest fish travel times within turbine efficiency ranges. Modified elevations are active March 25 to August 15. See old and new elevation targets above.

Banks Lake Diversion

Columbia Basin Irrigation Project Pumping (Banks Lake) data: Current water withdrawals were modified to the amounts shown in the table below.

Month	Diversion Flow Rate (cfs)
January	32
February	227
March	2,282
April 1–15	10,458
April 16–30	11,343
May	11,537
June	11,784
July	14,060
August 1–15	10,823
August 16–31	7,192

Month	Diversion Flow Rate (cfs)
September	8,722
October	4,367
November	634
December	293

Diversion Below Chief Joseph Dam

- A diversion was added just downstream of Chief Joseph Dam. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	3
May	19
June	42
July	50
August	34
September	7
October	2
November	0
December	0

Diversion at Flathead Lake

- A diversion was added at the upstream edge of Flathead Lake. Seasonal diversion volumes and flows are shown in the table below.

Month	Diversion Flow Rate (cfs)
January	0
February	0
March	0
April	0
May	0
June	0
July	493
August	493
September	494
October	0
November	0
December	0

- Same as the No Action Alternative operations.

COLUMBIA RIVER SYSTEM OPERATIONS PREFERRED ALTERNATIVE MODELING SHEET

Preferred Alternative Modeling Summary

Name:	CRSO Preferred Alternative
CRSO Projects	Modified U.S. operations at multiple reservoirs
Flood Risk	Changes were made to the Grand Coulee and Libby upper rule curves for flood risk management. The changes in rule curves were designed with an intent to maintain the current level of flood risk.
Power	Some modifications to generation practices that are designed to increase hydropower generation efficiency. Dworshak drafts deeper in January to March to increase hydropower during higher demand. Dworshak's refill should remain similar to the No Action Alternative.
Biological and Water Supply Objectives	Banks Lake diversions were modified. Improve adult, juvenile, and resident fish migration, passage, rearing, and/or survival. Reduce greenhouse gas emissions in the Pacific Northwest.
Modeling System Configuration	Same as the No Action Alternative
Canadian Treaty Projects	Same as the No Action Alternative
Hydrologic Data Sets Used for Monte Carlo Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Deterministic Evaluation	Same as the No Action Alternative
Water Supply Forecast Used for Monte Carlo Evaluation	Same as the No Action Alternative

ResSim Assumptions (General)

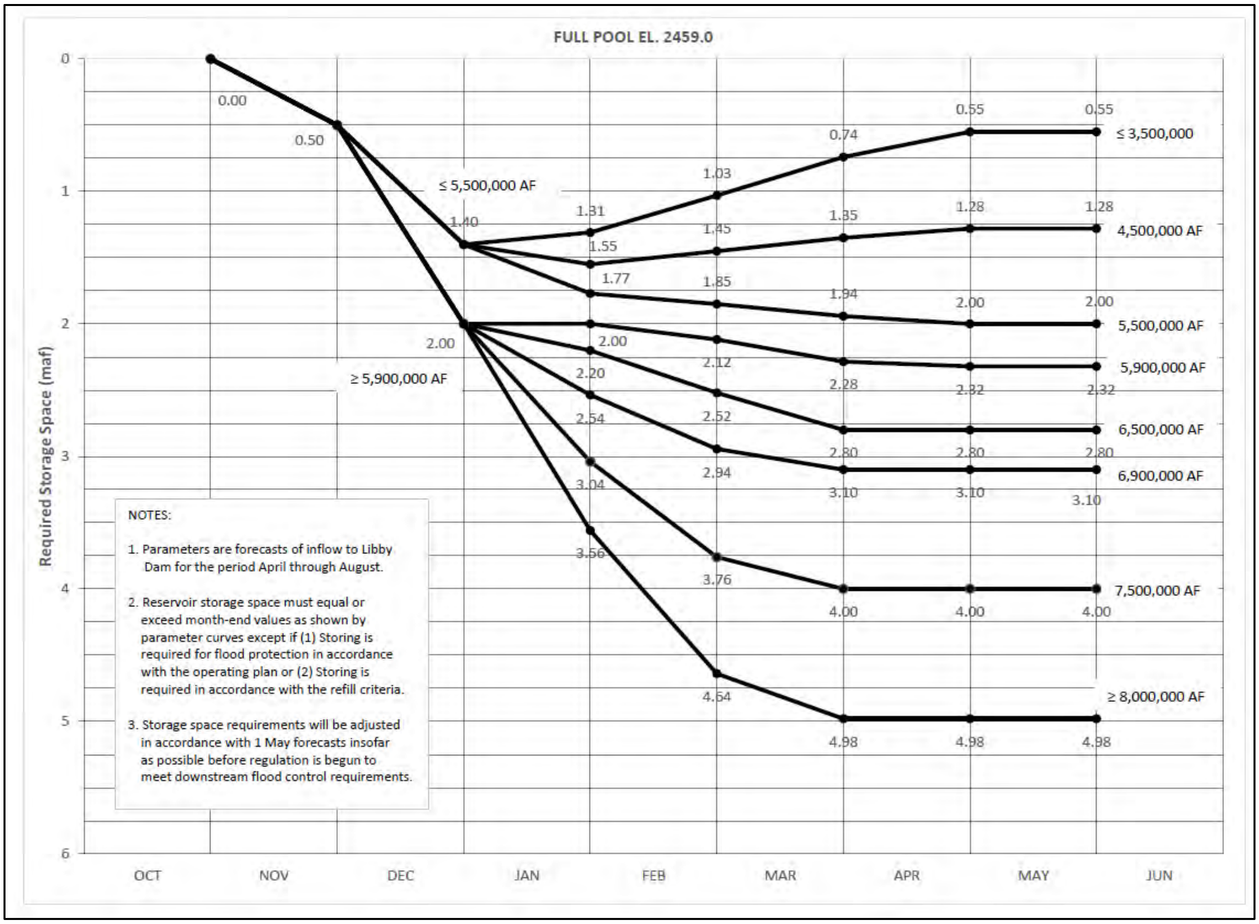
- Libby Dam URCs were modified to have deeper drafts in years with water supply forecasts less than 6.9 Maf. The VarQ refill procedure was modified to account for future releases during refill, refill start date and initial refill release flow.
- Sliding scale operations were included at Libby and Hungry Horse Dams.
- Grand Coulee includes a new FRM adjustment technique, 0.8' planned draft SRDs with flat spot operations, and new fall elevation targets. Additionally outflow restrictions were incorporated to account for maintenance.

- Banks Lake diversions were modified.
- Dworshak Dam supports a deeper January to March hydropower draft while limiting impact to refill later in the year.
- Increased Forebay Range Flexibility at the Lower Snake Dams for MOPs were included.
- John Day Dam change for Predator Disruption Operations, expanded MIP range, and full operating range outside of fish passage season, excepted as needed for flood risk management.
- Same modeling framework and operations as No Action Alternative everywhere else.

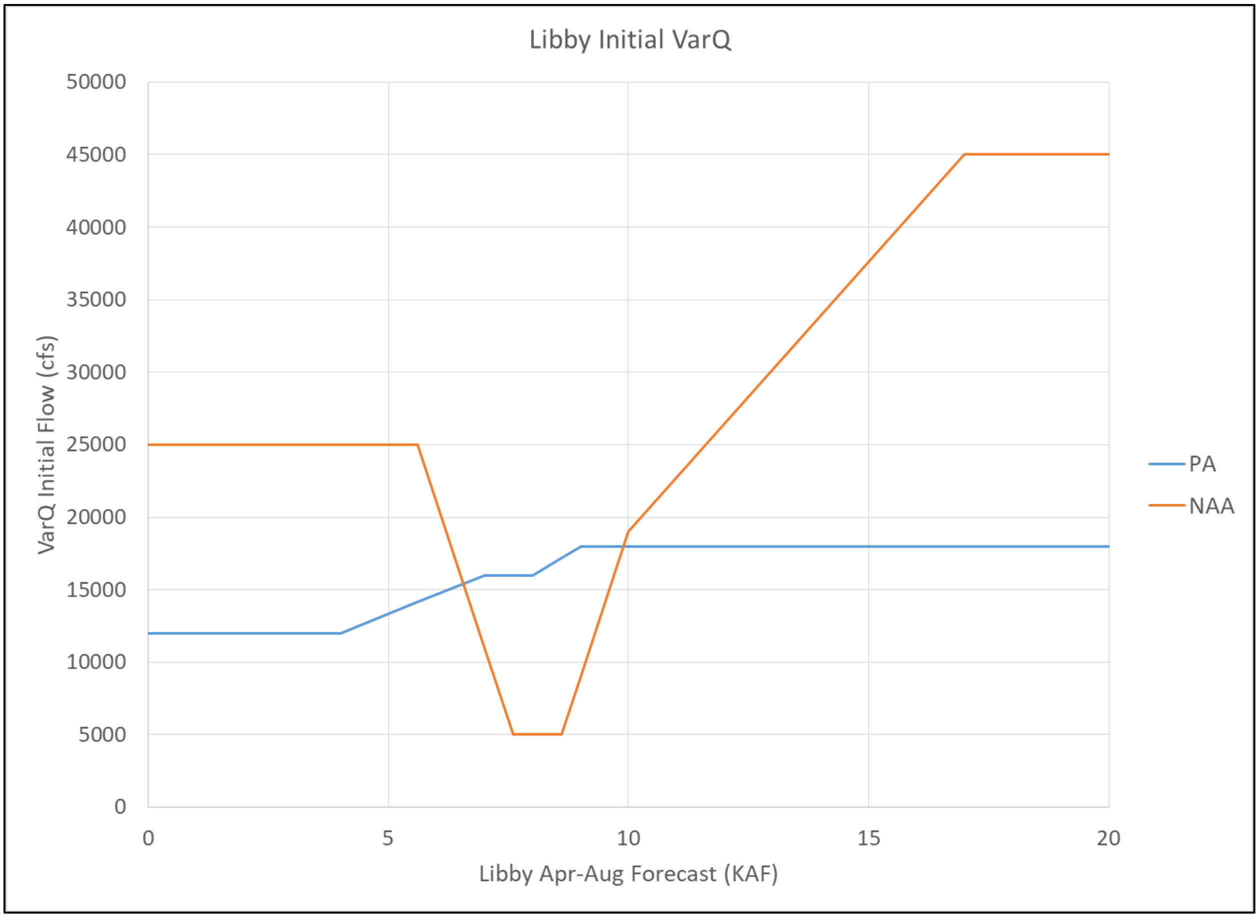
Note: all elevations are in NGVD 29

Libby Dam

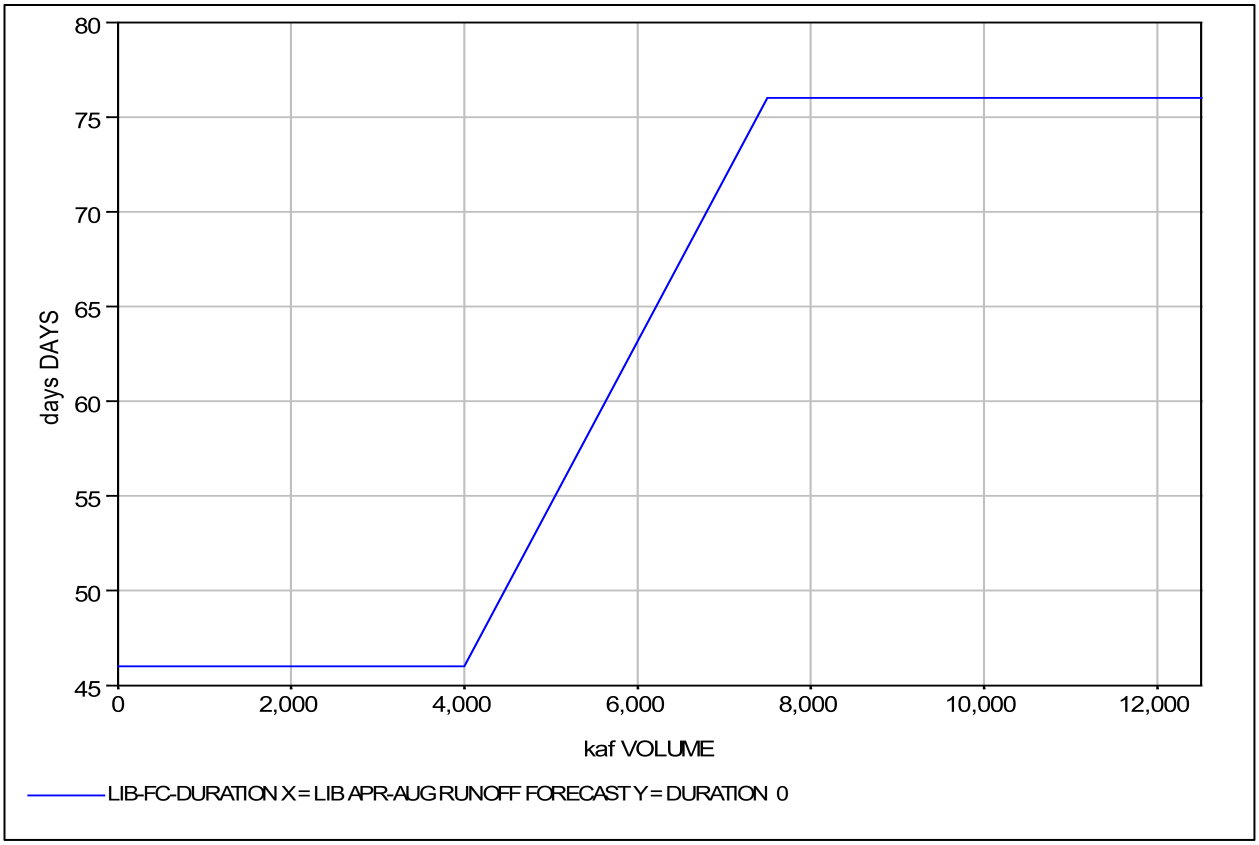
- Modify SRD and refill approach to operate for local interest in medium to low (<6.9 MAF Libby Apr-Aug forecast) water years.
- SRDs are different in draft calculation. They operate to local flood risk management needs below 6.9 MAF and to system needs (same as NAA_FC by end of April) above 6.9 MAF.



- Modify refill procedures to improve chances of refill by accounting for future planned releases in VarQ calculations, start of refill timing, and duration.
  - Changes to VarQ code:
    - New initial VarQ numbers that align with the Water Management Flexibility proposal



- Refill begins on May 1 if the Libby Apr-Aug forecast is less than 6.9 MAF and the earlier of May 1 or 10 days prior to the ICF for forecasts greater than 6.9 MAF.
- Refill duration is the maximum of the system and local refill duration. Updated local duration expectations. The No Action Alternative calculated local VarQ duration based on days between the start of refill and June 30, but PA calculates local refill duration in days since May 1 based on Libby’s April-August forecasts:



  - A new adjustment for planned releases was added. Planned releases are currently just Sturgeon Pulse releases. This adjustment subtracts out an estimate of releases higher than VarQ that are likely to be required in the refill season. This is a new method.
  - SRDs are different in refill calculation. They operate to local flood control needs below 6.9 MAF and to system needs (same as NAA_FC by end of April) above 6.9 MAF.
  - Previous release adjustment happens daily now rather than monthly as in NAA.

- September draft targets were updated to values that are interpolated from Libby forecasts. August targets are 2.5 feet higher than the interpolated values.

Libby Forecast (MAF)	September Elevation Target (feet)
4.66	2439
5.01	2449
6.78	2449
7.33	2454

- All other operations at Libby Dam are the same as the No Action Alternative.

Hungry Horse Dam

- September draft targets were updated to values that are interpolated from Hungry Horse forecasts.

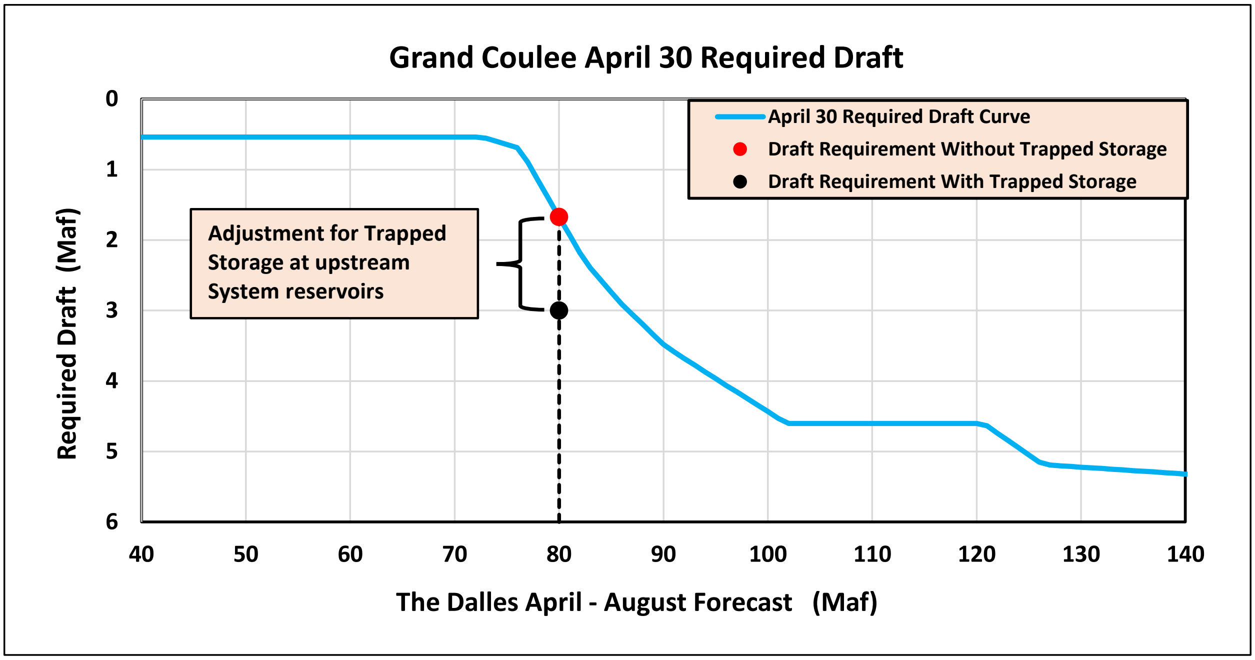
Hungry Horse Forecast (MAF)	September Elevation Target (feet)
1.407	3540
1.579	3550

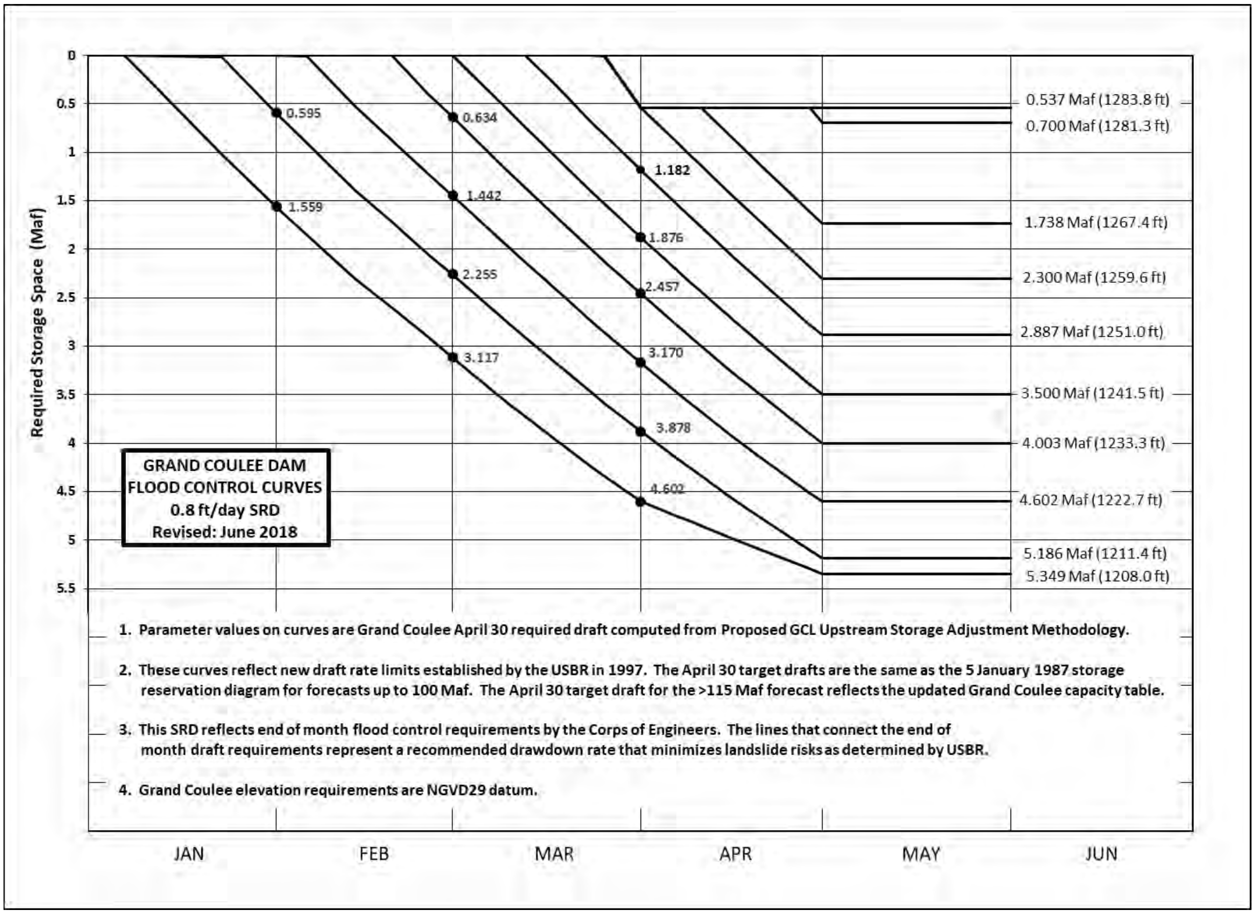
- All other operations at Hungry Horse are the same as the No Action Alternative.

Grand Coulee Dam

- A new method was implemented to adjust the Upper Rule Curve (URC) for upstream storage space. Rather than adjusting The Dalles forecast to determine the URC requirements as with the current methodology, The Dalles forecast is utilized directly to determine the end of April draft requirement for Grand Coulee Dam and requires a correction, in the form of a deeper draft target, when upstream storage reservoirs fail to achieve their required drafts for whatever reason. The Grand Coulee Dam April 30 draft is based on four things:
    - The Dalles water supply forecast
    - Upstream storage reservoirs' required draft or draft that is manageable and dependable for system flood risk management (called a Base Draft in the modeling)
    - The in-season draft (actual) of upstream reservoirs in relation to the Base Draft
    - The relative flood risk benefit of drafted space in upstream storage reservoirs as compared to storage at Grand Coulee Dam (weighting curves for certain projects)

    The steps to model this are a two-step process. First, a Grand Coulee Dam unadjusted April 30 requirement is determined using the curve below and The Dalles water supply forecast. Second, an adjustment is made to the Grand Coulee Dam April 30 required draft only if upstream storage projects have not been drafted to their Base Draft by April 30. If upstream projects are drafted equal to or deeper than their Base Draft, no adjustments are made. If upstream projects are shallower than their Base Draft, weighting factors are applied to each project's deviation from its Base Draft to compute an adjustment to Grand Coulee Dam, which is then added to the Grand Coulee Dam required draft target.





1. Parameter values on curves are Grand Coulee April 30 required draft computed from Proposed GCL Upstream Storage Adjustment Methodology.
2. These curves reflect new draft rate limits established by the USBR in 1997. The April 30 target drafts are the same as the 5 January 1987 storage reservation diagram for forecasts up to 100 Maf. The April 30 target draft for the >115 Maf forecast reflects the updated Grand Coulee capacity table.
3. This SRD reflects end of month flood control requirements by the Corps of Engineers. The lines that connect the end of month draft requirements represent a recommended drawdown rate that minimizes landslide risks as determined by USBR.
4. Grand Coulee elevation requirements are NGVD29 datum.

- The Grand Coulee Dam draft rate used in planning (in the SRD) was decreased from 1 to 1.5 feet/day to 0.8 feet/day. This does not occur in the real-time operational drawdown limit, only in the SRD.

- Draft deeper for hydropower:
    - September target minimum was changed to 1277 feet; October minimum target was changed to 1283 feet. As both month-end targets are a hydropower operation, the end elevations are variable depending on the year's market conditions. A similar method to No Action Alternative correlates TSR flow at The Dalles (as a proxy for market strength) with how deep Grand Coulee Dam should be drafted in a year. The new end of September and October elevations use the following relationships:

September		**October**	
TSR flow at The Dalles (cfs)	**End of month elevation (NGVD29)**	**TSR flow at The Dalles (cfs)**	**End of month elevation (NGVD29)**
0	1277	0	1283
83500	1277	73000	1283
88000	1278	75000	1283.2
95000	1280	81000	1284
98000	1281.5	86000	1285.8
103000	1283.5	88000	1286.5
106000	1284	100000	1287.2
107000	1284.5	110000	1287.5
111000	1285.3	155000	1288
116000	1286.5	999000	1288
146000	1287.4		
161000	1288		
999000	1288		

- A constraint was placed on the available hydraulic capacity through each power plant and spillway to represent maintenance activities at Grand Coulee Dam.
- All other operations at Grand Coulee Dam are the same as the No Action Alternative.

Banks Lake Diversion

Lake Roosevelt Additional Water Supply into the Columbia Basin Irrigation Project Pumping (Banks Lake) data: Current water withdrawals were modified to the amounts shown in the table below.

Month	**Diversion Flow Rate (cfs)**
January	24
February	170
March	1709
April	8,176

Month	Diversion Flow Rate (cfs)
May	8,670
June	8,872
July	10,590
August	6,748
September	6,556
October	3,277
November	425
December	220

Dworshak Dam

- TDG maximum, as referred in this section regarding Dworshak Dam, is based on an empirical equation from Columbia Basin Research study of 1998. The maximum release varies based on maximum powerhouse capacity and percentage of spill, both which are dependent on current head at the project from the forebay water surface elevation.
- Slightly Deeper Draft for Hydropower lower limits for drafting deeper during the winter months were proposed. The Flood Control Refill Curve (FCRC) targets were calculated for January and February directly from the Water Supply Forecast. The end of month targets are computed as the minimum elevation at which the space available would have a 95% likelihood of refilling by the end of June. In March the end of month targets revert to the URC elevations. To calculate the space required in January and February several steps were taken:
    - The end of month through July forecast was derived from the monthly WSF. To achieve this the expected runoff volume for the month (calculated as the % of normal of the WSF multiplied by the average runoff) was subtracted from the first-of month forecast.
    - The 95% cross-validated standard error (CVSE) of the first-of month forecast was subtracted to account for forecast uncertainty.
    - The end of month outflow volume was determined on a monthly basis to meet minimum outflows and additional reservoir operations requirements and was deducted from expected runoff volume.

  The equation and calculated metrics can be seen below. The FCRC was intended to ensure refill is reached and works backwards from the expected runoff to ensure the reservoir reaches full pool elevation by the end of July.

Month	95% Forecast Errors (KAF)	Month:	Jan, Feb, Mar, Apr, May, June, Jul
Jan	1046.6	Avg. Daily Outflow (kcfs):	1.6, 1.6, 1.6, 3.8, 1.6, 1.6, 12
Feb	776.1		
Mar	606.8		

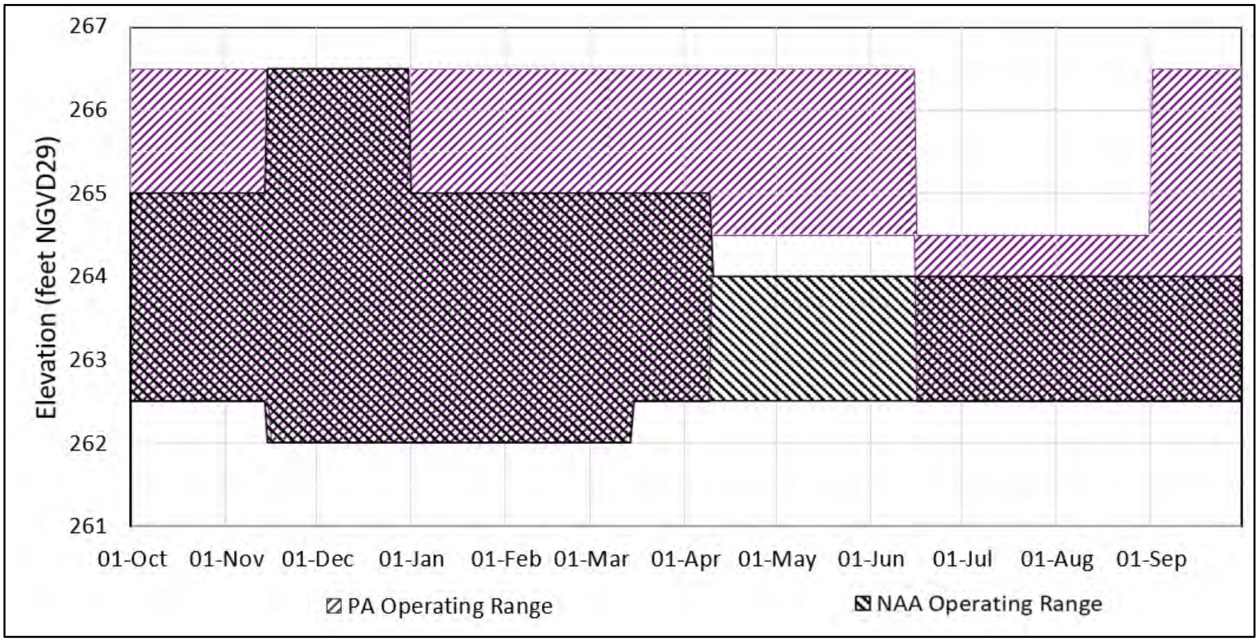
$$Jan31\ FCRC\ Target\ Space = [Fcst_{Jan1July31} - \%ofNorm_{JanWSF} * AvgRunoff_{Jan1Jan31}] - 95\%\ CVSE - Outflows_{Feb1July31}$$

- All other operations at Dworshak Dam are the same as the No Action Alternative.

Lower Snake Dams

- The measure called for modified MOP operations in the Lower Snake dams (MOP + 1.5 feet). This adjustment was incorporated by raising the model's targeted MOP by 0.5 feet. In all other respects, projects are modeled the same way as No Action Alternative.

John Day Dam



- John Day Dam is typically operated as a run of the river project unless needed for Flood Risk Management operations. There are three measures that change its operations: John Day Dam Full Pool, Predator Disruption Operations, and Increased Forebay Range Flexibility.
  - John Day Dam Full Pool allows the full use of the normal operating range (262.0 feet to 266.5 feet) outside of the fish passage season. The minimum irrigation pool (MIP - 262.5 feet) is still maintained during irrigation season from March 16 to November 15.
  - The Predator Disruption Operations limits the operating pool to the upper two feet (264.5 feet to 266.6 feet) from April 10 to June 15 to discourage bird nesting within the reservoir.
  - The Increased Forebay Range Flexibility adds a half foot to the No Action Alternative summer operating range (262.5 feet to 264.5 feet). This elevation band is held from June 16 to August 31. This elevation band ends a month earlier than the No Action Alternative.

Min	Max	Modeled	Date
262	266.5	265	Jan 1 - Mar 14
262.5	266.5	265	Mar 15 - Apr 9
264.5	266.5	265.5	Apr 10 - June 15
262.5	264.5	263.5	June 15 - Aug 31
262.5	266.5	265	Sep 1 - Nov 15
262	266.5	265	Nov 16 - Dec 31

- The transitions between the modeled elevation dates are smooth over several days so not to cause abrupt changes in outflow.
- All other operations at John Day Dam are the same as the No Action Alternative.

All Other Projects and Operations

- Same as the No Action Alternative operations.

DRAFT COLUMBIA RIVER SYSTEM OPERATIONS ENVIRONMENTAL IMPACT STATEMENT

Appendix B, Part 4

Hydrologic Data Development

EXECUTIVE SUMMARY

PURPOSE AND ORGANIZATION OF TECHNICAL APPENDIX B, PART 4

This appendix provides details on the hydrologic datasets developed for use in hydrologic analysis and reservoir operations modeling for the Columbia River System Operations and other Columbia River Basin studies. Chapter 1 provides background on why a standardized inflow dataset is needed and an overview of how it is used in modeling conducted by the U.S. Army Corps of Engineers, and describes the source and development of each hydrologic dataset. Chapters 2 and 3 describe the development of Spring and Winter Synthetic Flood Events datasets, respectively. Chapter 4 describes how a seasonal volume dataset, reflective of the trend and standard error of current forecast techniques, was created. Chapter 4 also describes the statistics that are used in Monte Carlo sampling of seasonal volume forecasts during Monte Carlo reservoir operations modeling.

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ACRONYMS AND ABBREVIATIONS

BC Hydro	British Columbia Hydro and Power Authority
Bonneville	Bonneville Power Administration
CCP	common computation point
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
CRT	Columbia River Treaty
FRM	flood risk management
HEC	Hydrologic Engineering Center
kcfs	thousand cubic feet per second
kaf	thousand acre-feet
Maf	million acre-feet
NRCS	National Resources Conservation Service
NRNI	no regulation no irrigation
NWRFC	Northwest River Forecast Center
PCA	principal components analysis
RAS	River Analysis System
Reclamation	U.S. Bureau of Reclamation
ResSim	Reservoir System Simulation
RMJOC II	River Management Joint Operating Committee II
SSP	Statistical Software Package
WAT	Watershed Analysis Tool

CHAPTER 1 - INTRODUCTION

Columbia River System hydrologic modeling uses standardized inflow datasets developed for use in hydraulic and reservoir modeling. Included in this standardized set of river system inflows are both pseudo-recorded inflows (Sections 1.2–1.5) and synthetic inflows (Chapters 2 and 3). A set of inflow volume forecasts for storage reservoirs, representing the current forecast skill, was also created (Chapter 4).

To simulate the hydrology of the Columbia River System (Figure 1-1), it is appropriate to start with measured water inflows from a long series of water years and to fill in gaps with scaled-up versions of the inflows from sample flood events. The full hydrologic dataset used for modeling the system should ideally meet the following objectives: include inputs for all modeled reservoirs and relevant tributaries, span the likely flow range to evaluate system operations with respect to high- and low-flow events, and reflect flow conditions that are not altered (regulated) by the dams/reservoirs.

An existing flow dataset for the Columbia River System, the 2010 Level Modified Streamflows dataset compiled under the Pacific Northwest Coordination Agreement in a cooperative effort among the Bonneville Power Administration (Bonneville), the U.S. Army Corps of Engineers (Corps) Columbia Basin Water Management division, and the U.S. Bureau of Reclamation (Reclamation), was used as the basis for hydrologic dataset development for the Columbia River System. The dataset is a combination of unregulated and partially regulated measured streamflows that have been adjusted to include dam/reservoir evaporation effects for all years and normalized so that the effects of irrigation are equal to the level corresponding to the last year of the dataset.

The 2010 Level Modified Streamflows dataset has been used regularly for decision support in flood risk management (FRM), power production, and water supply and it is widely accepted by operators and stakeholders throughout the Columbia River Basin as representative of the region’s hydrology (Bonneville 2011). For use in this study, the 2010 Level Modified Streamflows dataset has been modified and complemented by several other datasets. The 2010 Level Modified Streamflows dataset is primarily intended for power planning purposes. Since power planning is a fairly narrow scope, the development of supplemental datasets for Corps use for other modeling purposes is justified. For example, the dataset was supplemented with the 2010 Reclamation revised streamflow datasets for the Yakima River and the Snake River, and a dataset created to represent the 1894 flood event.

The period of record in the 2010 Level Modified Streamflows dataset is from July 1, 1928, to September 30, 2008, commonly referred to as the 1929 to 2008 period of record, since 1929 is the first water year with a complete record. A water year begins on October 1 of the previous year and ends on September 30. This 80-year period of record is not sufficiently long enough to adequately quantify the flood risk in the region. As a result, synthetic flows were developed to complement the period of record dataset and represent potential extreme flood events that are necessary to fully characterize flood risk.

Figure 1-1. Columbia River Watershed

Note: The colored shading indicates the extents of the distinct regions within the system, and dams/reservoirs are depicted with a red triangle.

Seasonal volume forecasts are a foundation of the reservoir operations models for the Columbia River Basin FRM dams/reservoirs. The objective of runoff volume forecasts is to provide estimates of the flow volume in total seasonal runoff. These forecasts can be used to guide reservoir operations that coordinate FRM and power generation. Both storage and power-generating dams/reservoirs have operational rule curves which use runoff volume forecasts to estimate the flood storage space required and the amount of power that can reliably be generated during an operating year.

The goal of this document is to provide details on the procedures and analysis used for hydrologic modeling. Chapter 1 describes the development and use of the inflow datasets for the Columbia River Basin. Chapters 2 and 3 describe the development and verification of both the Spring Synthetic Flood Events dataset and the Winter Synthetic Flood Events dataset. Chapter 4 describes the creation of the forecasted inflows for the full period of record.

1.1 BACKGROUND OF SAMPLING FORECASTS AND HYDROLOGY

The Corps uses the Columbia River System Hydrologic Engineering Center Watershed Analysis Tool (HEC-WAT) modeling framework with a Monte Carlo compute to incorporate hydrologic uncertainties into the modeling of reservoir operations for FRM. The HEC-WAT model performs hydrologic, hydraulic, and reservoir operations by integrating the specific models commonly used for each aspect of the system to quantify the operational uncertainty of the reservoir system. When the HEC-WAT framework is used, datasets and results from each model are shared with subsequent models to provide fully integrated, event-based predictions for reservoir operations.

The hydrologic sampler within the HEC-WAT model chooses a broad range of hydrologic events (hydrology and forecasts) to represent the natural variability in the period of record as potential runoff volume forecasts. The Columbia River System HEC Reservoir System Simulation (HEC-ResSim) Model emulates reservoir operations using a daily timestep, and the Columbia River System HEC River Analysis System (HEC-RAS) Model routes flood flows through the system, providing water depths and the extents of water inundation. The HEC-WAT suite of models also includes a Monte Carlo compute option such that uncertainty and variability of the inputs can be accounted for in the flood risk results. The Monte Carlo simulation incorporates knowledge uncertainties (such as flood event frequencies) and natural variability (such as flood event magnitude). This background section provides an abbreviated description of how uncertainty is incorporated into the HEC-WAT model and the application of Monte Carlo analysis.

For the Columbia River Basin, the prediction of the volume and timing of water runoff in the spring and the prediction of the peak flow frequency curve are substantial sources of uncertainty. Incorporating uncertainty is vital to understanding the implications of potential reservoir operation changes. Hydrologic uncertainties and the differences between the forecast and the observed runoff volumes are variabilities that real-time operators face in all water years. To capture the variability in the system, the Columbia River System HEC-WAT Model compute performs a Monte Carlo analysis through random sampling of flood events for the Columbia River Basin at The Dalles. The process of randomly sampling from the event collection can be visualized by imagining each event to be a marble in a jar. The size of each marble reflects its probability, with a larger marble more likely to be randomly selected than a smaller marble. One marble (event) is selected from the jar each time, and then the marble is returned to the jar prior to the next random sample.

The uncertainty in the volume and timing of spring seasonal inflow is represented in the HEC-WAT Monte Carlo computes by sampling the forecast skill at each forecast point in the basin. Forecast skill is the difference between the forecasted inflow volumes and the observed inflow volumes. Forecasts for a given year and location are generated by starting with the observed seasonal runoff volume and applying a forecast skill. The forecast skill is generated from random sampling of a probability distribution that represents current forecast skill. The skill probability distribution has been fitted to a set of parameters that are calculated from hindcasting of the current forecast method. The sampled forecast skills are entered into the hydrologic sampler model, which provides inputs for the HEC-WAT Monte Carlo compute. The inputs to the HEC-WAT model are as follows:

- A trend line that accounts for the bias towards the mean that is typical in a regression model (the trend line is described by the slope and intercept of a regression between the forecasted residual volumes and observed volumes)
- The standard error, which defines the spread in the skill around the trend line
- The serial correlation of the skill from month to month
- The minimum forecast that can be issued, which is set as the minimum from the record of forecasts

Further discussion of sampling is found in Chapter 4.

1.2 INFLOW HYDROLOGY DATASETS

The methodology selected to produce hydrologic streamflow inputs for the Columbia River System HEC-WAT and HEC-ResSim Models consisted of modifying several sets of existing streamflow datasets and supplementing them with a newly created dataset of synthetic events. The purpose was to establish an overall streamflow dataset for use in reservoir and hydraulic modeling. One of the existing streamflow datasets that was modified, the 2010 Level Modified Streamflows dataset, is based on measured data that has been modified to represent current irrigation/evaporation levels. The 2010 Level Modified Streamflows dataset, and its sister Modified Streamflows datasets, have been complemented by the addition of a Synthetic Flood Events dataset that was generated by scaling unregulated streamflows that were derived from the No Regulation No Irrigation (NRNI) Streamflow datasets. Also, the 1894 Flood Event dataset was used as another input to the Columbia River System HEC-WAT and HEC-ResSim Models to represent a known, large flood in the basin. Table 1-1 provides a description of all of the datasets and Sections 1.3 to 1.5 contain further descriptions of how the key datasets were developed.

Table 1-1. Hydrologic Streamflow Datasets, Descriptions, Developers, and Input Datasets Required

Dataset	Developed By	Datasets Used During Development	Description
CRT 2010 Level Modified Streamflows	Corps	• 2010 Level Modified Streamflows • CRT Upper Snake River 2010 Level Modified Flows • CRT Yakima River 2010 Level Modified Flows • CRT Willamette River 2010 Level Modified Flows • Lower Columbia Flows	Principle period of record input dataset for Columbia River Treaty (CRT) modeling. It contains daily local (i.e., non-cumulative) flows from July 1928 to September 2008 for the entire Columbia River Basin at CRT-specific model inflow points. It is an unregulated daily streamflow dataset. Strictly speaking, it is only semi-unregulated because regulation was removed only at major reservoirs (those reservoirs are modeled as part of the CRT effort) and at large natural lakes that are currently impounded by major dams. Historical net irrigation depletions and reservoir evaporation have been converted to 2010 level values, making this dataset a mixture of historical unregulated flows and non-historical irrigation and evaporation. The flows upstream of Brownlee are not used in current modeling efforts; Columbia River System Operations (CRSO) Brownlee Modified Flows are used instead. This dataset is used for deterministic and Monte Carlo CRSO headwater and local inflows minus the Yakima, above Brownlee, and Willamette systems.
Spring Synthetic Flood Events	Corps	• CRT 2000 Level NRNI Streamflows • 2000 Level Modified Streamflows • CRT 2010 Level Modified Streamflows	Daily local streamflows throughout the Columbia River Basin with synthetic spring freshet events that are used as rare events during Monte Carlo sampling. These events were derived by scaling the spring freshet from historical reference years that experienced substantial runoff. The flows are unregulated with net irrigation and reservoir evaporation converted to a 2000 level to make them compatible with the CRT 2000 Level Modified Streamflows. The spring freshet was scaled such that the resultant unregulated flow at The Dalles was equivalent to a 1.0, 0.5, 0.2, or 0.1 percent 60-day duration Annual Chance Exceedance spring event. The flows downstream of Bonneville Dam were not scaled and have since been replaced with the CRT 2010 Level Modified Streamflows. The flows upstream of Bonneville Dam have not been updated to reflect improvements made when creating the CRT 2010 Level Modified Streamflows. This dataset is used for Monte Carlo CRSO modeling.

Dataset	Developed By	Datasets Used During Development	Description
Winter Synthetic Flood Events	Corps	• CRT 2010 NRNI Streamflows • 2010 Level Modified Streamflows • Lower Columbia Flows • CRT Willamette River 2010 Level Modified Flows	Daily local streamflows throughout the Columbia River Basin with synthetic winter events that are used as rare events during Monte Carlo sampling. These events were derived by scaling hydrographs of individual events within a historical reference year that experienced substantial runoff. The flows are unregulated with net irrigation and reservoir evaporation converted to a 2010 level to make them compatible with the CRT 2010 Level Modified Streamflows. The winter events were scaled such that the resultant unregulated flow at the Columbia-Willamette confluence was equivalent to either a 1.0, 0.2, or 0.1 percent annual chance exceedance winter event. This dataset is used for Monte Carlo CRSO modeling.
CRSO Brownlee Modified Flows	Corps	• A variation of the 2010 Level Modified Flows for the Upper Snake River Basin provided by Reclamation • Spring Synthetic Flood Events • Winter Synthetic Flood Events	Cumulative regulated inflows to Brownlee Reservoir with irrigation depletions adjusted to a 2010 level. The flow volumes are based on a variation of Reclamation's monthly 2010 Level Modified Flows for the Upper Snake River Basin dataset. The flows were shaped to a daily timestep by the Corps. This dataset also includes synthetic events that were copied from the Spring Synthetic Flood Events and the Winter Synthetic Flood Events for the scaled portions of the year; the remainder of the year was taken from the template year.
1894 Event	Corps	• 1950s Columbia Basin Water Management 1894 dataset • CRT 2000 NRNI Streamflows	Daily streamflows of the Columbia River for the 1894 flood event. This data was used for the development of spring frequency curves and in some deterministic model runs. This dataset is used for deterministic CRSO modeling testing only.
2010 Level Modified Streamflows	Bonneville (in cooperation with Reclamation and the Corps)	• N/A – parent dataset	Semi-unregulated, daily streamflows of the Columbia River Basin, with irrigation and reservoir evaporation adjusted to a 2010 depletion level. The dataset is considered semi-unregulated because a single regulated flow is used to represent the Snake River upstream of Brownlee and a single regulated flow accounts for the Yakima River. In addition, elsewhere in the basin, regulation was only removed at major reservoirs and large natural lakes that have been impounded by dams. This dataset also includes the sub-datasets used to calculate the Modified Flows. In this table, when the 2010 Level Modified Streamflows are listed as a data source it is generally referring to these sub-datasets.

Dataset	Developed By	Datasets Used During Development	Description
CRT Yakima River 2010 Level Modified Flows	Corps	• 2010 Level Naturalized Streamflows for the Yakima River Basin	Unregulated, naturalized, daily streamflows of the Yakima River Basin. These flows consist of the 2010 Level Naturalized Streamflows for the Yakima River Basin, at the headwaters, and a Corps derivative of those flows at non-headwater locations. This dataset is sometimes referred to as a regulated flow. This is because the Yakima River Subbasin Columbia River System HEC-ResSim Model that uses these flows operates independently from the main CRT Model. Flows output from the Yakima subbasin model become the inflow at the Columbia-Yakima confluence node in the CRT System Model. The subbasin model regulates these flows and applies 2010 level irrigation depletions via a model diversion. This dataset is used for deterministic and Monte Carlo CRSO modeling.
CRT Upper Snake River 2010 Level Modified Flows	WEST Consultants, McMillen, Corps	• 2010 Level Modified Flows for the Upper Snake River Basin (gage data and drainage area ratios were also used)	Unregulated, daily streamflow dataset of the upper Snake River, which includes Brownlee Reservoir and upstream, with all streamflow data adjusted to reflect a 2010 level of irrigation depletion; irrigation not included in the flow is provided as a separate timeseries. The effects of regulation from 10 of the main reservoirs in the basin were removed. The flow volumes are based on Reclamation's monthly 2010 Level Modified Flows for the Upper Snake River Basin dataset. The flows were shaped to a daily timestep by WEST Consultants for the Corps, with some early work completed by McMillen. The Upper Snake River Subbasin Columbia River System HEC-ResSim Model uses these flows independently from the main CRT model. Flows output from that subbasin model become the inflow at the Brownlee node in the CRT System Model. This dataset has been replaced by the CRSO Brownlee Modified Flows, but was an important interim step in the development of the CRT 2010 NRNI Streamflows.
2010 Level Modified Flows for the Upper Snake River Basin	Reclamation	• N/A – parent dataset	Regulated monthly streamflows of the upper Snake River for locations upstream of Brownlee Reservoir, with all streamflow data adjusted to reflect a 2010 level of reservoir regulation and irrigation depletion. This is 14-period data.

Dataset	Developed By	Datasets Used During Development	Description
River Management Joint Operating Committee II (RMJOC II) 2010 NRNI Streamflows	River Management Joint Operating Committee (Corps, Reclamation, Bonneville)	• 2010 Level Modified Streamflows • Reclamation's Naturalized Streamflows for the Snake River Basin above Brownlee Reservoir, Yakima River Basin, and Deschutes Basin	Daily cumulative streamflows of the entire Columbia River Basin, developed by the RMJOC II. All reservoir regulation, irrigation depletion, reservoir-induced evaporation, and natural lake effects were removed from the historical flows. This dataset was generated from the 2010 Level Modified Streamflows sub-datasets and the associated irrigation source data, along with the listed Reclamation datasets.
CRT 2010 NRNI Streamflows	Corps	• 2010 Level Modified Streamflows • CRT 2010 NRNI Streamflows for the Upper Snake River Basin • 2010 Level Naturalized Streamflows for the Yakima River Basin	Daily incremental streamflows of the entire Columbia River Basin. Reservoir regulation, irrigation depletion, reservoir-induced evaporation, and natural lake effects were removed from the historical flows. Irrigation data developed as part of the RMJOC II 2010 NRNI Streamflows effort were used.
CRT 2010 NRNI Cumulative Streamflows with Natural Lakes	Corps	• CRT 2010 NRNI Streamflows Lower Columbia Flows	This dataset was used to compute frequency curves to determine the recurrence interval of the Synthetic Winter Events. It was developed by routing the CRT 2010 NRNI Streamflows and Lower Columbia Flows through a HEC-ResSim model that emulates the effects of six large historical natural lakes.
2010 Level Naturalized Streamflows for the Yakima River Basin	Reclamation	• N/A – parent dataset	Unregulated, naturalized, daily cumulative flows of the Yakima River Basin, with all reservoir regulation, irrigation depletion, and reservoir-induced evaporation effects removed from the streamflow data.
CRT 2010 NRNI Streamflows for the Upper Snake River Basin	Corps	• CRT Upper Snake River 2010 Level Modified Flows • 2010 level irrigation withdrawals obtained from Reclamation's MODSIM model for the upper Snake River Basin	Unregulated daily streamflow dataset of the upper Snake River, which includes Brownlee Reservoir and upstream. Reservoir regulation, irrigation depletion, and reservoir-induced evaporation effects from 10 reservoirs were removed from the streamflow data. This NRNI dataset was used only for the purposes of scaling synthetic events that would later be converted back to Modified Flow synthetic hydrographs, and as model input when developing the CRT 2010 NRNI Cumulative Streamflows with Natural Lakes.

Dataset	Developed By	Datasets Used During Development	Description
CRT Willamette River 2010 Level Modified Flows	Corps	• 2010 Level Modified Streamflows • Corps Northwestern Division, Portland District (NWP) daily average period of record control point flows	Unregulated, daily streamflow dataset of the Willamette River, with streamflow data adjusted to reflect a 2010 level of irrigation depletion. Unregulated flow volumes match the 2010 Level Modified Streamflows dataset, at Modified Flow points, and the NWP flow dataset at control points. This dataset is sometimes referred to as a regulated flow. This is because the Willamette River Subbasin Columbia River System HEC-ResSim Model that uses these flows is pre-run and used as input to the CRT System Model. Flows output from the subbasin model become the inflow at the model node above Willamette Falls in the CRT System Model.
Lower Columbia Flows	Corps	• N/A – parent dataset	The 2010 Level Modified Streamflows dataset did not account for all of the flow downstream of Bonneville Dam; that flow was not required for hydroregulation studies. The Lower Columbia Flows dataset accounts for the missing flow. It was developed by extending historical gaged data, and in some cases by using a drainage area method. Irrigation was assumed to be negligible and was therefore not adjusted to a 2010 level. Regulation was also deemed unimportant, and therefore not removed.
Extended Observed Flows	Corps	• N/A – parent dataset	This dataset contains four sub-datasets for water years 2008 to 2016 that were created with a similar, but much simplified, method to that of the 2010 Level Modified Streamflows. This dataset includes local inflows at the common computation points of the Columbia River System HEC-ResSim Models, cumulative flow outputs from an unregulated model with the effects of natural lakes, cumulative flow outputs from an unregulated model without the effects of natural lakes, and cumulative outflows from a regulated model that maintains several of the observed reservoir elevations. This dataset is used for CRSO extended year modeling for the water quality impacts team.

Note: The term “unregulated” is used loosely in this table and typically means that regulation was removed only at major reservoirs. When regulation was removed, the effects of the natural lakes that were impounded by dams were also removed. Irrigation was not removed, except for NRNI flows, but was adjusted in some instances, as described.

1.3 CRT 2010 LEVEL MODIFIED STREAMFLOWS DATASET

The CRT 2024 Review HEC-ResSim Model Inflow hydrology dataset was created as an intermediate step of distributing streamflow data to the Columbia River System HEC-WAT and HEC-ResSim Model nodes. The inflow dataset was created from three parent datasets whose flow locations did not always coincide with the model nodes. The three parent datasets were manipulated and distributed to align with the model nodes, forming the final inflow dataset termed the CRT 2010 Level Modified Streamflows. The three parent datasets are as follows:

- 2010 Level Modified Streamflows
- CRT Upper Snake River 2010 Level Modified Flows
- CRT Yakima River 2010 Level Modified Flows

The 2010 Level Modified Streamflows dataset is the largest of the three datasets and its development was coordinated by Bonneville (2011) with active and consistent participation by management and technical staffs from the Corps and Reclamation. The recorded flows were adjusted so that the amount of irrigated acres for all years was the same as had been irrigated in 2008 (for 2010 level flows). There is ample detail in the 2010 Level Modified Streamflows (Bonneville 2011) report as to how the flows were developed. Note that because irrigation depletions were modified for all years, coincident adjustments to evapotranspiration were made. Although current levels of reservoir evaporation and irrigation depletions were included in the flows, reservoir storage was removed, making the flows unregulated (see 2010 Level Modified Streamflows for more details on the incorporation of irrigation and evaporation effects in this dataset). The primary dataset used to develop the CRT 2010 Level Modified Streamflows, which are local incremental unregulated flows, was the 2010 Level Modified Streamflows. At many locations in the Columbia River System hydrologic models there was no 2010 Level Modified Streamflow data available for tributary flows. The flows for these tributaries were calculated using a disaggregation process reported in *Distribution of 2010 Level Modified Streamflows* (Corps 2015).

The 2010 Level Modified Streamflows dataset does not incorporate some portions of the Willamette and lower Columbia River Basins. The excluded regions were not important to the 2010 Level Modified Streamflow study, but are important for use in the Columbia River System HEC-ResSim Models used in this study. Flows for the regions omitted from the 2010 Level Modified Streamflows study were developed for this study by extending the recorded gage data in the region. These flows can also be thought of as a supplemental dataset.

Therefore, the Willamette Basin was disaggregated in a separate process than the one used for the rest of the Columbia River System, as discussed above, because the 2010 Level Modified Streamflows dataset did not include flows at control point locations used for reservoir regulation decisions in the Willamette. A supplemental dataset developed by the Corps Portland District for earlier reservoir studies was used as local flow inputs at the control point locations. Modified flows at locations downstream of these control points were then reduced using routing analyses so that total flows matched the 2010 Level Modified Streamflows.

The second parent dataset, CRT Upper Snake River 2010 Level Modified Flows, was derived from a Reclamation monthly Modified Flows dataset. This dataset was shaped to a daily timestep using nearby gage data as a shaping pattern. The shaped dataset was developed at model nodes and did not require disaggregation.

The third parent dataset, CRT Yakima River 2010 Level Modified Flows, is based on daily timestep data provided by Reclamation. The 2010 level dataset was developed as part of the 2000 level effort. As a result, this dataset was used “as-is” with no additional work required for the current effort.

Two final datasets were created, the Spring Synthetic Flood Events and Winter Synthetic Flood Events datasets. These datasets simulate rare flood events and were created by scaling up template flood events from selected winter and spring flood years.

Brownlee inflows are identical to CRSO Brownlee Modified Flows in 1928 to 2008 model runs, and in non-scaled portions of synthetics. Scaled portions of synthetic flows use CRT Upper Snake River 2010 Level Modified Flows hydrology with HEC-ResSim regulation.

1.3.1 2010 Level Modified Streamflows Dataset

The first Modified Flows dataset for the entire Columbia River Basin was developed in 1957 for the period of record from 1928 to 1948. The most recent update to the dataset was completed in 2010 and covers the period of record from 1929 to 2008; development of the 2020 Level Modified Streamflows dataset was scheduled to begin in late 2018.

The 2010 Level Modified Streamflows dataset assigns a complete period of record (1929 to 2008) total streamflow series to selected locations within the basin called modified flow points (Bonneville 2011). The gaged daily streamflow data for the period of record was converted to an unregulated condition using recorded changes in reservoir storage. Evaporation and/or irrigation depletion adjustments were used to normalize the data to the year 2010 level of irrigation depletion and evaporation. The input needed for the Columbia River HEC-WAT and HEC-ResSim Models are local streamflow contributions rather than total streamflows. Therefore, the original 2010 Level Modified Streamflows dataset was split into the local contributions. The resulting local streamflow contributions form the CRT 2010 Level Modified Streamflows dataset.

The 2010 (and 2000) Level Modified Streamflows dataset represents a semi-regulated condition because the effects of evaporation and the irrigation diversions are incorporated in the flows, while the flows within Canada incorporated irrigation. In addition, the effects of reservoir regulation within the Yakima River Basin, Deschutes River, and the Snake River Basin upstream of Brownlee Reservoir are included in the final 2010 Level Modified Streamflows dataset. Inflows from these three regulated basins were developed by Reclamation as a special study, which is discussed below. Also, the effects of regulation from smaller dams or utility-owned dams with limited flood control capacity remain in the dataset.

Studies were conducted to remove the reservoir regulation effects from the 2010 Level Modified Streamflows for the Upper Snake River Basin dataset. The Deschutes River 2000 Level Modified Streamflows dataset was used as-is with dam/reservoir regulation effects included. The rationale for including the Deschutes River 2000 Level Modified Streamflows dataset with regulation (as opposed to removing regulation effects) was that the flood storage capacity of the basin was relatively small compared to other dams/reservoirs in the Columbia River Basin, making the regulation effects negligible.

1.3.2 Upper Snake River CRT 2010 Level Modified Streamflows Dataset

The CRT Upper Snake River 2000 Level Modified Flows dataset incorporates the upper Snake River inflows upstream of Brownlee Reservoir. This data is based on the Reclamation monthly data that is shaped to a daily timestep by WEST Consultants for the Corps, with some early work completed by McMillen (Robison and Jensen 2011; WEST Consultants 2011). For the 2010 level update, the Corps extended the 2000 level data using spreadsheets and macros furnished by WEST Consultants for shaping the flows. No attempt was made to alter or otherwise improve WEST Consultants’ methodology. Like the other Modified Flow datasets, this dataset was created by removing the effects of reservoir regulation from historical data for major reservoirs and converting historical irrigation depletions and evapotranspiration to 2010 levels. These 10 major reservoirs are American Falls, Anderson Ranch, Arrowrock, Brownlee, Cascade, Deadwood, Jackson Lake, Lucky Peak, Owyhee, and Palisades.

Monthly streamflow volumes were determined from the 2010 Level Modified Flows for the Upper Snake River Basin, which are discussed in detail in Modified and Naturalized Flows of the Snake River Basin above Brownlee Reservoir (Parkinson 2010). This dataset, developed by Reclamation using their MODSIM model, is a monthly regulated flow dataset based on historical records simulated to reflect 2010 level reservoir regulation and irrigation demands. The dataset was developed by removing the effects of reservoir regulation from the Reclamation dataset for the 10 major reservoirs, and converting the flow to a daily timestep by shaping the monthly volumes to gaged stream data. In some cases gaged data did not span the full period of record and were extended using the MOVE1 technique (Hirsch 1982). MOVE1 is based on linear regression, where regression parameters are set to maintain the mean and variance of the location being predicted. For this application, the technique uses standardized monthly flows in the region to reconstruct unregulated data for streams that have been gaged for short time periods. In cases where gages were not available, the daily flows were derived using drainage area ratios.

When shaping the monthly volumes to gaged stream data, WEST Consultants conserved volume by shaping each month independently. This resulted in a discontinuity at the first of each month, which sometimes resulted in completely artificial, near vertical, peaks. For most of the sites these artificial peaks were small compared to the hydrologic signal, but at some sites, such as on the Boise River at Parma the artificial peaking is very prominent. As a result of the artificial peaking in the Boise River and other locations, the WEST Consultants upper Snake River hydrology is likely to be less reliable for FRM within the upper Snake River than other sections of the basin. This phenomenon was not rectified during the 2010 update because the cumulative impact at The Dalles was small.

1.4 1894 FLOOD EVENT DATASET

The largest flood event recorded in the 150 years of records for the Columbia River Basin occurred on June 6, 1894. As a major historical flood event, the 1894 flood provides additional information about peak and duration beyond the period of record of the dataset.

Streamflow data from the 1894 flood event is available for several locations throughout the basin (Figure 1-2). The dataset was originally developed in the 1950s by using the hydrograph for the 1894 flood at The Dalles since the historical data at The Dalles is considered to be the most reliable. Observed 1894 streamflow data upstream of The Dalles was sparse and the distribution of the flows was based on a developed watershed area/runoff diagram for the Columbia River Basin.

The original 1894 streamflow data includes locations where either total flow, local flow, or both are available. The original dataset was (1) inspected and adjusted if the flow data did not match the additionally available peak flow historical records from the 1894 flood, (2) extended to represent the entire 1894 water year (instead of only the 1894 flood event), and (3) distributed to the same locations that are represented within the hydrology models. The purpose of this step was to obtain local streamflow that was compatible for use as input to the hydrology models.

In order to distribute the 1894 streamflow data to the same locations that are represented within the hydrology models, each location was linked to the hydrologically nearest location represented within the 1894 total streamflow data. For each location that has 1894 total streamflow data, a spring flood event at the same location was selected from the period of record.

In order to obtain a complete 1894 total streamflow dataset at all locations represented in the hydrology models, the local inflows included in the newly developed 1894 Flood Event dataset were used as input to an unregulated HEC-ResSim model of the Columbia River Basin with natural lake effects. The output from the HEC-ResSim model was then compared to the available original 1894 total streamflow data at selected locations to match for accuracy.

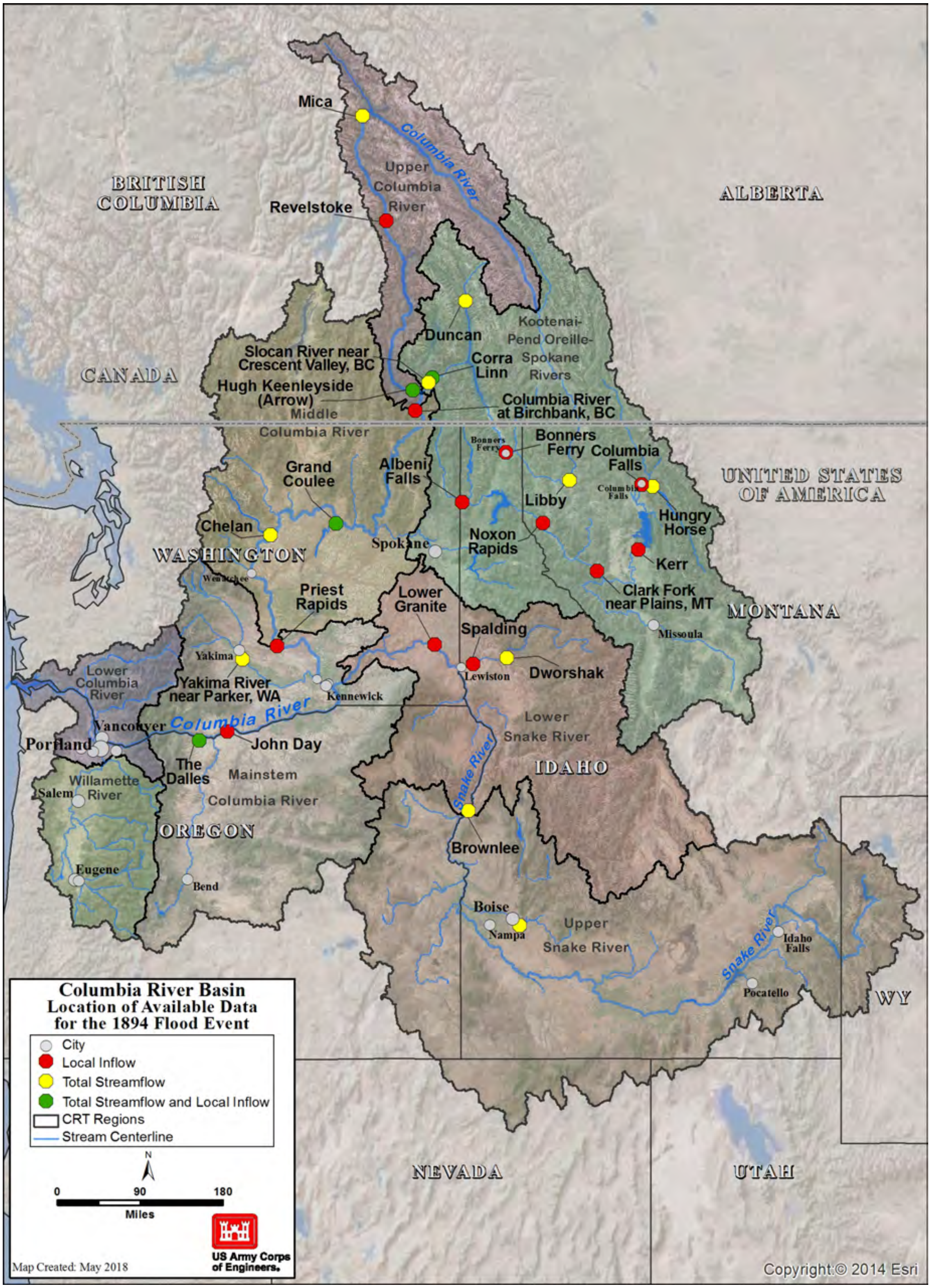


Figure 1-2. Locations where Water Inflow Data is Available for the 1894 Flood Event

1.5 COLUMBIA RIVER TREATY NO REGULATION NO IRRIGATION STREAMFLOWS DATASET

The NRNI dataset was developed to best represent a more natural streamflow in the Columbia River Basin and coastal basins in the Pacific Northwest without the effects of water resources development. The challenge with creating the NRNI dataset for the entire Columbia River Basin is that the systematic record of streamflow observations includes dam construction and operations, irrigation withdrawals and returns, and other developments which changed the natural flow regime. In addition, development of this infrastructure occurred throughout the twentieth century, which means the adjustments to the observed streamflows are spatially and temporally variable. A common practice by Bonneville, the Corps, and Reclamation is to create a homogeneous dataset of streamflows which reflect the current level development (2010 Level Modified Streamflows). The Modified Flows are then used to create the NRNI dataset. Appendix A of the 2010 Level Modified Streamflows report contains a list of flow locations that were used for the NRNI flow calculations and includes information on which locations use regulated, unregulated, and routed flow values.

The NRNI flows are used to create the synthetic flood hydrographs for assessing flood risk impacts for the Columbia River Basin. A key utility of this dataset is that it allows for more accurate calibration of hydrology models that simulate streamflow without of the effects of irrigation depletion and reservoir regulation. The NRNI flows also provide a more suitable basis for bias-correction for hydrology models such as the University of Washington variable infiltration capacity model. The NRNI data is more consistent with what is represented by processes in the hydrology models, thus the model calibration, simulated streamflow, and bias corrected products are likely to be more accurate. Locations where NRNI data was generated are shown in Figure 1-3.

HEC-ResSim Hydrology CCPs are those that are used as input locations within the Columbia River System HEC-ResSim Model (Table 1-2).

The process for developing NRNI streamflows includes calculating either observed or adjusted-observed streamflows, and then adding or subtracting volumes where anthropogenic activities have influenced the observations. The impacts of evaporation from reservoirs are also included in the adjustments to the observed streamflows. Both the irrigation and evaporation volumes for the 2010 Level Modified Streamflows and NRNI flows originate from the same source data. The main difference between the two datasets is that the 2010 Level Modified Streamflow irrigation depletions and evaporations use water year 2008 data for all years. The NRNI represent streamflow conditions without irrigation depletion and reservoir evaporation conditions rather than with irrigation depletion and evaporations from a specific water year.

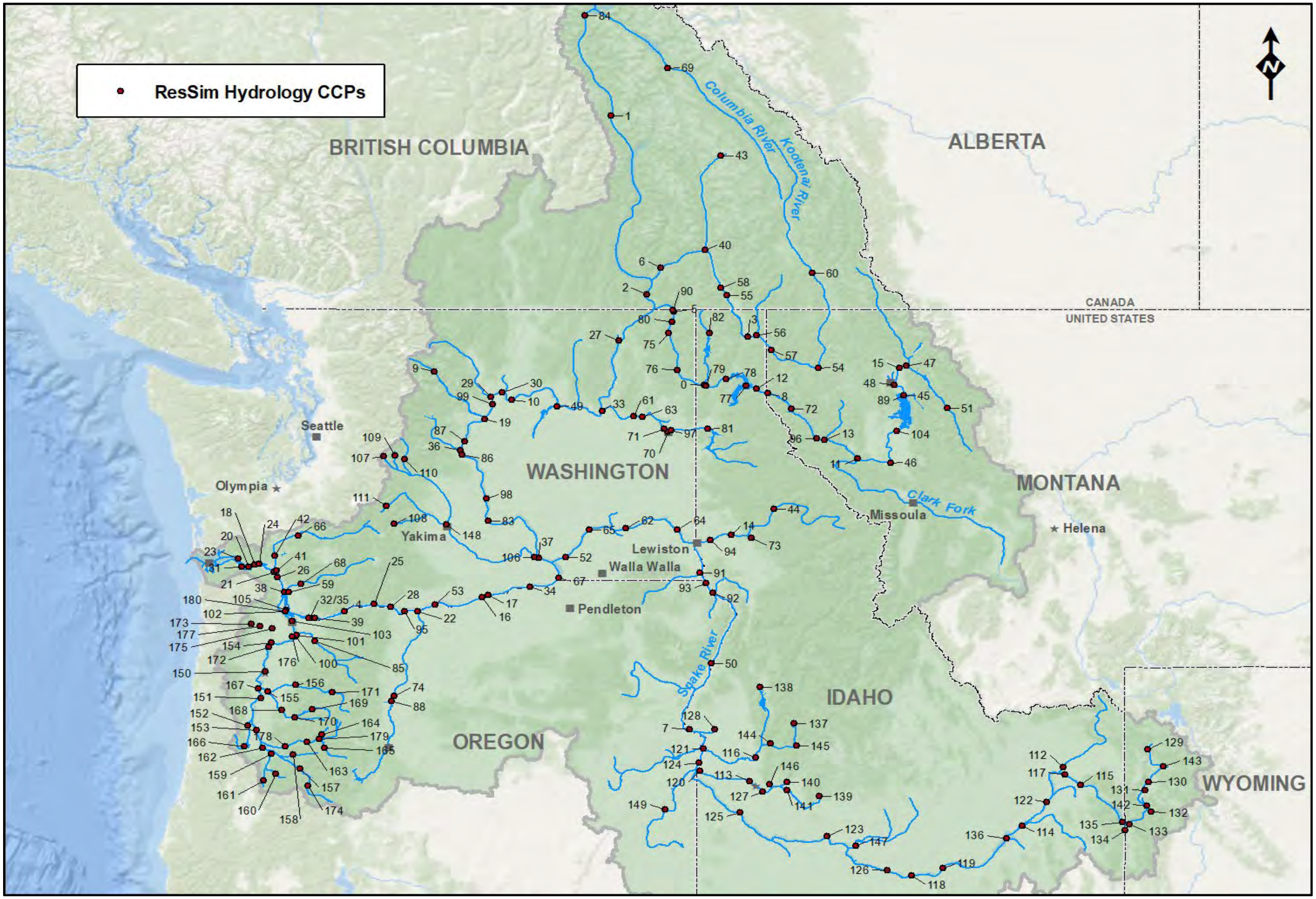


Figure 1-3. No Regulation No Irrigation Water Inflow Timeseries Locations

Note: CCP = common computation point.

Table 1-2. HEC-ResSim Locations by Common Computation Point

CCP	HEC-ResSim Location	CCP	HEC-ResSim Location	CCP	HEC-ResSim Location
0	Albeni Falls_IN	61	Little Falls_IN	121	Payette
1	Arrow Lakes_IN	62	Little Goose_IN	122	Shelley
2	Birchbank	63	Long Lake_IN	123	King Hill
3	Bonners Ferry	64	Lower Granite_IN	124	Nyssa
4	Bonneville_IN	65	Lower Monumental_IN	125	Murphy
5	Boundary_IN	66	Mayfield	126	Kimberly
6	Brilliant_IN	67	McNary_IN	127	DD_Boise nr Boise
7	Brownlee_IN	68	Merwin	128	Weiser_HW
8	Cabinet Gorge_IN	69	Mica_IN	129	Jackson Lake_IN
9	Chelan_IN	70	Monroe Street_IN	130	Moose
10	Chief Joseph_IN	71	Nine Mile_IN	131	Gros Ventre_HW
11	Clark Fork+Flathead	72	Noxon Rapids_IN	132	Hoback_HW
12	Clark Fork+Lightning Ck	73	Orofino	133	Greys_HW
13	Clark Fork+Thompson	74	Pelton_IN	134	Salt_HW
14	Clearwater+Potlach	75	Pend Oreille @ Box Canyon	135	Palisades_IN
15	Columbia Falls	76	Pend Oreille+Calispel Ck	136	American Falls_IN
16	Columbia nr Willow Ck	77	Pend Oreille+Clark Fork	137	Deadwood_IN
17	Columbia+Alder CK	78	Pend Oreille+LakePendOreille_IF	138	Cascade_IN
18	Columbia+Beaver Ck	79	Pend Oreille+Priest	139	Anderson Ranch_IN
19	Columbia+Chelan	80	Pend Oreille+Sullivan	140	Arrowrock_IN_MF
20	Columbia+Clatskanie	81	Post Falls_IN	141	Arrowrock_IN_SF
21	Columbia+Cowlitz	82	Priest Lake_IN	142	Snake DS Flat_Ck
22	Columbia+Deschutes	83	Priest Rapids_IN	143	Buffalo_HW
23	Columbia+Elochoman	84	Revelstoke_IN	144	Payette MF_HW
24	Columbia+Germany Ck	85	River Mill	145	Payette SF_HW
25	Columbia+Hood+Salmon	86	Rock Island_IN	146	Mores_HW
26	Columbia+Kalama	87	Rocky Reach_IN	147	Gooding_HW
27	Columbia+Kettle	88	Round Butte_IN	148	Yakima+Naches
28	Columbia+Klickitat	89	SKQ_IN	149	Owyhee_IN
29	Columbia+Methow	90	Seven Mile_IN	150	Willamette_at Salem
30	Columbia+Okanogan	91	Snake+Grande Ronde	151	Willamette_at Albany
31	Columbia+Plympton Ck	92	Snake+Salmon	152	Long Tom_at Monroe
32	Columbia+Sandy	93	Snake_RM178.27	153	Willamette_at Harrisburg
33	Columbia+Spokane	94	Spalding	154	Willamette_at Newberg
34	Columbia+Umatilla	95	The Dalles_IN	155	Santiam_at Jefferson
35	Columbia+Washougal	96	Thompson Falls_IN	156	No Santiam_at Mehama
36	Columbia+Wenatchee	97	Upper Falls_IN	157	Lookout Point_IN
37	Columbia+Yakima	98	Wanapum_IN	158	Fall Creek_IN
38	Columbia_at Multnomah Channel	99	Wells_IN	159	CF Willamette_nr Goshen
39	Columbia_at Washougal	100	Willamette Falls	160	Dorena_IN

CCP	HEC-ResSim Location	CCP	HEC-ResSim Location	CCP	HEC-ResSim Location
40	Corra Linn_IN	101	Willamette+Clackamas	161	Cottage Grove_IN
41	Cowlitz+Coweeman	102	Willamette_at Columbia Slough	162	Willamette_at Eugene
42	Cowlitz_at Castle Rock	103	Willamette_at Portland	163	McKenzie_at Vida
43	Duncan_IN	104	Kerr_IN	164	Blue River_IN
44	Dworshak_IN	105	Columbia+Willamette	165	Cougar_IN
45	Flathead @ Flathead Lake	106	Yakima_Modified	166	Fern Ridge_IN
46	Flathead+Mission+Jocko	107	Keechelus_IN	167	Willamette+Luckiamute
47	Flathead+SF	108	Tieton_IN	168	So Santiam_at Waterloo
48	Flathead+Stillwater	109	Kachess_IN	169	Green Peter_IN
49	Grand Coulee_IN	110	Cle Elum_IN	170	Foster_IN
50	Hells Canyon_IN	111	Bumping Lake_IN	171	Detroit_IN
51	Hungry Horse_IN	112	Rexburg Gage	172	Willamette+Yamhill
52	Ice Harbor_IN	113	Glenwood Bridge	173	Scoggins_IN
53	John Day_IN	114	Blackfoot_HW	174	Hills Creek_IN
54	Kootenai+Fisher	115	Heise	175	Tualatin_at Farmington
55	Kootenai+Goat	116	Horseshoe Bend	176	Tualatin_at West Linn
56	Kootenai+Moyie	117	Lorenzo	177	Tualatin_at Dilley
57	Kootenai+Yaak	118	Milner	178	McKenzie R. NR Walterville
58	Kuskunook	119	Minidoka	179	McKenzie+SF McKenzie
59	Lewis+EF Lewis	120	DD_Boise nr Parma	180	Willamette+Columbia Slough
60	Libby_IN				

The NRNI total flows are defined with an equation that identifies the constituent components making up the NRNI daily timeseries. Generally speaking, the individual site equation is composed of an average daily unregulated inflow as well as accumulated irrigation depletion and evaporation components. NRNI uses the dam/reservoir inflows and routed streamflows developed in the 2010 Level Modified Streamflow study and removes the irrigation depletion and evaporation. Irrigation withdrawals and return flows were derived using individual state and Federal diversion reports along with streamflow records and U.S. Department of Agriculture sprinkler and gravity irrigations and monthly rates of irrigation depletion and returns. Calculations were performed to estimate the daily irrigations/return flows with no dams in place. The Canadian return flows did not incorporate sprinkler or gravity irrigation as part of the overall irrigation depletions. Evaporation adjustments were made to the unregulated streamflow to reflect pre-dam conditions.

CHAPTER 2 - DEVELOPMENT OF SPRING SYNTHETIC FLOOD EVENTS DATASET

The objective of the spring synthetic hydrology analysis was to supplement the measured streamflow hydrology with flood events that are larger and less frequent than those available in the 2000 Level Modified Streamflows dataset. A basinwide Spring Synthetic Flood Events dataset was created based on measured flood events and their respective temporal and spatial patterns from the CRT 2000 Level NRNI Streamflows.

In order to quantify the severity of a specific flood at a location, it is important to define the peak flow, magnitude over a specific duration of time (i.e., 1 day, 5 days, 30 days, etc.), and return period. To quantify these parameters, a frequency analysis of maximum volumes from the CRT NRNI Streamflow dataset was performed using the Log-Pearson Type III distribution. These volumes were compiled into sets of curves called volume duration frequency curves, which were used to generate the Spring Synthetic Flood Events. The frequency of an event (1.0 percent, 0.2 percent, etc.) is defined as the annual chance exceedance probability and is the inverse of a return period.

In summary, the methodology to create the Spring Synthetic Flood Events follows a similar process as outlined in the article “Synthetic Rain Flood Hydrology for the Sacramento and San Joaquin River Basins” (Hickey et al. 2002):

- The computed set of volume duration frequency curves reflecting unregulated conditions was referenced to determine the unregulated flood volume associated with a chosen annual chance exceedance probability at a downstream location. The volume centering location was The Dalles Dam location. For each water year in the period of record, a date-specified timespan, called the flood window, was used to confine the timespan from which yearly peak duration streamflows can be selected.
- A flood volume matrix analysis was performed to identify basinwide temporal and spatial flooding patterns during extreme events. The flood volume matrix analysis used the volume duration frequency curves to analyze spatial relationships between each location’s local streamflow annual chance exceedance for a specified flood event.
- Using the results from the flood volume matrix analysis, flood events were selected and used as template flood events to be scaled to create synthetic flood events at The Dalles with specific annual chance exceedance probabilities.
- The template events were iteratively scaled with multipliers such that the streamflow duration volume at The Dalles equaled the 60-day duration volume of each annual chance exceedance probability from the volume duration frequency curve. If the total routed flood volume at The Dalles was within a 1 percent tolerance of the flood volume associated with the chosen annual chance exceedance, the scaled local inflows were accepted as part of the Spring Synthetic Flood Events dataset. If the streamflow volume was not within the 1 percent tolerance, the local streamflows associated with the template historic flood event were rescaled, rerouted, and the flood volumes at The Dalles were rechecked. Large historical natural lakes (now impounded by dams) were modeled during this process to

match routed volumes to the volume duration frequency curves, which also accounted for these natural lakes.

- Before finalizing, the streamflow data in the Spring Synthetic Flood Events dataset was adjusted to include the same reservoir regulation, irrigation depletion, and evaporation effects as reflected in the 2000 Level Modified Streamflows dataset.
- The Spring Synthetic Flood Events downstream of Bonneville Dam were not scaled. Instead, the CRT 2010 Level Modified Streamflows were used. They were not scaled due to their lesser impacts on spring flows and because the target scaling location for spring events was at The Dalles, which is unaffected by the flow downstream of Bonneville.
- For Brownlee Reservoir synthetic inflows, the non-scaled portions of synthetic events were identical to the CRSO Brownlee Modified Flows. Scaled portions (winter for winter synthetics, and spring for spring synthetics) used the techniques described above and below.

There are substantial uncertainties and limitations in the hydrograph scaling approach when extrapolating stage or outflow response beyond the observable record. First, the probability space of any given duration can vary within one observed hydrograph. For example, the 60-day duration of an observed hydrograph for a given location could be equivalent to a 100-year probability on a 60-day volume duration frequency curve. . Additionally, capturing a hydrologic regime driven by snowmelt volume in a model is more difficult than creating a rain flood model. Therefore, the required simplifying assumptions made via hydrograph scaling cover a broader area of hydrology.

The base NRNI dataset, which was used to create spring synthetics, does not reflect the attenuation due to the occurrence of natural lakes in locations where they were converted to reservoirs later in the period of record. There are 24 locations in the NRNI dataset in which natural lakes would be considered naturally occurring but were not accounted for in the base hydrologic dataset used for the synthetic hydrologic development.

2.1 SOURCE OF COLUMBIA RIVER FLOODING FOR SYNTHETIC YEARS

The synthetic flood events were linearly scaled up from observed, template water years that provide an array of types of flood events. To create these synthetic flood events, the template year's spring freshet hydrographs from different parts of the basin were increased by approximately 30 percent, and up to 50 percent. Six different water year templates were used to create different shaped hydrographs ranging from the 1 to 0.1 percent annual chance exceedance events. These six template years encompass all of the types of flow characteristics, such as snowmelt, rain on snow, and rain only that could have been the source of flooding in the lower basin. Section 2.1.2, below, describes each of the template years chosen and the type of flood event (rain, snowmelt, etc.) that they provide. Flow data for the synthetic water years was stored as if they occurred during water years 3012 to 3109 and the template water year that was used for each synthetic is listed in Table 2-1.

Table 2-1. Synthetic Water Year Descriptions, Template Years, and Probability of Occurrence

Synthetic Water Year File Name	Percent Recurrence Probability	Template Water Year
3012[1/]	1894 event	1894, 1961
3013	1.0	1948
2014	0.5	1948
3015	0.2	1948
3016	1.0	1956
3017	1.0	1971
3018	1.0	1972
3019	0.5	1972
3020	0.2	1972
3021	0.1	1972
3022	1.0	1974
3023	0.5	1974
3024	0.2	1974
3025	1.0	1997
3026	0.5	1997
3027	0.2	1997
3028	0.1	1997
3101	1.0	1934
3102	0.5	1965
3103	0.2	1965
3104	0.1	1965
3105	1.0	1974
3106	1.0	1982
3107	0.5	1996
3108	0.2	1996
3109	1.0	1997

1/ Synthetic Water Year 3012 is based on the “observed” hydrograph for 1894 for The Dalles location with scaled hydrographs from template water year 1961 from the 2000 Level Modified Streamflows dataset for other locations.

2.1.1 Study Background

The two types of flood events include rain on snowmelt driven floods, such as that seen in 1948, and pure snowmelt driven floods, such as the flood of 1974. Both of the example events produced unregulated flows above 1,000 thousand cubic feet per second (kcfs) at The Dalles. The research into the specific years was to address the plausibility of being able to scale these years to large flows. For example, water year 1948 could have been bigger because the snowpack was large, but it was not near record snowpack, and it is easier to add rain to an event to make it larger. After this research it does seem plausible that all of the years could be increased by 30 percent to perhaps up to 50 percent. The reasoning is that even a pure snowmelt year such as 1974 could have a rain event added to the snowmelt peak, causing a larger peak and volume.

2.1.2 Specific Water Years

Meteorological conditions for all of the water years were documented from a variety of resources to search for May and June heat waves or rainy periods. It is often difficult to tell which set of hydrologic conditions are the dominant flood driver, such as the proportion of snowmelt versus a rain event, unless there is an obvious dry and warm weather pattern. Most of the time there is at least some snowmelt in the system, which increases during heat waves and decreases when it is cooler and rainy. When rainy periods are observed, it is difficult to discern if it is rainy enough to be an important driver of the increased flows.

The following sections describe each of the template water years that were used to create the synthetic hydrology. Within the following sections and datasets, the term “unregulated” is used loosely and typically means that regulation was removed only at major reservoirs. Therefore, the peak flows should not appear as truly unregulated flows.

2.1.2.1 Reference Water Year 1948

For water year 1948, the peak of the flood event occurred in late May to early June with an unregulated peak water flow at The Dalles of 1,010 kcfs. The weather leading into the flood event was cool with snowpack near normal to above normal, which extended into the middle of May. As the modest background snowmelt runoff increased, a widespread rainstorm occurred from May 19 to 23. Another rainstorm, with considerable convective showers falling in the middle basin, occurred from May 26 to 29. The air temperature increased to above normal during this 2-week rainy period.

2.1.2.2 Reference Water Year 1956

For water year 1956, the peak of the flood event was from May 20 to June 6. The unregulated peak at The Dalles was 940 kcfs. It was a wet winter with record snowpack. A warm late March produced record April water surface elevations with little rainfall. May was cool with well above normal precipitation. The week from May 4 to 11 had the total precipitation of an average May. Freezing levels were above 12,000 feet from May 15 through June 4 with temperatures between low 80s°F and low 90s°F (around 30°C). There was a substantial rain event on the Snake River on May 24. June was both warm and cool with fairly generous rainfall. The heat-wave snowmelt was likely the primary driver of water flows in late May, with rain as a secondary driver of water flow in June.

2.1.2.3 Reference Water Year 1971

The peak of the flood event for water year 1971 was May 31. The unregulated peak at The Dalles was 740 kcfs. The snowpack was of unknown volume and it was assumed to be normal or above normal. There was a heat wave that occurred in early May with temperature in the 80s°F (30s°C). There was rain for May and much of June. Over that 2-month period, rain and snowmelt were both the likely flow drivers; however, there is a chance that rain may have occasionally been the dominant driver of flow.

2.1.2.4 Reference Water Year 1972

For water year 1972, the peak of the flood event was from May 31 through June 14. The unregulated peak was 1,053 kcfs. The snowpack volume was above normal, and, in some cases, at record levels. The snowpack lingered into April and May with occasional rain, and additional snow in the higher elevations. A heat wave hit in late May into early June, which increased runoff. The heat wave melting the snow is the likely the cause of the peak flow, but rain may have influenced the peak, as well.

2.1.2.5 Reference Water Year 1974

The peak of the flood event for water year 1974 was in the middle of June. The unregulated peak at The Dalles was 1,010 kcfs. There was a very large snowpack with record levels at many places. There was no significant liquid precipitation involved during the peak flow event. Most of the rest of the spring remained cold with a lot of snow in the regions of the river headwaters. On June 10, temperatures rose to 90°F to 100°F (32°C to 38°C) in the Columbia River Basin and stayed, on average, 13 degrees Fahrenheit (7 degrees Celsius) above normal until June 25. Therefore, much of the runoff into the streams consisted of snowmelt.

2.1.2.6 Reference Water Year 1997

The flood event for 1997 started in middle of May and lasted through most of June. The unregulated peak was 896 kcfs. It was a cool, wet spring with additional mountain snow accumulation up until early May. The snowpack was 110 to above 130 percent of the normal May 1 snow-water-equivalent. A modest heat wave developed (70s°F to mid-80s°F [20s°C to low 30s°C]) in the middle of May, with mainly dry weather. The peak streamflow was mainly driven by snowmelt, but there was additional rain in June.

2.2 VOLUME DURATION FREQUENCY ANALYSIS

Unregulated streamflows must be used for analytical methods to estimate volume duration frequency curves based on the guidelines contained in Bulletin 17B (Interagency Advisory Committee on Water Data 1982). This work was completed prior to the release of Bulletin 17C. The cumulative streamflows in the CRT NRNI dataset were used to develop streamflow versus frequency curves, fitting log-Pearson Type III distributions, by using annual maximum streamflow values for specified durations at the selected locations. An example of a set of developed volume duration frequency curves for the White Bird gage on the Salmon River is shown in Figure 2-1. These streamflow versus frequency curves are termed volume duration frequency curves. For each location, the flood volume corresponding to a selected annual chance exceedance value can be obtained from the corresponding volume duration frequency curve by multiplying the curve-indicated streamflow value by the duration. Annual maximums (i.e., annual maximum streamflows for selected durations) were used instead of instantaneous maximums (i.e., annual maximum streamflows at a particular time) to generate the distributions because they are more informative in regard to reservoir operations and the volume of water moving through a dam/reservoir over a given period of time.

Annual duration maximums for both local and total streamflows were computed based on the balanced hydrograph approach described in Cudworth (1989). The balanced hydrograph method consisted of computing moving averages of flow data for specific durations within a flood window for each water year at each location. Annual maximums of the moving averages (annual duration maximums) were used to develop volume duration frequency curves.

The number of distinct durations used to calculate the annual duration maximums at each location depended on the location's flood window. The standard durations (moving averages) used throughout the basin were 1, 5, 10, 15, 30, 45, 60, 90, 120, 150, and 180 days.

Skew coefficients, which indicate the symmetry of a distribution and were computed for each CRT NRNI Streamflow dataset location, are needed in order to describe the concavity of the volume duration frequency curves. For each location for which volume duration frequency curves were developed, Bulletin 17B (Interagency Advisory Committee on Water Data 1982) suggests using a (spatially) weighted skew coefficient instead of simply using the skew value computed for a single streamflow location. The suggested weighted skew coefficient is a weighted average of the skew coefficient computed at the location for which volume duration frequency curves are developed and a regional (generalized) skew coefficient. The inclusion of the weighted skew is mostly intended for analyses where the period of record is relatively small and therefore there is a high likelihood of an outlier having an excessively large influence on the skew coefficient. In this study, the necessity of computing a generalized skew coefficient is reduced due to the long period of record of the CRT NRNI Streamflow dataset. Regardless, weighted skew coefficients were used for the development of the volume duration frequency curves, and generalized skew coefficients were developed for both total and local CRT NRNI Streamflows for each duration. The generalized skew coefficients were determined through the creation of an isoline map of skew coefficients computed for each location within the CRT NRNI Streamflow dataset.

To generate the Columbia River Basin–specific generalized skew coefficients, a series of local and total streamflow isoline maps of skew coefficients were created with geographic information system (GIS) technology using both total and local CRT NRNI Streamflows for each duration. Local and total skew coefficients computed for each CRT NRNI Streamflow dataset location and their associated flood windows were used to conduct a spatial interpolation analysis using the ordinary kriging method. This method, which is available in the ArcDesktop Geospatial Wizard (part of the ArcGIS software suite), can model the correlation between data points that represent sampled areas and then predict values in unsampled areas. In order to maximize the accuracy of these modeled predictions, values for the skew coefficients were (1) assigned fixed-coordinate locations that represent the centroid of the drainage area whose contributing streamflow was used to compute the values; and (2) optimized using cross-validation with a focus on the estimation of the range parameter. The result of the ordinary kriging analysis was an equal-area raster grid containing the interpolated skew values within the extent of the processed points..

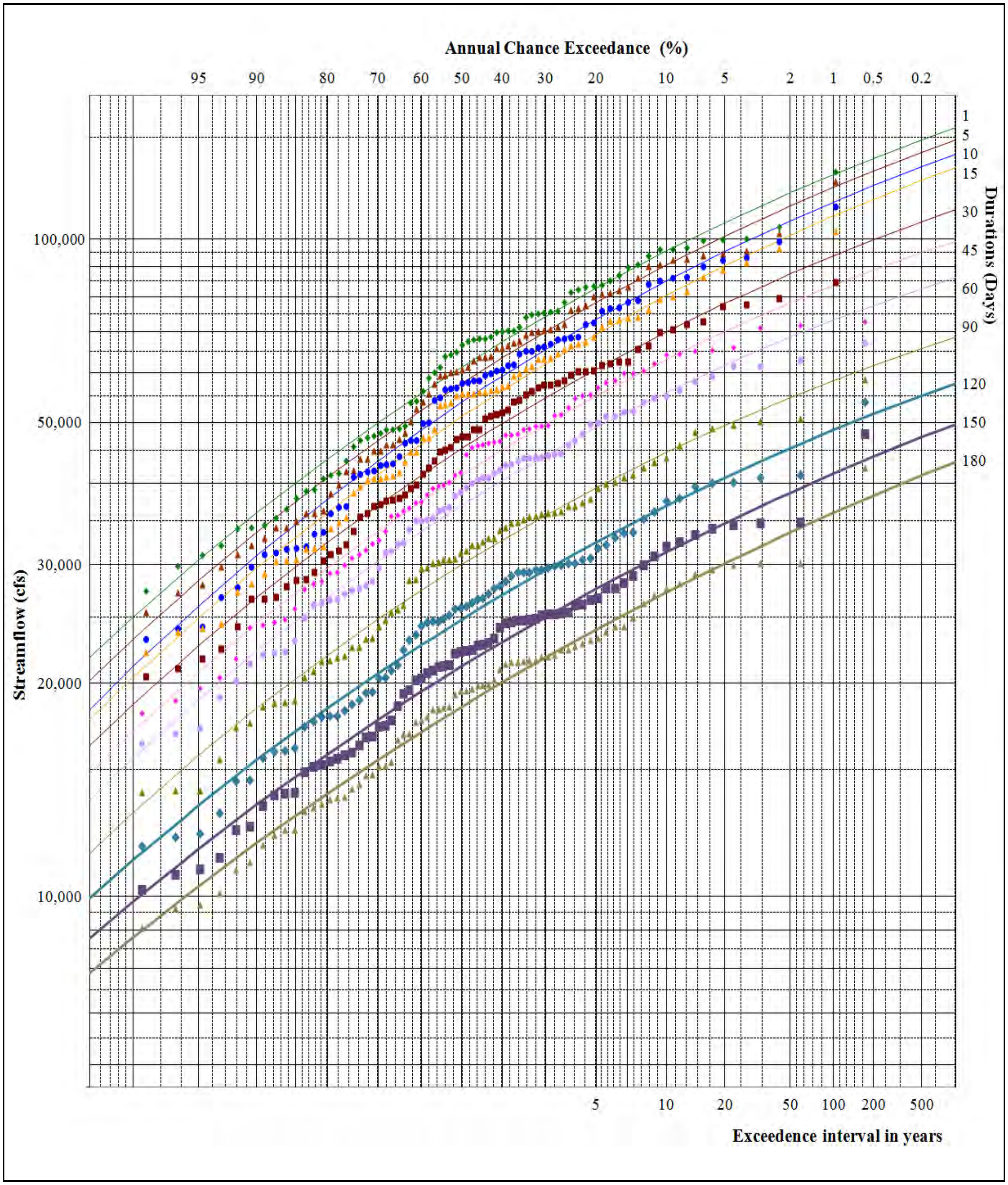


Figure 2-1. Volume Duration Frequency Curves for the White Bird Gage on the Salmon River

Note: Solid, colored lines represent the analytical flood frequency curves with durations as labeled on the right side of the plot. The top and bottom X-axis labels correspond to annual chance exceedance and exceedance return interval. The colored symbols represent annual peak flows of n-day duration used to calculate flood frequency curves of the same color.

Many of the flood events, such as the largest flood event of 1894, needed to be evaluated before being included in the volume duration frequency analysis. During the volume duration frequency analysis, particularly high and low spring flood events were identified, explored, and potentially removed from the analysis for each duration and location in accordance with Bulletin 17B (Interagency Advisory Committee on Water Data 1982). For example, the appropriateness of including the 1894 Flood Event dataset as a flood event was also evaluated at each location for both local and total streamflow for each duration. Data for the 1894 flood event was included in the volume frequency analyses if it improved the flood duration curve's fit for the upper end of the distribution. Particularly low streamflow years were removed from the analysis when those years created a bad fit for the volume duration frequency curve at the upper end of the distribution (i.e., the curve falls far from the largest floods in the record plotted against their empirical exceedance probabilities). Whenever a lower water year was identified, a conditional probability adjustment was performed, as specified in Bulletin 17B (Interagency Advisory Committee on Water Data 1982). If a particularly high or low spring flood event was found for a location and a specific duration, care was taken to incorporate the high or low outlier adjustment for other durations at that location when appropriate for consistency. When necessary, the standard deviation and skew were smoothed to avoid overlap of the curves for different durations, as outlined in EM 1110-2-1415 (Corps 1993), Section 3-8c.

2.3 FLOOD DURATION-VOLUME MATRIX ANALYSIS

This section describes the examination of the annual chance exceedance probabilities for local streamflows for each location within the dataset during the 80-year period of record. The examination identified locations for which the local streamflow is a regular contributor to downstream spring flooding, along with reoccurring spatial and temporal patterns among these identified locations. The process of evaluating patterns between local flow locations among multiple flooding events is called a storm matrix analysis (Hickey et al. 2002). Due to the Columbia River Basin flooding pattern being largely driven by snowmelt events, it was called the flood duration-volume matrix analysis rather than storm matrix analysis, in this study.

2.3.1 Volume-Centering Location Selection

To determine which water year's hydrology to examine for the flood duration-volume matrix analysis, it was necessary to select a downstream reference location, here termed the volume-centering location, where total flow duration volumes are most consistently available for computing the annual chance exceedance probability. The Dalles was chosen as the volume-centering location due to its proximity to the largest damage center in the study (Portland/Vancouver area). The Dalles is also an advantageous location to choose as the volume-centering location due to it being the furthest downstream local flow location east of the Cascade Range, where flood runoff is predominantly driven by snowmelt. The 20 largest streamflow flood volumes within the period of record (including the 1894 flood event) for the 30-, 45-, 60-, 90-, and 120-day durations at The Dalles Dam were included in the flood duration-volume matrix analysis.

2.3.2 Development of Flood Duration-Volume Matrices

In order to perform the flood duration-volume matrix analysis, a total of 93 subbasins were delineated at the locations in the Columbia River Basin within the streamflow dataset. Volume duration frequency curves were developed for all 93 locations, of which 43 were headwater locations (Table 2-2). A map of the delineated subbasins is shown in Figure 2-2.

Table 2-2. Streamflow Locations Used in the Flood Duration-Volume Matrix Analysis

Streamflow Dataset Location	Location ID	River	Location Type
Mica	MCD	Upper Columbia	Headwater
Revelstoke	RVC	Upper Columbia	Local
Arrow (Hugh Keenleyside)	ARD	Upper Columbia	Local
Grand Coulee	GCL	Middle Columbia	Local
Wells	WEL	Middle Columbia	Local
Chelan	CHL	Middle Columbia	Headwater
Rocky Reach	RRH	Middle Columbia	Local
Rock Island	RIS	Middle Columbia	Local
McNary	MCN	Lower Columbia	Local
John Day	JDA	Lower Columbia	Local
The Dalles	TDA	Lower Columbia	Local
Bonneville	BON	Lower Columbia	Local
Libby	LIB	Kootenai	Headwater
Bonners Ferry, ID, Gage	BFE	Kootenai	Local
Duncan	DCD	Kootenai	Headwater
Corra Linn	COR	Kootenai	Local
Brilliant	BRI	Kootenai	Local
Hungry Horse	HGH	Pend Oreille	Headwater
Columbia Falls, ID, Gage	CFM	Pend Oreille	Local
Seli'š Ksanka Qlispe'	KER	Pend Oreille	Local
Thompson Falls	TOM	Pend Oreille	Local
Noxon Rapids	NOX	Pend Oreille	Local
Cabinet Gorge	CAB	Pend Oreille	Local
Priest Lake	PSL	Pend Oreille	Headwater
Albeni Falls	ALF	Pend Oreille	Local
Box Canyon	BOX	Pend Oreille	Local
Boundary	BDY	Pend Oreille	Local
Seven Mile	SEV	Pend Oreille	Local
Post Falls	PFL	Spokane	Headwater
Upper Falls	UPF	Spokane	Local
Nine Mile	NIN	Spokane	Local
Long Lake	LLK	Spokane	Local
Yakima	YAK	Yakima	Local

Streamflow Dataset Location	Location ID	River	Location Type
Keechelus	KEE	Yakima	Headwater
Kachess	KAC	Yakima	Headwater
Cle Elum	CLE	Yakima	Headwater
Bumping Lake	BMP	Yakima	Headwater
Tieton	TTN	Yakima	Headwater
Naches River + Yakima River	NCH	Yakima	Local
Jackson Lake Dam	JCK	Upper Snake	Headwater
Buffalo Fork Creek Headwater	BUF	Upper Snake	Headwater
Moose, WY, Gage	MOO	Upper Snake	Local
Palisades Dam	PAL	Upper Snake	Local
Jackson, WY, Gage DS Flat Creek	FLT	Upper Snake	Local
Hoback River Headwater	HBK	Upper Snake	Headwater
Greys River Headwater	GRY	Upper Snake	Headwater
Salt River Headwater	SLT	Upper Snake	Headwater
Heise, ID, Gage	HES	Upper Snake	Local
Lorenzo, ID, Gage	LRZ	Upper Snake	Local
Rexburg Headwater	REX	Upper Snake	Headwater
Shelly, ID, Gage	SHL	Upper Snake	Local
Blackfoot River Headwater	BLK	Upper Snake	Headwater
Malad River at Gooding, ID, Gage	MAL	Upper Snake	Headwater
King Hill, ID, Gage	KNG	Upper Snake	Local
Murphy, ID, Gage	MPY	Upper Snake	Local
Owyhee Dam Inflow	OWI	Upper Snake	Headwater
Anderson Ranch Dam	AND	Upper Snake	Headwater
Arrowrock Inflow	ARM	Upper Snake	Headwater
Boise River at Diversion Dam	BDD	Upper Snake	Local
Boise River at Glenwood Bridge, ID, Gage	GLB	Upper Snake	Local
Parma, ID, Gage	PMA	Upper Snake	Local
Deadwood Dam	DED	Upper Snake	Headwater
Middle Fork Payette River Headwater	PMF	Upper Snake	Headwater
Cascade Dam	CAS	Upper Snake	Headwater
Payette, ID, Gage	PAY	Upper Snake	Local
Weiser River Headwater	WSR	Upper Snake	Headwater
Southfork Payette River Headwater	PSF	Upper Snake	Headwater
American Falls Dam	AMF	Upper Snake	Local
Kimberly, ID, Gage	KIM	Upper Snake	Local
Owyhee Dam Outflow	OWO	Upper Snake	Local
Lucky Peak Inflow	LKP	Upper Snake	Local
Horseshoe Bend, ID, Gage	HBD	Upper Snake	Local
Arrow Rock South Fork Inflow	ARS	Upper Snake	Headwater

Streamflow Dataset Location	Location ID	River	Location Type
Gros Ventre River	GRV	Upper Snake	Headwater
Brownlee	BRN	Lower Snake	Local
Hells Canyon	HCD	Lower Snake	Local
White Bird, ID, Gage	WHB	Lower Snake	Headwater
Anatone, WA, Gage	ANA	Lower Snake	Local
Orofino, ID, Gage	ORO	Lower Snake	Headwater
Dworshak	DWR	Lower Snake	Headwater
Spalding, ID, Gage	SPD	Lower Snake	Local
Lower Monumental	LMN	Lower Snake	Local
Lime Point	LIM	Lower Snake	Local

Flood duration-volume maps were created for the twenty largest 30-, 45-, 60-, 90-, and 120-day duration periods of the streamflow dataset events at The Dalles. Figure 2-3 shows an example of a large flood event at The Dalles for the water year 1972 flood event for a 60-day duration.

In each map:

- Annual chance exceedance probabilities are indicated by color shading. The map of annual chance exceedance probabilities illustrates which of the delineated subbasins experience a large local inflow volume during a flood event for a specific duration.
    - For delineated subbasins with annual chance exceedance values of up to 20 percent, the degree of gray shading for each subbasin indicates the annual chance exceedance corresponding to the event's local flood volume, obtained from the volume duration frequency curve, for that location. Darker shading represents delineated subbasins with lower annual chance exceedance probabilities (i.e., longer return period; less common event), while lighter shading represents basins with higher annual chance exceedance probabilities (i.e., shorter return period; more common event).
    - For delineated subbasins with an annual chance exceedance greater than 20 percent (return periods less than 5 years) for a specific duration during a flood event, the delineated subbasin is shaded yellow.
- Volume contributions to downstream flooding are indicated with blue dots, as in Figure 2-3.
    - A blue dot within each delineated subbasin represents its flood volume contribution to downstream flooding as a normalized percentage of the flood volume at The Dalles Dam.

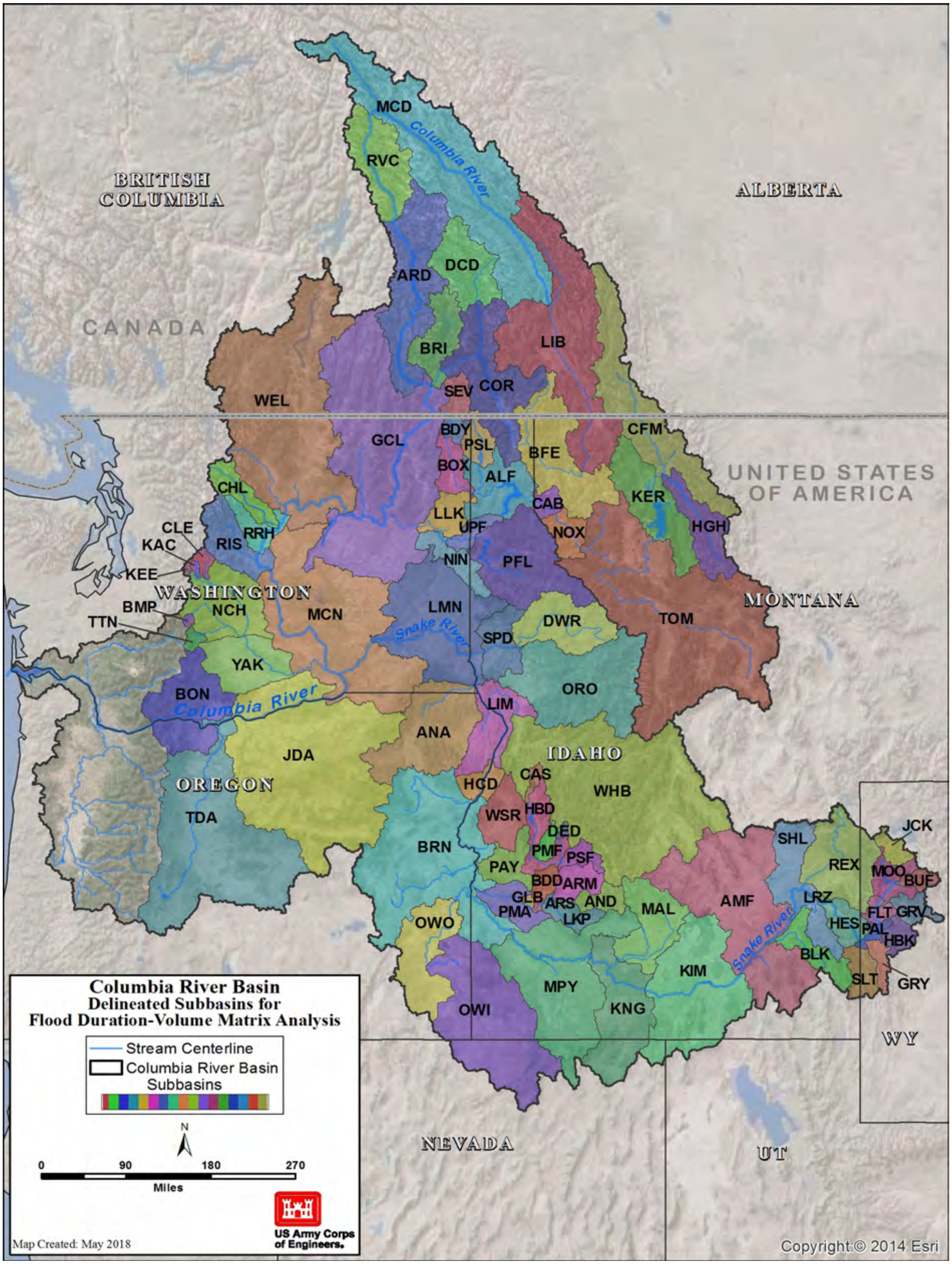


Figure 2-2. Delineated Columbia River Subbasins for Flood Duration-Volume Matrix Analysis

Note: A complete list of names of the subbasins is in Table 2-2.

2.3.2.1 Analysis of Flood Duration-Volume Matrices

The flood duration-volume matrices were analyzed to identify temporal and spatial patterns during flood events among the delineated subbasins. The analysis revealed that typically when a low annual chance exceedance probability flood event occurs at The Dalles, correspondingly low annual chance exceedance flood events also occur in most of the delineated subbasins located in or near the east and west sides of the basin. Hence, the subbasins that appear to contribute the most to flood events are in the mountainous regions: the west side of the Rocky Mountains, and the east side of the Cascade Range. The subbasins in the Columbia River Basin plateau (between the Cascade Range and the Rocky Mountains) typically have very little impact on large flood events.

A typical example of a large flood event at The Dalles is included in Figure 2-3 for the 1972 flood event for a 60-day duration. The green outline in Figure 2-3 delineates subbasins with low annual chance exceedance flood volumes occurring in or near the west side of the Rocky Mountains. The orange outline in Figure 2-3 delineates subbasins with low annual chance exceedance flood volumes occurring on the east side of the Cascade Range.

A flood duration-volume matrix analysis of the 1972, 60-day event revealed the following:

- Along the western edge of the Rocky Mountains, low annual chance exceedance probability streamflow volumes were observed
- Low annual chance exceedance probability streamflow volumes occurred on the eastern edge of the Cascade Range
- The delineated subbasins that have the largest contributions to the flood event, shown with blue dots in Figure 2-3, are the same delineated subbasins with low annual chance exceedance probability streamflow volumes
- The largest-contributing subbasins to downstream flood volumes for this flood were also typically the largest-contributing delineated subbasins for other measured flood events

Therefore, the subbasins in or near the western Rocky Mountains, and to a lesser extent those in or near the eastern Cascade Range, are the main contributors to runoff volumes in the lower Columbia River. Hence, when many of the subbasins near the mountain ranges have low annual chance exceedance probability volumes simultaneously, the lower Columbia River will likely experience a large flood event.

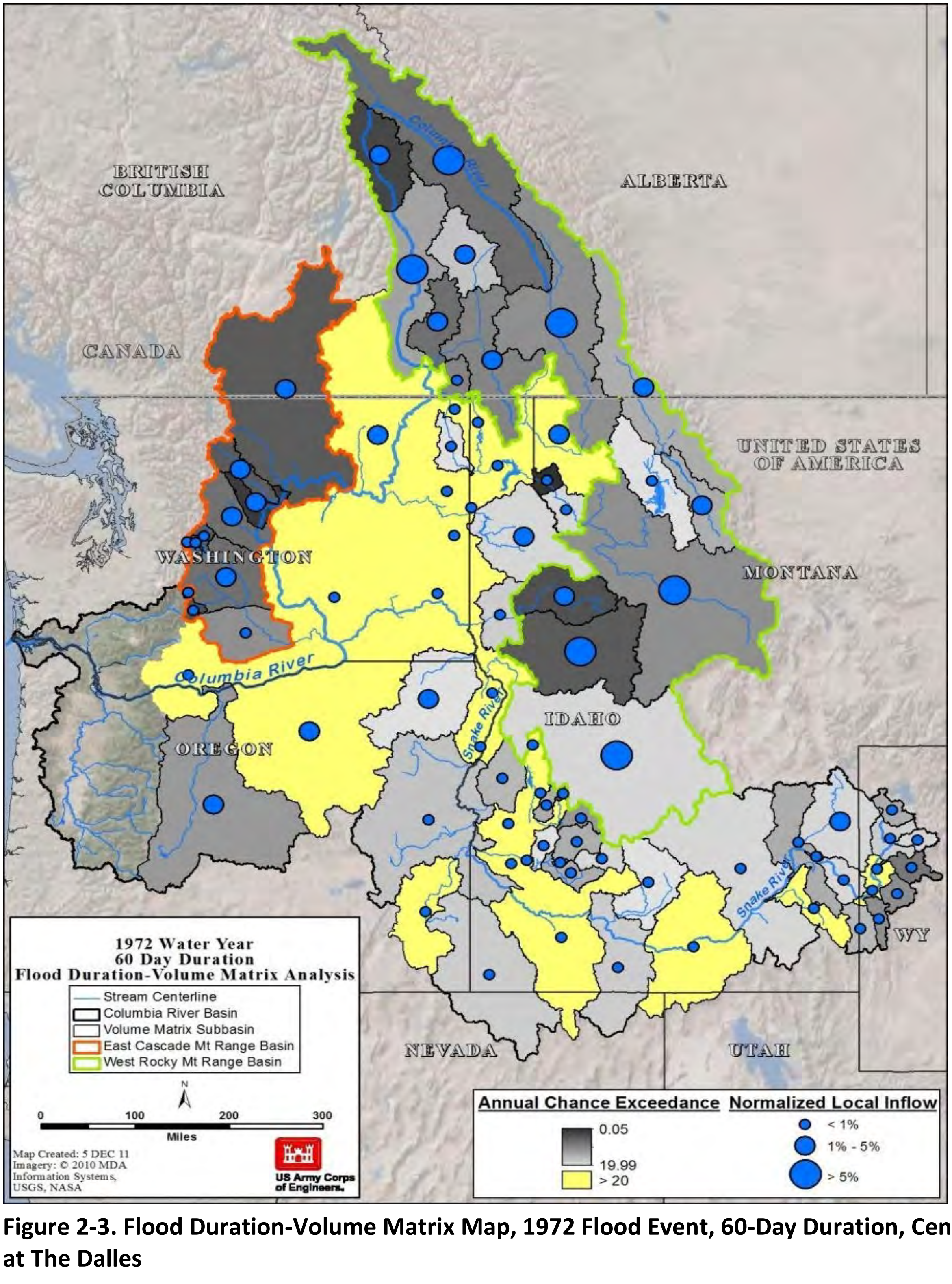


Figure 2-3. Flood Duration-Volume Matrix Map, 1972 Flood Event, 60-Day Duration, Centering at The Dalles

Note: Shading/color of subbasins represents the annual chance exceedance value for that subbasin; the size of the blue dots represents the amount of inflow contribution from that subbasin to the flood event. These subbasins do not indicate inflow points in the HEC-ResSim model. The intent of this figure is to provide a general sense of the basin's hydrologic behavior.

2.4 CRITICAL DURATION

The methodology for developing the Synthetic Flood Events dataset involved scaling hydrologic events from the streamflow dataset to target specific annual chance exceedance probability discharges (averaged over a given number of days duration, n) at The Dalles. The average discharge for an n-day duration associated with a specified annual chance exceedance event at The Dalles was determined using the n-day volume duration frequency curve created specifically for The Dalles. When scaling synthetic flood events to match a specific annual chance exceedance n-day discharge at The Dalles, a specific duration (e.g., 15-day, 30-day, 60-day) needs to be selected such that regulated daily peaks computed at The Dalles are larger than the peaks computed using other durations. A critical duration of 60 days was calculated for this study using regulated flow at The Dalles and the FRM storage in the system of reservoirs to determine the duration that fills system storage at the highest annual exceedance probability. The critical duration was used to scale the chosen unregulated streamflow dataset events up to specified unregulated annual chance exceedance events at The Dalles.

2.5 DEVELOPMENT OF SYNTHETIC FLOOD EVENTS

To develop synthetic events for selected annual chance exceedance probabilities, several streamflow events were scaled to a specific volume associated with the volume duration frequency curves at The Dalles for the 60-day critical duration. This section discusses the streamflow events chosen for scaling, the methodology used to scale the streamflows, and the iterative process used to adjust and verify each synthetic event within the dataset. The Synthetic Flood Events dataset is made up of local streamflows for each of the locations in the streamflow dataset. When a synthetic flood event’s total unregulated flow hydrograph is needed at a location, the Columbia River System HEC-ResSim Model was used to route the synthetic flood events local streamflows and compute total streamflows.

2.5.1 Template Water Years

Six events/water years from the streamflows dataset were selected to be used as templates for the development of the Synthetic Flood Event dataset: 1948, 1956, 1971, 1972, 1974, and 1997. These six events were chosen because they are the largest 60-day duration events within the period of record, and they fit the general temporal and spatial patterns observed during the flood duration-volume matrix analysis.

A total of 16 synthetic events were developed from the template events to be part of the Synthetic Flood Events dataset. The synthetic flood events were generated using a combination of the six template flood events and the 1.0, 0.2, 0.5, and 0.1 percent annual chance exceedance probabilities for the 60-day critical duration. The details of the 16 synthetic events were presented in Table 2-1. The annual chance exceedance probabilities chosen to scale the synthetic flood events were selected due to their acceptance as standard benchmark probabilities in hydrologic design studies.

2.5.2 Scaling Template Water Years

The template water year events were iteratively scaled to produce synthetic flood volumes at The Dalles that were equal to the flood volume specified by the 60-day volume duration frequency curve at the target annual chance exceedance probability. As a first step in creating a synthetic dataset using a template water year, the 60-day window of that water year with the largest volume of inflow was identified. Daily streamflow values within that 60-day window at each location were scaled with a first guess of a scaling factor between 1.0 and 1.3. The first guess scaling factor did not exceed 1.3 in order to preserve the integrity of the shape of the reference year hydrographs. An upper bound for the first scaling factor ensures that the correlation of temporal and spatial patterns between actual events and synthetic events is maintained. The underlying assumption is that large-volume synthetic flood events are supposed to mirror the spatial and temporal patterns of equally large-volume measured events, and therefore avoid the problem of using smaller events whose pattern may not be reasonable when applied to a large event. A decision was also made during the study to scale only local inflow at locations for which the computed annual chance exceedance was 20 percent or less (i.e., a flood with a 5-year or more return period). Scaling only large flow events maintained the patterns found in the flood volume matrix analysis and prevented basins that were non-contributing during a template event from becoming contributors during synthetic events. Also, if a scaled inflow was found to generate unrealistically large streamflows for each location, the scaling ratio was reduced and the decrease in the total volume of water at the centering-location was compensated for by increasing the scaling ratio at the remaining inflow locations.

After scaling up the 60-day window of the template water year with the first guess scaling factor, it is desirable to smooth the hydrograph near the transition between the scaled flows inside the 60-day window and the flows outside of the 60-day window. Essentially, the hydrograph will be scaled up outside the 60-day window with a smaller scaling factor to remove unrealistic "jumps" in the flow rates on the dates that the 60-day window begins and ends. In order to smooth the synthetic hydrographs at the beginning and end of the 60-day window limits, the streamflow values corresponding to dates outside the 60-day window, and within the flood window, were also scaled using a scaling factor less than or equal to the one used for the 60-day window. The scaling factor for the flood window outside of the 60-day window was selected by computing the average percent difference of the flow volumes within 60-day window and the flow volumes of a larger sized averaging window. For example, at a location where synthetic flood events were being developed, streamflow data outside the 60-day duration window but within the 90-day duration window were scaled by a factor equal to the ratio between the 90-day and the 60-day duration window maximum flows for that location.

There were two circumstances in which the hydrograph smoothing methodology was not performed:

- When the scaling factor that was required to maintain the average percent difference between two durations was larger than the scaling factor used for the 60-day critical duration. In this case, the 60-day scaling factor was used instead.

- When the scaling factor that was required to maintain the average percent difference between two durations was less than 1. When this occurred, the scaling factor for the hydrograph outside of the 60-day window was set to 1.0.

Figure 2-4 is a plot of the local inflow into Wells Dam for water year 1997 and a synthetic hydrograph for the same water year and a 45-day critical duration window. Local streamflows (green line) within the critical duration window (tan vertical lines) were scaled by a factor of 1.3 to produce the Synthetic Flood Event data (blue dashed line). Within the storm window (red dashed, vertical lines) but outside of the 45-day window, the local streamflows were scaled by a factor of less than or equal to 1.3. Figure 2-4 illustrates how values within the storm window were scaled and how using the average percent difference between durations helped create a smooth transition between scaled and non-scaled values. Figure 2-5 shows an example of several synthetic, unregulated flows at The Dalles dam for the 0.2 percent annual chance exceedance spring flood events and the water years that were used to create them over the spring time window.

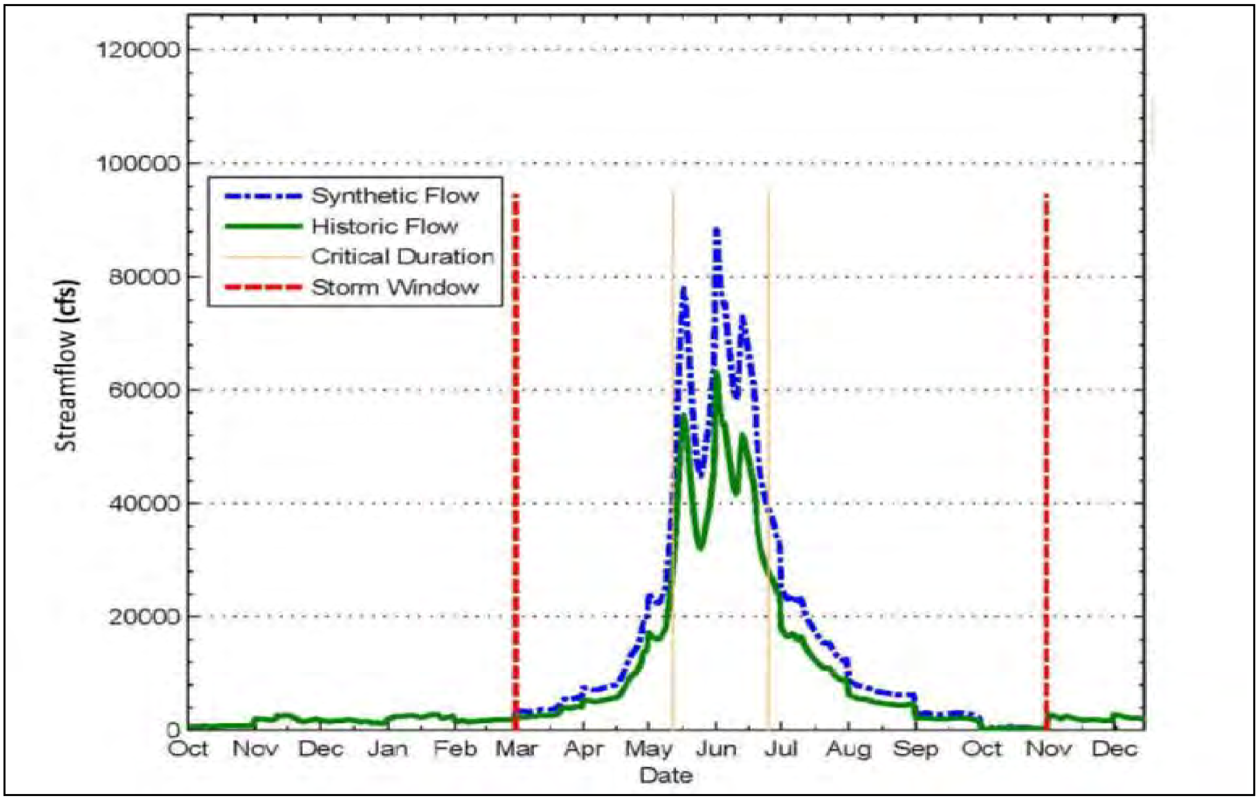


Figure 2-4. Comparison of the 1997 Water Year Local Inflow into Wells Dam and a Synthetic Hydrograph with the Critical Duration Scaled by a Factor of 1.3

Note: The green, solid line depicts the 1997 streamflow values; blue, dashed line is the scaled up synthetic streamflow values; tan, solid, vertical lines represent the 45-day critical duration window; and red, dashed vertical lines represent the storm window.

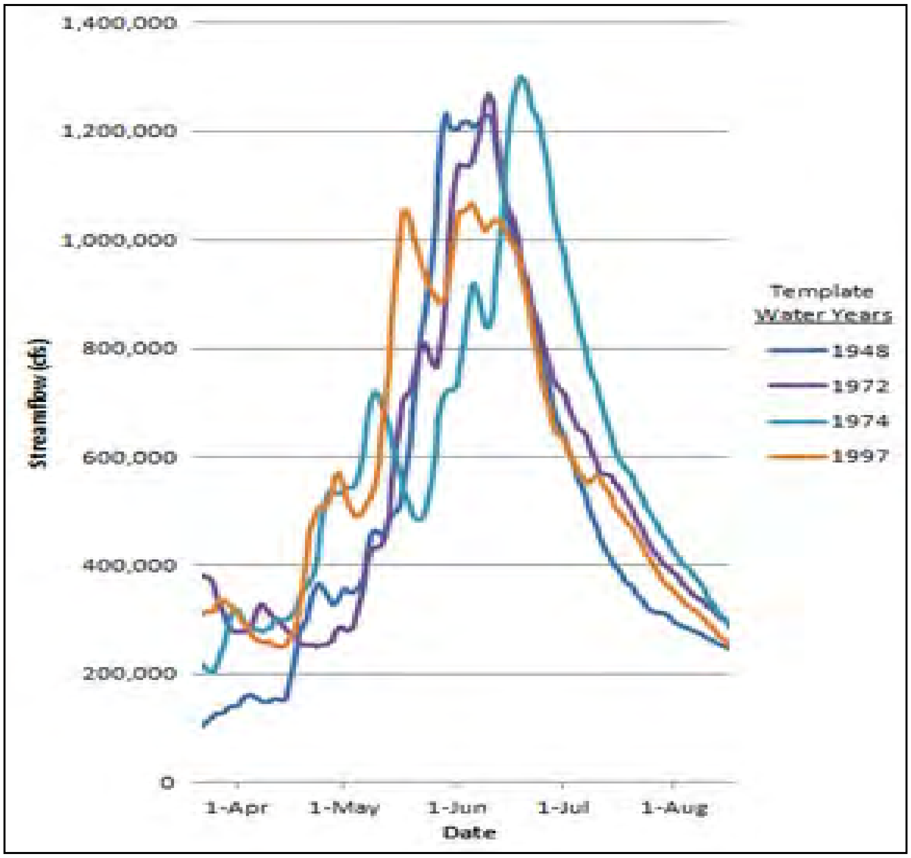


Figure 2-5. Spring Synthetic Flow at The Dalles Dam for 0.2 percent Unregulated Annual Chance Exceedance Events at The Dalles with a 60-day Duration

Note: Colored lines represent the streamflow on the calendar day for the template water years indicated in the legend.

2.5.3 Acceptance Criteria for Synthetic Hydrographs

Once the template water year was scaled, the flows were used as inflows to the unregulated Columbia River System HEC-ResSim Model. The resulting synthetic, total streamflow, 60-day duration volume computed at The Dalles was compared to the 60-day duration volume specified by the target annual chance exceedance probability event from The Dalles volume duration frequency curve. The acceptance criterion for this analysis was that the two volumes matched within 1 percent. If the estimated volume difference was greater than 1 percent, the template water year was rescaled (up or down) and rerun through the unregulated Columbia River System HEC-ResSim Model until the resulting synthetic event flood volume fell within the 1 percent tolerance level.

Also, another goal for the synthetic flow hydrology is to have similar annual chance exceedance probabilities at The Dalles and the other major subbasins. Therefore, the resulting 60-day critical duration flood volumes at all of the major subbasins were used to determine if their annual chance exceedance probability was substantially lower than that at The Dalles. If a major subbasin's annual chance exceedance probability was found to be too low compared to that of The Dalles, the scaling for all locations within that major subbasin were appropriately adjusted to better match exceedance probabilities. The scaling factors associated with the other locations throughout the basin would be altered to meet the 60-day flood volume specified by the target annual chance exceedance probability event at The Dalles.

2.6 ADJUSTMENT OF SYNTHETIC HYDROGRAPHS

In order to have consistent streamflow inputs into the Columbia River models, the Spring Synthetic Flood Events dataset was adjusted to include the same reservoir regulation, irrigation depletion, and evaporation adjustment effects reflected in the 2010 Level Modified Streamflows dataset.

The normalized irrigation depletion and evaporation data provided by Bonneville was used to adjust the Synthetic Flood Events dataset (except for the Yakima and upper Snake River Basins). The effects of the natural lakes, as opposed to reservoirs, were not altered because any differences at reaches where a natural lake was modeled was minor and alteration was deemed unnecessary.

Three HEC-ResSim flood models are used for modeling the Columbia River Basin: one of the Yakima River, one of the Snake River upstream of Brownlee Reservoir, and one for the rest of the system. Synthetic Flood Events dataset streamflows are routed through the Yakima River Model and the Snake River Upstream of Brownlee Reservoir Model first, with the output from these models used as input to the HEC-ResSim model for the rest of the system. Section 2.7 clarifies the application of the Brownlee model.

2.7 BROWNLEE SYNTHETIC HYDROGRAPHS

For the creation of the Brownlee inflow synthetics, the unscaled portion of the synthetic inflows were set as equal to the template years' inflows. The scaled portion of the Brownlee synthetic inflows were created using the same methods applied to the rest of the basin. The WEST Consultants hydrology dataset for the Brownlee inflow synthetics was also scaled in the same way as the rest of the basin. Finally, the WEST Consultants hydrology Brownlee inflow synthetics were used, in conjunction with the Upper Snake River HEC-ResSim Model, to provide synthetic Brownlee inflows in the scaled portions of the water year.

CHAPTER 3 - DEVELOPMENT OF WINTER SYNTHETIC FLOOD EVENTS DATASET

For the Spring Synthetic Flood Events, spring annual chance exceedance probabilities were calculated based on volume duration frequency curves at The Dalles. The spring synthetic development was predicated on a snowmelt runoff regime, which is the driving volume for flood risk and water management in the upper and middle Columbia River Basin and not so in the lower Columbia River Basin, such as in the Willamette Basin. Since the Willamette Basin, which has a hydrologic regime driven by winter rainfall events, is a major contributor to winter flooding in Portland, the target winter annual chance exceedance probabilities for Synthetic Winter Flood Events are calculated on the Columbia River just downstream of its confluence with the Willamette River.

Unregulated historically based flows were scaled up for six winter events to create nine basinwide winter synthetics. An example of the temporal variability of the six template water years at the Willamette at Portland location is provided in Figure 3-1. Though the 1965, 1974, and 1996 events appear to show a center-loaded peak (the peak occurring in the center of the event), the 1964 event is more front loaded at this location, with the peak occurring at the beginning of the storm. All of these were distributed very differently spatially in the basin. The 1997 event is also typical of an atmospheric river winter storm, where there are several waves of runoff. The 1982 event is temporally back loaded such that the peak occurs near the end of the event. The 1934 event had a smaller peak than the larger events (and was also back loaded at this location), but had a greater volume over the full duration. Additionally, one can see that the maximum duration of the 1965, 1974, 1982, and 1996 events occur within a 3- to 5-day window, whereas the 1934 and 1997 events have the bulk of runoff in 7- to 10-day window. The objective was to create a variety of winter events that represented a range of possible spatial/temporal storm distributions, durations, and exceedance probabilities.

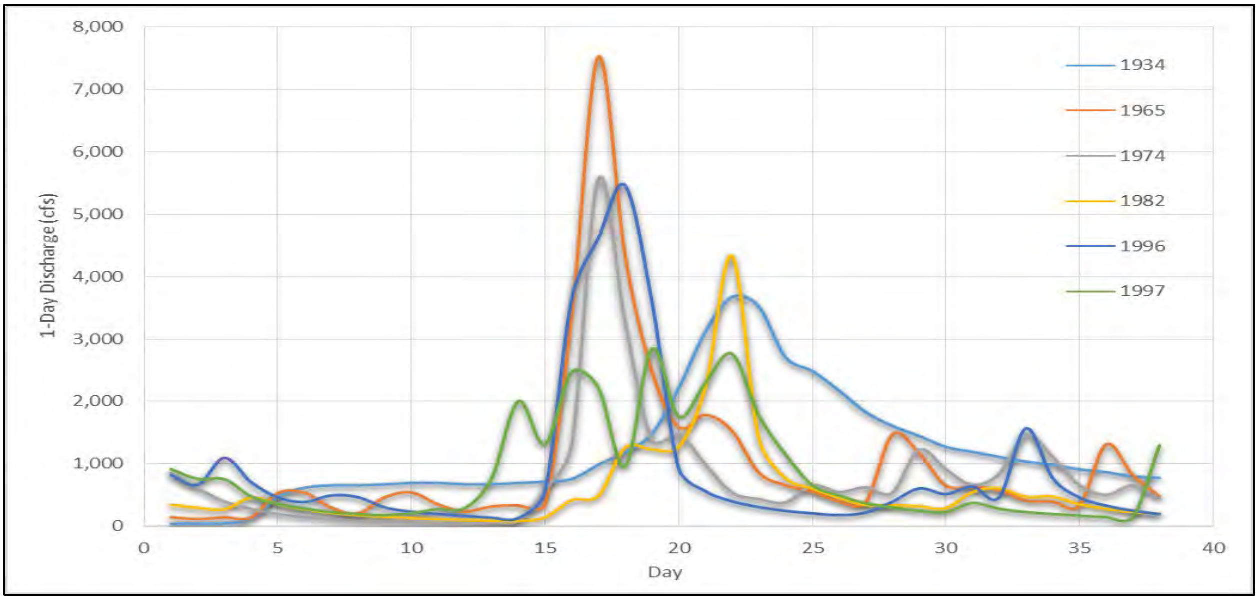


Figure 3-1. Example of Temporal Variability of the Six Template Water Years at the Willamette and Portland Locations

Major winter runoff events in the Columbia River Basin are dominated by rainfall, rather than snowmelt. As a storm track passes over the Columbia River Basin, rainfall begins at different times in each area and each watershed has a different time of concentration. This time offset coupled with the short duration of winter events, when compared to spring events, would result in inaccurate scaling if a single scaling time window were selected. For this reason each of the hundreds of individual local runoff hydrographs being scaled were examined visually to determine the extent of each event. At some high-elevation locations precipitation occurred in the form of snow during all or part of the event, and did not result in runoff. These locations were identified and their events were not scaled.

Runoff, rather than precipitation, was scaled; but precipitation was used to temporally isolate meteorological events to define temporal scaling extents. Justification is provided for scaling rainfall and snowmelt together as one event. Base flow was removed prior to scaling to maintain proper event spatial distribution.

Winter season volume duration frequency curves were created at all 2010 Level Modified Streamflow locations. Local NRNI events were scaled until target exceedance probabilities (1, 0.5, 0.2, and 0.1 percent) were achieved at the Columbia-Willamette confluence, using an unregulated HEC-ResSim model with natural lakes. The duration of each cumulative volume duration frequency curve at the confluence was based on the extent of the runoff event and the segment of the event with the smallest exceedance probability.

The general workflow used to develop the Winter Synthetic Flood Events is as follows:

- Route the local streamflows through a HEC-ResSim model to obtain cumulative streamflows with natural lakes.
- Select template years to scale by examining the events with the largest peaks and volumes at the Columbia-Willamette confluence, and selecting those events that represent the full spectrum of the following:
    - hydrograph shapes
    - winter season timing
    - geographic distribution of runoff and rainfall
- Identify the runoff event duration at the Columbia-Willamette confluence for each template year.
- Create volume duration frequency curves at the Columbia-Willamette confluence for each runoff event duration, and for durations shorter than the event duration.
- Create volume duration frequency curves for predetermined fixed durations.
- For each year being scaled, identify the temporal extents of the individual local runoff hydrographs that contribute to the cumulative flow hydrograph at the Columbia-Willamette confluence. Examine each location separately, as duration and timing differ throughout the basin.

- Remove base flow from the local runoff hydrographs through manual, visual identification of inflection points. Use linear approximations to identify the base flow components of the hydrographs.
- Iteratively scale up the local hydrographs (base flow is not scaled) and route them through the HEC-ResSim model until the runoff volume at the Columbia-Willamette confluence is equal to the target volume obtained from the volume duration frequency curve.
- Verify that other runoff durations at the Columbia-Willamette confluence are not associated with lower exceedance probabilities than the target duration and adjust the target duration if needed.
- Investigate any local events that have very low exceedance probabilities, to ensure that improbable events were not created. Where applicable, compare peak discharge to winter season probable maximum flood and standard dam/reservoir floods. Adjust individual local scale factors if needed.
- Convert the scaled local flows to scaled local disaggregated flows.

3.1 VOLUME DURATION FREQUENCY CURVES AND STORM MATRIX MAP

Winter flood season unregulated volume duration frequency curves were generated for locations throughout the Columbia River Basin. The local frequency curves were used to ensure that the synthetic events did not get scaled up to improbable runoff volumes, and to develop a storm matrix map that was used as a guide in selecting potential scaling years. Winter season cumulative flow volume duration frequency curves were developed at the Columbia-Willamette confluence and at The Dalles for reporting probabilities of scaled events.

3.1.1 Unregulated Basinwide Local Winter Volume Duration Frequency Curves

The CRT NRNI cumulative flow dataset with natural lakes was used to develop unregulated, local flow, winter season volume duration frequency curves by applying a Log Pearson Type III probability distribution, using guidelines outlined in Bulletin 17B (Interagency Advisory Committee on Water Data 1982), for all inflow locations for 1-, 3-, 7-, 10-, and 15-day durations. Selection of the 1- to 15-day duration was based on the meteorological and runoff regimes of the winter rain flood season. These durations are typical maximum runoff durations for this region that cover both large atmospheric river storms that characterize substantial winter storms in this region and localized convective systems that can also occur in some parts of the basin. These types of storms generally have a 1- to 3-day maximum runoff duration but can also be represented by multiple waves of precipitation that can extend up to 15 days, with the bulk of precipitation and runoff occurring well within a 15-day maximum window (this can also be seen clearly in the template water year shapes for the Willamette at Portland location shown in Figure 3-1, where the maximum duration of flow ranges from 3 to 5 days for some events and 7 to 10 days for others). This has been seen in examination of both precipitation and runoff hydrograph comparisons of historical winter storm events in the region. Longer durations, such as 20 or 30 days, were not used, as periods of those lengths are likely to result in the inclusion of two or more separate events into one maximum n-day duration for the winter events.

The cumulative flow volume duration frequency curves at the Columbia-Willamette confluence were used to establish the magnitude of the locally scaled synthetics. In contrast, the local frequency curves were used to develop the event-location matrices and to check that each region was not scaled to an out-of-proportion frequency. The intent of this study was to create a large number of curves with consistent methodology that reveal spatial distributions and provide a check for local scaling.

3.1.1.1 Volume Duration Frequency Curve Locations

The locations used to develop volume duration frequency curves for the spring synthetic study were the same as those selected for use in this winter synthetic study except that locations in the Willamette and lower Columbia Basins were added, as shown in Figure 3-2. A total of 100 frequency curves were developed for this study with 64 of sufficient quality to be used in the regional skew analysis. The subbasins that were delineated for each of the selected locations in the Columbia River Basin are shown in Figure 3-2.

The general flood time window selected for developing the winter synthetic flood season frequency curves was November 1 to March 31; this was further refined for each location, as appropriate, to limit the data to the plausible local winter rain flood season. A detailed review of each flow record was conducted to ensure that volume-duration data was computed from rain induced flood events, and not snowmelt or base flow. This review was limited to the cumulative flow frequency curves at The Dalles, the Columbia-Willamette confluence, and Libby Dam. The Columbia-Willamette confluence curves were selected for detailed review because exceedance probabilities at that location were targeted during scaling. The Dalles and Libby were selected because probabilities at those locations were of interest.

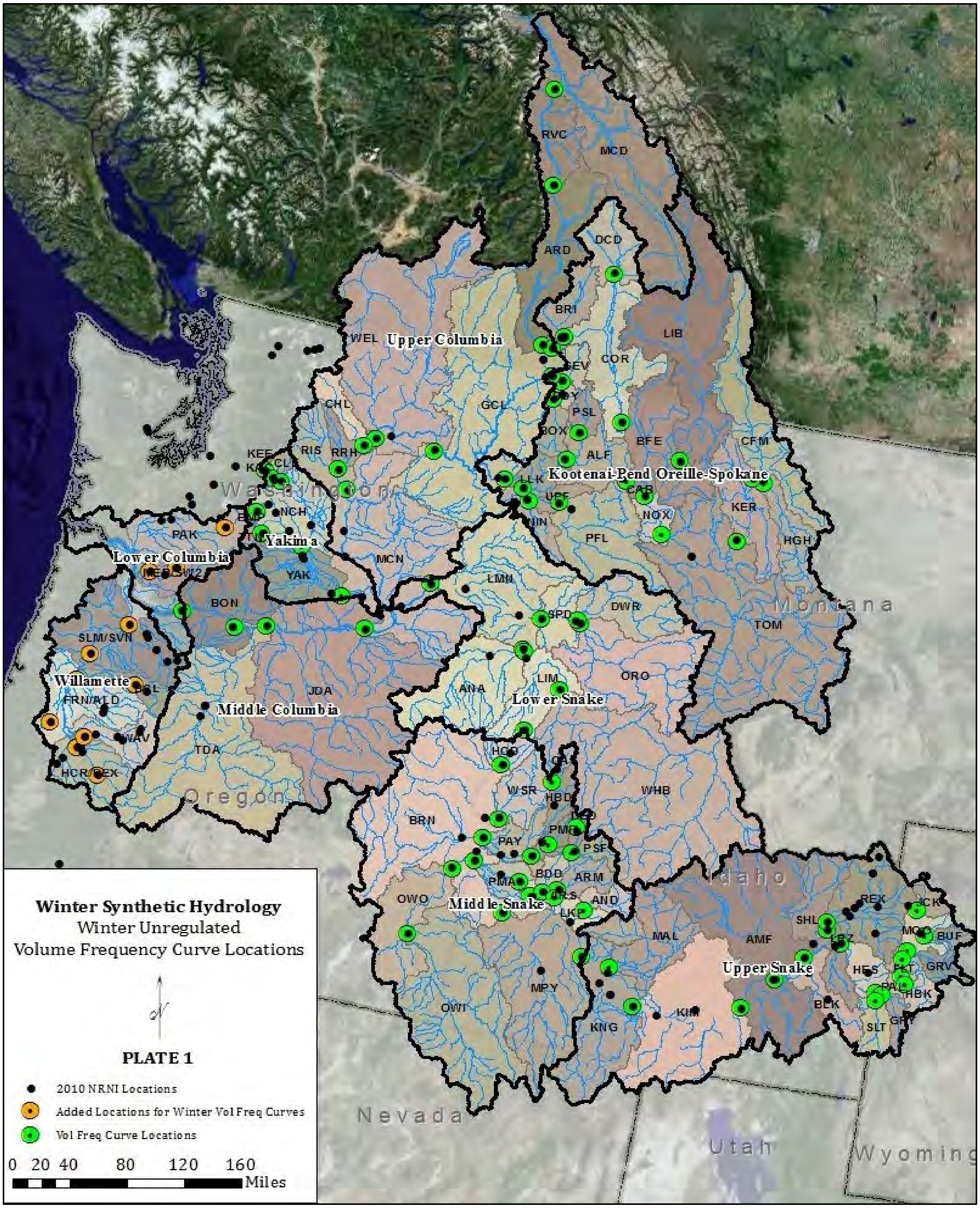


Figure 3-2. Winter, Unregulated Volume Duration Frequency Curve Locations for the Columbia River Basin

Note: Shaded regions represent subbasins, orange points represent locations used solely for the winter synthetics development, and green points represent locations used for both spring and winter synthetics.

3.1.1.2 Volume Duration Frequency Curve Computation

Low-flow events, determined by the Bulletin 17B Single Grubbs-Beck test (Interagency Advisory Committee on Water Data 1982), were examined for reasonableness. If determined appropriate, flows were censored or the low-flow threshold was adjusted to remove the designation as a low flow. Otherwise the Grubbs-Beck results were considered satisfactory. Often additional low-flow censoring occurred in drier basins. Since the rain-flood maximums for various durations are usually produced by the same storm, a low or high flow for one duration was generally treated as a low or high flow for the other durations. In general, adjustments to the frequency curve were made to improve the fit to the largest observed flood volume. Additional censoring of data increases the mean-square error of the station skew, which affects the weight placed on the station skew with the regional skew.

3.1.1.3 Skew Coefficients

The station skew coefficients were first developed for the set of volume duration frequency curves at each location. Then, the regional skew coefficients for each duration were determined from the station skew coefficients. Finally, the regional skew coefficients were used in conjunction with the station skew coefficients to compute volume duration frequency curves using weighted skew coefficients. Regional skew coefficients were determined for each duration, in each major subbasin.

Three methods for developing regional skew coefficients are outlined in Bulletin 17B (Interagency Advisory Committee on Water Data 1982): (1) skew coefficient isolines drawn on a map, (2) a skew coefficient prediction equation, and (3) the mean of the station skew coefficient values. Selection of the results for use in the final curves is based on the following criteria:

- The smaller mean-square error of the isolines and prediction equation methods should be compared to the variance of the skew coefficients for all of the stations
- If the mean-square error is much less than the variance of all of the skew coefficients, then the method with the smaller mean-square error should be used
- If the mean-square error is not much less than the skew coefficient variance, then neither the isoline nor the prediction equation method should be used as they will not be better than the mean of the station skew coefficient values method

For this study, only the skew coefficient isolines and the mean of the station skew coefficient values are examined. Predictive equations are developed by examining the basin characteristics, such as drainage area or mean basin elevation, and their relation to the skew coefficient.

The regional skew coefficient isolines for each duration were developed using the full Columbia River Basin regional skew coefficient set (Corps 2016); however, the variance of the station skew coefficients were computed for each of the major subbasins. The selection of the regional skew for each site and the associated mean-square error was determined based on the comparison of the estimated result of the regional skew coefficient for each site from the isolines and the mean and variance of the station skews for each major subbasin. The final adopted skew coefficient, which was used to compute the local frequency curves, was derived by weighting the regional skew coefficient with the station skew coefficient.

3.1.1.4 Storm Matrix Map

Using several major flood events that occurred during the winter season in the basin, the maximum 1-day volume duration frequency curves were used to develop an event-location matrix of the return period of each runoff event at each inflow location. The matrix was created by using the median plotting positions of the 1-day flood events to estimate the return period of the runoff for the selected year. The flood events analyzed occurred in the following water years: 1934, 1956, 1965, 1974, 1982, 1986, 1996, and 1997. The return periods estimated from the median plotting positions were spatially interpolated via inverse-distance weighting in ArcMap software, resulting in a storm matrix map that is a visual representation of the event-location matrices. The maps were used to ensure that the template years included a broad range of possible geographic runoff distributions. Considering their intended use, incorporating explicit orographic bias in the interpolation process was unnecessary, and coarse volume duration frequency curve coverage was adequate.

3.1.2 Unregulated Cumulative Flow Winter Volume Duration Frequency Curves

Cumulative flow, unregulated winter season volume duration frequency curves were generated at the Columbia-Willamette confluence and at The Dalles. The Columbia-Willamette confluence cumulative flow volume duration frequency curves were used to prescribe the magnitude of the scaled incremental winter synthetic flows. The incremental flows were routed through an unregulated model with natural lakes and the scale factors were adjusted to achieve the target cumulative flow probabilities at the confluence. Probabilities were also reported at The Dalles for informational purposes only. As a result, considerably more effort was expended in refining the cumulative flow curves than was spent for the basinwide local flow frequency curves, to ensure the accuracy of the scaled flows and the reported probabilities. These curve durations differ from the local curves because they are based on template year storm durations rather than the generic fixed durations used for the local frequency curves.

3.1.2.1 Frequency Curve Durations

Flood volume duration frequency curves are “used primarily for reservoir design and operation studies” (Corps 1993); for a given exceedance probability and permissible release rate, one can determine the storage required to minimize flood damage. The 60-day duration was used for calculating an exceedance probability at The Dalles for each spring synthetic event. This duration is much longer than the winter events, and therefore would not be an appropriate duration to use for calculating winter exceedance probabilities. While unregulated peak flows at the Columbia-Willamette confluence can have similar magnitudes in the winter and spring, the snowmelt-driven spring runoff events have substantially more volume than rain-driven winter runoff events. Many of the headwater reservoirs in the Columbia River Basin upstream of The Dalles have enough available storage to absorb the winter events, making a regulated flow analysis irrelevant in those regions. Severe winter flooding in the Columbia River Basin generally occurs when substantial rainfall takes place downstream of headwater reservoirs. The reservoirs farther downstream in the system may not be able to store the cumulative upstream runoff, and additional substantial runoff can occur downstream of those reservoirs. Reservoirs can play an important role in mitigating the impact of rainfall in these downstream regions by reducing upstream contributions. Both peak flow and volume are therefore important components of winter events.

Predetermined durations of 1, 3, 7, 10, and 15 days were used for creating the local winter volume duration frequency curves. Predetermined durations were not used for the cumulative flow volume duration frequency curves at the Columbia-Willamette confluence. Instead, the durations were initially set equal to the runoff event durations of the 6 years being scaled. The runoff event duration is the portion of the runoff hydrograph between the ascending limb and descending limb inflection points. Additional frequency curves were temporarily created for shorter durations to check if a shorter segment of any of the event hydrographs was associated with a lower exceedance probability than the full event. If this occurred, the frequency curve duration was based on the segment of the event with the smallest exceedance probability.

The event at the Columbia-Willamette confluence was not scaled, but rather the local flows throughout the basin were scaled and routed downstream. Local runoff events with differing local event durations accumulate to form the longer event at Columbia-Willamette confluence. In all cases, the full local event was scaled rather than a lower probability segment of the event, since scaling a full storm event rather than a segment of the event is more physically justifiable. The cumulative flow volume duration frequency curves were used to assign exceedance probabilities to the scaled events at the confluence. The smallest probability segment of each cumulative flow event determined the frequency curve duration. Since the probability is associated with a specific duration, that duration had to be used for volume matching. Scaling was applied across the full local event runoff durations and the scaled flows were routed downstream. At the Columbia-Willamette confluence the volume duration associated with the probability was checked for volume matching and additional iterations were performed as needed. Using the rarest segment of an event for assigning probability is in keeping with the idea that the damage induced is primarily caused by intense rainfall occurring downstream of the reservoirs, rather than reservoir storage volume being exceeded. In cases where there is little storage to reduce the peak, the runoff volume is of lesser importance, and hence the smaller segment of the event that contains the peak runoff is paramount.

For water years 1965, 1974, and 1996 the event duration was associated with the smallest exceedance probability. The rarest segment of the 1982 event was only 1 day shorter than the event duration. These four hydrographs were also reasonably balanced, in that the exceedance probabilities for shorter durations were roughly the same as the exceedance probability of the selected duration (Figure 3-3).

For water years 1934 and 1997, the exceedance probability was more dependent on duration. This is not surprising since these events had more than one peak (see Figure 3-3). For the 1997 event, the 12-day duration was selected for assigning probability, rather than the 16-day duration corresponding to the runoff event duration. Had the 16-day duration been used, this would have resulted in only a small increase of 2 percent in the scale factor, and the 12-day duration would have had an annual chance exceedance of 0.9 percent, rather than 1 percent.

Unlike the other years considered, the 1934 event has a few possible event durations (see Figure 3-3). For all other years, the event duration was defined as the region between inflection points on the ascending and receding limbs and corresponds to the main portion of the hydrograph being scaled. The 1934 event is unique because it is composed of a series of smaller events. The scaling window was therefore selected based on a break in continuous rain. While 35 days of runoff were scaled at the full scale factor, only 22 of those days were used for calculating the probability and matching the scaled volume to that probability. The 22-day segment of runoff was selected because it was the segment within the 35-day event with the lowest exceedance probability.

3.1.2.2 Frequency Curve Computation

Volume duration frequency curves were created at the confluence of the Willamette River and Columbia River for each of the durations listed in Table 3-1. Beginning and ending dates are included in the volume calculation (through 24:00 hours). Probabilities for the same event and same duration are also reported for The Dalles, as a reference, but the dates were shifted as needed to find the rarest segment of the hydrograph for that duration.

Table 3-1. Unregulated Volume Duration Frequency Curve Details

Event Water Year	Probability and Volume Matching Window			Exceedance Probabilities	
	Beginning Date	Ending Date	Duration (days)	Confluence with Willamette	The Dalles
1934	December 18, 1933	January 8, 1934	22	1.0%	1.4%
1965	December 22, 1964	December 31, 1964	10	0.1%, 0.2%, 0.5%	1.5%, 2.4%, 4.4%
1974	January 15, 1974	January 22, 1974	8	1.0%	1.0%
1982	February 15, 1982	February 28, 1982	14	1.0%	1.0%
1996	February 7, 1996	February 13, 1996	7	0.2%, 0.5%	0.3%, 0.9%
1997	December 27, 1996	January 7, 1997	12	1.0%	2.5%

Cumulative flow volume duration frequency curves at The Dalles and at the Columbia-Willamette confluence were generated with HEC Statistical Software Package (HEC-SSP) using methodology similar to that previously discussed for the basinwide local frequency curves. However, since these curves determine the target scaling volumes and associated probabilities, more care was taken in refining the flood time window. HEC-SSP allows the user to remove specific years from the dataset, but does not allow the user to use a different time window for individual years. The spring and fall runoff encroach on the winter flows on different dates each year. During some years, the largest winter storms occurred very early or very late in the season, requiring a broad time window. Yet, during other years, winter events were small enough that HEC-SSP selected partial spring or fall runoff as events. To force HEC-SSP to select actual events, a broad time window was set and then portions of the spring or fall runoff that did not contain rainfall runoff were removed. In essence, this is the same as customizing the time window for problematic years, but HEC-SSP does not provide this option. The frequency curves are provided in Figure 3-3 and Figure 3-4.

3.1.2.3 Exceedance Probability

As previously mentioned, for the Spring Synthetic Flood Events, spring annual chance exceedance probabilities were calculated based on volume duration frequency curves at The Dalles. Since the Willamette River Basin is a major contributor to winter flooding in Portland, the target winter annual chance exceedance probabilities for Winter Synthetic Flood Events are calculated on the Columbia River just downstream of the confluence with the Willamette River.

The exceedance probabilities are based on a winter season specific analysis and are technically seasonal chance exceedance probabilities, rather than annual chance exceedance. As stated by Cudworth (1989, 188): “the resulting probabilities are no longer ‘annual’ probabilities. Rather, the probabilities are the frequency or chance of exceedance in any given single season of the type of flood being studied.” Winter and spring floods are dominated by different hydrometeorological conditions, namely rainfall and snowmelt. Reporting the seasonal probabilities as an annual chance exceedance is justified by assuming that the floods during each season were dominated by independent causes, but one should acknowledge that there may be some minor dependence.

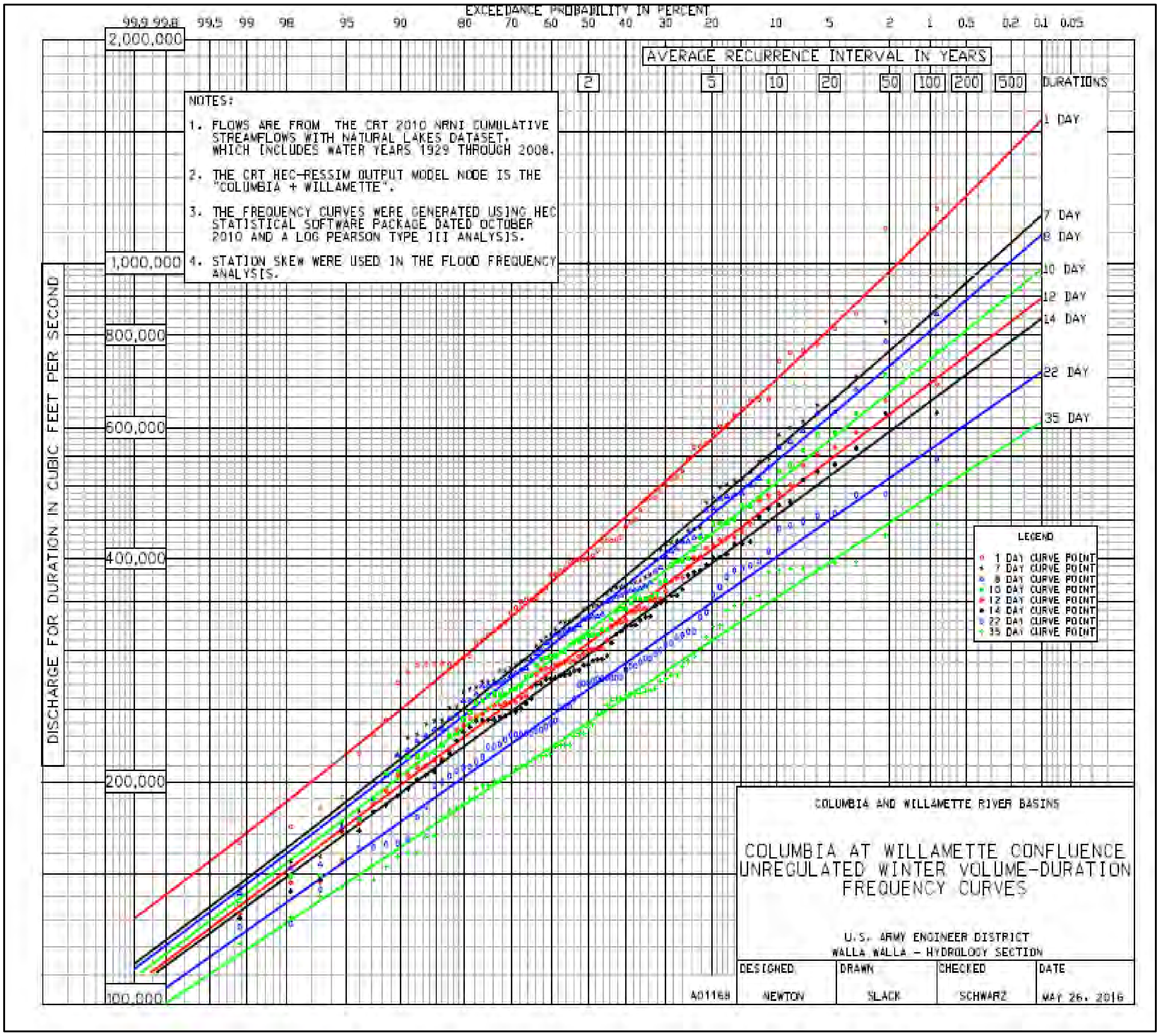


Figure 3-3. Unregulated Winter Volume Duration Frequency Curve for the Columbia River at its Confluence with the Willamette River

Note: The solid, colored lines represent the flood frequency curves with durations as labeled on the right side of the plot. The top two X-axis labels correspond to reciprocal values of annual chance exceedance and exceedance interval. The colored symbols represent flood flows that correspond with the flood frequency curve of the same color.

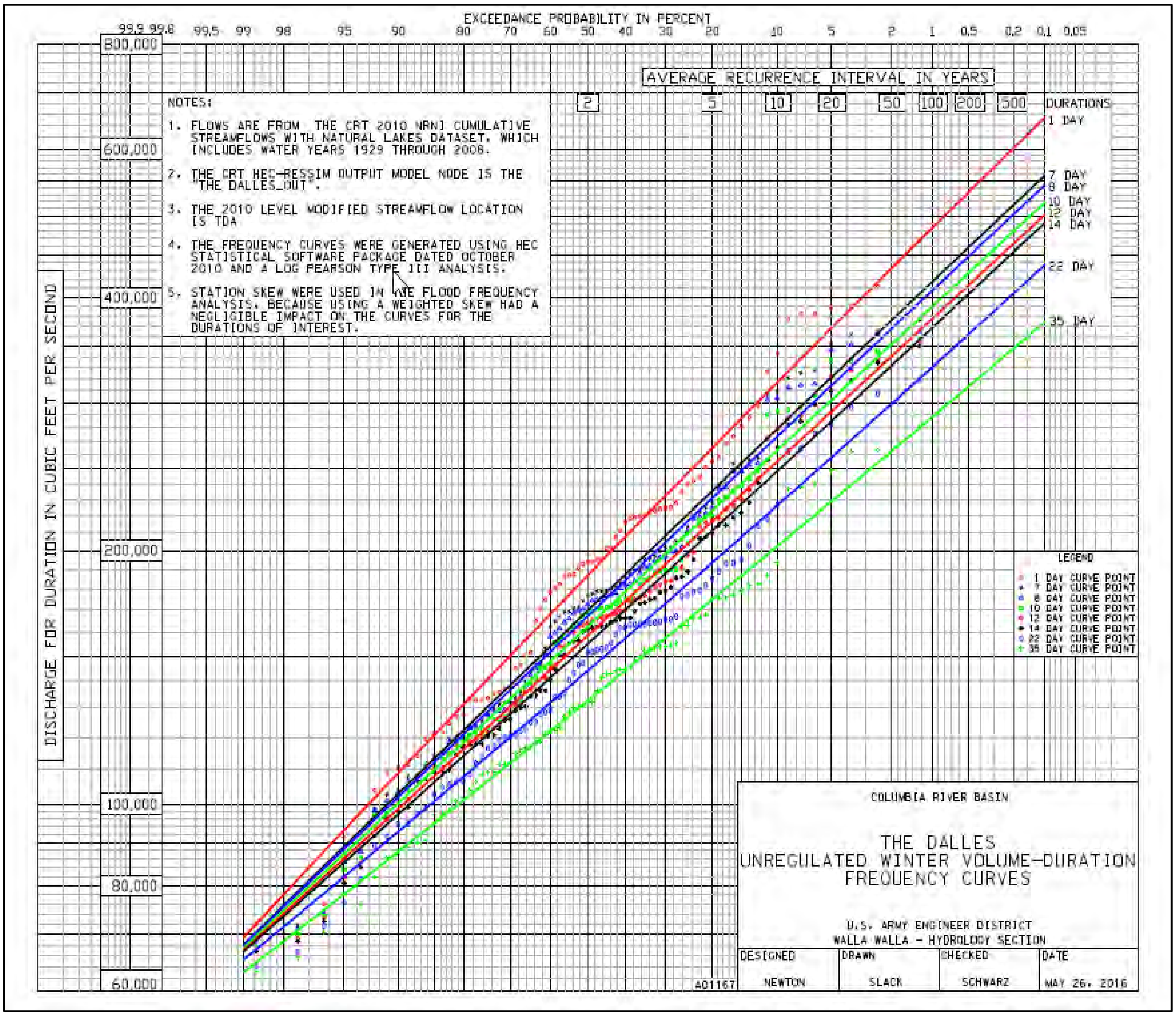


Figure 3-4. Unregulated Winter Volume Duration Frequency Curves for the Columbia River at The Dalles

Note: The solid, colored lines represent the flood frequency curves with durations as labeled on the right side of the plot. The top two X-axis labels correspond to reciprocal values of annual chance exceedance and exceedance interval. The colored symbols represent flood flows that correspond with the flood frequency curve of the same color.

3.2 PRECIPITATION AND RUNOFF EVENT ANALYSIS

Precipitation data was analyzed to identify the temporal extents of meteorological events. This was necessary to accurately define the corresponding extents of the runoff hydrographs, which would be scaled. Precipitation data was not used for scaling or as model inputs.

3.2.1 HEC-ResSim Natural Lakes Model

A HEC-ResSim model of the Columbia River Basin was developed with an alternative that uses incremental NRNI inflows at their non-disaggregated geographic locations. The non-disaggregated locations correspond to the 2010 Level Modified Streamflows geographic locations, with additional points on the Snake and Yakima Rivers. This model emulates the effects of six large natural lakes, as though downstream dams had not been constructed. The six lakes and their downstream dams are Upper Arrow Lake (Hugh Keenleyside Dam), Lower Arrow Lake (Hugh Keenleyside Dam), Kootenay Lake (Corra Linn Dam), Flathead Lake (Kerr Dam, now called Seli'š Ksanka Qlispe' Dam), Lake Pend Oreille (Albeni Falls Dam), and Lake Coeur d'Alene (Post Falls Dam). Other smaller natural lakes are not modeled. Due to model improvements since the 2000 level Spring Synthetic Flood Events were generated, a new NRNI model was adapted specifically for the Winter Synthetic Flood Events. Incremental NRNI flows were scaled up and routed through the model. Then cumulative volume was checked at the confluence of the Columbia River with the Willamette River. Scaling was repeated with new scale factors until the volume for the specified duration matched the frequency curve volume.

3.2.2 Selection of Template Scaling Years

The template hydrographs water years 1934, 1965, 1974, 1982, 1996, and 1997 were selected based on the magnitude of the peaks, the shape of the hydrograph, and the geographic and seasonal distribution of runoff. The peak winter event for each year in the dataset was plotted at the Columbia-Willamette confluence and at The Dalles. The hydrographs were time shifted such that the peaks aligned and natural breaks in peak magnitudes were identified. Based on the natural breaks, the smaller hydrographs were eliminated. Families of hydrograph shapes were identified to ensure that each type of shape was included as a synthetic event. These years were plotted as a function of time of year, as illustrated in Figure 3-5, to ensure that a substantial portion of the winter season would be represented by the synthetic events.

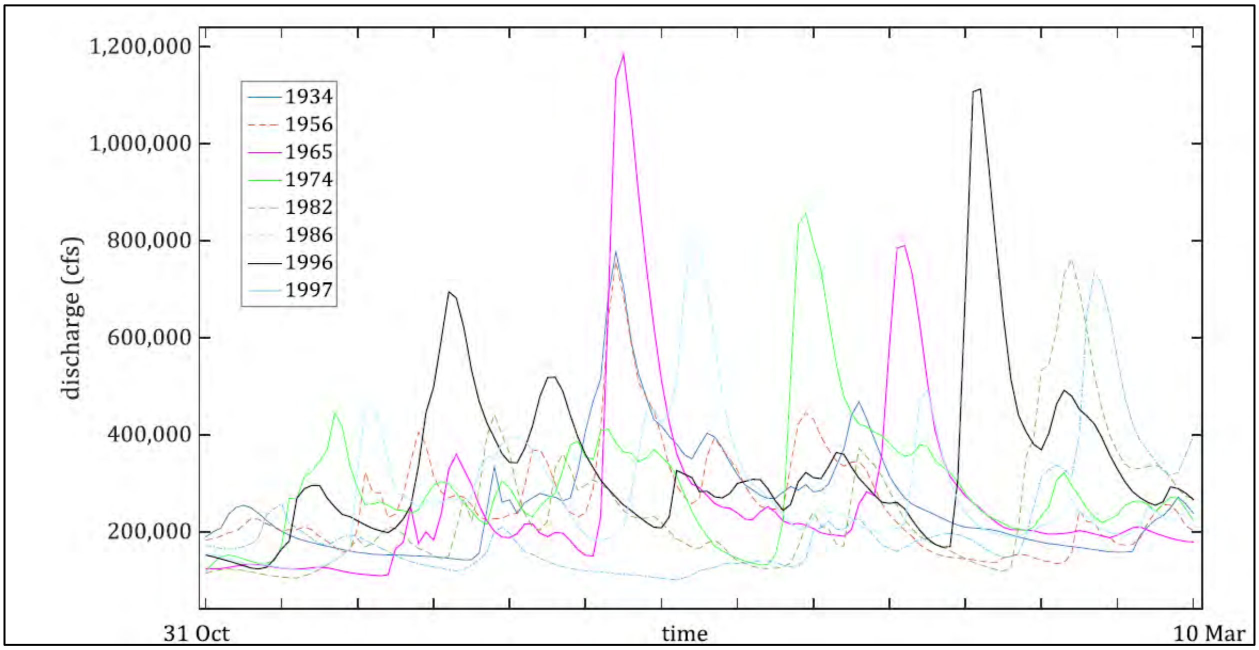


Figure 3-5. Largest Winter Peaks at the Columbia-Willamette Confluence During 1929 to 2008

Note: Colored lines each represent a specific water year as shown in inset.

Geographic distributions of both runoff and precipitation were examined to ensure that the synthetic event template years would include storms centered over a variety of locations throughout the Columbia River Basin. The peak daily precipitation during each storm event was plotted as graduated symbols that represent the actual magnitude of precipitation. In Figure 3-5 these precipitation markers are overlaid on an interpolated grid of runoff exceedance probabilities for 1-day average discharges, derived from the frequency curves.

The exceedance probability grid was developed using a comparatively small number of locations and did not account for orographic effects during interpolation (these issues could have been mitigated to some extent by assigning probabilities to subbasins, as was done with the spring synthetics, but the maps were sufficiently accurate for the present purposes). In contrast, the precipitation data contains a much larger number of points and implicitly accounts for orographic effects since it has point measurements. The exceedance probability grid does not provide direct information about storm centering, although there is some correlation. The precipitation data, on the other hand, provides an accurate picture of rainfall intensity, but reveals nothing about the rarity of the event. Both the precipitation points and runoff exceedance probability grid methods have weaknesses in visualizing geographic distribution, but together they provide a complementary picture of rainfall and runoff distribution.

The magnitude of the peaks, hydrograph shapes, seasonal distribution of events, and the geographic distribution of precipitation and runoff were examined using the methods discussed. The analysis justified eliminating two additional events, 1956 and 1986, which are included in Figure 3-5, because they provided little additional diversification of template years. The combined peak daily precipitation and exceedance probability regional maps for the template years selected to create the Winter Synthetic Flood Events are provided in Figure 3-6.

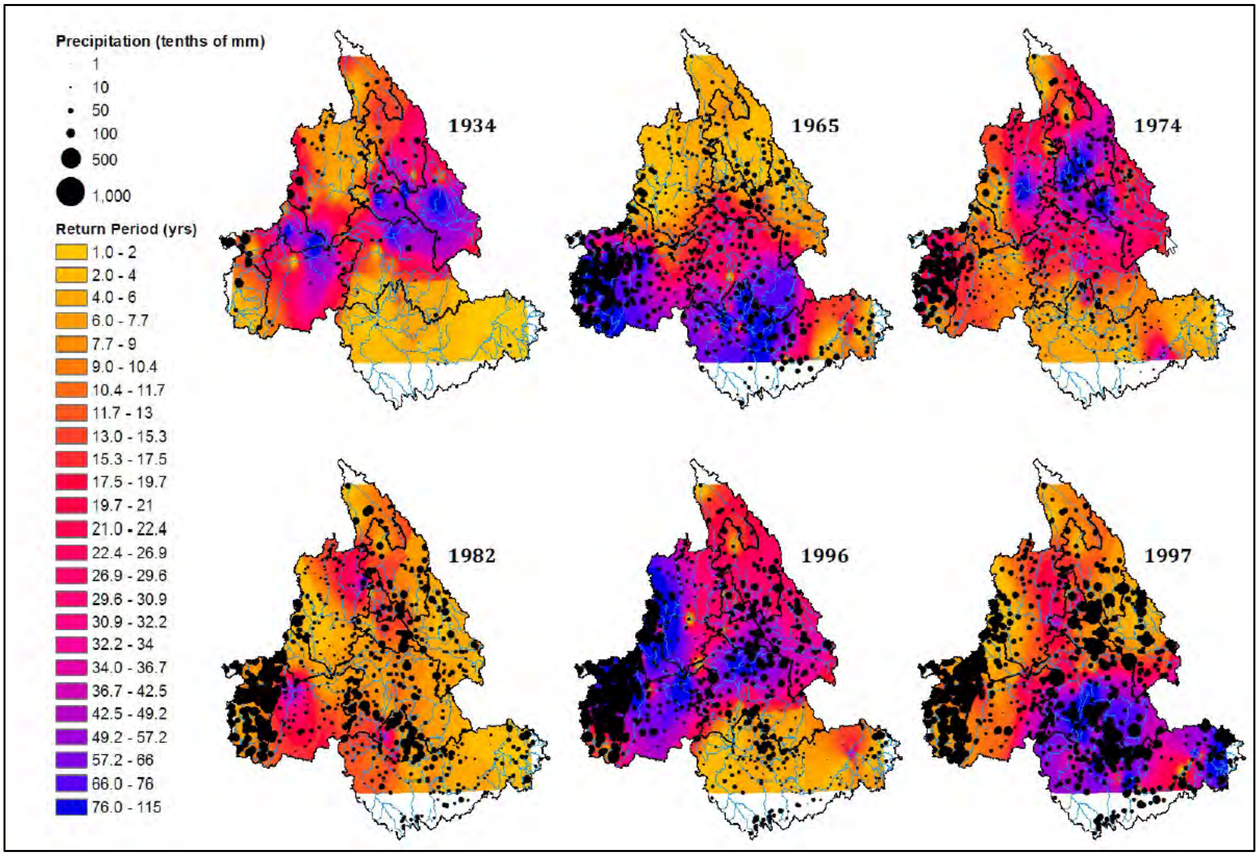


Figure 3-6. Regional Geographic Distribution of Precipitation and Runoff Return Periods Template Events for the Winter Synthetic Development

Note: The geographic distribution of precipitation is shown in circles and runoff return periods are shown with shading to show general regional trends.

3.2.2.1 December 1933–January 1934 (Water Year 1934) Event

This event has the longest duration of winter high flows out of the template events selected. The heaviest precipitation leading to the highest peak during the duration occurred between December 16 and 25. This precipitation was centered on the lower Columbia River and Pend Oreille River regions. During this event, the freezing level remained within the elevation range of the surface topography, leading to snow accumulation at high elevations.

3.2.2.2 December 1964 (Water Year 1965)

Intense precipitation associated with an atmospheric river event targeting the Willamette River, lower Columbia River, and Snake River regions led to low probability runoff in the lower river system. The precipitation associated with this event occurred over a short duration, December 19 to 25.

3.2.2.3 January 1974

Heavy precipitation accumulated over the period of January 11 to 20 in the Willamette, upper Columbia, Kootenai, and Pend Oreille regions. This resulted in low probability runoff response in the northern regions.

3.2.2.4 February 1982

The basin experienced widespread heavy precipitation from February 11 to 26. Precipitation accumulation was the greatest in the lower Columbia and Willamette Rivers, however the runoff response was less extreme than other template events.

3.2.2.5 February 1996

A strong atmospheric river impacted the Willamette, Cascades, Spokane, and Pend Oreille regions February 3 to 11. This event brought short-duration, flood inducing rainfall and resulted in low probability runoff in the impacted regions.

3.2.2.6 December 1996–January 1997

December and January experienced an extended period of continuous precipitation. The heaviest precipitation occurred between December 29 and January 3 and impacted the lower and upper Snake River, Willamette River, and Cascade Range regions. Through this period, the freezing level remained within the elevation range of the topography, leading to snow accumulation at high elevations.

3.2.3 Defining Storm and Runoff Durations

The scaling duration was determined from the shape of the runoff hydrograph and from storm patterns, which required examining both precipitation and runoff data. In some cases it was desirable to scale runoff from a single rainfall event, while in other cases multiple successive, but continuous, storms formed the runoff event and the successive events were therefore scaled as a block.

3.2.3.1 Storm Durations

Average daily precipitation measurements are shown in Figure 3-7 for the entire Columbia River Basin for each of the template events; storm durations are shown as the time periods between the diamond markers. No spatial or orographic weighting was used and areas with denser distributions of gages biased the mean. However, the purpose of the plots was not to obtain an accurate spatial mean precipitation, but rather to define the temporal limits of the storm event. These final temporal limits were used as a guide for identifying the actual limits of the rainfall-induced runoff. The temporal extents of each local runoff hydrograph were identified separately since timing differed throughout the basin.

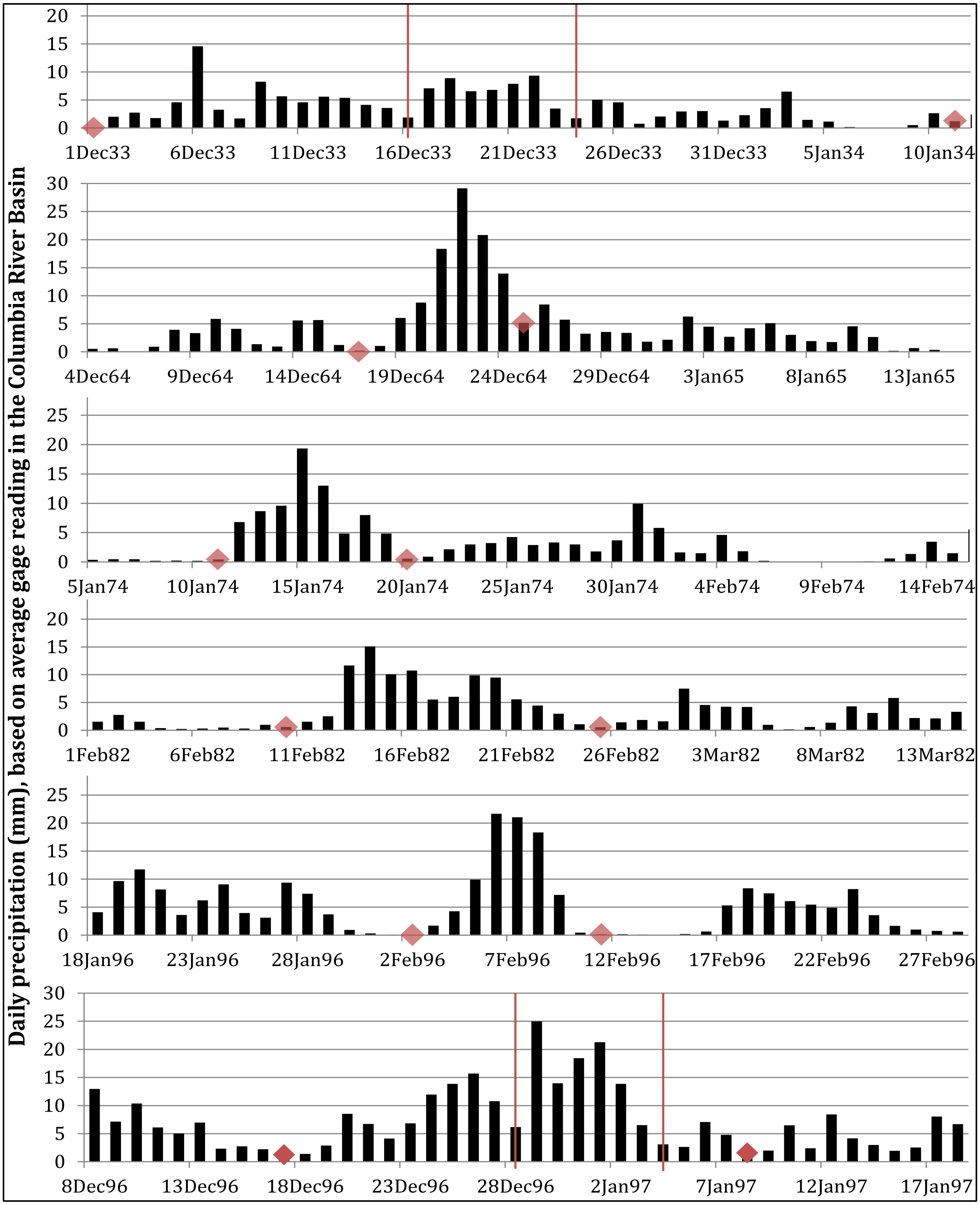


Figure 3-7. Precipitation Measurements for Template Years of the Winter Synthetics Development

Note: Red diamonds indicate beginning and ending of storm events and vertical lines indicate the dominant rainfall segment of the storm.

Intense rainfall and weather conditions that promote snowmelt are the physical drivers that produce severe runoff. Scaling runoff can therefore be thought of as a surrogate for scaling precipitation and weather conditions. Hydrograph scaling was inclusive of both rainfall and snowmelt. No attempt was made to separate the rainfall and snow melt components of the runoff during scaling.

During portions of the 1934 and 1997 events precipitation in the form of snowfall occurred at higher altitudes, resulting in no runoff. For scaling purposes it was helpful to define a segment of these two storms that was dominated by rainfall throughout most of the basin. The dominant rainfall segment of each storm is identified by the vertical lines in Figure 3-7. Snowfall and temperature measurements were examined, to aid in defining the rainfall-dominated storm segment. The temperature and snowfall measurements were averaged in the same manner as the precipitation data, and were used to obtain a rough estimate of when runoff was primarily rainfall, rather than snowmelt, induced. During the scaling process the rainfall-dominated segments of the 1934 and 1997 events were examined first. Then any runoff outside of the time window (vertical lines in Figure 3-7) that was continuous with the runoff in the time window was included for scaling. For example, if rainfall was continuous at a given site from the start to end date of the storm, identified by the diamond markers in Figure 3-7, the runoff was scaled for the full event. However, if there were breaks in the rainfall-induced runoff, only that portion of the runoff that was continuous with the segment of the storm identified by the vertical bars in Figure 3-7 was scaled. Rainfall did not occur throughout the basin for the full 1934 and 1997 event durations, and scaling snowmelt-dominated runoff was undesirable. Also, scaling occurred for rain events with continuous rainfall and each event was visually inspected to ensure that a rain event was actually present.

3.2.3.2 Local Runoff Durations

Local runoff that resulted from the storm events defined in Figure 3-7 was scaled up to create the Winter Synthetic Flood Events. The beginning of each local runoff event could be clearly identified and was generally within a few days of the beginning of the storm event. The end of the runoff event was more subjective due to a more gradual descending limb, which is a function of local basin characteristics.

Because only continuous runoff was scaled, portions of the basin were scaled only during the dominant segment of the event and areas that received snowfall were not scaled. This type of scaling mimics what could occur in a major flood event because a more intense storm would not result in more runoff in regions that experienced only snowfall, if the temperature patterns prevailed.

3.3 HYDROGRAPH SCALING

3.3.1 Conceptual Framework

Due to storm movement, local variations in basin runoff characteristics, topography, temperature, wind, and other meteorological factors, runoff does not begin and end at the same time throughout the basin. In addition, winter runoff events are much shorter than spring events and in some cases 1 day can be a substantial portion of the hydrograph. For these reasons, a fixed scaling window could not be used for all locations in the basin; instead a separate scaling window was identified for each of the 137 inflow nodes of the Columbia River System HEC-ResSim Model, for each flood event. Hydrograph extents for each of the 137 inflows were defined visually and independently for all six template years. However, the scaling for the winter and spring Brownlee inflow synthetics were created independently from the rest of the system as is described in Section 2.7.

3.3.1.1 Scaling Justification

For this effort to be successful, hydrograph temporal boundaries needed to be clearly and systematically defined. Scaling only flow (and not the flood event duration) by a constant scale factor required physical justification. In Figure 3-8 the winter events with the 10 largest peaks were scaled up by a constant scale factor such that the new peaks had the same magnitude as the 1996 peak, which was the largest winter peak in the dataset, at The Dalles. The hydrographs were time shifted so that the ascending limbs aligned with one another, with the exception of 1982 which had a multi-peak storm within the ascending limb. The hydrograph for 1982 was aligned by peak.

The storm events that produced the runoff hydrographs are distinctly different from each other, as seen in Figure 3-7. Therefore, it is not necessarily expected that their hydrographs would be highly similar. If, however, one could show that the hydrograph shapes are reasonably similar after scaling the hydrographs up to the same peak magnitude, it would provide some justification for scaling. The intent is simply to demonstrate that scaling the hydrographs would not result in events that are outside the realm of physically plausible events.

The ascending limb is similar for all of the template years shown in Figure 3-8, except for 1982. Prior to the inflection point at the beginning of the ascending limb, flows are a function of pre-storm conditions and should not be scaled. However, for the purposes of this figure the full time period was scaled to maintain historical shapes. It is less obvious whether or not the entire receding limb should have been scaled by the full scale factor. The receding limb flow is a function of the storm runoff and pre- and post-storm conditions, and is less likely to be similar when comparing years. For most events, the final discharge is greater than the initial discharge.

In the peak region, prior to the inflection point on the descending limb, water years 1934, 1965, and 1997 (solid lines in Figure 3-8) are reasonably similar to water year 1996. The similarity demonstrates that scaling these events by a constant scaling factor over this region results in fairly realistic synthetic events. A single adjustment for time (e.g., applying a scale factor along the abscissa) would not be beneficial in all cases; as a result scaling time could not be justified. The events with dashed lines in Figure 3-8 required a scaling factor of at least 1.5. The peak region, and in particular the ascending limb, were less similar for the events with shown with dashed lines in Figure 3-8. Therefore, there may be an upper limit for appropriate scale factors.

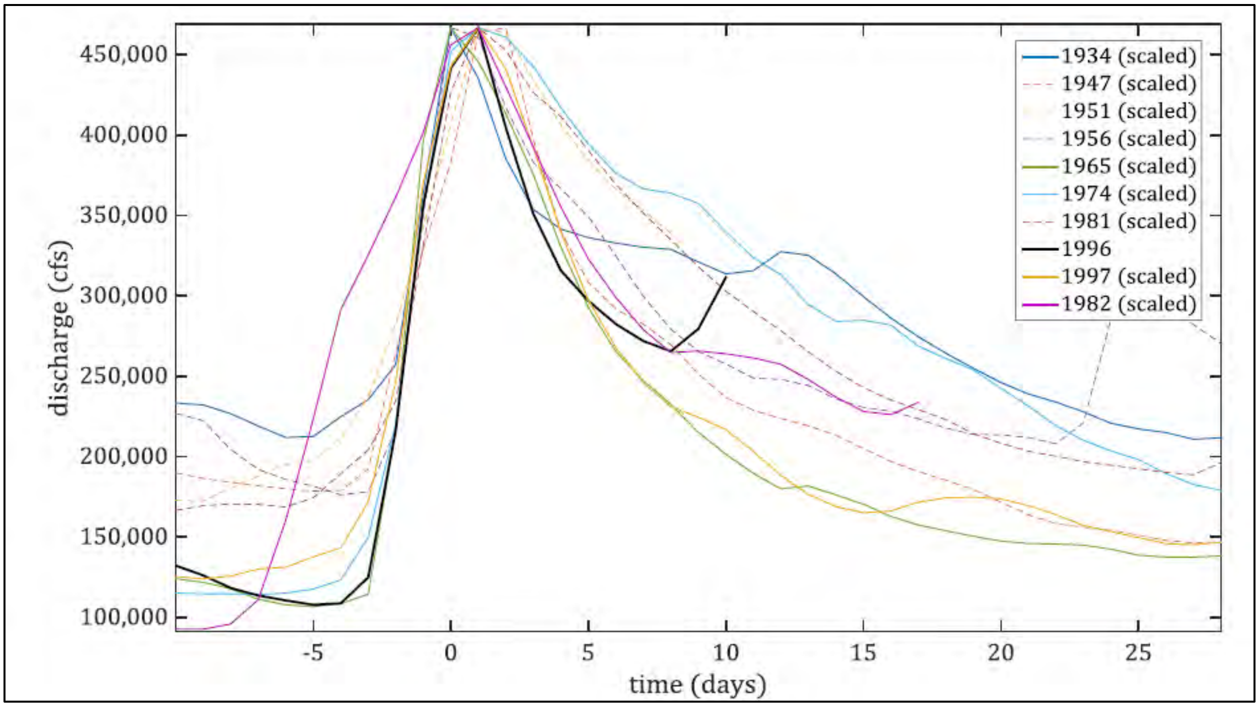


Figure 3-8. Largest Unregulated Events at The Dalles

Note: The events have been scaled up to match the 1996 peak discharge, for comparing hydrograph shapes.

Both water years 1974 and 1981 have broader peak regions when compared to the rest of the template years. The 1981 event was scaled up by more than 1.3 times the scaling factor used for the 1974 event, and these two scaled events have reasonably similar shapes. The similar shapes of these two events suggests that scaling other runoff shapes, such as multi-peak storm events, is justified.

The events shown in Figure 3-8 are scaled cumulative flows, but the flows that require scaling are the local flows. To demonstrate that scaling local flows produces hydrographs similar to scaled cumulative flows, Figure 3-9 shows an example for water year 1982 that compares the flood event created from scaling and routing incremental flows to scaled cumulative flows at the Columbia-Willamette confluence. Target volumes at the confluence are the same for the methods being compared.

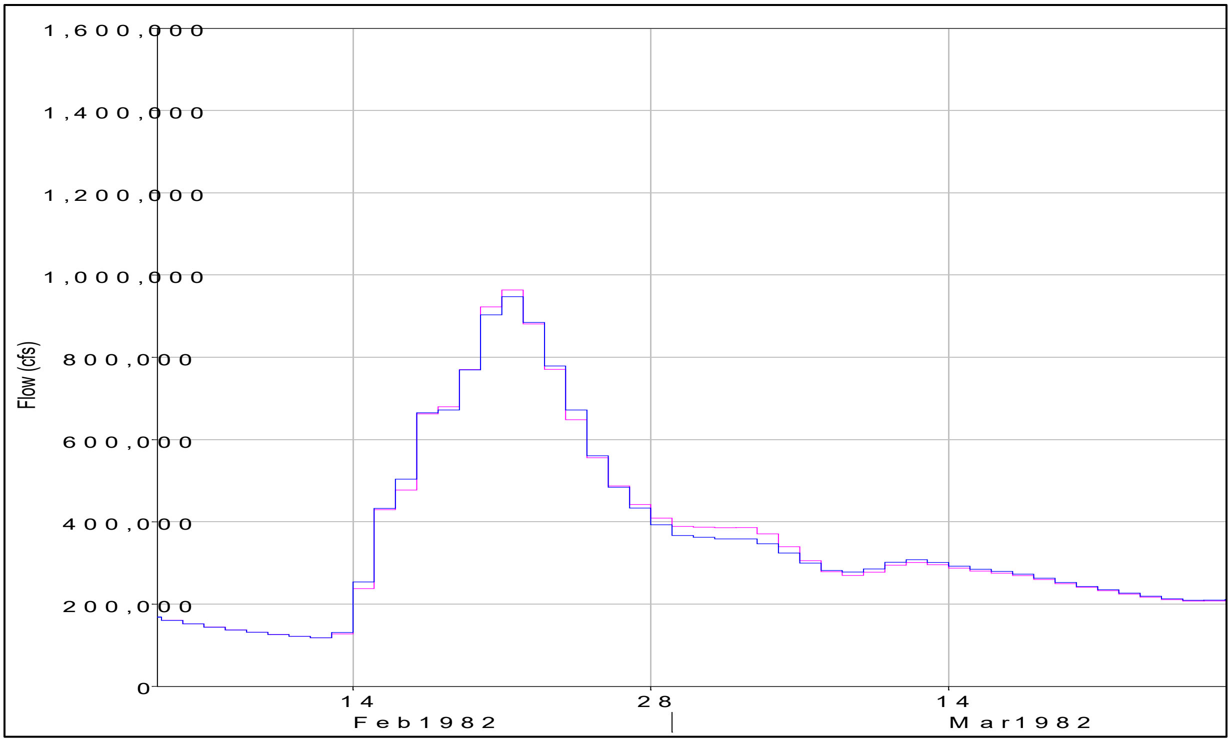


Figure 3-9. Hydrograph of the Scaled Cumulative Flow at the Confluence of the Columbia River and Willamette River

Note: The hydrograph represents the winter flood event for water year 1982 with 1 percent exceedance probability. It compares the local flow event scaling (blue) to the cumulative event scaling (magenta).

3.3.1.2 Local Hydrograph Scaling

The key inflection points and base flow illustrated in Figure 3-10 were visually identified for each of the 137 scaled inflow hydrographs in each template year. Due to the large number of hydrographs (822), a MATLAB script was written that plotted each hydrograph and allowed the user to identify the key points. After each point was identified, the hydrograph was scaled and plotted automatically for review. Each hydrograph was visually inspected to verify that a realistic shape was maintained and that unrealistic transitions or discontinuities were not introduced in the rising or receding limbs. This visual selection and inspection of hydrographs introduces subjectivity to the scaling process.

Base flow can be substantially large compared to rainfall runoff in some regions of the Columbia River Basin during a winter event, and negligible at other locations. It was therefore necessary to remove base flow prior to scaling in order to maintain a realistic spatial distribution of runoff. Had the base flow not been removed, regions with substantial base flow would have received a larger percentage of the basinwide scaled flow, thus changing the rainfall distribution. In contrast, removing the base flow allows the portion of the runoff caused by the event (rainfall plus snowmelt) to be scaled by the same factor everywhere, thus maintaining the event-induced runoff distribution, while appropriately altering the total runoff distribution.

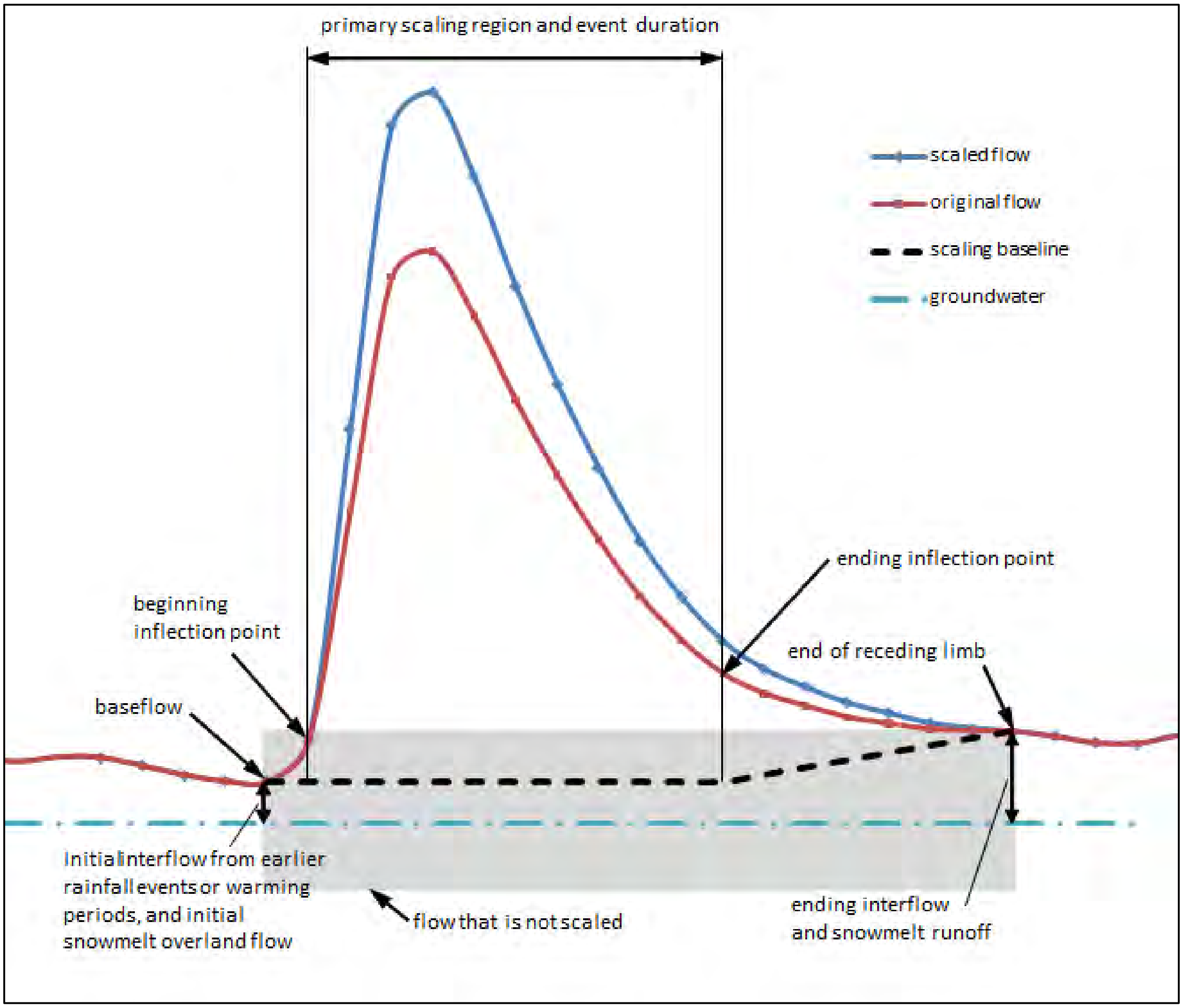


Figure 3-10. Conceptual Scaling Schematic and Definition Sketch for Scaled and Unscaled Hydrographs

Base flow, as defined in this study, is flow from earlier events in the form of groundwater, interflow, or overland flow. No attempt was made to separate these base flows further into the individual components that contribute to the base flow, but the components are briefly mentioned conceptually to justify lumping them together. Interflow can be defined as shallow subsurface flow that moves quickly, compared to deeper subsurface flow. Overland flow moves even more quickly than interflow. Streamflow response to groundwater is delayed compared to the response to overland flow and interflow, and may occur after the event. In regions where the ground is frozen or has been saturated for long periods of time, a response to groundwater during the event is even less likely. For these reasons groundwater has been approximated as a horizontal line, as illustrated in Figure 3-10.

Preexisting overland flow or interflow reduces initial infiltration rates, resulting in a faster and larger runoff response. When the storm event begins, if there is preexisting interflow or overland flow, that flow should not be scaled (nor should groundwater). Considerable effort would be required to separate out the effects of preexisting interflow and/or overland flow from event flow as the event progresses, and that would also necessitate some approximation. For simplicity a horizontal line approximation designates an estimate of preexisting interflow and overland flow, as shown in Figure 3-10, acknowledging that a downward trend could persist for an unknown period of time. At the receding limb inflection point, the base flow line in Figure 3-10 tilts upward for scaling purposes that are not necessarily related to the preexisting interflow.

3.3.2 Model Iterations

Inflow hydrographs were scaled and routed through the Columbia River System HEC-ResSim Model. The scaling factor was iteratively increased (or decreased) until the runoff volume at the confluence of the Columbia River with the Willamette River matched the frequency curve volume for the exceedance probabilities specified in Table 3-2. The same scale factor was initially applied to every local hydrograph for a given template year. The local hydrographs were inspected to ensure that scaling did not produce improbable local events. If improbable events were identified, the scaling factor at those individual locations was reduced and the iteration was repeated. A scaling factor reduction was only necessary at a small number of sites. The remainder of the sites used the same global basin scale factors for a given template year. The final global scale factor applied to the local hydrographs is reported in Table 3-2. Template years 1965 and 1996 were scaled several times to create multiple synthetic events, but only the scale factors for the largest synthetic event (lowest probability) are shown in the table.

Table 3-2. Scaling Factors Used to Create the Winter Synthetic Flood Events from the Template Flood Events

Event Template Water Year	Largest Local-Scale Factor Applied to Local Inflows	Corresponding Cumulative Probability of Scaled Events at the Columbia-Willamette Confluence
1934	1.28	1%
1965	1.36	0.1%
1974	1.24	1%
1982	1.29	1%
1996	1.34	0.2%
1997	1.29	1%

During the iteration process local hydrograph volumes were compared to the volume of the 3-day 0.2 percent chance exceedance event, as reported by the local frequency curves. Events that exceeded this volume criteria were considered unlikely and were therefore examined further to determine if the scale factor needed to be reduced. When water year 1965 was scaled to a 0.1 percent chance exceedance, the 3-day 0.1 percent chance exceedance event was used as a volume screening criterion instead of the 3-day 0.2 percent event. Only 24 of the 1,233 local inflow hydrographs exceeded either of these criteria. Of the 24 events, 17 were unique; the remaining 7 events were 1965 events that were scaled for multiple recurrence intervals and violated the criteria more than once. The 24 events were investigated and the scale factors were reduced for 5 of the 24 events (3 of the 17 unique events). The maximum scale factor reduction applied was 15 percent.

The 3-day duration was used for screening because the majority of local events that contributed to the Columbia-Willamette confluence event were longer than 3 days. A given local runoff event tended to have similar exceedance probabilities across most durations selected from within the event duration. As a result, the probability associated with any duration shorter than the event duration could have been used as an indicator for identifying unusual events, but the longest duration, 3 days, that could be applied to all local events was selected because it was closest to the event duration.

The 0.2 percent and 0.1 percent chance exceedance criteria were used only as screening tools, as opposed to hard limits. These probabilities were justifiable because rare runoff events are generally made up of less rare events at smaller geographic scales. It is possible to have some localized events that are rarer. The intent was to identify unusual events that needed to be examined on a case-by-case basis.

Where possible, events were compared to winter season probable maximum flood peak discharge to ensure that scaling did not result in physically impossible flows. Only the probable maximum floods developed for the Willamette River Basin could be applied as a winter season probable maximum flood. However, winter standard dam/reservoir floods, which are smaller than probable maximum floods, were developed for Dworshak and Spalding. The winter standard dam/reservoir flood peak flows for both of these locations were obtained from the Dworshak water control manual (Corps 1986). The maximum scaled peak flows were 114 and 205 kcfs at Dworshak and Spalding, respectively, which is smaller than the standard dam/reservoir flood values of 160 and 280 kcfs. Therefore, the scaled peak flows were smaller than the maximum floods expected at Dworshak and Spalding and scaling of the template years is not likely to have resulted in physically impossible flows.

A standard dam/reservoir flood was developed for spring runoff at the Columbia-Willamette confluence (Corps 1969). The two largest peak flows at the confluence between 1929 and 2008 occurred during the winter, December 1964 and February 1996, while the next largest events occurred during the spring. Since the maximum winter and spring peaks are of similar magnitude, the standard dam/reservoir flood peak is provided for comparison, but it should be emphasized that the spring and winter hydrographs are dissimilar in all other respects and that spring and winter events are not directly comparable. The maximum scaled winter peak flow was 1,563 kcfs and the spring standard dam/reservoir flood peak was 1,620 kcfs.

3.3.3 Irrigation and Evaporation Adjustments

To generate winter synthetic streamflows for use with the 2010 Level Modified Streamflows dataset, irrigation and evaporation depletions were applied to the scaled, cumulative winter synthetic streamflows as described in Section 2.6. The adjusted, cumulative flows were disaggregated to create local flows at the Columbia River System HEC-ResSim local flow locations.

CHAPTER 4 - RUNOFF VOLUME FORECASTING

4.1 SUMMARY OF RESERVOIR OPERATIONS

Reservoir operations in the Columbia River Basin are often based on runoff volume forecasts. These forecasts estimate the volume during the runoff season for each of the dams/reservoirs and for the Columbia River System as a whole. The runoff volume forecasts are used along with storage reservation diagrams to determine the upper rule curve (maximum elevation of a reservoir while drawing down the water surface elevation to meet FRM purposes, also sometimes referred to as the flood control rule curve). Some dams/reservoirs also have flood control refill curves or refill guide curves that are used for determining reservoir refill water release schedules using forecast error statistics to increase the confidence of the ability of the reservoir to refill.

Once the runoff volume for each dam/reservoir has been forecasted, the storage reservation diagrams are used to specify maximum reservoir water surface elevations at each of the dam/reservoir locations. The runoff volume forecast at each location is updated on the first day of each month during the forecast period. Some locations are updated on the 15th day of the month, but the end-of-month water surface elevation point is not altered at these locations. The upper rule curve is updated using the forecast and the storage reservation diagram, and operations within the system are adjusted to accommodate the new forecasted runoff volume. Once the reservoirs have released water to their fully evacuated point, they may hold that pool elevation and pass inflow. If the amount of inflow is less than other minimum outflow requirements at a dam/reservoir, holding the pool elevation may not be possible, and the pool elevation may continue to drop until the refill period commences. The refill period for dams/reservoirs included in the Columbia River Basin operations begin when the forecasted, unregulated flow at The Dalles is expected to exceed the Initial Controlled Flow, which is determined by balancing the reservoir space in the system available for refill and the seasonal runoff volume remaining in the basin. Refill typically begins in April and continues through July. During this time the reservoirs are allowed to refill gradually, containing enough of the runoff to maintain downstream flows at targeted levels.

The dams and reservoirs within the Columbia River System are regulated in coordination with one another to maximize the benefits provided by the storage reservoirs. One of the primary benefits is power generation and many of the storage reservoirs and run-of-river dams/reservoirs in the Columbia River Basin provide power generation for the Pacific Northwest region. Since the Columbia River Basin operations are limited by FRM objectives, power generation guidelines are set to operate within the FRM guidelines that are discussed above.

The Columbia River has other uses and requirements that are taken into consideration when the operating guidelines are developed each year. These include, but are not limited to, flow augmentation for fish, irrigation, navigation, recreational uses, and water quality and environmental factors for native species in the river system. The coordination effort that is required by the many agencies involved in setting the operational guidelines for the reservoirs is essential in maintaining a balance for flood protection and power generation throughout the Columbia River Basin along with the other uses of the natural resources.

4.2 FORECAST PROCESS

Runoff volume forecasts for the period of 1929 to 2008 were generated for the 12 forecasting locations, listed in Table 4-1, and are used by the 21 major FRM dams included in the Columbia River System hydrologic models, which include the flood and power models. Each of these forecast locations has an associated set of operational runoff volume forecast equations. The forecast equations are used to estimate runoff volume during the runoff season associated with each dam/reservoir, the most common being April to August, or a residual runoff forecast from the forecast date through the end of July, commonly referred to as a “Date-July” forecast.

The Columbia River System forecast dataset is comprised of hindcasts from the most current forecast equations and supplemented with, in order of preference, hindcasts from previous forecast equations, Kuehl-Moffitt forecasts (Kuehl and Moffitt 1986), and development of new or modified forecast equations. Hindcasts is the term used to describe forecasts created for past water years. For example, in 1995 a forecast was created for that year’s flood season which provided the best guess of the likely inflow to the system; this set of data is called the historical forecast. Throughout flood season in 1995, inflows to the system were measured, which gave an actual value of inflows during that flood season. Recently, the inflows for the flood season of 1995 have been re-forecasted with the most up-to-date forecast equations, which is called the hindcast. Therefore, for water year 1995 there are three sets of inflows or inflow predictions: the historical forecast, the measured inflows, and the hindcast. In the event that current forecast equations were not available for hindcast (such as for Brownlee and The Dalles), historical operational forecasts were used and supplemented with Kuehl-Moffitt forecasts. In order to maintain and reflect current level of forecast accuracy, source datasets not produced by the hindcasting of current forecast equations were adjusted for the over- and under-forecasting pattern, referred to as the trend adjustment, and for standard error. The trend adjustment was used to maintain patterns in under- and over-forecasting in the current forecast equations. The standard error adjustment was used to reflect the current level of forecast accuracy. The intent of the adjustments is to bring the CRSO forecast dataset as a whole to the same statistical accuracy (commonly referred to as “skill”) as the current forecast equations that are used to operate the system.

Of the 12 forecast locations, 8 are used in the power model. The power model requires residual forecasts (inflow remaining) for Date-July. Date-July forecasts are developed from seasonal forecasts plus observed runoff data from January through the forecast date. Table 4-1 summarizes the forecasting locations used in the flood model and the power model. The table also includes the forecast period and the agency that provides the forecast for each location, as well as the operation objectives that use the forecast as input. Figure 4-1 shows the location of the 12 forecast points in the basin.

Table 4-1. Water Supply Forecast Locations Used in the Columbia River System Models

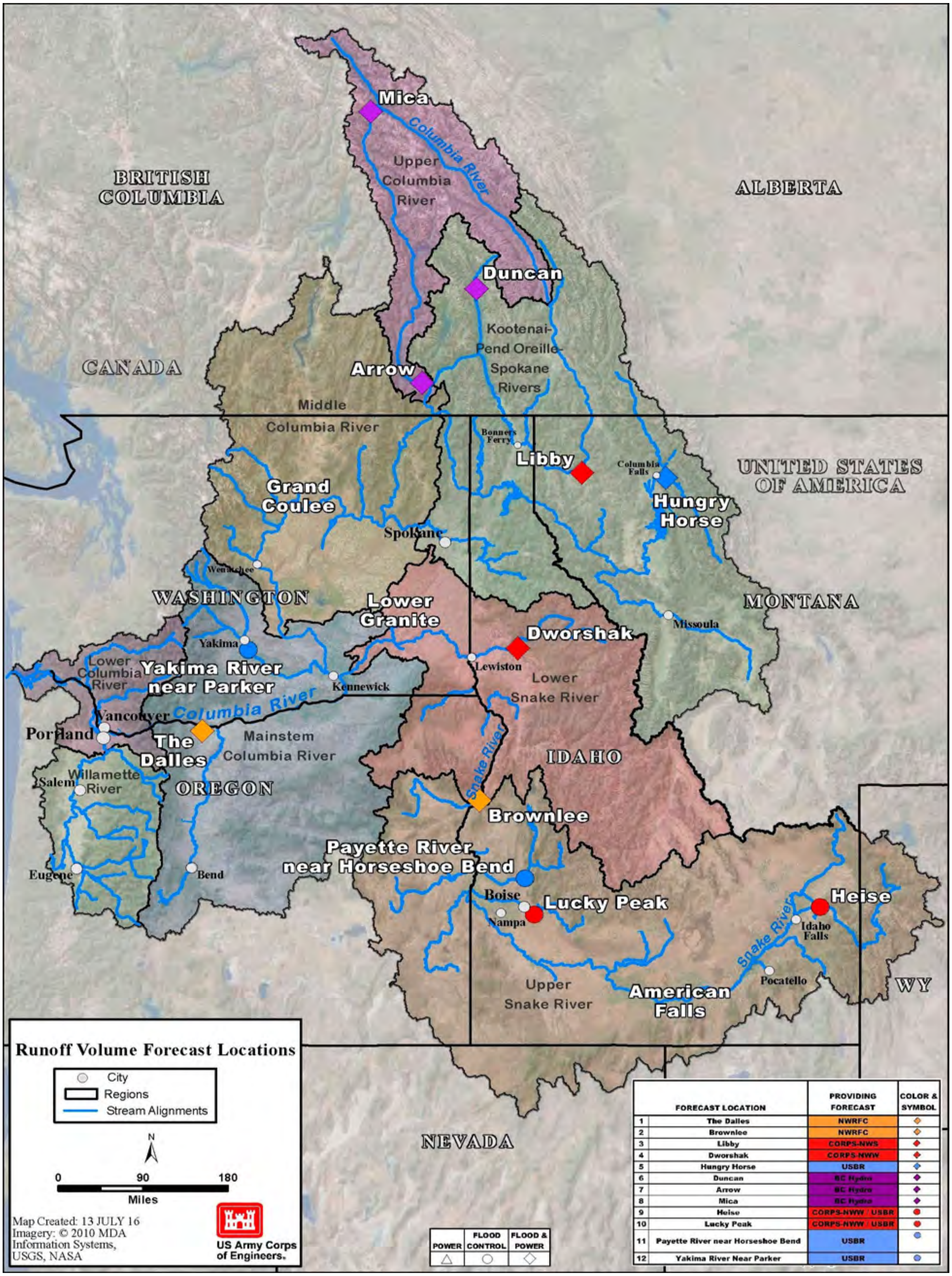
Forecast Location	Primary Forecast Period	Agency Providing Forecast[1/]	Purpose: Power Generation	Purpose: Flood Control
Mainstem Columbia River Region				
The Dalles	April–August	NWRFC	X[2/]	X
Yakima River near Parker	Date-July	Reclamation	–	X
Lower Snake River Region				
Dworshak	April–July	Corps-NWW	X	X
Upper Snake River Region[3/]				
Heise	Date-July	Corps-NWW/Reclamation	–	X
Lucky Peak	Date-July	Corps-NWW/Reclamation	–	X
Payette River near Horseshoe Bend	Date-July	Reclamation	–	X
Brownlee	April–July	NWRFC	X	X
Kootenai(y)–Pend Oreille–Spokane Region				
Libby	April–August	Corps-NWS	X	X
Hungry Horse	May–September	Reclamation	X	X
Duncan	April–August	BC Hydro	X	X
Upper Columbia River Region				
Mica	April–August	BC Hydro	X[4/]	X
Arrow	April–August	BC Hydro	X[4/]	X

1/ Abbreviations are as follows: NWRFC = Northwest River Forecast Center; Corps-NWW = U.S. Army Corps of Engineers Northwestern Walla Walla District; Corps-NWS = U.S. Army Corps of Engineers Northwestern Seattle District; BC Hydro = British Columbia Hydro and Power Authority.

2/ The Dalles forecast is used in the power model only as it relates to Grand Coulee operations.

3/ The Snake River Water Supply forecasts upstream of Brownlee Dam (Heise, Lucky Peak, and Payette River near Horseshoe Bend) are only used to create winter and spring synthetic hydrology datasets.

4/ For real-time operations Arrow and Mica provide monthly forecasts which are summed to get a Date-July forecast period used in the Power Model. A Date-July seasonal forecast is provided for use in the power model.



POWER	FLOOD CONTROL	FLOOD & POWER
△	○	◇

	FORECAST LOCATION	PROVIDING FORECAST	COLOR & SYMBOL
1	The Dalles	NWRFC	◆
2	Brownlee	NWRFC	◆
3	Libby	CORPS-NWS	◆
4	Dworshak	CORPS-NWW	◆
5	Hungry Horse	USBR	◆
6	Duncan	BC Hydro	◆
7	Arrow	BC Hydro	◆
8	Mica	BC Hydro	◆
9	Heise	CORPS-NWW / USBR	●
10	Lucky Peak	CORPS-NWW / USBR	●
11	Payette River near Horseshoe Bend	USBR	●
12	Yakima River Near Parker	USBR	●

Figure 4-1. Forecast Locations for HEC-ResSim Flood and Power Models

Multiple agencies and offices prepare runoff volume forecasts for the Columbia River Basin FRM dams/reservoirs, and more than one forecast was prepared for many locations in an effort to improve forecast accuracy.

4.3 FORECAST INFORMATION BY REGION

There are a total of 12 forecast locations in the Columbia River System HEC-ResSim Model:

- Kootenai(y)–Pend Oreille–Spokane Rivers Region: Libby, Hungry Horse, Duncan
- Upper Columbia River Region: Mica; Arrow
- Upper Snake River Region: Heise, Brownlee, Lucky Peak, Payette River near Horseshoe Bend
- Lower Snake River Region: Dworshak
- Mainstem Columbia River Region: The Dalles, Yakima at Parker

4.3.1 Regions without Forecast Locations

The middle Columbia, lower Columbia, and Willamette River regions do not have runoff volume forecast locations. The main control point for FRM operations in the Columbia River System is the Columbia River at The Dalles location, which is upstream of two of these regions. Therefore, flood risk reduction at The Dalles is not impacted by operations in the lower Columbia and the Willamette River regions. Flow volumes in the lower Columbia and Willamette River regions are also predominantly rain driven and typically see peak flows in the winter, while most of the other subbasins in the Columbia River Basin are snowmelt driven and have peak flows in late spring and early summer. Therefore, winter peaks in these two regions may cause local flooding, but do not contribute substantially to the overall system's flooding.

Grand Coulee Dam is located in the middle Columbia River region and is owned and operated by Reclamation but the Corps regulates flood space in the reservoir. Grand Coulee flood control during stored water release requires a volume forecast at The Dalles. While not included in this effort, the Grand Coulee Date-July forecast is an input to power operations modeling and its development should be considered in future forecast development efforts. The other projects in the middle Columbia River region are predominately run-of-river projects, which pass inflow to the downstream projects and do not require runoff volume forecasts.

4.3.2 Kootenai(y)–Pend Oreille–Spokane River Region

4.3.2.1 Libby Forecast

Libby Dam, located on the Kootenai(y) River, is operated by the Corps for FRM, power generation, and fisheries interests. Historically, multiple regression based approaches have been used to develop water supply forecasts. These use observed precipitation, snow water equivalent measurements, and/or climate indices to predict seasonal runoff volume. A complete long-term record of historic April to August operational forecast data has not been maintained by the Corps for the Libby forecast location. Historic operational forecasts for this location are available for the period of 1998 to 2010. In the event that the historical operational forecasts are needed, the hindcast data, supplemented with Kuehl-Moffitt data, would be used.

The Corps provided hindcast data from the 2014 principal components regression equations for the period of 1984 to 2009 and from the 2004 principal components regression equations for the period of 1961 to 1983 (1975 to 1983 in January). For the period of 1948 to 1960 (1948 to 1974 in January), hindcast data from the 1986 equations was used, these are referred to hereafter as the Morrow-Wortman equations (Wortman 1986). The Morrow-Wortman equations used a split-basin regression approach to forecast Libby inflows. This approach subdivided the Libby Basin into two subbasins, fitted a regression model to the runoff from each subbasin, and then combined the individual subbasin forecasts into a composite basin forecast. With the 2004 equation update, the Corps abandoned the split-basin regression approach and began using principal components equations to make first-of-month forecasts of an April to August runoff volume for the entire Libby basin. Kuehl-Moffitt data for the period of 1929 to 1947 was used to fill in the remaining years of 1929 to 1947. Each of the three segments of the Libby unadjusted dataset were statistically adjusted.

Operations at Libby Dam require an early season forecast in order to determine the variable end-of-December flood control draft requirement of the reservoir. The Corps used hindcast data for the December 1 forecast from the 2014 principal components equations for the period of 1984 to 2009. For the period of 1929 to 1983, the Corps provided the period-of-record data for the four precipitation stations and the two climate variables used in the 2010 forecast equation. The data was analyzed to identify periods of time that consistent data could be used to generate hindcast data using the principal components method. This resulted in three forecast equations to complete the December forecast dataset. The forecast equations were used to generate hindcast data for the periods of 1961 to 1983, 1950 to 1960, and 1929 to 1949. Each of the final three hindcast datasets were statistically adjusted.

4.3.2.2 Hungry Horse Forecast

Hungry Horse Dam is located on the South Fork Flathead River, which merges with the Middle Fork Flathead River to create the mainstem Flathead River, merging with Clark Fork River before entering Lake Pend Oreille. Hungry Horse Dam is owned and operated by Reclamation for FRM, power generation, and fisheries interests. The forecast period begins later and extends further into the year when compared to other projects because Hungry Horse Dam is located high in the Rocky Mountains where the mountain peaks may stay snow covered year round. A multivariate linear regression forecast was used for the purposes of this study and uses observed runoff and various hydrometeorological data (e.g., precipitation, snow water equivalent).

The hindcast data used in this study came from two sources: the hindcast data from the 2011 multivariate linear regression equations, and a Reclamation study produced in 2003 (Reclamation 2003). The hindcast data from the 2011 forecast equations covered the period from 1944 to 2009. The 2003 Reclamation study generated first-of-month forecast data for the period of 1929 to 2002 by compiling data from three sources. For the period of 1944 to 2002, Reclamation used their 2002 forecast equations to back-generate forecast volumes. Since very little precipitation and snow data exists prior to 1944, modified forecasts for the period of 1932 to 1943 developed by Reclamation were used. Prior to 1932, precipitation and snow station data is not available, and Reclamation used Kuehl-Moffitt data to supplement the dataset for the period of 1929 to 1931. The dataset was compiled using the 2011 hindcast data from 1944 to 2009, and the dataset produced from Reclamation's 2003 study is used for the remaining period from 1929 to 1943.

In order to maintain the current forecasting abilities at this location, the trend and standard error for the 1944 to 2009 data was used to statistically adjust the other two data source periods. Since only 3 years of Kuehl-Moffitt data were used, the trend and standard error for the 1929 to 1982 Kuehl-Moffitt dataset were calculated and used in the statistical adjustments. The 1932 to 1943 forecast data was adjusted for trend and standard error.

4.3.2.3 Duncan Forecast

Duncan Dam is located in British Columbia on the Duncan River, which flows into the Kootenai(y) River. BC Hydro owns and operates Duncan Dam for FRM, power generation, and fisheries interests.

BC Hydro uses principal components forecast equations to estimate monthly runoff volumes into Duncan Reservoir. In real-time operations, BC Hydro provides the monthly forecasts to the United States, so that the monthly forecasts can be summed for a variety of forecast periods. For modeling purposes, the United States requires an April to August forecast volume for use in flood models and a Date-July forecast for use in the power models.

BC Hydro provided the monthly hindcast data for Duncan for the period of 1966 to 2009. The April to August forecast was compiled by summing the individual monthly forecasts for April, May, June, July, and August. Kuehl-Moffitt April to August data was used to supplement the hindcast data for the period of 1929 to 1965.

4.3.3 Upper Columbia River Region

The upper Columbia River region lies completely within Canada and contains the headwaters of the Columbia River. The two major dams in this region are Arrow (Hugh Keenleyside) and Mica, which are owned and operated by BC Hydro for FRM, power generation, and fisheries interests. Both projects have local and system FRM objectives which must be met and coordinated with the United States. Local FRM at both projects is based on April to August forecasts and system FRM is determined by The Dalles April to August forecast.

4.3.3.1 Mica Forecast

BC Hydro uses principal components forecast equations with hydrometeorological variables to estimate monthly runoff volumes into Mica Reservoir. In real-time operations, BC Hydro provides the monthly forecasts to the United States, so that the monthly forecasts can be summed to get a variety of forecast periods. For modeling purposes, the United States requires an April to August forecast volume for use in flood models and a Date-July forecast for use in the power models. An April to August forecast period was provided in lieu of the individual monthly volumes. Supplemental monthly data is not available and the monthly forecasts would have to be summed outside of the flood and power models before they could be used with the hydrologic sampler.

BC Hydro provided the monthly hindcast data for Mica for the period of 1966 to 2009. Kuehl-Moffitt April to August data was used to supplement the hindcast data for the period of 1929 to 1965. Since the independent variable data used in the forecast equations was not made available, it was assumed that continuous variable data was used to generate the hindcast data, such that no modified forecasts would be identified.

4.3.3.2 Arrow Forecast

BC Hydro uses principal components forecast equations with hydrometeorological variables to estimate monthly runoff volumes into Arrow reservoir. For local FRM at Arrow Dam, BC Hydro's monthly runoff volume forecasts only include inflow at Arrow, which excludes inflow from upstream projects. However, this study defines the required forecast at Arrow as the area between Mica Dam and Arrow Dam. Therefore, for real-time operations, BC Hydro produces monthly forecasts for Arrow, Whatshan, and Revelstoke Dams. The monthly volumes at each of the three projects are then summed to create the local monthly inflow to Arrow Reservoir, which is provided to the United States. The United States sums the local monthly inflow at Arrow to get an April to August volume for use in the flood modeling and a Date-July volume for use in power models. Only an April to August forecast period was provided in lieu of the local monthly Arrow inflow volumes because supplemental monthly data is not available. Therefore, the monthly forecasts would have had to be summed outside of the flood and power models before they could be used with the hydrologic sampler.

BC Hydro provided the monthly hindcast data for Arrow, Whatshan, and Revelstoke Dams for the period of 1966 to 2009. Kuehl-Moffitt April to August data, for the total inflow at Arrow, was used to supplement the hindcast data for the period of 1929 to 1965. It was assumed that continuous variable data was used to generate the hindcast data at each of the three projects, such that no modified forecasts would be identified.

4.3.4 Upper Snake River Region

The upper Snake River region has four forecast locations: Heise and Brownlee on the Snake River; Lucky Peak on the Boise River; and the Payette River near Horseshoe Bend. The forecasts for three of the four locations are used in the Upper Snake River Reservoir HEC-ResSim Model, which computes the regulated inflow to Brownlee Reservoir. All of the forecasts upstream of Brownlee are solely used in the scaled portions of the synthetic events to apply a daily shape to the Brownlee inflows. The forecasts upstream of Brownlee are not used in the flood risk analyses. FRM uses the calculated Brownlee inflows for analysis. The synthetic scaling process is described in greater detail in Chapters 2 and 3. The daily shaping of the flows at Brownlee is described in Section 4.3.4.2 and the table in Section 4.5.2. The water supply forecast for the regulated inflow at Brownlee is used in the Columbia River HEC-ResSim Model, which routes the flow to The Dalles and beyond.

4.3.4.1 Heise Forecast

Palisades Dam and Jackson Lake use the Heise Date-July runoff volume forecast for operational purposes. Both of these projects are owned and operated by Reclamation for irrigation purposes. Reclamation and the Corps coordinate flood operations under a formal flood control agreement for flood risk reduction. Due to the combined operational objectives, both agencies prepare first-of-month forecasts for Heise. Mid-month forecasts are not required under the flood operating criteria of the agreement; however, both agencies prepare a mid-month forecast which is only used on an as-needed basis. In real-time operations, the two agencies negotiate a final operational forecast that is based on their respective agency forecasts and observed basin conditions. For this study, the two forecasts are averaged. In real time, the space required in each reservoir is determined by a forecast-based rule curve that takes into account the following constraints:

- No less than 75 percent of the space is allocated to Palisades Reservoir
- A minimum of 200 thousand acre-feet (kaf) of space must be available in Jackson Lake prior to May 1

Within these constraints, it is at Reclamation’s discretion as to how the space is distributed between the two reservoirs. For modeling purposes for this study, a 75/25 split between Palisades and Jackson Lake Reservoirs was consistently applied.

Reclamation uses multivariate linear regression equations which forecast an October to July seasonal volume and the runoff to date is subtracted from it to calculate the residual Date-July runoff volume. The Corps uses simple linear regression equations which forecast a Date-July runoff volume directly. Both agencies’ current forecast equations were used to generate first-of-month and mid-month hindcast data for the entire period of 1929 to 2009. The precipitation and snow station data used in the current Reclamation forecast equations has measurements that date back to 1929. The precipitation and snow station data used in the Corps’ current forecast equations for all forecast dates, except June first-of-month and June mid-month, has measurements that date back to 1929. The Corps’ current forecast equations for the June first-of-month and June mid-month forecasts do not have data prior to 1970 and 1981, respectively. The precipitation and snow station data for each agency’s forecast was reviewed in order to identify the modified historical forecasts. The agencies’ hindcast data was statistically adjusted and averaged to get the final forecast dataset for Heise. For the June first-of-month and June mid-month forecast only Reclamation’s statistically adjusted hindcast dataset was used.

4.3.4.2 Brownlee Forecast

Brownlee Dam is owned and operated by Idaho Power Company but the Corps regulates the flood storage space in the reservoir. NWRFC provides the first-of-month April to July regulated runoff volume forecast for Brownlee. The Brownlee forecast uses regulated inflow data because reservoirs upstream of this location, combined with a large number of irrigation diversions, highly regulate the Snake River above the reservoir. For this study, the Upper Snake River Reservoir HEC-ResSim Model is used to route the 2010 Level Modified Streamflows to Brownlee Reservoir. The Brownlee regulated inflow, computed by the Upper Snake River Reservoir HEC-ResSim Model, and the Brownlee forecast dataset are used as inputs to the Columbia River System models.

The Brownlee monthly runoff volume forecast is produced by NWRFC with a forecasting period of April to July. Historically, the Brownlee forecast was developed using simple linear regression of a seasonal index that consisted of a variety of indicators. Over the past 10 years NWRFC has transitioned to the use of Ensemble Streamflow Prediction, which uses a modeling system to simulate current hydrologic conditions and historical meteorological data to create equally likely sequences of future hydrologic conditions. Due to NWRFC's unique forecasting methodology and its associated model calibration, the concept of developing hindcast data did not apply effectively here. As a result it was determined that the historical operational forecasts would be used in place of hindcast data. Furthermore, the regression-based operational forecasts were chosen for this analysis due to the long-term record of available data. NWRFC provided the historical operational forecasts for Brownlee for the period of 1983 to 2009. Since hindcast data could not be generated, Kuehl-Moffitt data for the period of 1929 to 1982 was used to supplement the dataset. The Kuehl-Moffitt data was statistically adjusted.

4.3.4.3 Lucky Peak Forecast

Anderson Ranch, Arrowrock, and Lucky Peak Dams use the Lucky Peak Date-July runoff volume forecast for operational purposes. The Corps owns and operates Lucky Peak Dam. Anderson Ranch and Arrowrock Dams are operated by Reclamation; however, the Corps regulates flood storage space in both reservoirs. Due to the combined operational objectives, both agencies prepare first-of-month and mid-month forecasts for Lucky Peak. In real-time operations, the agencies negotiate a final operational forecast that is based on their respective agency forecasts and observed basin conditions. For the purposes of this study, these two forecasts are averaged. First-of-month historical operational forecasts, agreed upon by the agencies, were provided by Reclamation for the period of 1983 to 2009. Reclamation did not maintain any historic mid-month operational forecasts and the Corps has not maintained complete long-term records of actual agreed-upon forecasts. The historic operational forecasts were supplemented with the hindcast data because Kuehl-Moffitt data are not available for this location.

Reclamation uses multivariate linear regression equations to forecast an October to July seasonal volume and the runoff to date is subtracted to compute the residual Date-July runoff volume. The Corps uses simple linear regression equations which forecast a Date-July runoff volume directly. Both agencies' current forecast equations were used to generate first-of-month and mid-month hindcast data for the 1929 to 2009 period. Negative Date-July volumes were generated for the June mid-month forecast in 1936 and for the April, May, and June mid-month forecasts and the June first-of-month forecast date in 1977. Negative Date-July forecasts are calculated when an under-forecast has occurred for the seasonal (October to July) volume and the entire volume difference is continually moved into a smaller and smaller residual time period. In real-time operations, an alternative forecasting method would be used in the event that a negative residual forecast was produced. For modeling purposes in this study these negative values were set to zero. The precipitation and snow station data used in the current Reclamation forecast equations has historical data that dates back to 1929. The Corps first-of-month forecast equations rely on both precipitation and snow station data, which is available back to 1929 for all forecast dates except June. The Corps mid-month forecasts only use snow data, which does not have a complete record for the 1929 to 2009 period. The statistically adjusted forecasts were averaged to obtain the final forecast dataset for Lucky Peak.

4.3.4.4 Payette River near Horseshoe Bend Forecast

Cascade and Deadwood Dams, located on the North Fork Payette and Deadwood Rivers, respectively, are both owned and operated by Reclamation with the primary purpose of irrigation water supply. In addition, these projects are operated informally for flood risk reduction where such operation does not risk irrigation supply; no formal flood control authorization exists. Cascade and Deadwood Dams use the Payette River near Horseshoe Bend Date-July runoff volume forecast created by Reclamation for operational and FRM purposes. Both projects supply a combined flood risk reduction space, which is split 80/20 between Cascade and Deadwood Reservoirs, respectively. Reclamation makes a first-of-month forecast and has the ability to make a mid-month forecast; however, the mid-month forecast is used on an infrequent basis.

In real time, Reclamation reviews multiple forecasts for this location before making an operational forecast. For the current study, a current multivariate linear regression equation forecasts a Date-July runoff volume. The current multivariate forecast equations were used to generate first-of-month hindcast data for the entire period of 1929 to 2009. Two modified forecast periods were identified for each of the six forecast dates.

4.3.5 Lower Snake River Region

Dworshak Dam is the only project in the lower Snake River region that requires a runoff volume forecast for FRM operations. Dworshak Dam is located near Orofino, Idaho, on the North Fork of the Clearwater River, which is a tributary of the Snake River. The runoff volume forecast at Dworshak is used to estimate FRM storage and power generation.

4.3.5.1 Dworshak Forecast

The operational forecast at Dworshak is prepared by the Corps and forecasts an April to July runoff volume. Principal components and linear regression equations based on snow and precipitation measurements are used to prepare first-of-month runoff volume forecasts which are used for operational purposes. Linear regression equations are used for mid-month forecasts. The principal components equations were used to generate first-of-month hindcast data for the period of 1961 to 2009. Prior to 1961, only a few of the precipitation and snow station datasets exist. Instead of using average station data to extend the hindcast dataset, it was decided that the Kuehl-Moffitt data would be used to fill in the dataset for the period of 1929 to 1960.

4.3.6 Mainstem Columbia River Region Forecast Locations

The Mainstem Columbia River region has two forecast locations: The Dalles and the Yakima River near Parker. Aside from being the main control point, The Dalles is an important forecast location because many projects, including Grand Coulee in the United States and Arrow and Mica in British Columbia, use The Dalles forecast for operational purposes. Flow from the Yakima River is one of the major regulated flow components of the total Columbia River volume at The Dalles. The Yakima River system has approximately 1 million acre-feet (Maf) of storage. Although the Yakima River system is mainly operated for irrigation purposes, it does provide some incidental FRM in the Yakima Basin and in the lower Columbia River.

4.3.6.1 The Dalles Forecast

The Dalles monthly runoff volume forecast is produced by NWRFC with a forecasting period of April to August. Historically, The Dalles forecast was developed using simple linear regression of a seasonal index that consisted of a variety of indicators and involved some subjective input. Over the past 10 years NWRFC has transitioned to the use of Ensemble Streamflow Predictions, which use a modeling system to simulate current hydrologic conditions and historical meteorological data to create equally likely sequences of future hydrologic conditions. The Ensemble Streamflow Predictions process is continually being updated. Therefore, it was determined that the historical forecasts would be used in place of the hindcast data, and residuals and standard error values would be generated using the historical forecast dataset. The historical operational forecasts for The Dalles are available for the period of 1983 to 2009. Kuehl-Moffitt data for the period of 1929 to 1982 was used to supplement the dataset. The trend and standard error of the Kuehl-Moffitt data was adjusted to match the trend and standard error of the historical forecasts.

The forecast procedure for The Dalles uses a semi-regulated volume in its derivation with inputs from both unregulated flows and regulated flows. The unregulated flow is estimated by summing the observed runoff volume at The Dalles Dam, the Feeder Canal at Grand Coulee, and the change in lake storage volume at several locations. The locations where the change in lake storage is used to estimate the runoff volume at The Dalles are as follows:

- Mica Dam
- Revelstoke Dam
- Arrow Lakes at Nakusp
- Arrow Reservoir near Fauquier
- Libby Dam
- Duncan Dam
- Kootenay Lake at Queens Bay
- Hungry Horse Dam
- Seli’š Ksanka Qlispe’ Dam
- Lake Pend Oreille near Hope
- Priest Rapids near Priest River
- Noxon Rapids Dam

- Lake Coeur D'Alene
- Spokane – at Long Lake
- Grand Coulee Dam
- Lake Chelan Dam
- Brownlee Dam
- Dworshak Dam
- John Day Dam

The major contributors to the regulated flow component of The Dalles forecast are the Yakima River and the Snake River upstream of Brownlee Dam. The observed runoff volume dataset for The Dalles consisted of actual semi-regulated volumes for the period of 1983 to 2009 and the Kuehl-Moffitt observed volumes for the period of 1929 to 1982.

4.3.6.2 Yakima River near Parker Forecast

The Yakima River system has approximately 1 Maf of storage from five major dams: Bumping Lake, Cle Elum, Kachess, Keechelus, and Tieton. Reclamation computes the operational forecasts for the five dams as well as for the Yakima River near Parker, Washington. For real-time operations, Reclamation produces first-of-month forecasts, and has the ability to produce mid-month forecasts.

The current forecast equations supplied by Reclamation are multivariate linear regression equations, which forecast an October to July seasonal volume; and the runoff to date is then subtracted to determine the residual Date-July runoff volume. The current forecast equations were used to generate first-of-month hindcast data for the entire period of 1929 to 2009. The hindcast data produced a negative runoff volume for the June first-of-month forecast in 1934 and 2005. These negative values were set to the previous month’s forecast value. In real time operations, if the residual Date-July volume is negative then an alternative forecast equation would be used. The precipitation and snow station data used in the current forecast equations was provided by Reclamation. The data for the snow and precipitation stations was reviewed to identify the modified forecast periods for each January and February forecast date and each of the remaining four forecast dates. Each of the modified forecasts for forecast dates were statistically adjusted to match trends and standard errors of the current forecasts.

4.4 USE OF FORECASTS IN RESERVOIR OPERATIONS

Many reservoir operations in the Columbia River Basin use runoff volume forecasts to guide or inform operational decisions. The forecasts estimate the volume of water flowing into the system during the runoff season for each of the reservoirs and for the Columbia River System as a whole. The list below provides a non-comprehensive list of some of the major reservoir operations that use seasonal runoff forecasts:

- Seasonal volume forecasts generally developed from December to April guide the volume of space that will be evacuated from storage reservoirs for FRM.
- Seasonal volume forecasts developed for individual storage reservoirs for March to July guide decisions to start refill of the reservoirs and affect how quickly refill of the reservoirs occurs.
- Seasonal volume forecasts made at various times of the year are used for biological operations such as the Libby sturgeon pulse volume and the summer/fall flow augmentation volume.
- Seasonal volume forecasts are taken into account when planning for maintenance activities (such as drum gate maintenance).
- Seasonal volume forecasts inform limits on drafting for hydropower production and meeting energy requirements throughout the year.

4.5 FORECAST PRODUCTS

An 80-year set of forecasts for the period of 1929 to 2008 were generated for each forecast location from one of four sources:

- Hindcasts from Current Forecast Equations: Hindcasting refers to the process of using recorded historical independent variable data to generate forecasts using the current forecast equations. Hindcasts from current forecast equations spanned the period when all independent variables used in the current forecast equation have recorded data.
- Modified Forecasts: Modified forecasts refer to forecasts generated by modifying or removing independent variables from the current forecast equations which no longer have recorded data. Hindcasts were then generated using the modified independent variable data or the modified equation which excludes variables that have no recorded data.
- Kuehl-Moffitt Forecasts: This forecast dataset was generated as part of a study performed in 1983 by the Corps. Kuehl-Moffitt data was used when hindcasts from current forecast equations datasets and modified forecasts were not available.
- Historical Operational Forecasts: This dataset includes the actual historical forecasts that were used by the FRM dams/reservoirs for real-time operations. In the event that the current forecast equations were not supplied and hindcast data could not be generated, historical operational forecasts were used.

The hindcasts from current forecast equations datasets were first supplemented with modified forecasts and, if needed, with Kuehl-Moffitt data. The historical operational forecast datasets were first supplemented with Kuehl-Moffitt data, when available, and, if needed, with modified forecasts. The 80-year period of 1929 to 2008 was chosen as the representative period of record because it has already been used for other hydrologic applications in this study.

To maintain similar trends in the full set of forecasts, the supplemental and modified forecasts were adjusted to match the statistical characteristics of the hindcasts. The four forecast types discussed above are called segments. The generated 80-year dataset is called the unadjusted forecast dataset. Each segment of the unadjusted dataset was adjusted to reflect the over- and under-forecasting pattern seen in the current forecast procedures at each location. This adjustment is referred to as the “trend adjustment.” The trend adjustment was used so that the trend of each segment is the same as the trend of the current forecast procedures. This generates the trend-adjusted forecast dataset. The trend-adjusted forecast dataset was adjusted to match the standard error of the current forecasts. This final dataset is called the trend and standard error adjusted forecast dataset. This trend and standard error adjusted forecast dataset reflects the current forecast tendency to overestimate small volumes and underestimate large volumes. The adjustments to the datasets were made following the same logic as used to adjust the 2010 Level Modified Streamflows dataset which adjusts historical basin inflow hydrology to reflect current operations. Runoff volume forecasts are a part of the operations and the adjustment to the runoff volume forecasts is consistent with the 2010 Level Modified Streamflow dataset, in that the entire period of record reflects the forecasting accuracy of the current runoff volume forecasts. In addition, the statistics that characterize the current forecast trends are used in Monte Carlo analysis, resulting in a more meaningful measure of uncertainty.

4.5.1 Hindcasts from Current Forecast Equations

To maintain current forecasting capabilities, current forecast equations and their hindcast volumes were gathered. Hindcasts from current forecast equations are only available for years where all independent variable data used in the current forecast equations had recorded data. Independent variables are typically precipitation and snow-water-equivalent data that was obtained from snow monitoring stations and, in some instances, other climate variables are used. Hindcast results were often used in lieu of the current forecast equations. For those locations where hindcast results were not available, independent variables for the current forecast equations were obtained and hindcast results were generated. Hindcasts of the current forecast equations spanned the period when all of the independent variable data used in the current forecast equation was available. Developing hindcast data from the current equations was limited by data availability for the independent variables. In fact, most independent variable data for precipitation and snow station data used in the current forecast equations was not available during the early years of the period of record. When changes in independent variable data availability were identified, the independent variables used in the current forecast equations were modified or removed from the equations and hindcast data was generated using the modified data.

The process of using the current forecast equations to generate Date-July hindcast data can at times generate forecasts of runoff volume with negative values in the late season during drought years. Negative Date-July forecasts are produced when an under-forecast has occurred for the seasonal volume and the entire error is continually moved into a smaller and smaller residual time period. Due to the physical impossibility of having negative runoff volumes, these negative values were set to the previous month's forecast volume. Negative-volume forecasts were observed in the hindcast data for the Yakima and Lucky Peak forecasting locations.

4.5.2 Modified Forecasts

Modified forecasts were generated by modifying independent variables used in the current forecast equations in order to produce a hindcast dataset for the period of 1929 to 2008. Modified forecasts were used to supplement the hindcast data produced by the current forecast equations in years when independent variable data used in the current forecast were not available. Hindcasts of the current forecast equations spanned the period when all of the independent variable data used in the current forecast equation was available. In the case when the independent variables used in the current forecast equations did not have recorded data for the entire period of 1929 to 2008, the independent variables were modified or removed from the equations in order to continue generating hindcast data. Modified forecast periods were selected for each location and forecast date where the number of modified independent variables used in the equations showed an increase. Modified forecasts were developed for 6 of the 12 forecast locations: Heise, Lucky Peak, Payette River near Horseshoe Bend, Yakima River near Parker, Libby, and Hungry Horse. The process for selecting a modified forecast depends on the type of forecasting equation used.

The simple linear forecast equations, which consist of indexes that are made up of multiple independent variables, were modified for periods of time when the multiple independent variables did not have recorded data. The equations were modified by removing the independent variables that did not have recorded data. Hindcast data was generated using this modified equation until multiple independent variables used in the equation no longer had recorded data. This iterative process was continued until hindcast data was generated for the entire period of 1929 to 2008.

Multivariate linear regression forecast equations use an average value of the historical record of the independent variable for periods of time when data is not available. In the earlier years of the 1929 to 2008 period, average values are used in the forecast equations for a greater number of independent variables. As a greater number of average values are used for the independent variables, the forecast tends each year toward an average forecast value, which does not reflect how the current forecast equation would generate a forecast. Since no other forecast data sources were available for the sites that use multivariate linear regression equations, the current forecast equation was used to hindcast the entire period of 1929 to 2008, and modified forecasts were selected for the periods in which average values had to be used for an increasing number of independent variables in the current forecast equation.

Principal components regression equations are similar to the multivariate regression in that an average value is used for periods of time when independent variable data is not available. Average variable data could have been used to continue hindcasting, but Kuehl-Moffitt data is available for the five sites that use a principal components regression equation. Since using average variable data tends to forecast an average volume, it was decided that the Kuehl-Moffitt data would be the more appropriate data source to use.

Many of the independent variables used in the current and modified forecasting equations have recorded data for February, March, and April but have limited data for the other forecasting dates. This causes the number of valid forecasting years for each of the current and modified equations to be different for each date of a forecasting location. Table 4-2 summarizes the valid forecasting periods of the current and modified forecasts for each forecast location and date.

The advantage of creating hindcasts is that there are forecasted volumes and measured volumes for each of the water years that were hindcasted. The difference between the forecasted volume and the observed volume for all of the hindcasts were evaluated and used to adjust the modified forecast data by taking into account changes in trend and standard error. This effort resulted in normalizing the forecasts data from older forecast methods to match the trend and standard error of the current forecast. This effort distorts the modified forecast by creating a forecast set with consistent skill for the entire period that is equal to the current forecast skill.

Table 4-2. Summary of Current and Modified Equation Forecasting Periods

Forecast Location	December 1	January 1	January 15	February 1	February 15	March 1	March 15	April 1	April 15	May 1	May 15	June 1	June 15
	Forecasting Period for Current and Modified Equations[1/]												
Heise (Corps)[2, 3/]	No forecast made	1981–2009 c 1952–1980 m 1940–1951 m 1929–1939 m	1981–2009 c 1952–1980 m 1940–1951 m 1929–1939 m	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–2009 c 1949–1960 m 1938–1948 m 1929–1937 m	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–2009 c 1949–1960 m 1938–1948 m 1929–1937 m	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–1999 c 1949–1960 m 1938–1948 m 1929–1937 m	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1988–2009 c 1961–1987 m 1949–1960 m 1929–1948 m	1981–2009 c (no data before 1981)	1981–2009 c 1970–1980 m (no data before 1970)
Heise (Reclamation)[3/]	No forecast made	1981–2009 c 1954–1980 m 1944–1953 m 1929–1943 m	1981–2009 c 1954–1980 m 1944–1953 m 1929–1943 m	1960–2009 c 1949–1959 m 1938–1948 m 1929–1937 m	1960–2009 c 1949–1959 m 1938–1948 m 1929–1937 m	1949–2009 c 1938–1948 m 1929–1937 m	1949–2009 c 1938–1948 m 1929–1937 m	1949–2009 c 1936–1948 m 1929–1935 m	1949–2009 c 1936–1948 m 1929–1935 m	1984–2009 c 1949–1983 m 1929–1948 m	1984–2009 c 1949–1983 m 1929–1948 m	1984–2009 c 1949–1983 m 1929–1948 m	1984–2009 c 1949–1983 m 1929–1948 m
Lucky Peak (Corps)[2, 3/]	No forecast made	1981–2009 c 1952–1980 m 1940–1951 m 1929–1939 m	1981–2009 c 1958–1980 m (no data before 1958)	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–2009 c 1957–1960 m (no data before 1957)	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–2009 c 1957–1960 m (no data before 1957)	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1961–2009 c 1957–1960 m (no data before 1957)	1981–2009 c 1958–1980 m 1945–1957 m 1929–1944 m	1987–2009 c 1961–1986 m 1952–1960 m (no data before 1952)	1981–2009 c (no data before 1981)	1981–2009 c 1972–1980 m (no data before 1970)
Lucky Peak (Reclamation)[3/]	No forecast made	1961–2009 c 1945–1960 m 1929–1944 m	1961–2009 c 1945–1960 m 1929–1944 m	1951–2009 c 1929–1950 m	1951–2009 c 1929–1950 m	1951–2009 c 1929–1950 m	1951–2009 c 1929–1950 m	1951–2009 c 1929–1950 m	1951–2009 c 1929–1950 m	1979–2009 c 1951–1978 m 1929–1950 m	1979–2009 c 1951–1978 m 1929–1950 m	1979–2009 c 1951–1978 m 1929–1950 m	1979–2009 c 1951–1978 m 1929–1950 m
Payette River near Horseshoe Bend	No forecast made	1961–2009 c 1945–1960 m 1929–1944 m	No forecast made	1961–2009 c 1949–1960 m 1929–1948 m	No forecast made	1951–2009 c 1944–1950 m 1929–1943 m	No forecast made	1949–2009 c 1938–1948 m 1929–1937 m	No forecast made	1975–2009 c 1945–1974 m 1929–1944 m	No forecast made	1975–2009 c 1945–1974 m 1929–1944 m	No forecast made
Hungry Horse	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made	1944–2009 c 1932–1943 m 1929–1931 k	No forecast made
Yakima River near Parker, WA	No forecast made	1982–2009 c 1961–1981 m 1940–1960 m 1929–1939 m	No forecast made	1976–2009 c 1957–1975 m 1940–1956 m 1929–1939 m	No forecast made	1941–2009 c 1929–1940 m	No forecast made	1940–2009 c 1929–1939 m	No forecast made	1939–2009 c 1929–1938 m	No forecast made	1939–2009 c 1929–1938 m	No forecast made
Libby[4/]	1984–2009 c 1961–1983 m 1950–1960 m 1929–1949 m	1984–2009 c 1975–1983 m 1948–1974 mw 1929–1947 k	No forecast made	1984–2009 c 1961–1983 m 1948–1960 mw 1929–1947 k	No forecast made	1984–2009 c 1961–1983 m 1948–1960 mw 1929–1947 k	No forecast made	1984–2009 c 1961–1983 m 1948–1960 mw 1929–1947 k	No forecast made	1984–2009 c 1961–1983 m 1948–1960 mw 1929–1947 k	No forecast made	1984–2009 c 1961–1983 m 1948–1960 mw 1929–1947 k	No forecast made
Duncan	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made
Dworshak	No forecast made	1961–2009 c 1929–1960 k	No forecast made	1961–2009 c 1929–1960 k	No forecast made	1961–2009 c 1929–1960 k	No forecast made	1961–2009 c 1929–1960 k	No forecast made	1961–2009 c 1929–1960 k	No forecast made	1967–2009 c 1929–1966 k	No forecast made
Arrow	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made
Mica	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made	1966–2009 c 1929–1965 k	No forecast made
Brownlee	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made
The Dalles	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made	1983–2009 r 1929–1982 k	No forecast made

1/ Abbreviations: c = current forecast, m = modified historic forecast, k = Kuehl-Moffitt data, r = Northwest River Forecast Center data, mw = Morrow-Wortman data.

2/ Corps mid-month forecast only includes snow course stations leaving many early years without mid-month forecasts.

3/ Final operational forecasts for Heise and Lucky Peak are negotiated based on forecasts from the Corps and Reclamation. For this study the forecasts are averaged. For years when the Corps mid-month forecast does not have snow data, only Reclamation's forecast is used in the final adjusted data.

4/ Libby has a December 1 forecast which is used to set the variable December draft of the reservoir. Libby is the only location in which the Morrow-Wortman data was used. The 2014 principal components analysis (PCA) equation was used to hindcast first, then the 2004 PCA hindcast filled in data from 61 to 83, Morrow Wortman data was used for 48 to 60, then Kuehl-Moffitt data was used to fill in the remaining period from 29 to 47.

4.5.3 Kuehl-Moffitt Forecast Dataset

Two water supply studies for the Columbia River Basin were conducted in 1967 and 1983 by NWRFC and by the Corps, respectively. The NWRFC study was based on the forecasting techniques then employed by the National Weather Service and covered the period of 1929 to 1965. The study developed volume forecasts for the time period of 1929 to 1965 for reservoirs in the Columbia River Basin and was used by the reservoir operating agencies to define operating criteria between 1967 and 1982. The 1967 study was the basis of the 1983 study that was initiated by the Corps and carried out by Donald Kuehl and Robert Moffitt.

The Kuehl-Moffitt forecast dataset was generated as part of a 3-year study which recomputed the forecasts from the 1967 study and prepared forecasts up to 1982 using more current NWRFC forecasting procedures. The Kuehl-Moffitt study simulated forecasts at 53 river forecast points for forecast dates on the first of the month for January through June. The 1982 study used monthly precipitation and climatological stations data, snow-water-equivalent records, and monthly river flow data for the Columbia River Basin to compute the primary forecasts. The forecasting procedures used in the Kuehl-Moffitt study compute seasonal runoff by correlating runoff with seasonal indices, which are combinations of precipitation and snow-water-equivalent data. The indices are composed of measurements of hydrologic events preceding the forecast date and estimates of probable future events. The combined index to expected runoff is the weighted sum of the seasonal indices. The weightings are derived by the correlation of the three indices with seasonal river flow. The forecasting procedures used in the Kuehl-Moffitt study are very similar to those employed by NWRFC up until 2009. For the purposes of this study, the Kuehl-Moffitt forecasts were also adjusted to have the same statistical trends as the hindcasts datasets.

Of the 53 river forecast points in the Kuehl-Moffitt study, 8 locations being used in this study had Kuehl-Moffitt data: Mica, Arrow, Duncan, Hungry Horse, Libby, Dworshak, Brownlee, and The Dalles.

4.5.4 Historical Operational Forecasts

Historical operational forecasts are the actual historic forecasts that were used by the FRM projects for real-time operations during each water year. Historical operational forecasts were only used at two of the forecast locations of this study: The Dalles and Brownlee. The historic forecasts at these two locations were generated by NWRFC. Previous versions of the forecast equations from NWRFC were linear regression of a seasonal index that consists of a variety of indicators and involved some subjective input. However, over the past 10 years NWRFC has transitioned to the use of an Ensemble Streamflow Prediction, a model which has had frequent changes and updates over those years. Given the frequent forecast equation changes, it was determined that the regression-based historic operational forecasts would be used in this study at The Dalles and Brownlee forecast locations since stream flow data is through 2009.

4.6 TREND AND STANDARD ERROR ADJUSTED FORECAST DATASET

Prior to adjusting supplemental forecasts, the hindcasts from the current forecasts and the historical operational forecasts, hereafter referred to as current forecasts, were reviewed for patterns in over- and under-forecasting, referred to as trend, and standard errors. Current forecasts showed a trend toward predicting mean runoff volumes and large residual volume differences in extreme flow years, which is typical for forecast equations. More specifically, for most sites, the current forecasting procedures tend to over-predict low runoff volumes and under-predict high runoff volumes. The modified forecasts and the Kuehl-Moffitt forecasts, hereafter referred to as supplemental forecasts, were statistically adjusted to match the trend and standard error of the current forecasts. Adjustments were made to the difference between the forecasted volume and the actual inflow volume, volume differences, for that water year for each segment of the supplemental forecast datasets. The adjustments were made for the trends, and a trend-adjusted forecast volume was computed. The trend-adjusted forecast was adjusted for standard error, and a forecast volume adjusted for standard error was computed. In order to preserve the standard error of the current forecast in the final adjusted dataset and to maintain the current forecasts' ability to predict runoff volumes, the standard error adjustment was performed last.

For the trend adjustment, regression coefficients for each forecast date were calculated for the current forecast and each segment of the supplemental forecasts. The difference between the supplemental forecast volume difference and the volume difference calculated from the supplemental regression equations was computed and then added to the calculated volume difference from the current forecast regression equation. This process preserves the scatter of volume differences about the trend line of the current forecast data and produces a dataset for the period of 1929 to 2008 with the same statistical trend as the current forecasts. The standard error adjustment was performed on each segment of the trend-adjusted supplemental data. The volume difference of the supplemental data was multiplied by the ratio of the standard error of the current forecast to the standard error of the segments of the trend-adjusted supplemental forecast data. The end result of this adjustment is a dataset for the period of record of 1929 to 2008 with the same standard error as the current forecast.

The plots below demonstrate the process of the trend adjustment for The Dalles supplemental January 1 forecast date, which comes from the Kuehl-Moffitt forecast data. The highlighted data point in Figure 4-2 is the forecast volume differences (Kuehl-Moffitt forecast minus actual runoff volume) for the 1965 January 1 Kuehl-Moffitt data before any adjustment has been made. The difference between this volume difference and the volume difference as calculated by the regression line is represented by the vertical distance between the point and the regression line. For example, the 1965 Kuehl-Moffitt forecast was 113,827 kaf and the actual runoff volume was 108,038 kaf, which results in a volume difference of 5,789 kaf (the highlighted dot is 5,789 kaf above zero volume difference at an actual runoff volume of 108,038 kaf). The volume difference calculated by the regression equation fit to the Kuehl-Moffitt data is -8,850 kaf (the regression line intersects -8,850 kaf at an actual runoff volume of 108,038 kaf).

Therefore the vertical distance between the point and the regression line is 14,639 kaf, which is the difference between 5,789 kaf and -8,850 kaf.

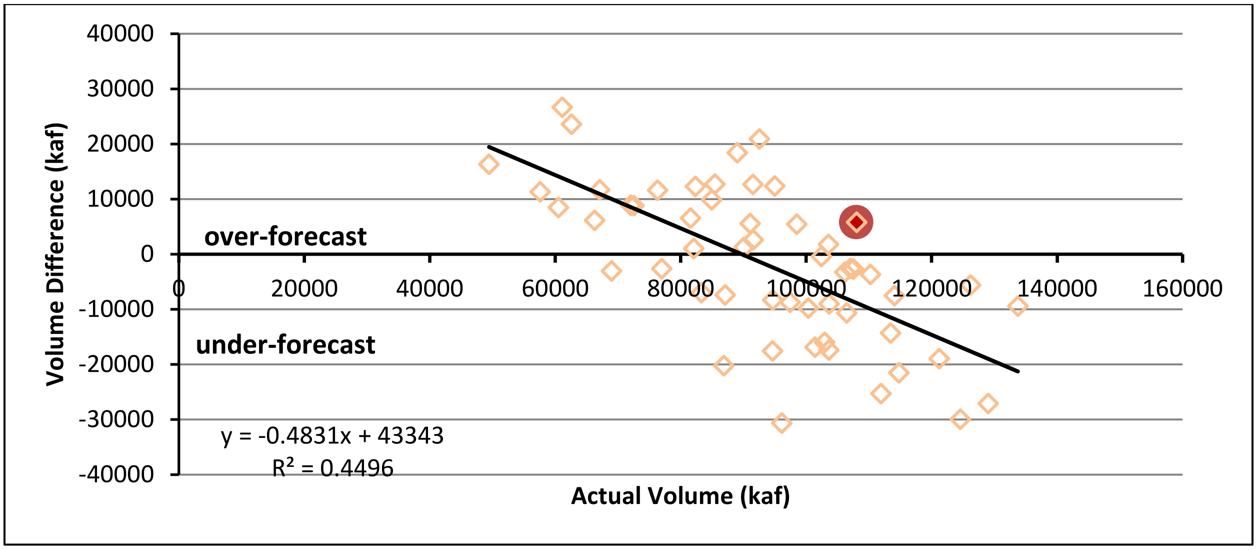


Figure 4-2. Unadjusted Kuehl-Moffitt Forecast Volume Differences Versus Actual Runoff Volume for The Dalles, January 1

Note: The black line is the linear regression of the data points. The red circle represents the data value from the 1965 flood season.

The regression equation from the current forecast is used to calculate the forecast volume differences associated with the actual runoff volume from the 1965 Kuehl-Moffitt data (108,038 kaf), which results in a calculated volume difference of -9,875 kaf. In order to place this point in its proper location, we add the vertical distance calculated in Figure 4-2 (14,639 kaf) to the calculated volume difference of -9,875 kaf, which results in a final adjusted volume difference of 4,764 kaf. The highlighted data point in Figure 4-3 shows the placement of the 1965 Kuehl-Moffitt data after the trend adjustment.

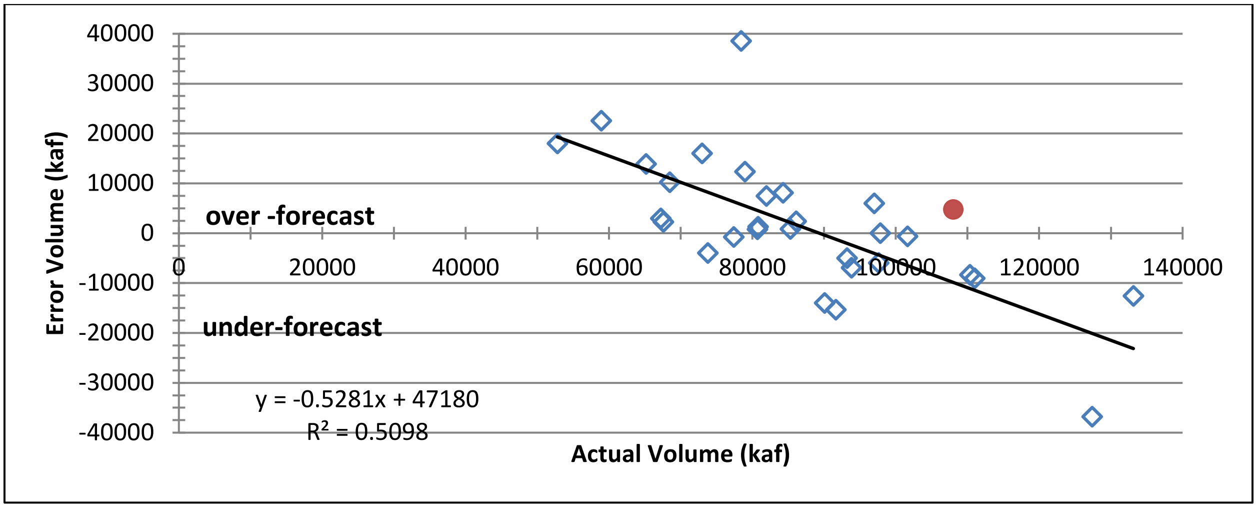


Figure 4-3. Volume Differences of The Dalles, January 1, Current Forecast Versus Actual Runoff Volumes with the 1965 Kuehl-Moffitt Trend Adjusted Data

Note: The black line is the linear regression of the data points. The red circle represents the data value from the 1965 flood season.

The trend adjustment was completed for each year in which the Kuehl-Moffitt data was used in The Dalles January 1 forecast and the adjustment process was followed for each forecast date, with the corresponding regression coefficients. The forecasts created here yield comparable errors to the Kuehl-Moffitt synthetic forecasts.

The standard error adjustment was performed on The Dalles trend adjusted January 1 Kuehl-Moffitt data (Figure 4-4). The forecast volume difference of the Kuehl-Moffitt data was multiplied by the ratio of the standard error of the current NWRFC forecast to the standard error of the trend adjusted Kuehl-Moffitt data. The Dalles final trend and standard error adjusted forecast data versus actual runoff volume for January 1 is shown in Figure 4-4. Note that the final adjusted forecast dataset results only in adjustments to the Kuehl-Moffitt data, and no change is made to the current NWRFC forecast data.

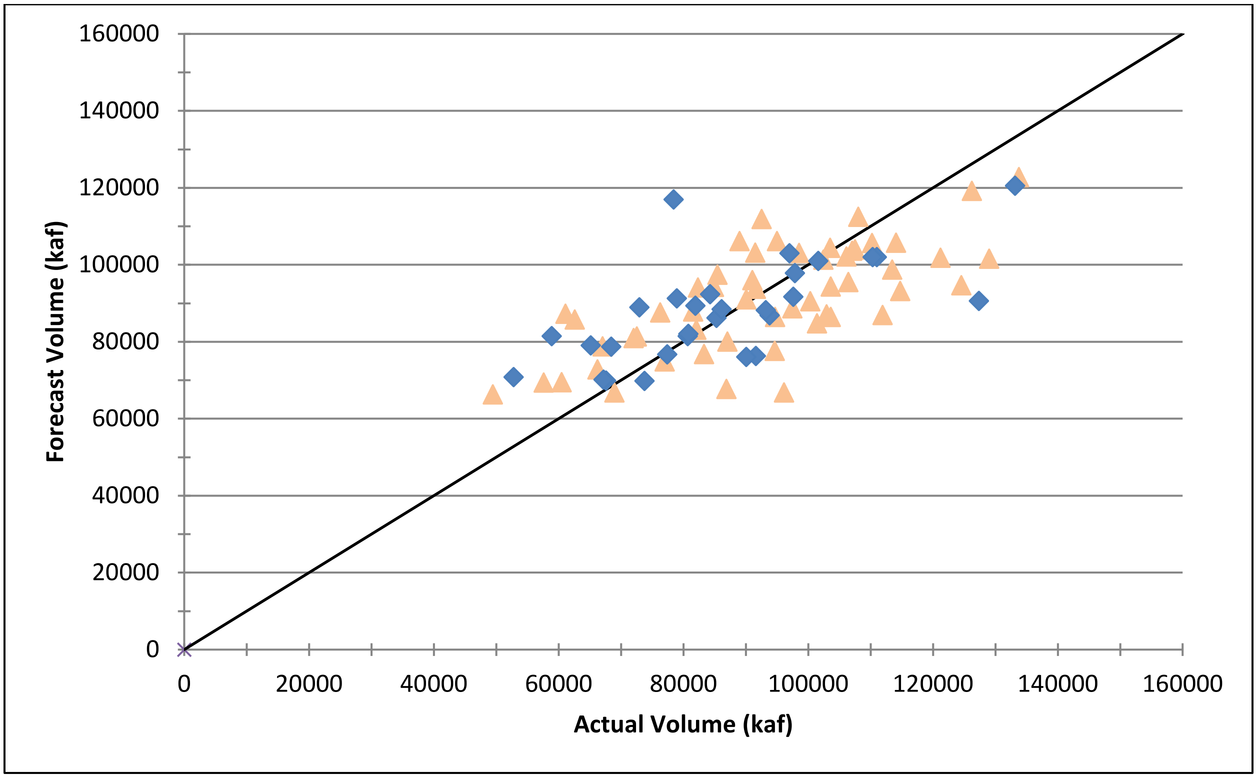


Figure 4-4. The Dalles January First Final Adjusted Forecast

Note: Blue diamonds represent the current forecasts, beige triangles represent the adjusted Kuehl-Moffitt forecasts.

The process described above is the general process used to statistically adjust each segment of the supplemental forecast datasets for each of the 12 forecast locations in the study. The combination of the current forecast dataset with the trend and standard error adjusted forecast dataset is the forecast dataset to be used in the flood risk analysis. The combination of the datasets makes up the 80-year period of forecast data for each of the 12 forecast locations. This final forecast dataset is referred to hereafter as the Flood Risk Analysis forecast dataset.

4.7 RANDOM SAMPLING FORECASTS

The final goal of forecasting is to obtain actual runoff volumes and the associated parameters to be used in the hydrologic modeling of the reservoir system, which includes a forecast sampling ability.

The standard error of the forecast dataset, regression coefficients (slope and intercept) from a regression line fitted through the forecast volume differences versus actual runoff volume, and the standard error of the forecast around that linear regression line are used within the hydrologic sampler to produce a randomly generated forecast dataset. The hydrologic sampler chooses a sample of 5,000 events from the set of hydrology for Monte Carlo simulation depending on the probability of each forecasted event. Forecasts are created for each of the 5,000 events by perturbing the observed inflow values by an amount that is based on both the standard error of the forecast and a random number. The regression line is used to capture the tendency of the forecasts to overestimate small runoff volumes (positive values) and underestimate large runoff volumes (negative values), and to maintain the probability distribution of the standard error around the linear regression line.

Actual runoff volumes are compiled for each forecast location and date, and the parameters needed in the hydrologic sampler are computed. For synthetic events, actual runoff volumes were developed from the synthetic data, and the parameters calculated from the existing forecasts are used for the hydrologic sampler. The runoff volume forecast using this approach will be randomly sampled around the actual value in the historic record within the volume differences distribution of the runoff volume forecast.

The month-to-month serial correlation is estimated for each forecast date and for each site, and randomly sampled forecasts will maintain the estimated correlation to the previous forecast date. A comparison of the correlation of forecast volume differences between locations is also completed.

4.8 MONTE CARLO COMPUTES INCLUDING FORECAST UNCERTAINTY

The Columbia River System HEC-WAT Monte Carlo Model computes that are used for the CRSO EIS studies depend on the monthly forecast flow trend and standard error for the forecasted flow for each seasonal water supply forecast location. The forecasts are generated during a Monte Carlo compute by taking the observed inflow volume and applying a forecast skill generated from random sampling of a probability distribution that represents current forecast skill. This distribution has been fitted to a set of parameters that are calculated from hindcasting of the current forecast method, and entered into the Columbia River System HEC-WAT Model. For more information on the use of the hydrologic sampler model and HEC-WAT Monte Carlo compute see the Corps HEC document (Corps 2016). Table 4-3 summarizes the statistical inputs for each forecast location and month, which include the regression coefficients of the forecast volume differences trend line (slope and intercept), standard error about the forecast volume differences trend line, the serial correlations between forecast dates, and the standard error of the flood risk analysis forecasts.

The hydrologic data used for the Snake River above Brownlee Reservoir (also called the upper Snake River) was a combination of the deterministic (fixed) 2010 Level Modified Streamflows dataset and synthetic hydrology that were created by up-scaling several large events from the 2010 Level Modified Streamflows dataset. The 2010 Level Modified Streamflows dataset for the upper Snake River region comes from detailed modeling performed by Reclamation that reflected water-rights accounting and water supply delivery, resulting in storage and carryover representation that was reflective of water uses in the basin. In order to preserve the effects of the water rights accounting and water supply delivery, while creating a daily time series for inflows to Brownlee reservoir, the chosen approach for modeling this basin was to scale the daily hydrographs created from the HEC-ResSim model for the upper Snake River to the monthly volumes that were used in the 2010 Level Modified Streamflow dataset. An approach using daily spatially disaggregated hydrographs and sampling of water supply forecast uncertainty was considered for this portion of the basin, but such an approach would have provided less robust modeling for the irrigation season operations.

The hydrology used to create 2010 Level Modified Streamflow dataset was disaggregated to create daily inflow time series at locations in the upper Snake River Basin, which were fed into the Upper Snake Hybrid HEC-ResSim Model. The daily output from this model was scaled to match the monthly volumes used in the 2010 Level Modified Streamflow dataset for historical years (1929 to 2008). Whenever one of these template historical years is sampled during the Monte Carlo computes, the effect of the monthly scaling is that there is no error applied to the water supply forecasts for the locations upstream of the Brownlee Reservoir.

In order to create the Brownlee reservoir inflows, the synthetic hydrology was run through the Upper Snake Hybrid Model and the results of Brownlee’s inflow during the flood event were inserted into the hydrograph from the monthly-volume matched data from the template year. For these events, the water supply forecasts had an error applied that was based on the error distributions calculated during the 2013 Charter Hydrology work. The winter synthetics used the Upper Snake Hybrid Model results during the time period of December through February, while the spring synthetics used Hybrid Model results from March through August.

Table 4-3. Summary of Statistical Inputs for use in the Hydrologic Sampler

The Dalles	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	49,000.00	43,988.08421	-0.48880	9,474.48605	–
February	49,000.00	26,742.95869	-0.30872	7,887.91679	0.57838
March	49,000.00	20,930.09794	-0.26800	8,353.41427	0.67928
April	49,000.00	13,382.25658	-0.18973	7,052.55590	0.57245
May	49,000.00	7,589.86944	-0.10685	5,937.28974	0.79545
June	49,000.00	947.92803	0.00138	5,958.90606	0.49757
July	49,000.00	566.99548	0.01077	5,582.67554	0.86866
Arrow	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	16,637.54	10,845.88675	-0.46703	1,746.96047	–
February	16,637.54	5,834.63406	-0.24811	1,467.63600	0.71039
March	16,637.54	4,853.28513	-0.21014	1,332.43518	0.78968
April	16,637.54	3,644.00544	-0.15588	1,108.65529	0.78749
May	16,637.54	3,191.15940	-0.13769	965.83986	0.89532
June	16,637.54	2,383.87129	-0.10365	905.25498	0.72506
July	16,637.54	1,714.18016	-0.07728	831.75845	0.73098
Mica	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	8,654.18	5,830.00559	-0.51006	804.87938	–
February	8,654.18	2,793.73175	-0.24046	605.90082	0.53983
March	8,654.18	2,264.40584	-0.19751	574.66775	0.71596
April	8,654.18	1,865.37178	-0.16218	470.29007	0.74919
May	8,654.18	1,402.11199	-0.12199	440.02593	0.90008
June	8,654.18	990.70119	-0.08867	454.14870	0.66368
July	8,654.18	741.44601	-0.06296	358.65508	0.50445

Duncan	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	1,423.88	914.01281	-0.43878	129.96620	–
February	1,423.88	620.12875	-0.29662	123.14968	0.65339
March	1,423.88	447.84057	-0.21578	112.65674	0.67670
April	1,423.88	333.37260	-0.15766	96.74513	0.60694
May	1,423.88	220.67347	-0.10320	83.99812	0.78765
June	1,423.88	140.20679	-0.06697	73.12092	0.56100
July	1,423.88	96.96115	-0.04546	70.24770	0.60652
Libby	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
December	3,055.52	2,070.63641	-0.33199	687.93090	–
January	3,055.52	1,792.23852	-0.26708	582.28687	0.25053
February	3,055.52	879.58849	-0.11420	552.00543	0.48741
March	3,055.52	810.50600	-0.10105	521.84982	0.62939
April	3,055.52	477.82251	-0.06016	494.01209	0.61468
May	3,055.52	633.24461	-0.09616	472.82688	0.72425
June	3,055.52	579.70183	-0.08722	382.32180	0.38996
Hungry Horse	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	1,009.00	1,263.25647	-0.69051	179.45791	–
February	1,009.00	976.87327	-0.53649	189.59271	0.65438
March	1,009.00	675.69471	-0.37338	186.67258	0.71178
April	1,009.00	503.37521	-0.27362	164.88813	0.66456
May	1,009.00	173.17035	-0.08645	154.07980	0.38389
June	1,009.00	86.81780	-0.04230	142.11180	0.71164

Dworshak	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	947.14	863.54148	-0.32922	419.52204	–
February	947.14	438.01698	-0.16221	340.41982	0.64143
March	947.14	349.19531	-0.12882	309.03126	0.74951
April	947.14	245.00811	-0.08784	253.57467	0.47117
May	947.14	184.02089	-0.06720	227.66181	0.58984
June	947.14	34.76020	-0.01046	142.63586	0.57068
Yakima	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January	82.00	1,396.61225	-0.52233	306.66660	–
February	82.00	648.86362	-0.25080	267.80807	0.18152
March	82.00	288.57953	-0.13015	282.78509	0.33150
April	82.00	-25.59313	0.02422	225.88913	0.60971
May	82.00	-8.02809	0.01558	199.82917	0.78864
June	82.00	37.65114	-0.02513	159.76976	0.56832
Brownlee	**Minimum Forecasted Flow (kaf)**	**Mean Skill Intercept (kaf)**	**Mean Skill Slope**	**Standard Error of the Forecast Flow (kaf)**	**Serial Correlation**
January 1	1,656.85	2,610.23884	-0.60469	1,534.11635	–
February 1	1,656.85	2,106.42258	-0.53387	1,463.24056	0.66898
March 1	1,656.85	1,838.30131	-0.49952	1,385.88597	0.73776
April 1	1,656.85	1,138.83954	-0.35315	1,055.86553	0.61788
May 1	1,656.85	522.26741	-0.25138	992.86760	0.66037
June 1	1,656.85	22.63730	-0.06323	591.71930	0.46364
July 1	1,656.85	21.60756	-0.06430	587.06556	0.91108

Note: Skill is the difference between the forecasted inflow volume and the observed inflow volume and the Serial Correlation is the correlation of the forecasted volumes between subsequent months.

4.9 DATA SOURCES

While some agencies and offices provided hindcast data for their current forecast equations, hindcast data needed to be generated at some locations. The three types of independent data gathered were Snow Course 16F[1] / SNOTEL 17F[2] data, precipitation data, and unregulated flow data. Unregulated flow data was also needed for generating actual runoff volumes for determining residuals and standard error. The data came from the following sources unless otherwise noted:

- Snow Course data from National Resources Conservation Service (NRCS): http://www.wcc.nrcs.usda.gov/snow/snowhist.html
- Precipitation data from National Climate Data Center: http://www.ncdc.noaa.gov/oa/climate/stationlocator.html
- Unregulated flow data from Reclamation: http://www.usbr.gov/pn/hydromet/arcread.html

Exceptions to the above sources are as follows:

- The supplement precipitation data for the Yakima River Forecast was obtained from Reclamation.
- Dworshak and Boise River unregulated flow data was obtained from the Corps.
- Brownlee regulated flow data for the period of 1929 to 1982 was from the observed volume provided with the Kuehl-Moffitt study, and NWRFC provided the observed volumes for the period of 1983 to 2009.
- Unregulated flow data for Libby was obtained from four different sources: observed volumes provided with the Kuehl-Moffitt study for the period of 1929 to 1947, observed volumes provided with the Morrow-Wortman study for the period of 1948 to 1960 (1948 to 1974 in January), observed volumes used to hindcast the 2004 equations for the period of 1961 to 1987 (1975 to 1987 in January), and observed volumes used to hindcast the 2014 equations for the period of 1988 to 2009.
- Arrow, Mica, and Duncan unregulated flows were obtained from two sources: for the period of 1929 to 1965, flow values came from the observed values used in the Kuehl-Moffitt study, while BC Hydro supplied the unregulated flow for the period of 1966 to 2009.

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[1] A snow course is a permanent site where manual measurements of snow depth and snow water equivalent are taken by trained observers.

[2] The NRCS installs, operates, and maintains an extensive, automated system to collect snowpack and related climatic data in the Western United States called SNOTEL (for Snowpack Telemetry). The system evolved from NRCS's Congressional mandate in the mid-1930s "to measure snowpack in the mountains of the West and forecast the water supply." The programs began with manual measurements of snow courses; since 1980, SNOTEL has reliably and efficiently collected the data needed to produce water supply forecasts and to support the resource management activities of NRCS and others.

- The Dalles partially regulated inflow data for the period of 1929 to 1982 was from the observed volumes provided with the Kuehl-Moffitt study. NWRFC provided The Dalles partially regulated inflow for the period of 1983 to 2010.
- Flow data for generating actual runoff volumes for synthetic hydrology was obtained from Bonneville.

CHAPTER 5 - REFERENCES

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DRAFT COLUMBIA RIVER SYSTEM OPERATIONS ENVIRONMENTAL IMPACT STATEMENT

Appendix B, Part 5

Columbia River System Extended Observed Flows Water Years 2008–2016

Development of Input Hydrology

EXECUTIVE SUMMARY

TECHNICAL APPENDIX B, PART 5

The Columbia River watershed includes over 60 dams in the northwestern United States and southwestern Canada. The United States has significant flood risk exposure due to the river system, particularly in the Portland, Oregon, and Vancouver, Washington, regions. An 80-year record of water flow conditions, 2010 Level Modified Streamflows dataset, at key locations throughout the watershed is available for the water years of 1928 through 2008. This hydrologic record had been adjusted such that the irrigation depletions and evaporation rates are equivalent to those of water year 2008. The Modified Streamflows dataset is used and specified under the 1997 Pacific Northwest Coordination Agreement with the Bonneville Power Administration designated as the lead agency for preparation, coordination, and publication. The 2010 Level Modified Streamflows dataset, which is updated every 10 years, was created by a joint effort of the Bonneville Power Administration, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation sharing resources under a memorandum of agreement. This daily water flow dataset is used by the Columbia River System Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) Model to regulate and route flows throughout the system for the development of reservoir operations for future hydrologic conditions and forecasts.

More extensive and reliable water quality data is available for recent water years, after 2008, so having flow records at the key locations in the watershed for water years 2009 to 2016 is very important to the Columbia River System Operations (CRSO) water quality impacts team in making conclusions regarding water quality in the basin. However, the 2020 Level Modified Streamflows are not expected to be completed until the year 2020. Therefore, a less robust effort was undertaken to quickly create acceptable, albeit less refined, flow records throughout the basin for the 8 most recent water years (2009–2016) specifically for water quality impact analysis for CRSO, and application of them should be limited to that use. The team also created 2008 streamflows with the simplified process for comparison to the 2010 Level Modified Streamflows dataset. This 2008 hydrology dataset was created with many simplifying assumptions and should be used with caution and a firm understanding of the limitations of any conclusions that result from its use. One simplifying assumption made during this project is that observed cumulative flows from gage data and calculated reservoir inflows over the recent water years would reflect the losses from evaporation and irrigation depletions, so those parameters would not be estimated explicitly for this flow dataset.

To create a set of flows for water years 2008 to 2016, daily gage measurements for flows and reservoir elevations at gage locations throughout the Columbia River System were collected and quality controlled. Raw gage measurements often have missing, incorrectly measured, or incorrectly recorded values that must be removed and replaced. This process can take a significant amount of time and skill as determining incorrect measurement values is often subjective. This project used both quality control scripts and visual inspection to correct the data records throughout the system. For this dataset, a cursory quality control check of the data was deemed acceptable.

The U.S. Army Corps of Engineers Annual Flood Damage Reduction ResSim model uses similar equations to those in the Modified Streamflows process to create the local hydrologic flows at most of the key locations in the Columbia River System HEC-ResSim Model. Therefore, this project used portions of the Annual Flood Damage Reduction ResSim model process to create many of the flow time records for water years 2008 to 2016 and supplemented this process with hand calculation to create the remaining flows needed for the system.

With the many assumptions and simplifications used in this project to create the local hydrologic inputs for the Columbia River System ResSim Model, this dataset must be considered stand-alone hydrology for water years 2008 to 2016. It would be easy to incorrectly interpret and use this dataset as an extension of the 2010 Level Modified Streamflows dataset. Therefore, water year 2008 was added to the calculation to highlight the differences between the 2010 Level Modified Streamflows dataset and this Extended Observed dataset. When the two datasets are compared, there are significant differences in the local flows for many of the key points in the system for water year 2008 that highlight the differences in the approaches used to create the flows. However, the Extended Observed dataset can be used as representative of the hydrology in the Columbia River System for water years 2008 to 2016 for the explicit purpose of water quality modeling and subsequent impact analyses, for this particular historical period, in the CRSO process.

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ACRONYMS AND ABBREVIATIONS

AFDR	Annual Flood Damage Reduction
BC Hydro	British Columbia Hydro and Power Authority
Corps	U.S. Army Corps of Engineers
Corps-NWS	U.S. Army Corps of Engineers Northwestern Seattle District
Corps-NWW	U.S. Army Corps of Engineers Northwestern Walla Walla District
CRS Model	Columbia River System HEC-ResSim Model
CRSO	Columbia River System Operations
CWMS	Corps Water Management System
DSS	Data Storage System
EIS	Environmental Impact Statement
HEC	Hydrologic Engineering Center
NWIS	National Water Information System
NWRFC	Northwest River Forecast Center
RAS	River Analysis System
Reclamation	U.S. Bureau of Reclamation
ResSim	Reservoir System Simulation
RM	River Mile
SSARR	Streamflow Simulation and Reservoir Regulation
TDG	total dissolved gas
USGS	U.S. Geological Survey
WSF	water supply forecast

CHAPTER 1 - PROJECT INTRODUCTION

The purpose of the task described in this document was to generate input hydrology for water years 2009 to 2016 with an overlap year of water year 2008 for comparison with the 2010 Level Modified Streamflows dataset, to be used in water quality modeling efforts for the Columbia River System Operations (CRSO) study. The Modified Streamflows dataset is used and specified under the 1997 Pacific Northwest Coordination Agreement with the Bonneville Power Administration (Bonneville), which is designated as the lead agency for preparation, coordination, and publication. The 2010 Level Modified Streamflows dataset, which is updated every 10 years, was created by a joint effort of Bonneville, the U.S. Army Corps of Engineers (Corps), and the U.S. Bureau of Reclamation (Reclamation) sharing resources under a memorandum of agreement. This data was developed outside of the River Management Joint Operating Committee official modified flows development process to allow the CRSO Water Quality Impacts group to have observed and modeled regulated hydrology for years where observed water quality data was available. Ideally, the 2020 Modified Streamflows dataset would provide robust flow information for the Columbia River System for the most recent 8 years; however, the 2020 Modified Streamflows dataset creation is not set to begin for another few years and it would likely take considerable time to develop. Therefore, a less robust effort was undertaken to quickly create acceptable, albeit less refined, flow records throughout the basin for the 8 most recent water years (2009 to 2016) specifically for water quality impact analysis for CRSO; application of it should be limited to that use. This Extended Observed flow dataset is not a homogeneous extension of the 80-year 2010 Level Modified Streamflows dataset due to differences in methodology and the simplifying assumptions described below. The water supply forecasts used for reservoir operation modeling were the official forecasts except in the case of the Libby and Dworshak Dams where hindcasts of the latest official forecasts were used because those forecast methods have been updated. Hindcasts is the term used to describe forecasts created for past water years.

1.1 BACKGROUND AND JUSTIFICATION

Prior to 1995, water temperature and total dissolved gas (TDG) data in the Corps Water Management System (CWMS) database or the U.S. Geological Survey (USGS) National Water Information System (NWIS) database is scarce. From 2005 to 2016, there is consistent, basinwide temperature and TDG data available in CWMS. Unfortunately, the current 2010 Level Modified Streamflows dataset, which is available for input into the water quality models, spans 1929 to 2008, leaving only 3 years of overlap between good water quality datasets and flow and weather information. As a result, the CRSO water quality team's approach is to model more recent water years where consistent water quality data exists, under a variety of flow and meteorological conditions. Therefore, the purpose of creating the Extended Observed flow record is for it to be used in water quality modeling efforts for the CRSO study.

The two models used for water quality assessments under the CRSO Environmental Impact Statement (EIS) project are CE-QUAL W2 and Hydrologic Engineering Center River Analysis System (HEC-RAS). These models will be used to predict the effects of the EIS alternatives on water temperature and TDG. The water quality models are data-intensive models, requiring a large amount of water quality, meteorological, and flow information to run. A hydrologic dataset that captures a variety of water years that range from hot/dry to cold/wet will be needed to evaluate impacts to water temperature and TDG for the EIS.

The years that the water quality team has specifically identified for calibration and alternatives analysis are 2011, 2014, and 2015. Although the calibration years do not have to be the same as the alternative analysis years, it is preferable. The conditions of each year were as follows:

- 2011: Spring and early summer air temperatures were well below average, with persistently high levels of TDG. There is adequate data for temperature and TDG tailwater sites. Flows were comparable to ones observed in 1996 and 1997, but temperatures in both those earlier summers were near average, and the availability of water quality data for those years is very limited.
- 2014: Both air temperatures and flows in the spring and early summer were near the long-term average. The water temperature response was also near average with a slightly below-average TDG response.
- 2015: Water temperatures were well above average during the spring and summer (second highest for the average of the site exceedances, since 1995) and the lowest for TDG metrics. There is adequate data for temperature and TDG tailwater sites. In comparison, flows were near all-time lows in the summer of 2001, but temperatures were only slightly above average overall, and water quality data from that earlier period is very limited.

In order to use these years for alternatives analysis, HEC Reservoir System Simulation (HEC-ResSim) and HydSim input data needed to be modified to simulate the newly created dataset for water years 2008 to 2016.

HEC-ResSim is a tool that was developed by the HEC to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints. The software simulates reservoir operations, which can be used to guide flood risk management, low flow augmentation, water supply planning studies, detailed reservoir regulation plan investigations, and real-time reservoir operations. HEC-ResSim will be used to simulate the 2010 Level Modified Streamflows dataset, the Extended Observed flows (created here), and Monte Carlo dataset for CRSO analysis.

HydSim is a seasonal planning model developed by Bonneville and is used for a variety of purposes. HydSim models the Columbia and Snake Rivers and their tributaries, and includes modeling of both storage and run-of-river categories, both Federal and non-Federal dams/reservoirs in the basin. HydSim currently runs on the 2010 Level Modified Streamflows dataset from 1929 to 2008, so an additional input flow dataset is required to generate more recent regulated flow data for input into the water quality models.

The Extended Observed flow record set was created with many simplifying assumptions and should be used with caution and a firm understanding of the limitations of any conclusions that result from its use. Both the accuracy and precision of the Extended Observed dataset is limited when compared to the standards of Modified Streamflows datasets. For example, the Extended Observed dataset assumes that the evaporation rates and irrigation depletions over the recent water years are similar to those of water year 2008 and that the flows do not need to be adjusted to for irrigation depletion. In contrast, one of the main goals of the Modified Streamflow dataset is to adjust the historical flows as if they all occurred with the irrigation-depletion conditions of a chosen example year. The 2010 Level Modified Streamflows dataset has flow records from water years 1928 through 2008, as if they all occurred with the irrigation-depletion conditions of water year 2008. Also, the Extended Observed dataset was created with a daily water balance and not smoothed over a monthly time frame, as in the calculation of the 2010 Level Modified Streamflows dataset. This daily water balance has resulted in some large day-to-day fluctuations for many of the time records, which do not occur in the more smoothed versions of the Modified Streamflows dataset. Finally, the quality control techniques for the Modified Streamflow process are extensive and thorough, whereas a much faster and less thorough process was used for the Extended Observed dataset due to accelerated project timelines. Therefore, incorrect or false values may remain within the source stream gage flow and elevation records used to calculate the Extended Observed flows.

1.2 INPUT ASSUMPTIONS

The assumptions used for the hydrology input were as follows:

- Years 2008 to 2016 observed gage data and calculated reservoir inflow data reflect losses of volume from upstream irrigation and depletions. For the Extended Observed dataset a simplifying assumption was that similar irrigation practices and land use occurred in the basin in water year 2008. Local inflows in the dataset reflect observed irrigation depletions. This assumption removes the need to adjust the input explicitly for depletions from irrigation or evaporation since that data will not be available until the 2020 Level Modified Streamflows. Banks Lake pumping will be accounted for as diversion by the Columbia River System ResSim Model (CRS Model); this was outside of the scope of this input development study.
- The hydrology flows created by Annual Flood Damage Reduction (AFDR) model are sufficient for use in the CRS Model (with modifications when required).
- Hydrology inflows for the following subbasins within the Columbia River System were not required for this study (except where specified, below): Upper Snake River above Brownlee Dam, Yakima River, and most of the Willamette River. For these basins, the observed, regulated flow data will be used as boundary conditions in reservoir operations modeling for the extended years for the CRS Model.

1.3 PRODUCTS

Products that were generated were as follows:

- Local inflow dataset throughout the basin for water years 2008 to 2016

- Official Water Supply Forecasts for water years 2009 to 2016
- Cumulative unregulated flow throughout the basin with and without natural lake effects for water years 2008 to 2016
- Cumulative, Streamflow Simulation and Reservoir Regulation (SSARR) routed observed, regulated flow throughout the basin with pool elevations kept at observed values and outflow allowed to adjust for several reservoirs (Albeni Falls, Grand Coulee, Chief Joseph, Wells, Rocky Reach, Rock Island, Wanapum, Priest Rapids, McNary, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, John Day, The Dalles, Bonneville) for water years 2008 to 2016

All products listed above were provided in HEC-Data Storage System (DSS) format. A summary of product development procedures and summary results are given in Chapters 2 through 6 and Annex A.

CHAPTER 2 - DEVELOPMENT OF HYDROLOGY INPUTS FOR COLUMBIA RIVER SYSTEM HEC-RESSIM MODEL

The input hydrology requirements of the CRS Model are a collection of local flows at the model common computation points. These local flow records are a prerequisite to run the reservoir models. To smoothly transition the Extended Observed input gage data for use in the CRS Model, the outputs of this task consisted of a HEC-DSS file with the required flows presented in Annex B, List 1 for water years 2008 to 2016.

2.1 USE OF THE ANNUAL FLOOD DAMAGE REDUCTION HEC-RESSIM MODEL TO CREATE EXTENDED OBSERVED LOCAL FLOW DATASETS

Annual flood damage reductions are calculated yearly for the Columbia River System and presented in a report to the U.S. Congress. These calculations are reported as dollars of flood damage that would have occurred over the previous water year had the flood risk management reservoirs and levee systems not been in operation. The AFDR process uses HEC-ResSim, HEC-RAS, and HEC-FIA models to go from input hydrology to economic losses. Within the AFDR HEC-ResSim reservoir model, input hydrology is determined at computational nodes prior to running the reservoir model from observed gage datasets throughout the system. The process of preparing to run the AFDR HEC-ResSim model is similar to the process that created the 2010 Level Modified Streamflows dataset that is used by the CRS Model. In fact, most of the computation points within the AFDR HEC-ResSim model overlap with the CRS Model (Bonneville Dam was added as a common computation point in the AFDR HEC-ResSim model). Therefore, portions of the AFDR process were used to create input hydrology for water years 2008 to 2016 at many of the CRS Model's common computation points. Since both the 2010 Level Modified Streamflows dataset and the Extended Observed flows dataset include water year 2008, that year was used for comparison and to quantify the implications of using the Extended Observed dataset in CRS Model and water quality model runs.

Within the AFDR process there are several ways in which local flow rates are calculated on an average daily basis. First, many of the tributaries of the Columbia River System are gaged streams. In those cases, the gage flow rates were directly used to represent the flows in the tributaries over the period of record. Second, often gages are located on nearby streams or in locations along tributaries that are upstream of where the stream enters the river mainstem. In these cases, area ratios were used to "move" or simulate the gage data at a more advantageous location in the watershed. Depending on the dam/reservoir, reservoir inflows and outflows were used directly from gages or calculated from gaged flows and storage records within the reservoir. Between dams/reservoirs where no gages are located, local flows were disaggregated by routing flows between dams/reservoirs and by applying watershed area ratios at key locations. Finally, water balances were forced at the inflows to reservoirs to maintain consistent water volumes. When volumes are forced to be maintained, the local flows can be strangely shaped or even generate negative estimated flows. These irregularities were accepted as necessary to maintain the water volumes in the system, which is particularly important as discrepancies could accumulate moving downstream within the river system.

By using the AFDR process to create the water inflow time records for the CRS Model, the flows inherit any assumptions that are made within the AFDR model hydrologic calculations. The observed flows (except in some reservoir inflows as described below) are used throughout the AFDR model system and the equations that are used to calculate and disaggregate the local inflows exactly match the observed volumes. Therefore, the local flows can be considerably erratic with many negative values and a fair amount of what looks like noise in the signal. This means the local flow inputs do not necessarily look like realistic hydrographs, see discussion in Section 2.3. Also, since the observed flows are used, many of the reservoir outflow values are significantly different than those used to calculate the 2010 Level Modified Streamflows, see Chapter 4.

Since the AFDR process is relatively similar to that which created the 2010 Level Modified Streamflows dataset, we assume that the equations used for a majority of the computation points within the AFDR process are sufficient to calculate the local flows at those points. While many of the local flows are likely to be created with similar equations between the two processes, there may be differences depending on the flow location and availability of gage measurements for the required dates. This task assumes that the differences in the equations between the creation of the two datasets are, in most cases, acceptable. In several locations, as described below, the local datasets that were created by the AFDR process were hand modified to better reflect the flows at those locations.

After using the process outlined below, the local inflow hydrology files were collected, renamed, and exported in a form ready to be used by the CRS Model.

2.1.1 Annual Flood Damage Reduction HEC-ResSim Model Set Up

Most of the local flow datasets required for this task were created through the first several steps of the AFDR process that creates the local flows input for the HEC-ResSim models of the Columbia River. The remainder of the AFDR process was unnecessary for the purposes of this task. Common computation points from the CRS Model are similar in location to the computation points for the AFDR HEC-ResSim model since they have similar names, gage numbers, or location identifiers.

2.1.2 Annual Flood Damage Reduction Calculation of Local Flows

The following sections describe how the AFDR modeling sequence was used to obtain observed streamflow data, conduct quality control, and calculate local flows.

2.1.2.1 Extract Gage Flow Records

The first two steps within the AFDR modeling process are used to extract and compile the gage flow and stage data from CWMS or NWIS databases. Annex B, Table B-2 contains a list of the flow gages that were extracted to create the CRS Model local input flow datasets.

Note: To create the inflow dataset for **Thompson Falls**, the daily flow rate values at USGS Gages 12389000 and 12389500 were added together.

2.1.2.2 Timeseries Record Quality Assurance/Quality Control Process

Flow time records often contain incorrect values that must be discarded and replaced. Therefore, the extracted time records were quality controlled using a multi-step approach. First, any gaps in the time record were filled by interpolation. All gaps of fewer than 5 to 20 days were filled linearly between the two data records before and after the gap. Any gaps larger than approximately 5 to 20 days were filled with other data sources such as nearby gages or by adding (or subtracting) surrounding flows. Second, the datasets were combed for inaccurate values that could cause model instability. Potentially inaccurate flow values were "flagged" using a quality control script that could be adjusted for different rate of change thresholds and the flagged values were assessed manually by the user. If the user determined that a flagged flow value was likely to be inaccurate, it was replaced by a linearly interpolated value between the two adjacent daily flows. The script used a time window of 21 days to calculate rolling means and standard deviations. The rate of change thresholds used to flag the data for review by the user for this study were the following:

- Flows that were greater than four times and less than minus three times the standard deviation from the rolling mean. These were generally caused by an extreme, erroneous spike. Spikes were replaced with interpolated values.
- Any daily changes of greater than five times and less than minus four times the standard deviation in one day. These were also generally caused by an extreme, erroneous spike. Spikes were replaced with interpolated values.
- Any flows less than -5 cubic feet per second, to find negative flow values. These were generally present in noisy flow data that was calculated from pool elevations. Flow values were smoothed to reduce the noise, generally resolving the negative flow issue. If the calculated flow remained negative for many days, the data was replaced with interpolated values, or values from a nearby gage.

In this study, most of the flow values that were flagged by the script as possibly erroneous were removed and replaced by the user; a few of the flagged values were deemed not erroneous by the user. After reviewing all of the flagged flow values, a complete review of the updated time records revealed that there were cases of erroneous data that were not flagged by the script with the settings that were used. It was decided that rather than changing the settings in the script and re-running the script, the first pass was a good starting point. Therefore, the remaining erroneous data values were quality controlled by hand.

2.1.2.3 Compute Reservoir Inflows

First, the AFDR Recompute Reservoir Inflows step was used to calculate inflows for several of the reservoirs in the system, as well as outflows for **The Dalles**. The inputs required for this step are the daily reservoir outflow values, the daily reservoir pool elevation, and the elevation-storage curves for each reservoir. The AFDR model uses the elevation-storage curves stored within the watershed model to calculate the daily inflows (or outflows) to the reservoir. Reservoir inflows were calculated for the following reservoirs in the Columbia River System:

- Seli'š Ksanka Qlispe'
- Grand Coulee
- Chief Joseph
- Wells
- Rocky Reach
- Rock Island
- Wanapum
- Priest Rapids
- McNary
- John Day

All other reservoir inflows were collected from the CWMS database and used directly.

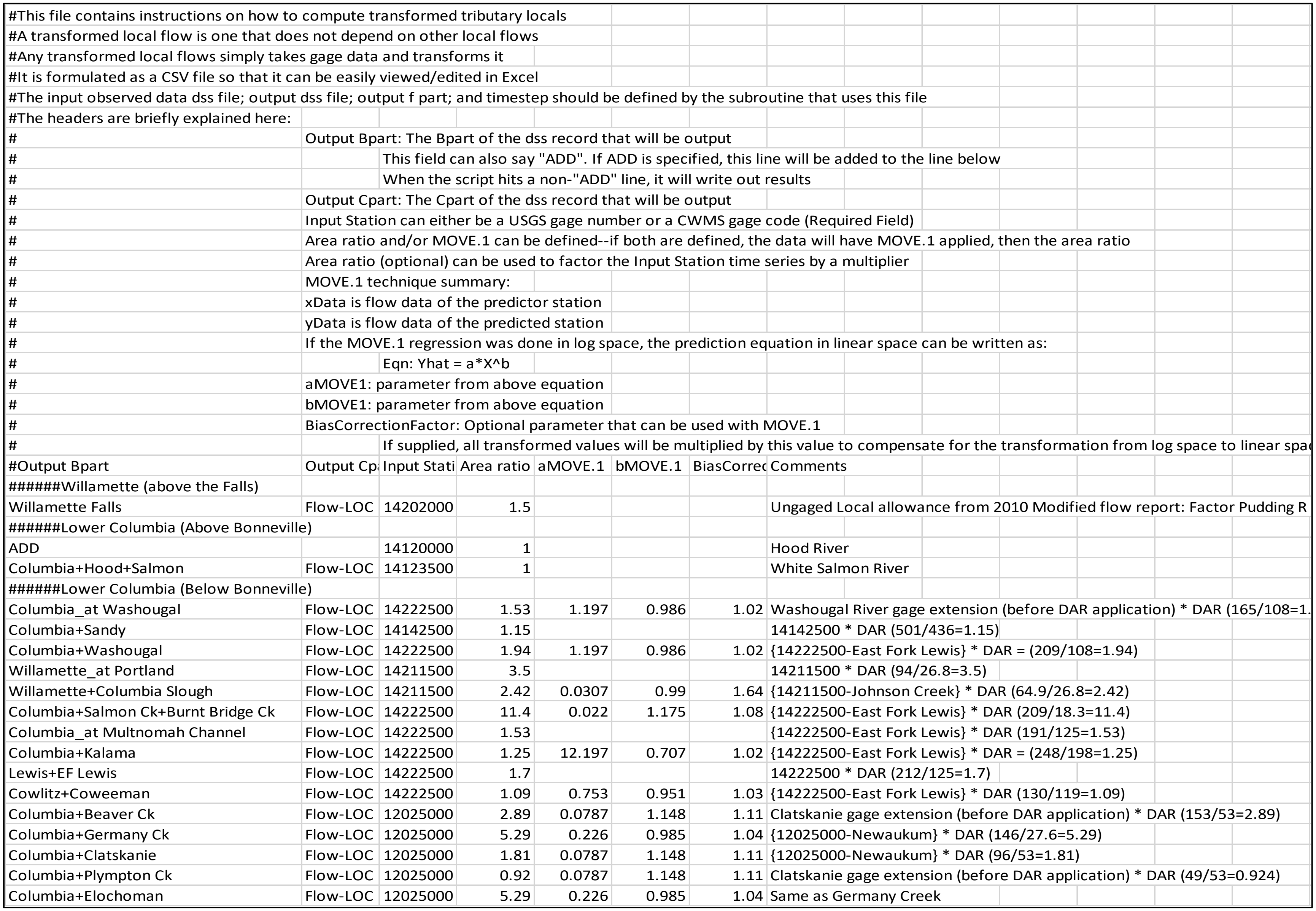
At **The Dalles** reservoir, the most reliable flow information for the system is the upstream inflow gage. Therefore, the inflow gage flow rates, **The Dalles** pool daily elevation values, and **The Dalles** elevation-storage curve were used in the AFDR model to calculate the outflows of the dam at **The Dalles**.

2.1.2.4 Transform Gage Data

Once the flow and elevation gage data was gathered and quality controlled, the gage data was used to determine the local inflows at the common computation points. In cases where the local flow depends only on data from one gage, the gage data was either used directly or relocated to the common computation point. The relocation process consists of moving gage data to new locations or multiplying the gage data by an area ratio. Figure 2-1 is a copy of the NWDLocals-Transformed.csv file that was used within the AFDR process to create 17 of the required local flows. The local flows that were created in this step are listed on the bottom left of the figure. An example of a transformed local flow is presented in Chapter 4.

Assumptions were as follows:

- The inflow to Priest Lake is calculated from USGS Gage 12395000 using the equation from the 2010 Level Modified Streamflows report (Bonneville 2011).



#This file contains instructions on how to compute transformed tributary locals							
#A transformed local flow is one that does not depend on other local flows							
#Any transformed local flows simply takes gage data and transforms it							
#It is formulated as a CSV file so that it can be easily viewed/edited in Excel							
#The input observed data dss file; output dss file; output f part; and timestep should be defined by the subroutine that uses this file							
#The headers are briefly explained here:							
#	Output Bpart: The Bpart of the dss record that will be output						
#		This field can also say "ADD". If ADD is specified, this line will be added to the line below					
#		When the script hits a non-"ADD" line, it will write out results					
#	Output Cpart: The Cpart of the dss record that will be output						
#	Input Station can either be a USGS gage number or a CWMS gage code (Required Field)						
#	Area ratio and/or MOVE.1 can be defined--if both are defined, the data will have MOVE.1 applied, then the area ratio						
#	Area ratio (optional) can be used to factor the Input Station time series by a multiplier						
#	MOVE.1 technique summary:						
#	xData is flow data of the predictor station						
#	yData is flow data of the predicted station						
#	If the MOVE.1 regression was done in log space, the prediction equation in linear space can be written as:						
#		Eqn: Yhat = a*X^b					
#	aMOVE1: parameter from above equation						
#	bMOVE1: parameter from above equation						
#	BiasCorrectionFactor: Optional parameter that can be used with MOVE.1						
#		If supplied, all transformed values will be multiplied by this value to compensate for the transformation from log space to linear spa					
#Output Bpart	Output Cpa	Input Stati	Area ratio	aMOVE.1	bMOVE.1	BiasCorrec	Comments
######Willamette (above the Falls)							
Willamette Falls	Flow-LOC	14202000	1.5				Ungaged Local allowance from 2010 Modified flow report: Factor Pudding R
######Lower Columbia (Above Bonneville)							
ADD		14120000	1				Hood River
Columbia+Hood+Salmon	Flow-LOC	14123500	1				White Salmon River
######Lower Columbia (Below Bonneville)							
Columbia_at Washougal	Flow-LOC	14222500	1.53	1.197	0.986	1.02	Washougal River gage extension (before DAR application) * DAR (165/108=1.
Columbia+Sandy	Flow-LOC	14142500	1.15				14142500 * DAR (501/436=1.15)
Columbia+Washougal	Flow-LOC	14222500	1.94	1.197	0.986	1.02	{14222500-East Fork Lewis} * DAR = (209/108=1.94)
Willamette_at Portland	Flow-LOC	14211500	3.5				14211500 * DAR (94/26.8=3.5)
Willamette+Columbia Slough	Flow-LOC	14211500	2.42	0.0307	0.99	1.64	{14211500-Johnson Creek} * DAR (64.9/26.8=2.42)
Columbia+Salmon Ck+Burnt Bridge Ck	Flow-LOC	14222500	11.4	0.022	1.175	1.08	{14222500-East Fork Lewis} * DAR (209/18.3=11.4)
Columbia_at Multnomah Channel	Flow-LOC	14222500	1.53				{14222500-East Fork Lewis} * DAR (191/125=1.53)
Columbia+Kalama	Flow-LOC	14222500	1.25	12.197	0.707	1.02	{14222500-East Fork Lewis} * DAR = (248/198=1.25)
Lewis+EF Lewis	Flow-LOC	14222500	1.7				14222500 * DAR (212/125=1.7)
Cowlitz+Coweeman	Flow-LOC	14222500	1.09	0.753	0.951	1.03	{14222500-East Fork Lewis} * DAR (130/119=1.09)
Columbia+Beaver Ck	Flow-LOC	12025000	2.89	0.0787	1.148	1.11	Clatskanie gage extension (before DAR application) * DAR (153/53=2.89)
Columbia+Germany Ck	Flow-LOC	12025000	5.29	0.226	0.985	1.04	{12025000-Newaukum} * DAR (146/27.6=5.29)
Columbia+Clatskanie	Flow-LOC	12025000	1.81	0.0787	1.148	1.11	{12025000-Newaukum} * DAR (96/53=1.81)
Columbia+Plympton Ck	Flow-LOC	12025000	0.92	0.0787	1.148	1.11	Clatskanie gage extension (before DAR application) * DAR (49/53=0.924)
Columbia+Elochoman	Flow-LOC	12025000	5.29	0.226	0.985	1.04	Same as Germany Creek

Figure 2-1. CSV File Used to Transform Gage Data to Create Local Inflows for Water Years 2008 to 2016

2.1.2.5 Compute Intermediate Water Balance Locals

Computing water balance locals at modified flow points was an intermediate step and did not create the final local flows. This step used HEC-ResSim to calculate intermediate local flows that were disaggregated to upstream computation points and recomputed in a later step. To calculate the intermediate local flow values successfully, the gaged flows needed to be known at the key location at which a local flow was required and at one or more upstream locations, depending on the number of branches of the river that were upstream of the key location. The location of the datasets for the observed flows (both upstream and downstream locations) needed to be mapped onto the Observed Data tab of the ResSim Alternative Editor for the alternative. Table 2-1 shows the intermediate local flows that were calculated in this step and the upstream flow time records required to complete the calculation. For example, to calculate the local inflow time record at Flathead Lake, both the total inflow time record to Flathead Lake and the outflow time record of Hungry Horse Dam were required to be known for the entire period of interest.

The assumptions used in the computation were as follows:

- The inflow and outflow time records for **Corra Linn** are not available; therefore, the inflow and outflow time records at Queen’s Bay were used.
- The time record for **Brilliant** inflow was assumed to be the same as the time record for Brilliant outflow.
- **Cabinet Gorge** inflow was merged from two datasets for different time periods.
- **Albeni Falls** inflow was assumed to be USGS Gage 12395500.
- **Libby** outflow was assumed to be USGS Gage 12301933.
- **Bonner’s Ferry** inflow was assumed to be USGS Gage 12310100.
- **Box Canyon** inflow was assumed to be USGS Gage 12396500.
- **Seven Mile** inflow and **Seven Mile** outflow were assumed to be equal to **Boundary** inflow.
- **Post Falls** inflow was assumed to be Gage **COEI**.
- Observed **Brownlee** outflow was used as a boundary condition to start water balance calculations downstream of **Brownlee**.
- Observed **Brownlee** inflow was provided for input into the reservoir operations model for flood risk management and flow augmentation modeling.
- **The Dalles** inflow was assumed to be USGS Gage 14105700.
- **The Dalles** outflow was calculated from the inflow gage, the reservoir elevation, and the storage-elevation curve for **The Dalles** Reservoir.
- **Albeni Falls local** inflow was calculated by hand using the same process as described in the AFDR, albeit without routing the flow.

Table 2-1. Local Flows to Calculate and the Upstream Flow Records Required

Water Balance Locals to Calculate	Upstream Flow Records Required
Albeni Falls local inflow	Cabinet Gorge outflow
Arrow Lakes local inflow	Revelstoke outflow
Birchbank local flow	Brilliant outflow, Arrow Lakes outflow
Bonners Ferry local flow	Libby outflow
Bonneville local inflow	The Dalles outflow
Brilliant local inflow	Corra Linn outflow
Cabinet Gorge local inflow	Noxon Rapids outflow
Chief Joseph local inflow	Grand Coulee outflow
Columbia Falls local flow	Hungry Horse outflow
Corra Linn local inflow	Bonners Ferry outflow, Duncan outflow
Cowlitz at Castle Rock local flow	Mayfield outflow
Hells Canyon local inflow	Brownlee outflow
Ice Harbor local inflow	Lower Monumental outflow
John Day local inflow	McNary outflow
Seli'š Ksanka Qlispe' local flow (formerly Kerr)	Columbia Falls Flow
Little Goose local inflow	Lower Granite outflow
Lower Granite local inflow	Snake + Grande Ronde flow, Spalding
Lower Monumental local inflow	Little Goose outflow
McNary local inflow	Ice Harbor outflow, Priest Rapids outflow
Noxon Rapids local inflow	Thompson Falls outflow
Pend Oreille @ Box Canyon local flow	Albeni Falls outflow
Priest Rapids local inflow	Wanapum outflow
Revelstoke local inflow	Mica outflow
Rock Island local inflow	Rocky Reach outflow
Rocky Reach local inflow	Chelan outflow, Wells outflow
Seven Mile local inflow	Boundary outflow
Snake _RM 178.27 local flow	Hells Canyon outflow
Snake + Grande Ronde inflow	Snake_RM 178.27
Spalding local flow	Dworshak outflow
The Dalles local inflow	John Day outflow
Thompson Falls local inflow	Clark Fork at Plains flow
Wanapum local inflow	Rock Island outflow
Wells local inflow	Chief Joseph outflow
Clark Fork_at Plains local flow	Seli'š Ksanka Qlispe' outflow (Formerly Kerr)

2.1.2.6 Disaggregate Local Flows

After the intermediate water balance locals had been calculated, local flow datasets were disaggregated to computation points between the upstream and downstream locations in Table 2-1. These computation points are for tributaries that contribute to the flow in the mainstem of the river, but do not have associated gages. They are calculated by taking the intermediate local flow from the downstream location and applying an area ratio multiplier to the time records (for an example, see Section 2.3). The AFDR process used the file Locals-Disaggregated.csv to instruct the AFDR HEC-ResSim model as to which local flows to calculate and the equations used to calculate them. Figure 2-2, Figure 2-3, and Figure 2-4 show the CSV file that was used to create the local flows using the included equation inputs, except for the equations noted below in the assumptions section.

The assumptions used for the disaggregation were as follows:

- The equations, area ratios, etc., used in the AFDR model are correct except where noted in subsequent bullet points.
- There is evidence that the area ratios for ***Pend Oreille + Calispel CK Local Flow****[1] and ***Inflow**** may be interchanged. The correct values were not determined for the purposes of this project and it was assumed that the volumes of water coming into the system would be correct, regardless.
- ***Clark Fork + Lightening CK Inflow**** daily flow values were calculated as 0.06 of the intermediate flow values of ***Albeni Falls Local Flow****.
- ***Clark Fork + Lightening CK Local Flow**** daily flow values were calculated as 0.04 of the intermediate flow values of ***Albeni Falls Local Flow****.

It is important to note the following about local flows:

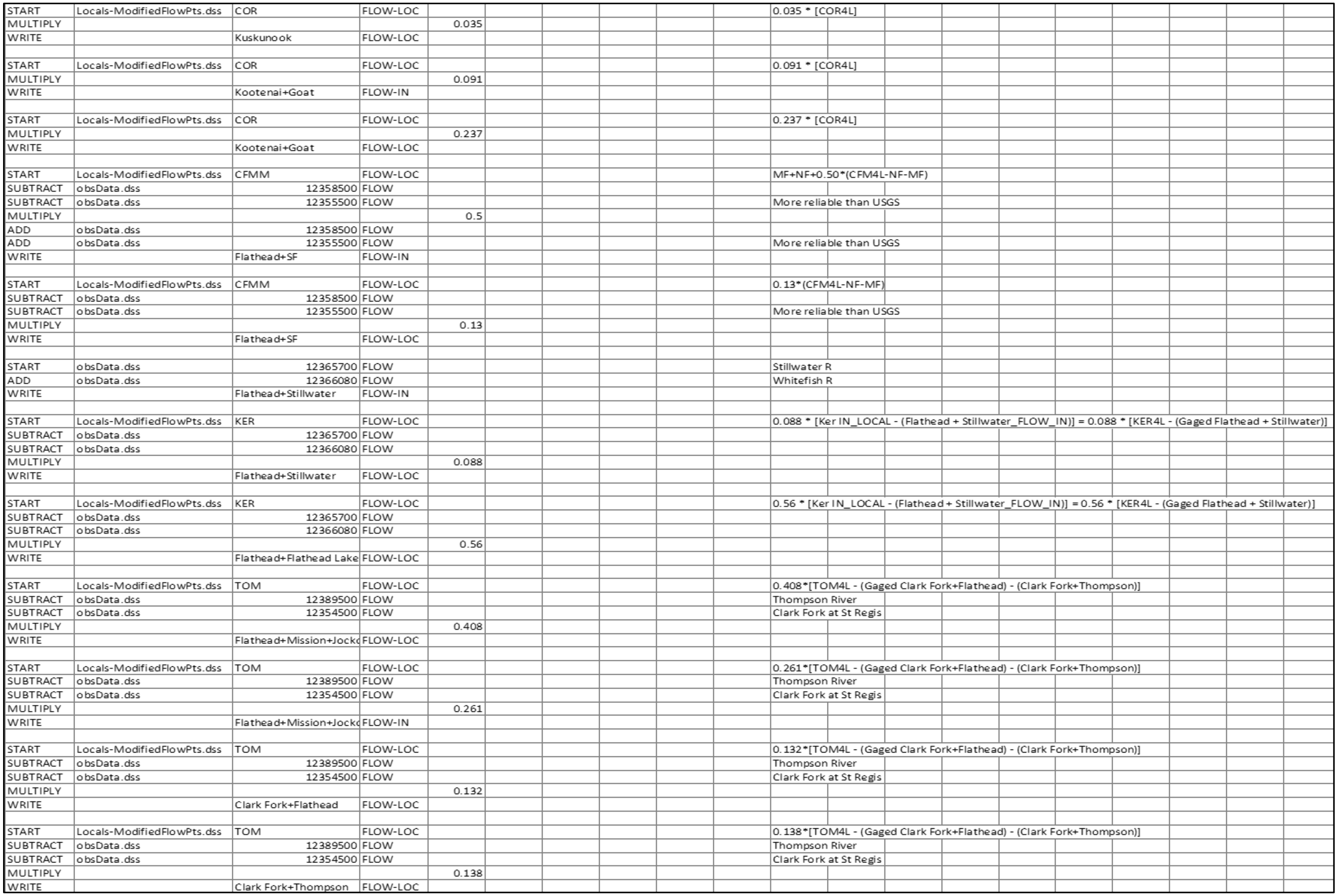
- The AFDR and the Columbia River System HEC-ResSim models have flipped the naming convention between the local flows for the Flathead River (Local Flow vs. Inflow) (Corps 2015).
- Most of the local flows upstream of Albeni Falls were smoothed using a moving average of 5 to 15 days using DssVue smoothing equations.

---

[1] Asterisk and italics indicate the name of observed gage data or Extended Observed Hydrology data value.

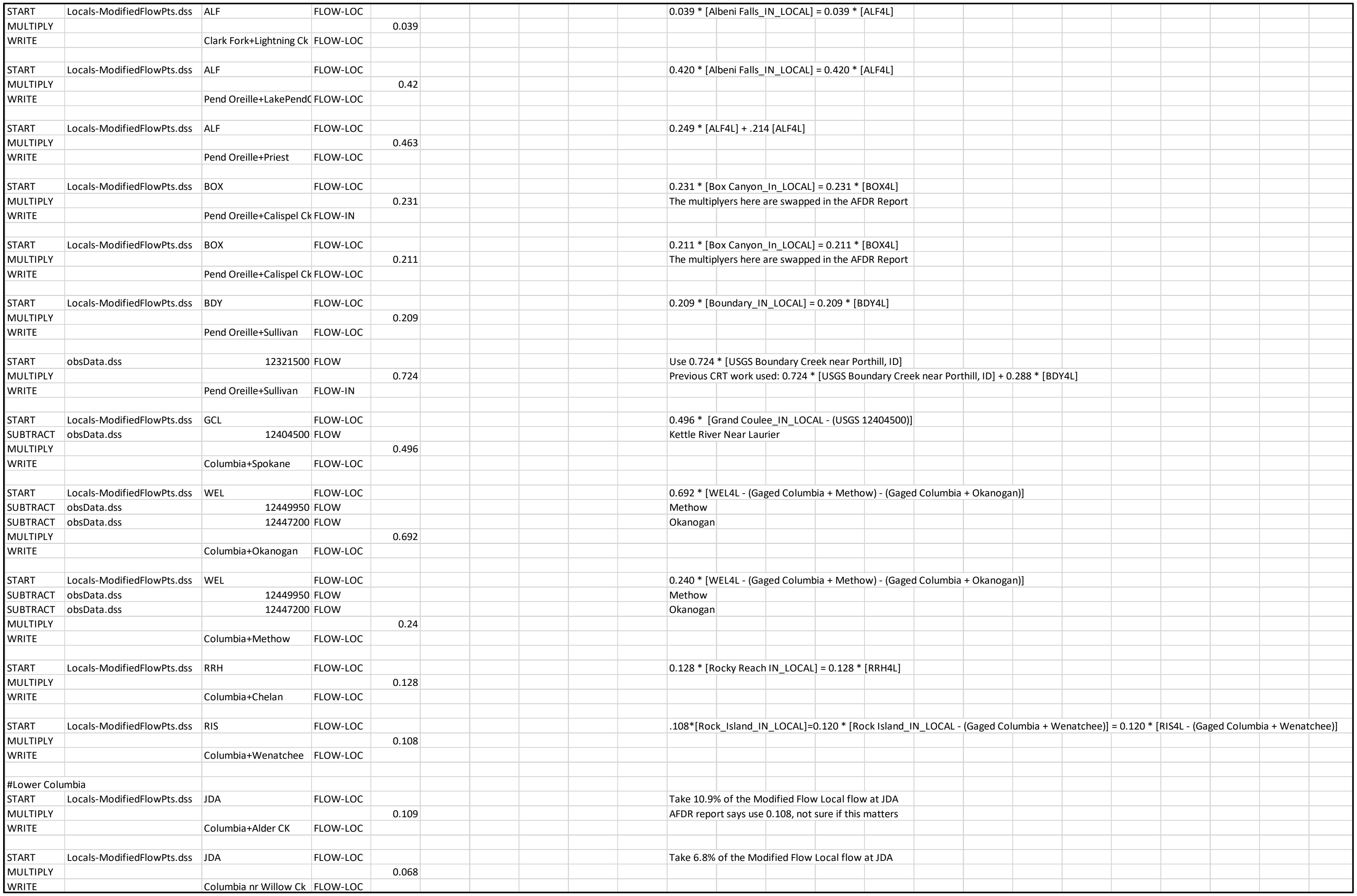
#This file contains instructions on how to compute disaggregated tributary locals										
#A disaggregated local flow is one that depends on other local flows already existing (modified flow points)										
#It is formulated as a CSV file so that it can be easily viewed/edited in Excel										
#The output dss file; output fPart; and timestep should be defined by the subroutine that uses this file										
#The headers are briefly explained here:										
#	Command: The script will run through the list of commands. Each block must begin with START and end with WRITE									
#		START	The timeseries to read in at the beginning and set as "active"							
#		ADD	A timeseries to be added to the active TS							
#		SUBTRACT	A timeseries to be subtracted to the active TS							
#		MULTIPLY	Multiply the active TS by a constant							
#		FLOOR	Caps all values in the time series to the minimum value specified as "Constant"							
#		CEILING	Caps all values in the time series to the maximum value specified as "Constant"							
#		SHIFTHRS	Shifts all values by the number of hours specified as "Constant" (positive or negative)							
#		INDEX	Not functional yet							
#		MOVE1	Uses the MOVE.1 technique to extend streamflow records based on a nearby gage							
#			MOVE.1 technique summary (uses logarithm base 10 of flows):							
#				xData is log10 of flow data of the predictor station during period of concurrent data						
#				yData is log10 of flow data of the predicted station during period of concurrent data						
#				Eqn: Yhat = Ybar + Sy/Sx(X-Xbar)						
#		ROUTE	Routes flow directly from US_JuncName to DS_JuncName (no other locals added in) using ResSim routing parameters defined							
#		WRITE	The timeseries to be written out (Bpart and Cpart defined)							
#	DSS File: the name of the DSS file to read from (in the shared directory)									
#	Bpart: the Bpart of the record to be read or written, depending on the command									
#	Cpart: the Cpart of the record to be read or written, depending on the command									
#	Constant: a constant (typically used with MULTIPLY to factor the timeseries)									
#	US_JuncName: only used with ROUTE--the upstream junction to route from as named in ResSim									
#	DS_JuncName: only used with ROUTE--the upstream junction to route to as named in ResSim									
#	YBarMOVE1: average of the yData (only used in MOVE1)									
#	XBarMOVE1: average of the xData (only used in MOVE1)									
#	SlopeMOVE1: Sy/Sx (std dev of y-data divided by std dev of x-data) (only used in MOVE1)									
#Command	DSS File	Bpart	Cpart	Constant	US_JuncNa	DS_JuncNa	YBarMOVE	XBarMOVE	SlopeMOV	Comments
START	Locals-ModifiedFlowPts.dss	BFEI	FLOW-LOC							0.027 * [BFE4L - (Kooteai+Moyie) - (Kootenai+Yaak) - (Kootenai+Fisher)]
#SUBTRACT	obsData.dss									Moyie River gage at Eileen discontinued
SUBTRACT	obsData.dss	12304500	FLOW							Yaak River gage
SUBTRACT	obsData.dss	12302055	FLOW							Fisher River gage
MULTIPLY				0.027						
WRITE		Kootenai+Fisher	FLOW-LOC							
START	Locals-ModifiedFlowPts.dss	BFEI	FLOW-LOC							0.792 * [BFE4L - (Kooteai+Moyie) - (Kootenai+Yaak) - (Kootenai+Fisher)]
#SUBTRACT	obsData.dss									Moyie River gage at Eileen discontinued
SUBTRACT	obsData.dss	12304500	FLOW							Yaak River gage
SUBTRACT	obsData.dss	12302055	FLOW							Fisher River gage
MULTIPLY				0.792						
WRITE		Kootenai+Yaak	FLOW-LOC							
START	Locals-ModifiedFlowPts.dss	BFEI	FLOW-LOC							0.144 * [BFE4L - (Kooteai+Moyie) - (Kootenai+Yaak) - (Kootenai+Fisher)]
#SUBTRACT	obsData.dss									Moyie River gage at Eileen discontinued
SUBTRACT	obsData.dss	12304500	FLOW							Yaak River gage
SUBTRACT	obsData.dss	12302055	FLOW							Fisher River gage
MULTIPLY				0.144						
WRITE		Kootenai+Moyie	FLOW-LOC							
START	Locals-ModifiedFlowPts.dss	BFEI	FLOW-LOC							0.248 * [BFE4LN] - 76.3
MULTIPLY				0.248						
SUBTRACT				76.3						
WRITE		Kootenai+Moyie	FLOW-IN							

Figure 2-2. CSV File used to Disaggregate Intermediate Local Flow Data to Create Local Inflows for Water Years 2008 to 2016 (1 of 3)



START	Locals-ModifiedFlowPts.dss	COR	FLOW-LOC		0.035 * [COR4L]
MULTIPLY				0.035	
WRITE		Kuskunook	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	COR	FLOW-LOC		0.091 * [COR4L]
MULTIPLY				0.091	
WRITE		Kootenai+Goat	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	COR	FLOW-LOC		0.237 * [COR4L]
MULTIPLY				0.237	
WRITE		Kootenai+Goat	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	CFMM	FLOW-LOC		MF+NF+0.50*(CFM4L-NF-MF)
SUBTRACT	obsData.dss	12358500	FLOW		
SUBTRACT	obsData.dss	12355500	FLOW		More reliable than USGS
MULTIPLY				0.5	
ADD	obsData.dss	12358500	FLOW		
ADD	obsData.dss	12355500	FLOW		More reliable than USGS
WRITE		Flathead+SF	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	CFMM	FLOW-LOC		0.13*(CFM4L-NF-MF)
SUBTRACT	obsData.dss	12358500	FLOW		
SUBTRACT	obsData.dss	12355500	FLOW		More reliable than USGS
MULTIPLY				0.13	
WRITE		Flathead+SF	FLOW-LOC		
START	obsData.dss	12365700	FLOW		Stillwater R
ADD	obsData.dss	12366080	FLOW		Whitefish R
WRITE		Flathead+Stillwater	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	KER	FLOW-LOC		0.088 * [Ker IN_LOCAL - (Flathead + Stillwater_FLOW_IN)] = 0.088 * [KER4L - (Gaged Flathead + Stillwater)]
SUBTRACT	obsData.dss	12365700	FLOW		
SUBTRACT	obsData.dss	12366080	FLOW		
MULTIPLY				0.088	
WRITE		Flathead+Stillwater	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	KER	FLOW-LOC		0.56 * [Ker IN_LOCAL - (Flathead + Stillwater_FLOW_IN)] = 0.56 * [KER4L - (Gaged Flathead + Stillwater)]
SUBTRACT	obsData.dss	12365700	FLOW		
SUBTRACT	obsData.dss	12366080	FLOW		
MULTIPLY				0.56	
WRITE		Flathead+Flathead Lake	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	TOM	FLOW-LOC		0.408*[TOM4L - (Gaged Clark Fork+Flathead) - (Clark Fork+Thompson)]
SUBTRACT	obsData.dss	12389500	FLOW		Thompson River
SUBTRACT	obsData.dss	12354500	FLOW		Clark Fork at St Regis
MULTIPLY				0.408	
WRITE		Flathead+Mission+Jockc	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	TOM	FLOW-LOC		0.261*[TOM4L - (Gaged Clark Fork+Flathead) - (Clark Fork+Thompson)]
SUBTRACT	obsData.dss	12389500	FLOW		Thompson River
SUBTRACT	obsData.dss	12354500	FLOW		Clark Fork at St Regis
MULTIPLY				0.261	
WRITE		Flathead+Mission+Jockc	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	TOM	FLOW-LOC		0.132*[TOM4L - (Gaged Clark Fork+Flathead) - (Clark Fork+Thompson)]
SUBTRACT	obsData.dss	12389500	FLOW		Thompson River
SUBTRACT	obsData.dss	12354500	FLOW		Clark Fork at St Regis
MULTIPLY				0.132	
WRITE		Clark Fork+Flathead	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	TOM	FLOW-LOC		0.138*[TOM4L - (Gaged Clark Fork+Flathead) - (Clark Fork+Thompson)]
SUBTRACT	obsData.dss	12389500	FLOW		Thompson River
SUBTRACT	obsData.dss	12354500	FLOW		Clark Fork at St Regis
MULTIPLY				0.138	
WRITE		Clark Fork+Thompson	FLOW-LOC		

Figure 2-3. CSV File used to Disaggregate Intermediate Local Flow Data to Create Local Inflows for Water Years 2008 to 2016 (2 of 3)



START	Locals-ModifiedFlowPts.dss	ALF	FLOW-LOC		0.039 * [Albeni Falls_IN_LOCAL] = 0.039 * [ALF4L]
MULTIPLY				0.039	
WRITE		Clark Fork+Lightning Ck	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	ALF	FLOW-LOC		0.420 * [Albeni Falls_IN_LOCAL] = 0.420 * [ALF4L]
MULTIPLY				0.42	
WRITE		Pend Oreille+LakePend	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	ALF	FLOW-LOC		0.249 * [ALF4L] + .214 [ALF4L]
MULTIPLY				0.463	
WRITE		Pend Oreille+Priest	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	BOX	FLOW-LOC		0.231 * [Box Canyon_In_LOCAL] = 0.231 * [BOX4L]
MULTIPLY				0.231	The multiplyers here are swapped in the AFDR Report
WRITE		Pend Oreille+Calispel Ck	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	BOX	FLOW-LOC		0.211 * [Box Canyon_In_LOCAL] = 0.211 * [BOX4L]
MULTIPLY				0.211	The multiplyers here are swapped in the AFDR Report
WRITE		Pend Oreille+Calispel Ck	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	BDY	FLOW-LOC		0.209 * [Boundary_IN_LOCAL] = 0.209 * [BDY4L]
MULTIPLY				0.209	
WRITE		Pend Oreille+Sullivan	FLOW-LOC		
START	obsData.dss	12321500	FLOW		Use 0.724 * [USGS Boundary Creek near Porthill, ID]
MULTIPLY				0.724	Previous CRT work used: 0.724 * [USGS Boundary Creek near Porthill, ID] + 0.288 * [BDY4L]
WRITE		Pend Oreille+Sullivan	FLOW-IN		
START	Locals-ModifiedFlowPts.dss	GCL	FLOW-LOC		0.496 * [Grand Coulee_IN_LOCAL - (USGS 12404500)]
SUBTRACT	obsData.dss	12404500	FLOW		Kettle River Near Laurier
MULTIPLY				0.496	
WRITE		Columbia+Spokane	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	WEL	FLOW-LOC		0.692 * [WEL4L - (Gaged Columbia + Methow) - (Gaged Columbia + Okanogan)]
SUBTRACT	obsData.dss	12449950	FLOW		Methow
SUBTRACT	obsData.dss	12447200	FLOW		Okanogan
MULTIPLY				0.692	
WRITE		Columbia+Okanogan	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	WEL	FLOW-LOC		0.240 * [WEL4L - (Gaged Columbia + Methow) - (Gaged Columbia + Okanogan)]
SUBTRACT	obsData.dss	12449950	FLOW		Methow
SUBTRACT	obsData.dss	12447200	FLOW		Okanogan
MULTIPLY				0.24	
WRITE		Columbia+Methow	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	RRH	FLOW-LOC		0.128 * [Rocky Reach IN_LOCAL] = 0.128 * [RRH4L]
MULTIPLY				0.128	
WRITE		Columbia+Chelan	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	RIS	FLOW-LOC		.108*[Rock_Island_IN_LOCAL]=0.120 * [Rock Island_IN_LOCAL - (Gaged Columbia + Wenatchee)] = 0.120 * [RIS4L - (Gaged Columbia + Wenatchee)]
MULTIPLY				0.108	
WRITE		Columbia+Wenatchee	FLOW-LOC		
#Lower Columbia					
START	Locals-ModifiedFlowPts.dss	JDA	FLOW-LOC		Take 10.9% of the Modified Flow Local flow at JDA
MULTIPLY				0.109	AFDR report says use 0.108, not sure if this matters
WRITE		Columbia+Alder CK	FLOW-LOC		
START	Locals-ModifiedFlowPts.dss	JDA	FLOW-LOC		Take 6.8% of the Modified Flow Local flow at JDA
MULTIPLY				0.068	
WRITE		Columbia nr Willow Ck	FLOW-LOC		

Figure 2-4. CSV File used to Disaggregate Intermediate Local Flow Data to Create Local Inflows for Water Years 2008 to 2016 (3 of 3)

2.1.2.7 Final Water Balance Local Flows

The final water balance locals step recalculates all of the local flows, moving from upstream to downstream in the system.

2.2 EXTENDED OBSERVED FLOW DATASETS REQUIRED BUT NOT CALCULATED BY THE AFDR MODEL

There are several datasets that are determined outside of the AFDR calculations, such as dam/reservoir inflows or gaged tributaries. Some of the required local flows represent tributaries that happen to have conveniently located gages. Therefore, in the cases presented in Table 2-2, the gage time records are used directly.

Table 2-2. Local Flows with Gages

Local Flow Name	USGS Gage Number or Location Identifier
Clackamas River Inflow	14210000
Clark Fork+Flathead Inflow	12354500
Clark Fork+Lightening Ck Inflow	12392155
Clark Fork+Thompson Inflow	12389500
Clearwater+Potlach Local Flow	13341570
Columbia+Deschutes Local Flow	14103000
Columbia+Kettle Local Flow	12404500
Columbia+Klickitat Local Flow	14113000
Columbia+Methow Inflow	12449950
Columbia+Okanogan Inflow	12447200
Columbia+Umatilla Local Flow	14033500
Columbia+Wenatchee Inflow	12462500
Columbia+Yakima Flow	12510500
Cowlitz River inflow	14238000
Kootenai+Fisher Inflow	12302055
Kootenai+Yaak Inflow	12304500
SF Clearwater_HW Local Flow	13340000
Snake+Salmon Inflow	13317000
Willamette+Clackamas Local Flow	14211010
Willamette+Luckiamute Inflow	14190500

Headwater dam inflows were collected from the CWMS data at the following locations:

- Mica inflow
- Libby inflow
- Duncan inflow
- Hungry Horse inflow

- Chelan inflow
- Dworshak inflow
- Merwin inflow

2.3 RESULTING FLOW DATASETS

The following figures are examples of the local flow files that were created through the AFDR HEC-ResSim model for use in the CRS Model as part of the deliverables for this project. Figure 2-5 is the local flow time record for Hungry Horse Reservoir and is an example of an inflow file for a headwater dam. Inflow files are used directly for the local flow into that computation point.

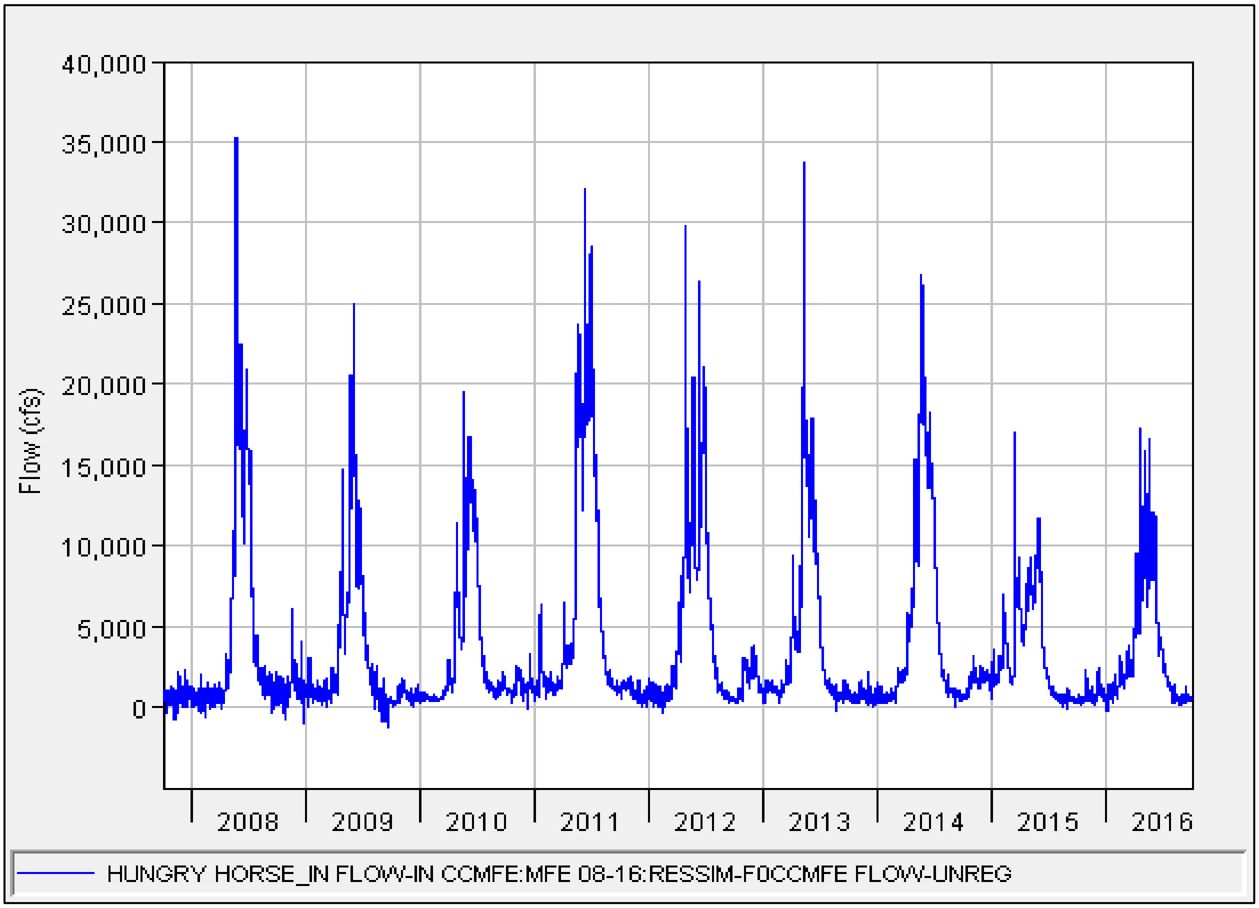


Figure 2-5. Hungry Horse Reservoir Inflows for Water Years 2008 to 2016

A water balance type calculation was used to calculate the local inflows to **Flathead Lake** (Figure 2-6). Water balance type calculations use the gaged flow value at a computation point and subtract an upstream gaged flow that has been routed to the point using SSARR routing in all areas without tidal influence. As seen in Figure 2-6, there are often very large or very small, obviously incorrect, flow values in the time records. These can occur for several reasons, including errors that remain in the inflow gage data from the quality control process or the forcing of a volume balance in the calculations.

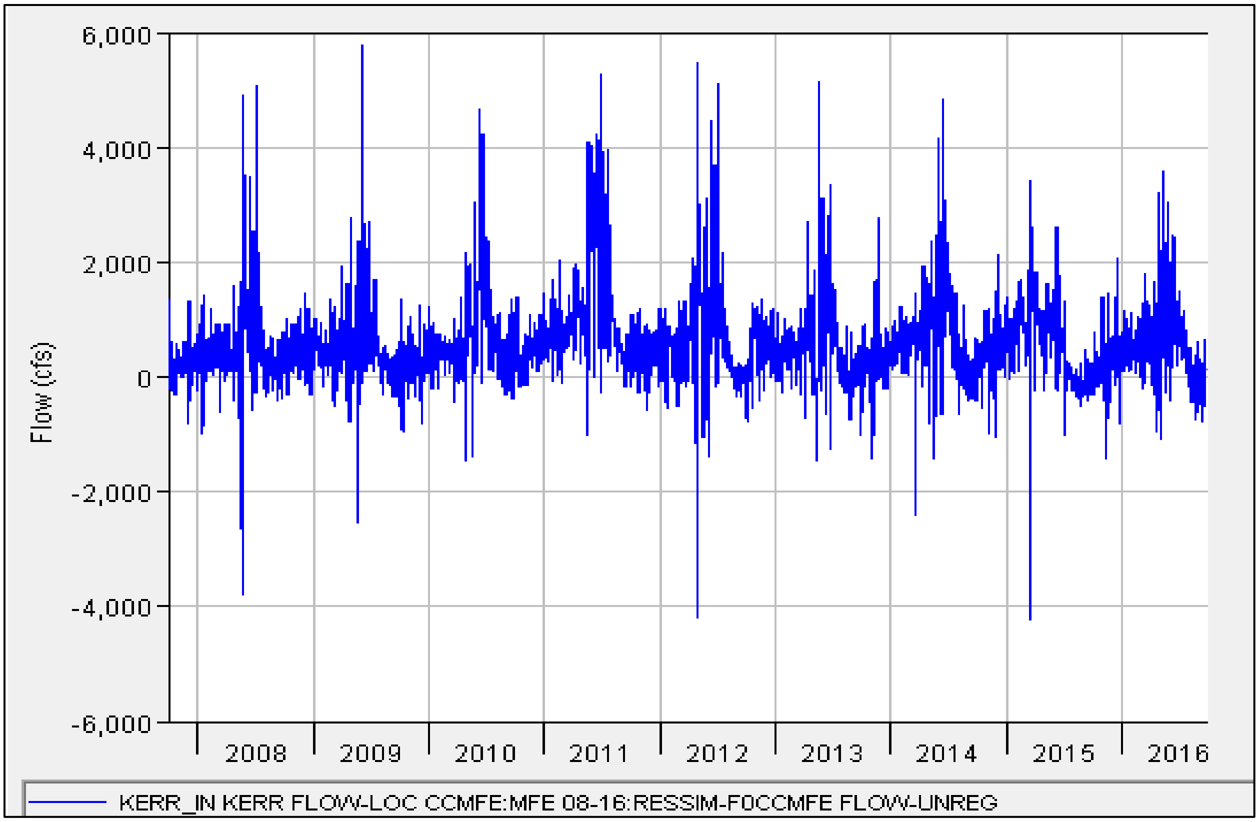


Figure 2-6. Daily Local Inflow Values for Flathead Lake for Water Years 2008 to 2016

Often the tributaries of the system have gages located near their mouths, and in these cases the gage data is used directly as the local inflow for those locations. An example of a local gaged tributary being used for the local inflow time record is the gage data from the **Kettle River** being used as the local flow, **Columbia + Kettle** (Figure 2-7).

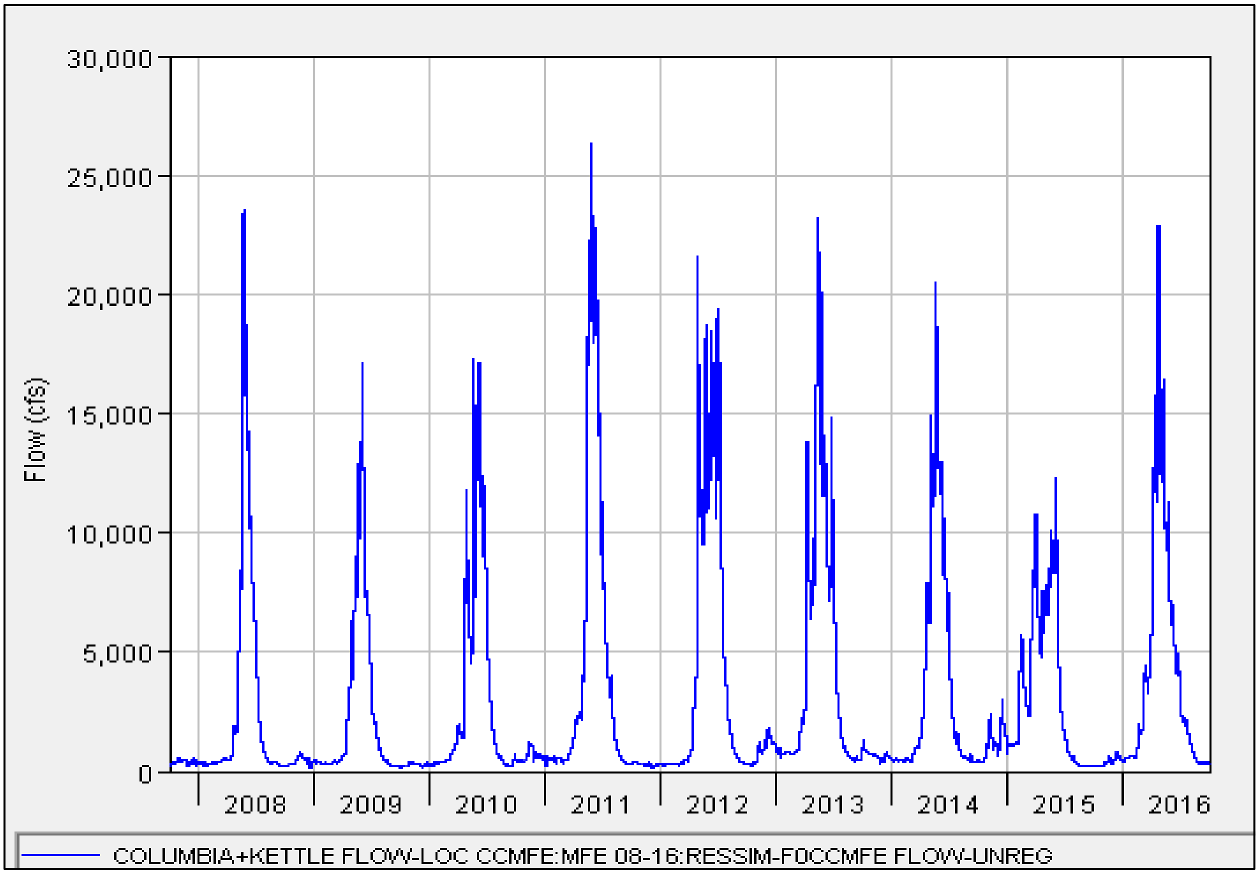


Figure 2-7. Local Inflow at Computation Point Columbia + Kettle for Water Years 2008 to 2016

The local inflow to **Chief Joseph** dam is presented in Figure 2-8 and is another example of data calculated from a water balance type equation. The total amount of water flowing into the reservoir is much larger than the local inflow at this location.

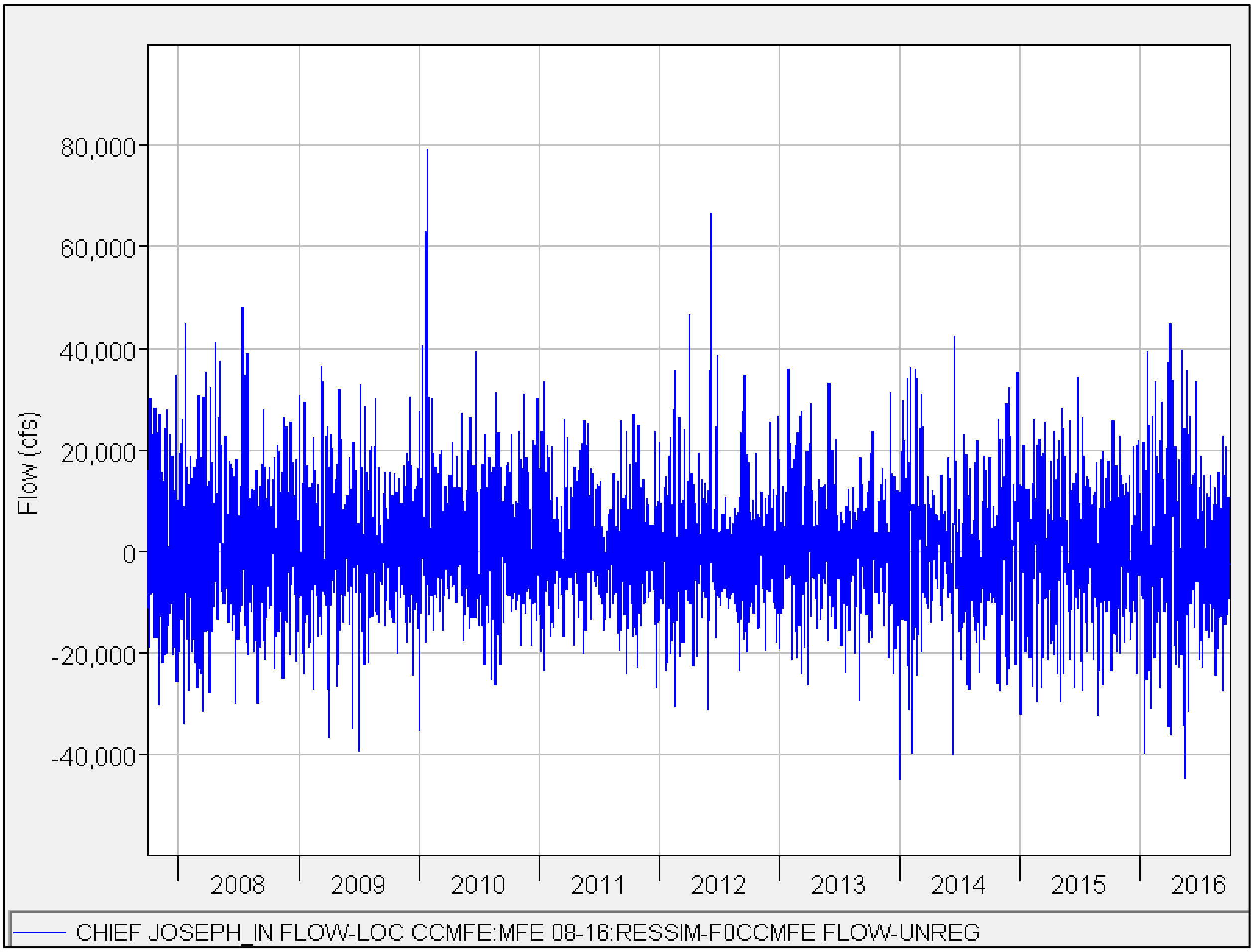


Figure 2-8. Local Inflow at the Reservoir at Chief Joseph Dam for Water Years 2008 to 2016

An example of a disaggregated local flow is presented for **Columbia + Chelan** in Figure 2-9. This is a case where a large tributary does not have a conveniently located gage. Therefore, this local flow is calculated using a watershed area ratio multiplier. The disaggregated flows tend to have significant negative flow values and appear to be fairly noisy and are often more representative of gage noise/error than actual local flows; however, daily water volumes are preserved with this method.

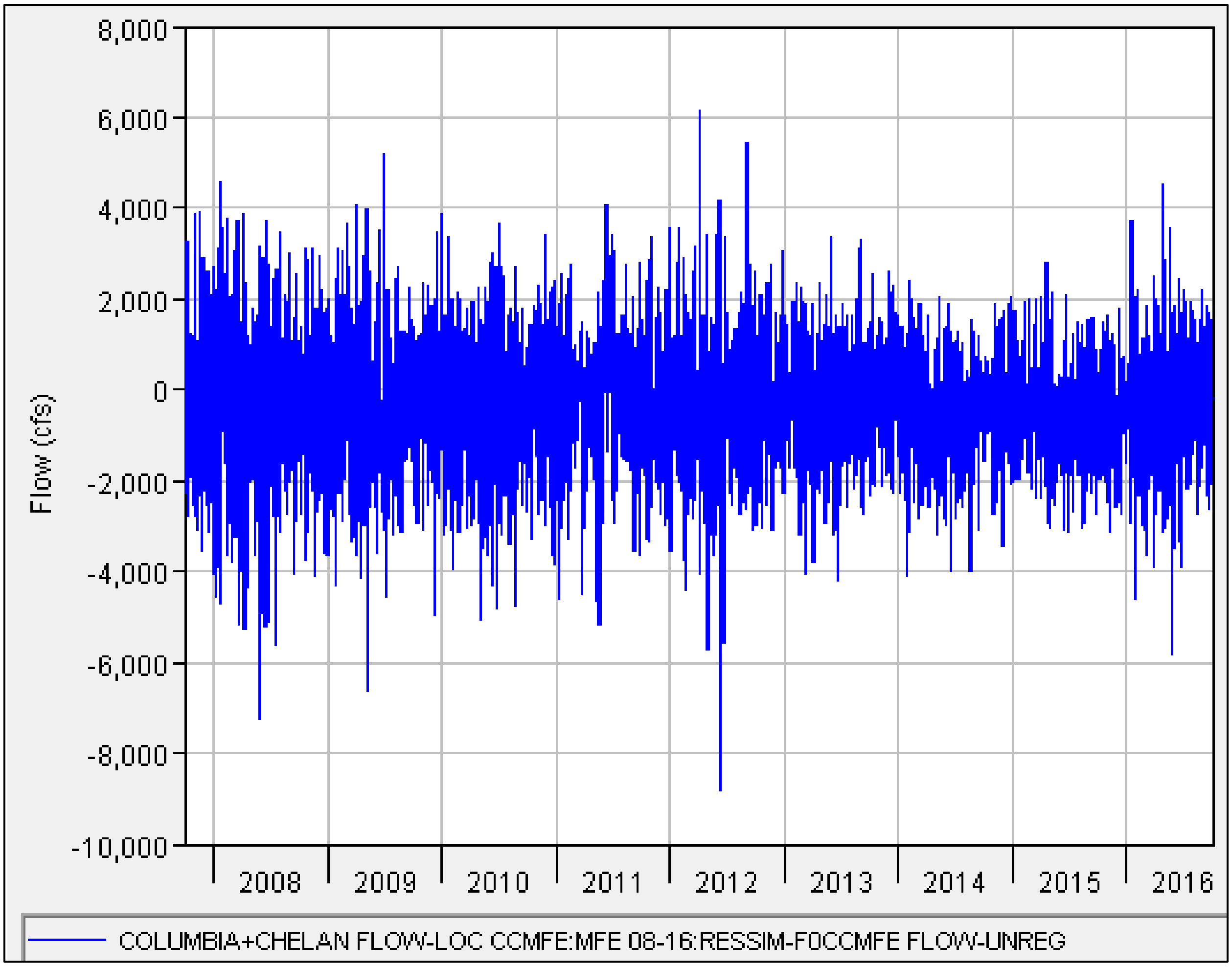


Figure 2-9. Local Inflow at Computation Point Columbia + Chelan for Water Years 2008 to 2016

Finally, Figure 2-10 is an example of transformed gage data since there are several gages that have been moved and combined to form this local flow daily timeseries. This again shows a great deal of noise. Noise is often more representative of gage error than actual local flows; however, daily water volumes are preserved with this method.

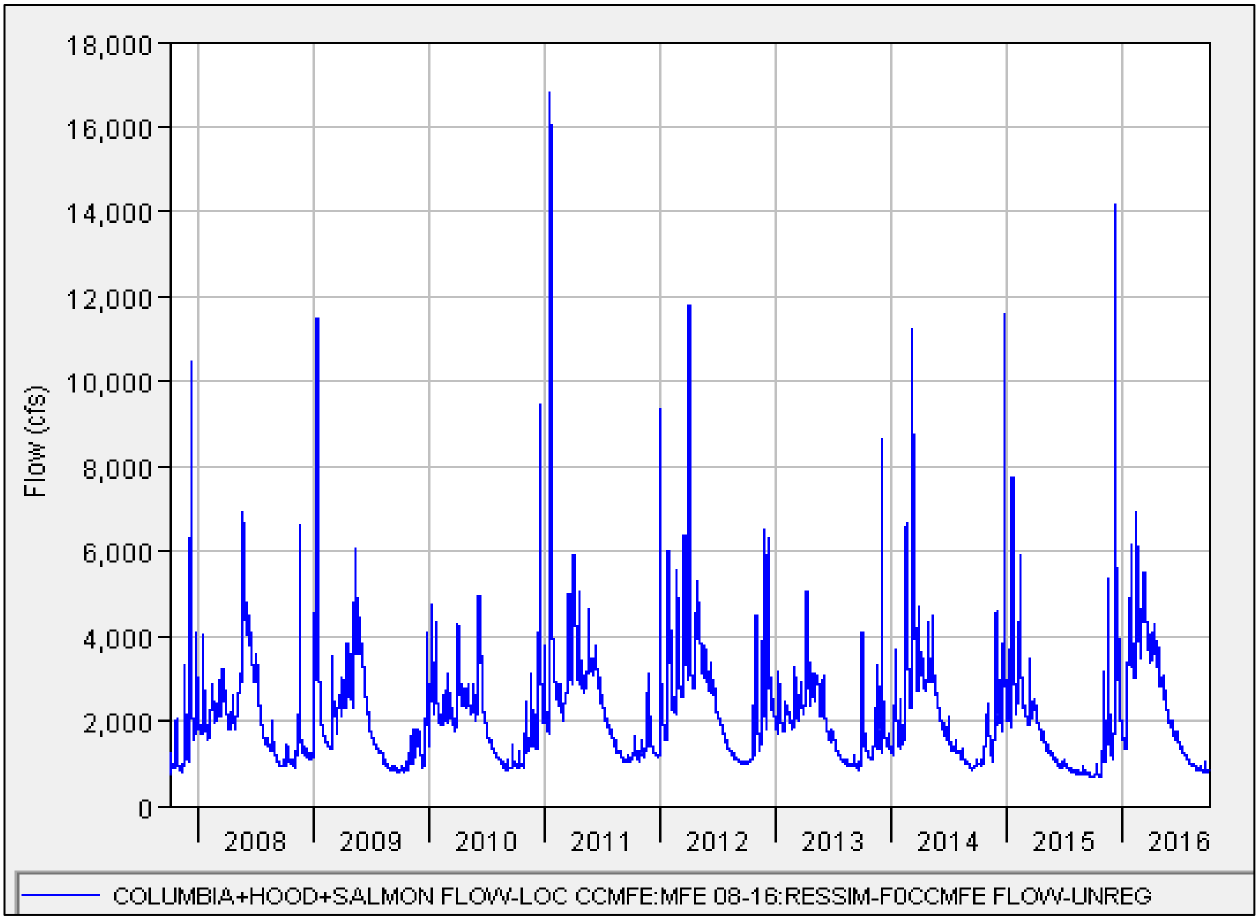


Figure 2-10. Local Inflow at Computation Point Columbia + Hood + Salmon for Water Years 2008 to 2016

2.4 EXTENDED OBSERVED HYDROLOGY DATA ERROR AND LIMITATIONS

Extended Observed hydrology data error and limitations come from sources such as incomplete data, inaccurate data, and different data processing than traditional CRSO hydrology sets. First, some error comes from an incomplete dataset within the Columbia River Basin at all locations of interest. Some local flows needed to be estimated from other flow sources using formulas and assumptions because complete datasets at key locations were not available. These transformation formulas and assumptions provide estimates of the inflow values at the key locations and carry some inherent risk of error. In addition, despite significant quality control efforts, the gage measurements used to derive local flows can contain noise, measurement error, and potential bias. Inflow datasets derived from these gage measurements inherently contain some flaws. Finally—though this is not necessarily an error—the Extended Observed hydrology dataset does not include processing to remove the irrigation and evaporation impacts of the region as is the case for more traditionally used hydrology datasets. Though this is not an error, it is a potential limitation to the use of the Extended Observed dataset. This limitation is a particular caveat should a comparison be made between the results obtained while using the Extended Observed dataset and those obtained while using the 2010 Level Modified Streamflows dataset.

CHAPTER 3 - WATER SUPPLY FORECASTS

Water supply forecasts (WSFs) were extended for HEC-ResSim modeling with the Extended Observed flow dataset. Details of this process are documented in the Hydrologic Data Appendix to the CRSO Draft EIS. For this dataset, official forecasts were compiled for the locations listed in Table 3-1.

Table 3-1. Forecast Locations, Seasonal Periods, and Sources

Forecast Location		**Primary Forecast Period**	**Agency Providing Forecast**$^{1/}$
Mainstem Columbia River Region			
1	The Dalles	April–August	NWRFC
Lower Snake River Region			
2	Dworshak	April–July	Corps-NWW
3	Lower Granite	April–August	NWRFC
Upper Snake River Region			
4	Brownlee	April–July	NWRFC
Middle Columbia River Region			
5	Grand Coulee	April–August	NWRFC
Kootenay–Pend Oreille–Spokane Region			
6	Libby	April–August	USACE-NWS
7	Hungry Horse	May–September	Reclamation
8	Duncan	April–August	BC Hydro
Upper Columbia River Region			
9	Mica	April–August	BC Hydro
10	Arrow	April–August	BC Hydro

1/ NWRFC = Northwest River Forecast Center; Corps-NWW = U.S. Army Corps of Engineers Northwestern Walla Walla District; Corps-NWS = U.S. Army Corps of Engineers Northwestern Seattle District; BC Hydro = British Columbia Hydro and Power Authority.

The Libby WSF was updated in 2014 (Corps 2014) and the Dworshak WSF was updated officially in 2013 (Corps 2013). Hindcast volumes derived during the training period of these latest forecast equations were used for the 2009–2016 WSF extension.

CHAPTER 4 - CUMULATIVE, UNREGULATED FLOWS WITHOUT NATURAL LAKES

To compare the Extended Observed flows to the 2010 Level Modified Streamflows dataset, the CRS Model was run using the calculated local inflows to create the cumulative, unregulated flows in the river system. All reservoirs in the system were operationally set to run as reservoirs passing inflow, regardless of any natural constrictions to flows that may be present in the channel. Therefore, this set of cumulative flows is modeled similarly to the 2010 Level Modified Streamflows dataset without natural lake effects which allows comparisons for water year 2008. Figure 4-1 shows a comparison of the cumulative unregulated flows at **The Dalles** between the 2010 Level Modified Streamflows dataset and the Extended Observed flows dataset. Annex A contains flows for the two datasets at other locations of interest in the basin.

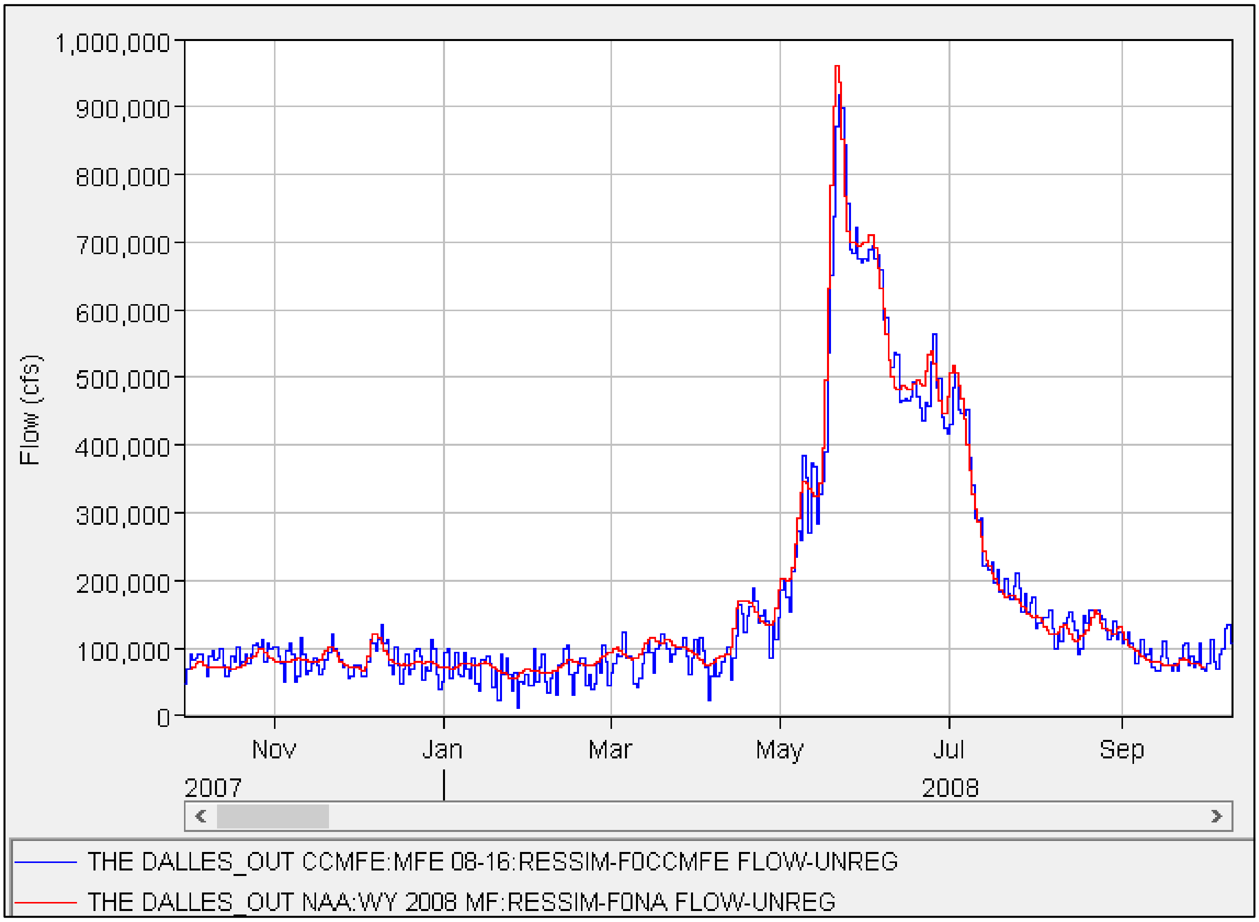


Figure 4-1. The Dalles Outflow for Water Year 2008

Note: Blue is the Extended Observed dataset, red is the 2010 Level Modified Streamflows dataset.

CHAPTER 5 - ROUTING OBSERVED REGULATED FLOWS WITH HEC-RESSIM TO SUPPORT WATER QUALITY MODELING

A SSARR routed cumulative observed flows dataset was created using the AFDR model to specifically support water quality model development and validation. For most of the Columbia River System, the AFDR model allows the reservoir pool elevations to adjust so as to match the observed reservoir inflows and outflows. However, because pool elevation gages are considered fairly reliable and small changes in pool elevations significantly impact water quality calculations, several reservoirs in the model were set to match observed pool elevations and allow outflows to adjust to account for mass balance. Pool elevations were set as observed at the following reservoirs within the AFDR model at these projects: **Albeni Falls**, **Grand Coulee**, **Chief Joseph**, **Wells, Rocky Reach**, **Rock Island**, **Wanapum**, **Priest Rapids**, **McNary**, **Dworshak**, **Lower Granite, Little Goose**, **Lower Monumental**, **Ice Harbor**, **John Day**, **The Dalles**, and **Bonneville**. All other reservoirs in the system were operated with fixed inflows and outflows, and pool elevations were allowed to adjust. This dataset was created to allow the water quality team to validate their model. It also allows the water quality team to assess the degree to which a normal regulated ResSim run with model operating rules compares in terms of water quality modeling to similarly routed observed flows.

CHAPTER 6 - REFERENCES

Bonneville (Bonneville Power Administration). 2011. 2010 Level Modified Streamflows 1928–2008. DOE/BPA-4352. Produced with cooperating agencies U.S. Army Corps of Engineers and U.S. Bureau of Reclamation.

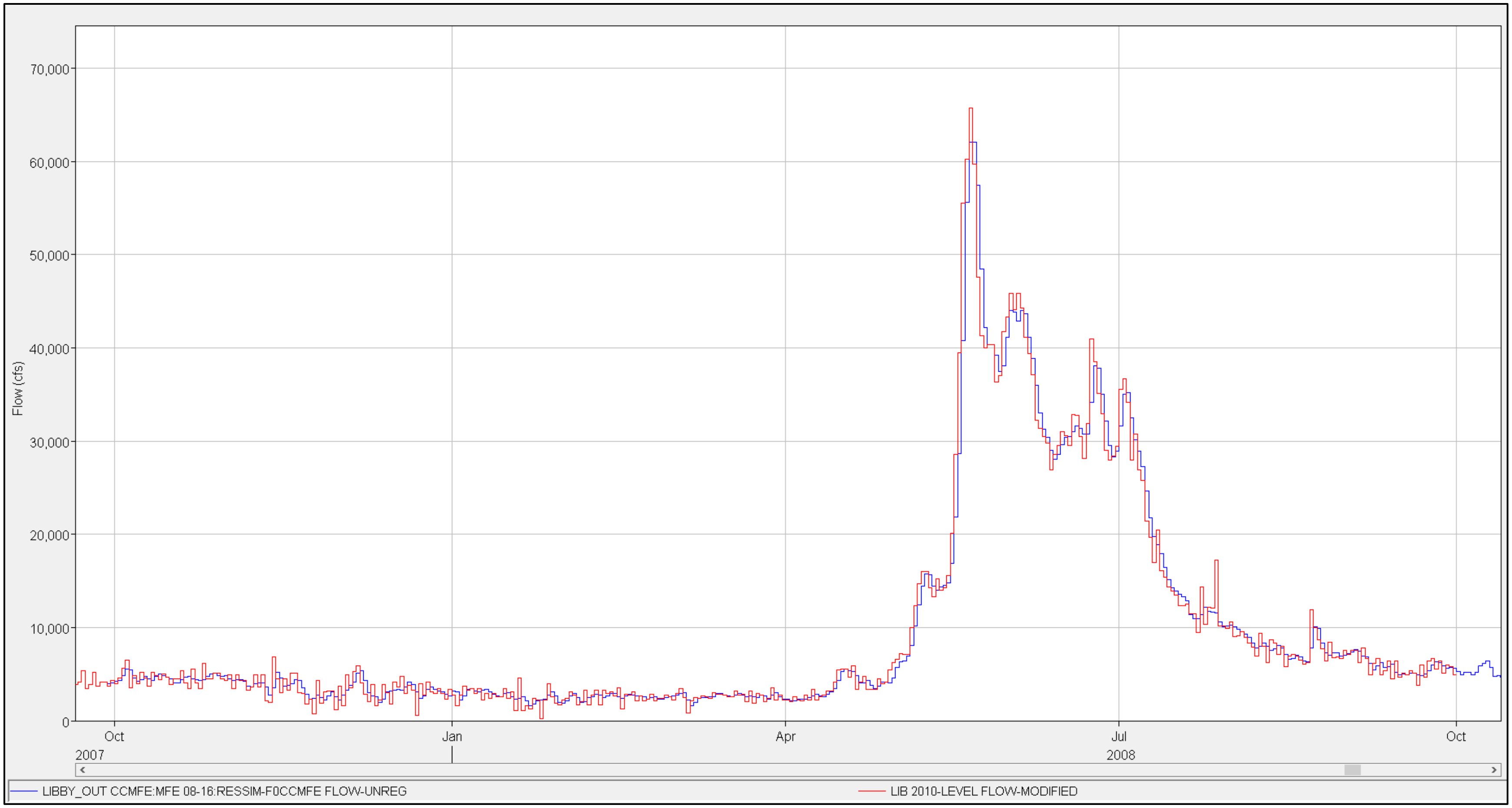
Corps (U.S. Army Corps of Engineers). 2013. Dworshak Water Supply Forecast. http://www.nwdwc.usace.army.mil/report/dwrf/study_2011.pdf. Walla Walla District. Walla Walla, WA.

———. 2014. Water Supply Forecasting Models for Libby, MT. 2014 Revision. http://www.nwd-wc.usace.army.mil/report/libf/lib_wsf_2014.pdf. Seattle District, Hydraulics and Hydrology Branch, Water Management Section. Seattle.

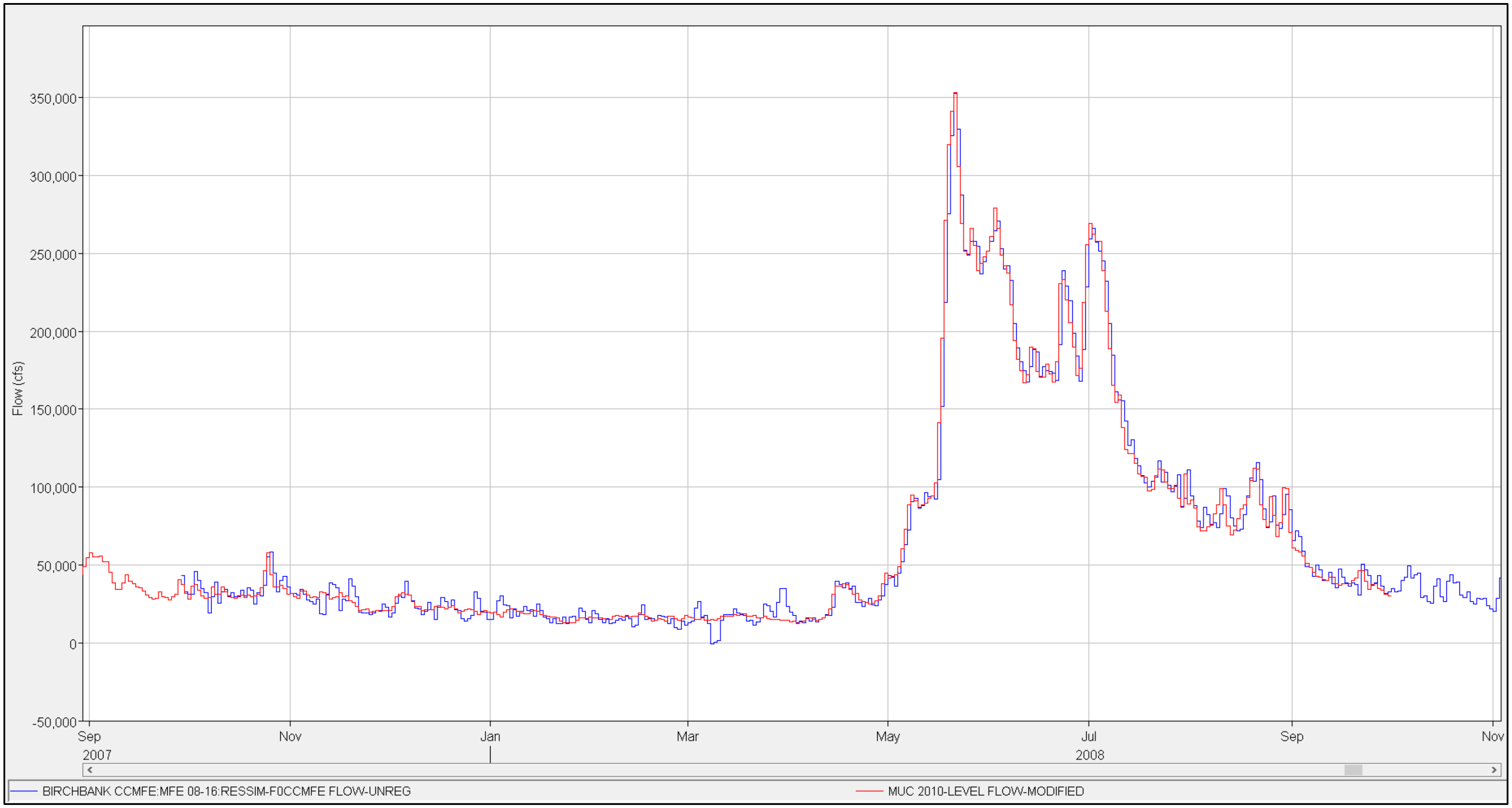
———. 2015. Distribution of 2010 Level Modified Streamflows to CRT HEC-ResSim Computation Inflow Points. Walla Walla District. Walla Walla, WA.

ANNEX A

COMPARISON PLOTS OF WATER YEAR 2008 FOR 2010 LEVEL MODIFIED FLOW AND EXTENDED OBSERVED FLOW AT LOCATIONS OF INTEREST

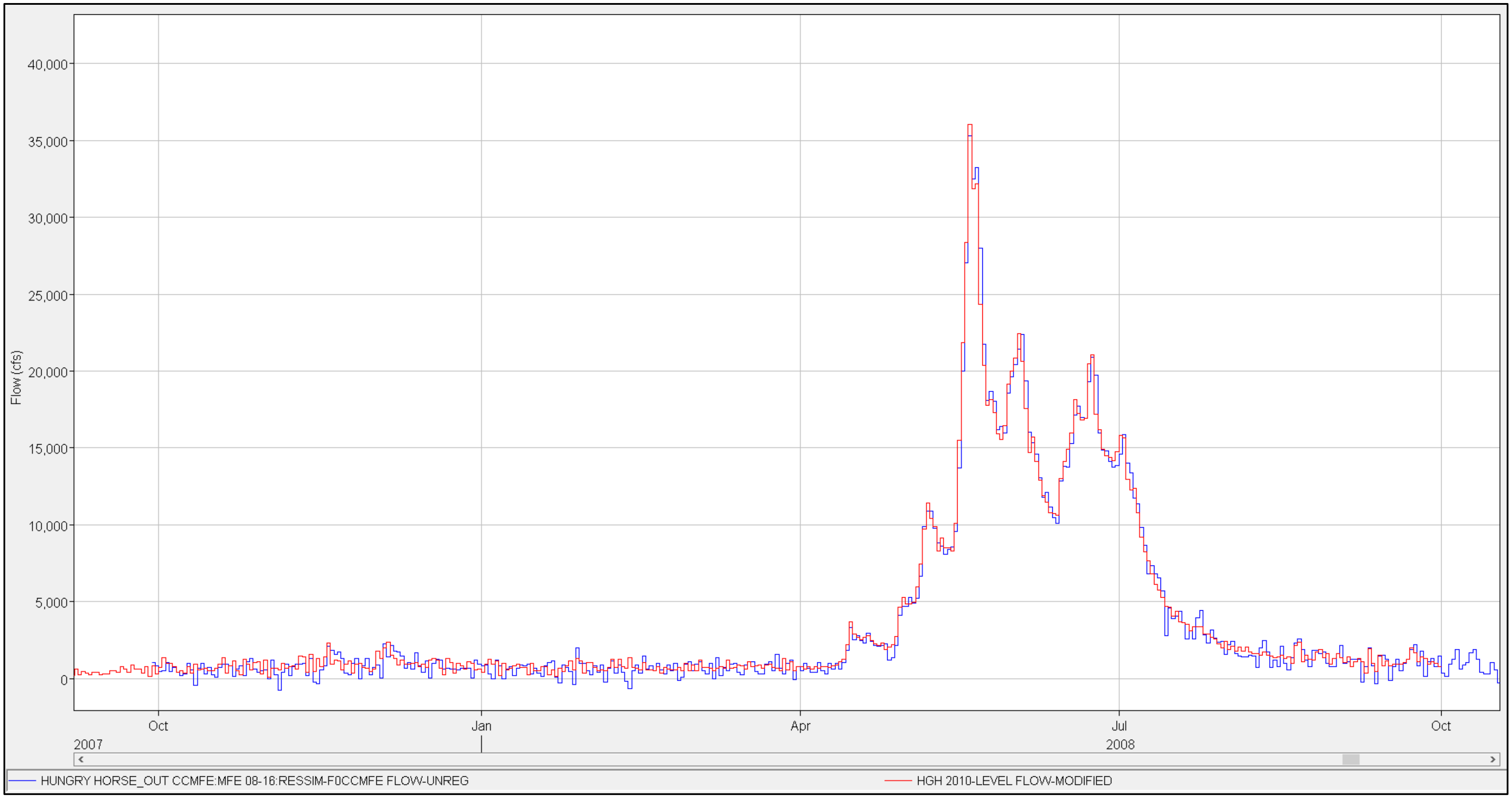


Libby; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows



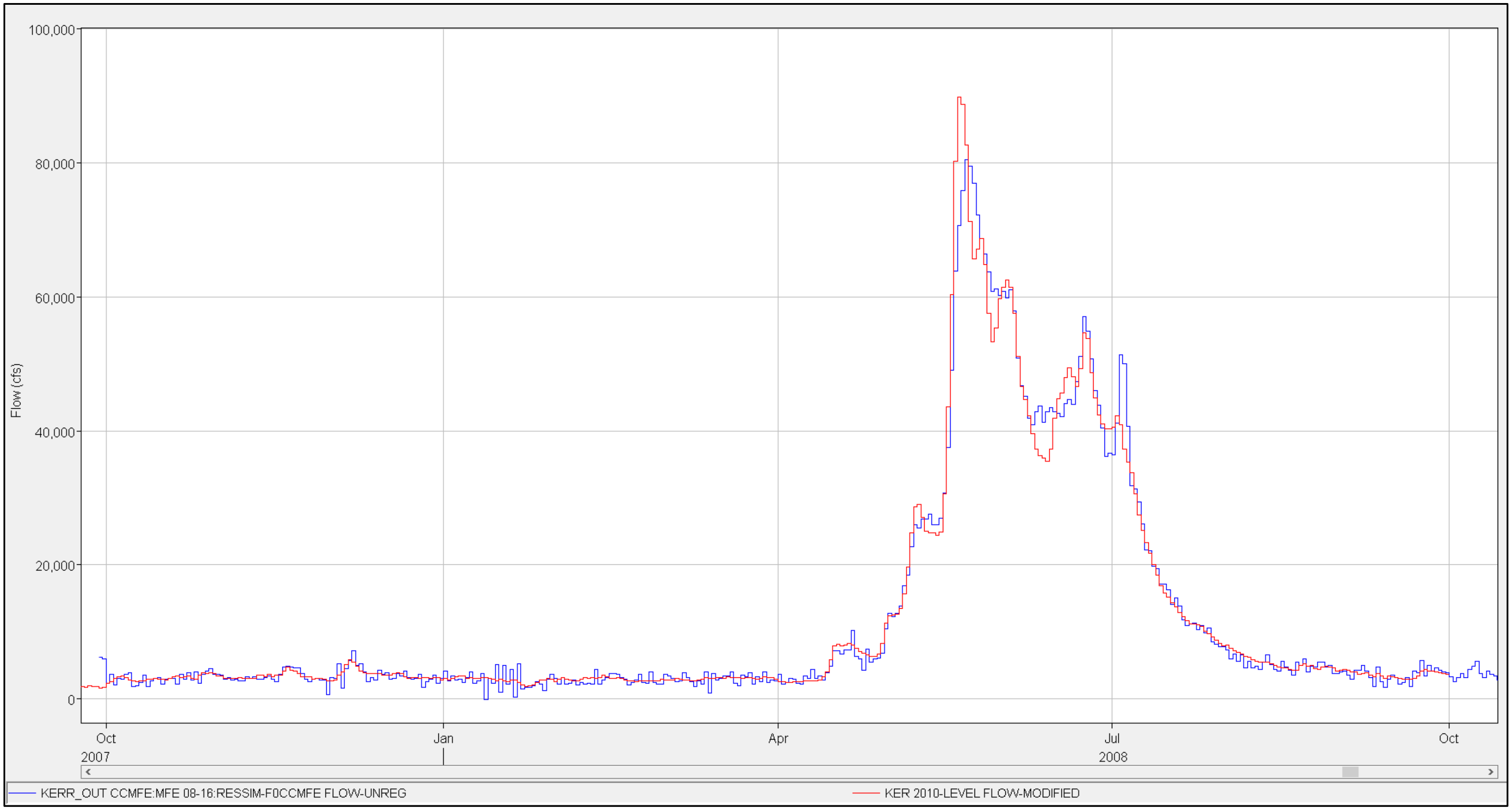
608

609 **Birchbank (flow at the U.S.-Canada border); Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**



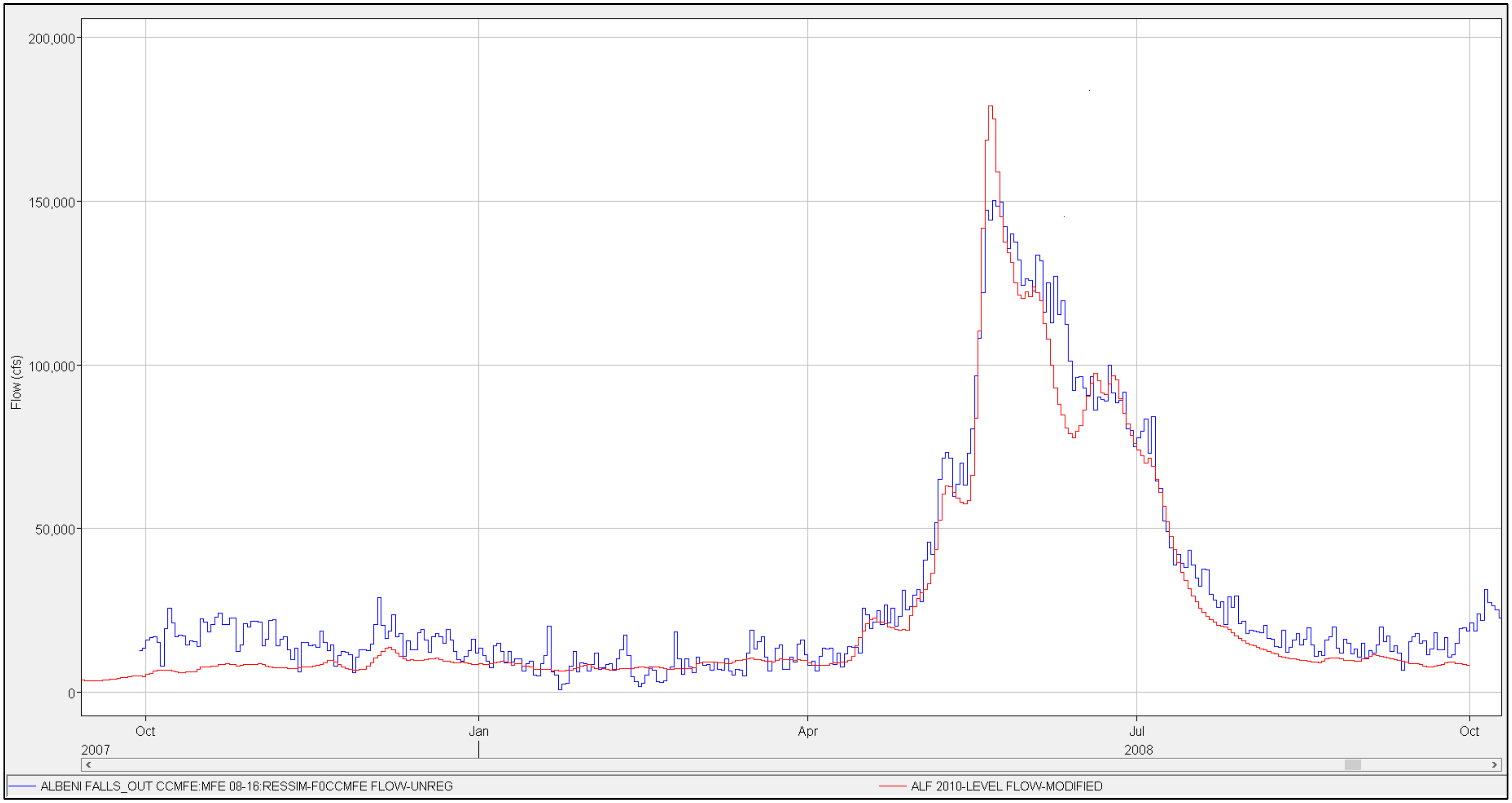
610

611 **Hungry Horse; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**



612

613 **Seli'š Ksanka Qlispe' (formerly known as Kerr); Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**



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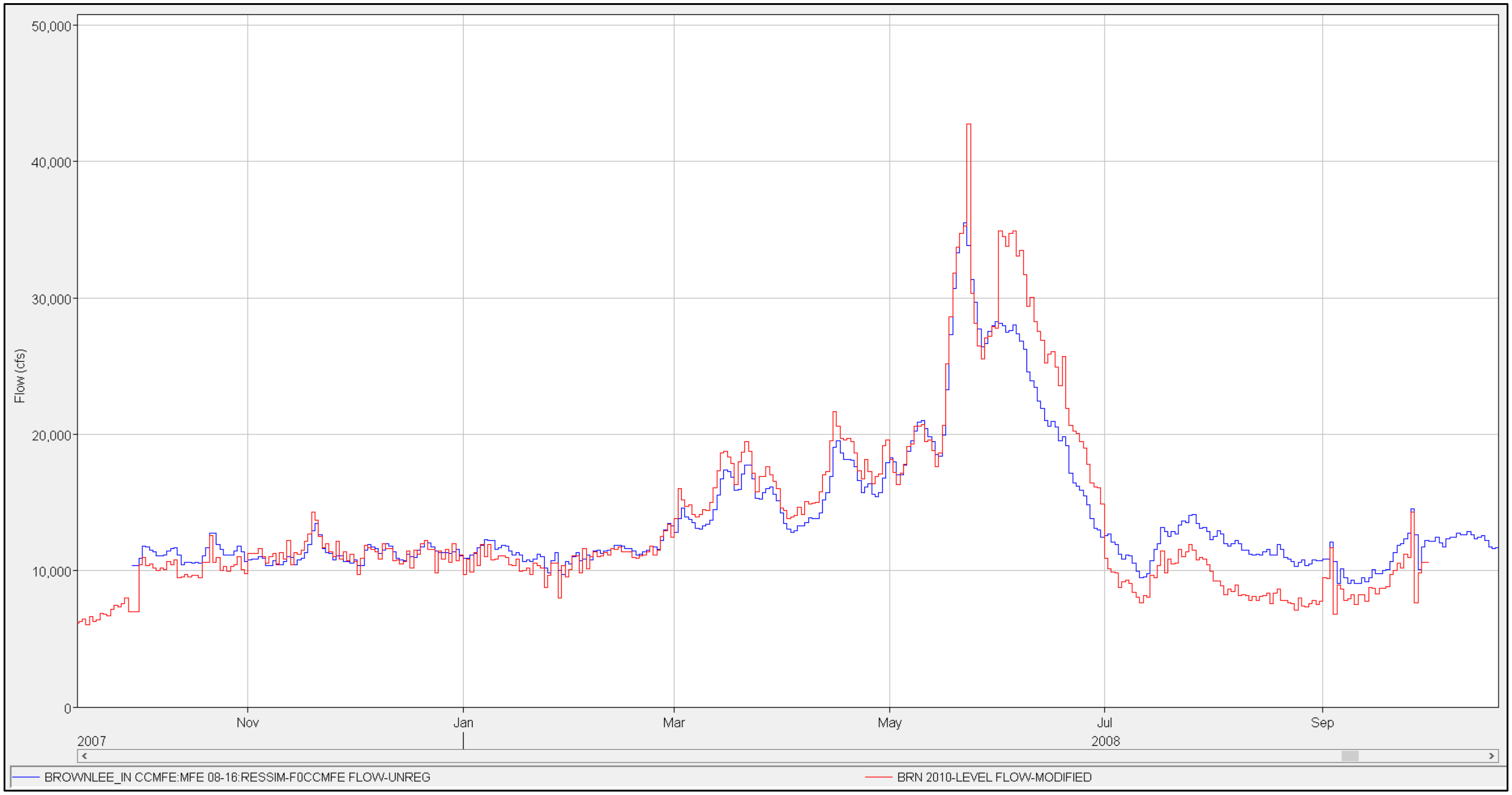
615 **Albeni Falls; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**

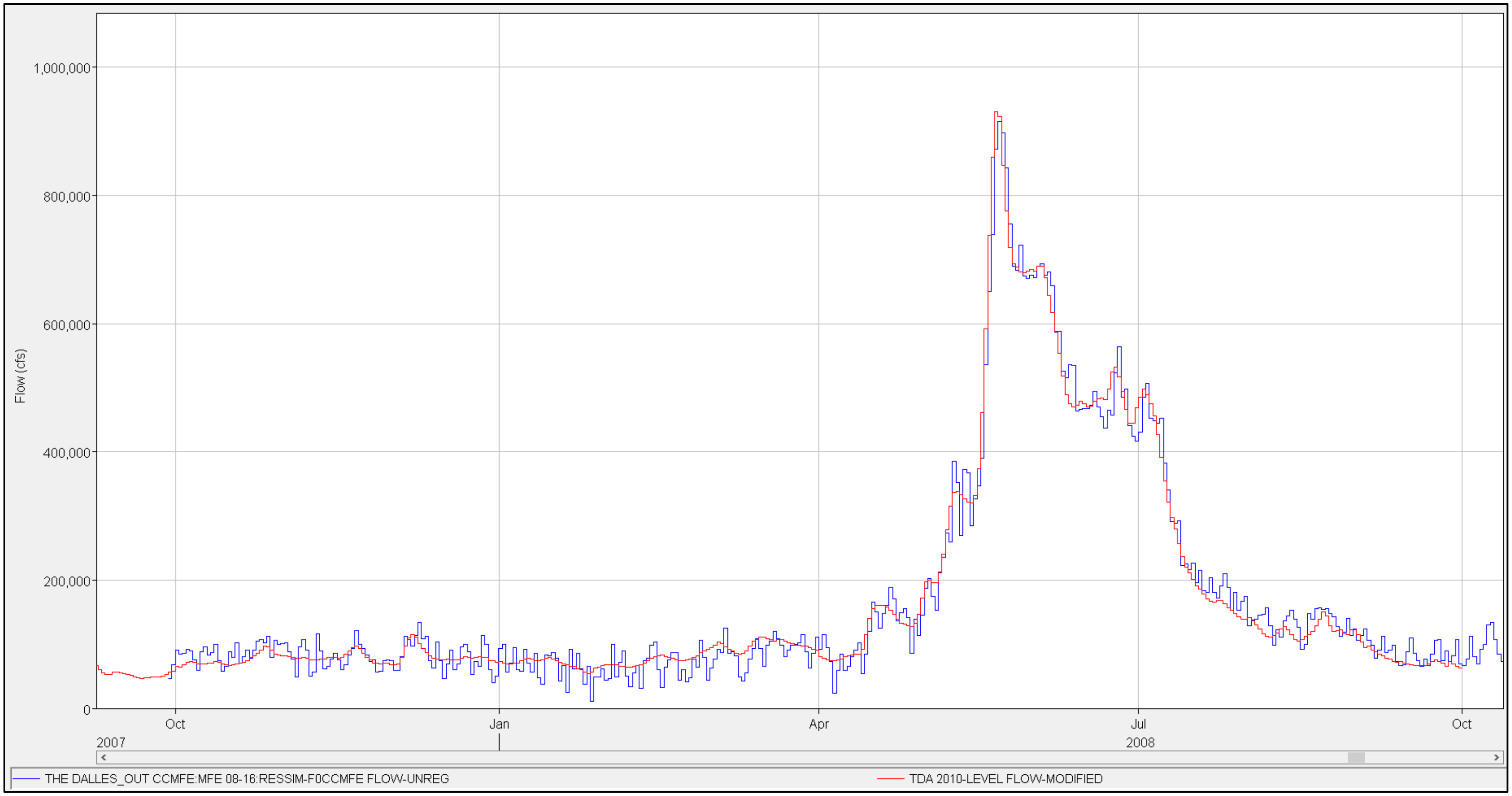
616
617 **Grand Coulee; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**



Brownlee; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows

620

621 **Lower Granite; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**

622 

623 **The Dalles; Red = 2010 Level Modified Streamflow, Blue = Extended Observed Flows**

ANNEX B

FLOW DATA RECORDS REQUIRED AND EXTRACTED GAGE DATASETS

Table B-1. Flow Data Records Required for the Columbia River System HEC-ResSim Model

Flow Data Records for the CRS HEC ResSim Model		
Mica Inflow	Snake+Grande Ronde Inflow	Upper Pend Oreille Local flow
Duncan Inflow	Bonners Ferry Local flow	SF Clearwater_HW Local flow
Corra Linn Local inflow	table Local flow	Seven Mile Local inflow
Upper Falls Local inflow	Spalding Local flow	Williamette River Inflow
Thompson Falls Local inflow	Birchbank Local flow	Clackamas River Inflow
The Dalles Local inflow	Columbia+Yakima Inflow	Lewis River Inflow
Round Butte Inflow	Snake+Salmon Inflow	Cowlitz River Inflow
Rocky Reach Local inflow	Pend Oreille+Sullivan Local flow	Columbia+Wenatchee Inflow
Rock Island Local inflow	Pend Oreille+Priest Local flow	Flathead+Stillwater Inflow
Revelstoke Local inflow	Pend Oreille+LakePendOreille_IF Local flow	Kootenai+Goat Inflow
Priest Lake Inflow	Pend Oreille+Calispel Ck Local flow	Pend Oreille+Calispel Ck Inflow
Post Falls Inflow	Kuskunook Local flow	Clark Fork+Lightning Ck Inflow
Pelton Local inflow	Kootenai+Yaak Local flow	Salem Gage (BiOp only)
Noxon Rapids Local inflow	Kootenai+Moyie Local flow	Willamette+Clackamas Local flow
Nine Mile Local inflow	Kootenai+Goat Local flow	Kootenai+Fisher Inflow
McNary Local inflow	Flathead+Stillwater Local flow	Kootenai+Moyie Inflow
Lower Monumental Local inflow	Flathead+SF Local flow	Kootenai+Yaak Inflow
Lower Granite Local inflow	Flathead+Mission+Jocko Local flow	Columbia+Okanogan Inflow
Little Goose Local inflow	Columbia+Umatilla Local flow	Columbia+Methow Inflow
Little Falls Local inflow	Columbia+Okanogan Local flow	Clark Fork+Flathead Inflow
Libby Inflow	Columbia+Klickitat Local flow	Clark Fork+Thompson Inflow
Seli'š Ksanka Qlispe' (Formerly Kerr) Local flow	Columbia+Kettle Local flow	Flathead+Mission+Jocko Inflow
John Day Local inflow	Columbia+Hood+Salmon Local flow	Pend Oreille+Sullivan Inflow
Ice Harbor Local inflow	Columbia+Deschutes Local flow	Columbia+Germany Ck Local flow
Hungry Horse Inflow	Columbia+Alder CK Local flow	Columbia+Beaver Ck Local flow
Hells Canyon Local inflow	Columbia nr Willow Ck Local flow	Columbia+Elochoman Local flow
Grand Coulee Local inflow	Clearwater+Potlach Local flow	Columbia+Plympton Ck Local flow
Dworshak Inflow	Clark Fork+Thompson Local flow	Columbia+Clatskanie Local flow
Chelan Inflow	Clark Fork+Lightning Ck Local flow	Willamette+Columbia Slough Local flow
Cabinet Gorge Local inflow	Clark Fork+Flathead Local flow	Columbia_at Multnomah Channel Local flow
Brownlee Inflow	Columbia+Chelan Local flow	Columbia+Salmon Ck+Burnt Bridge Ck Local flow
Brilliant Local inflow	Kootenai+Fisher Local flow	Cowlitz+Coweeman Local flow
Boundary Local inflow	Columbia+Methow Local flow	Willamette_at Portland Local flow

Flow Data Records for the CRS HEC ResSim Model		
Bonneville Local inflow	Columbia+Wenatchee Local flow	Columbia+Washougal Local flow
Arrow Lakes Local inflow	Columbia+Spokane Local flow	Columbia+Sandy Local flow
Albeni Falls Local inflow	Flathead @ Flathead Lake Local flow	Lewis+EF Lewis Local flow
Chief Joseph Local inflow	Pend Oreille @ Box Canyon Local flow	Kalama River Inflow
Long Lake Local inflow	Snake_RM178.27 Local flow	Washougal River Inflow
Monroe Street Local inflow	Wanapum Local inflow	MCR Hourly Stage
Wells Local inflow	Priest Rapids Local inflow	Cowlitz_at Castle Rock Local flow

628 Table B-2. Extracted Gage Datasets, Water Years 2008 to 2016

Location Name	Location Identifier	USGS Gage Code	Data Type	Location Name	Location Identifier	USGS Gage Code	Data Type
Albeni Falls	ALF	12395500	FLOW	Lower Monumental	LMN	–	FLOW-OUT
Albeni Falls	ALF	–	FLOW-OUT	Lower Granite	LWG	–	FLOW-IN
Anatone	ANAW	13334300	FLOW	Lower Granite	LWG	–	FLOW-OUT
Arrow	ARDB	–	FLOW-OUT	Mayfield	MAY	14238000	FLOW
Arrow	ARDB	–	FLOW	Mica	MCDB	–	FLOW-OUT
Astoria	ASTO	–	Hourly Stage	Mica	MCDB	–	FLOW
Boundary	BDY	–	FLOW-OUT	McNary	MCN	–	FLOW-IN
Boundary	BDY_IN	–	FLOW	McNary	MCN	–	FLOW-OUT
Birchbank	BIRB	–	FLOW	Merwin	MERW	14220500	FLOW
Bonneville	BON	–	FLOW	–	MODO	14103000	FLOW
Box Canyon	BOX	12396500	FLOW	Noxon	NOX	–	FLOW-OUT
Box Canyon	BOX	–	FLOW-OUT	Noxon	NOX	–	FLOW
–	BRDB	–	FLOW-OUT	–	OKMW	12447200	FLOW
Brownlee	BRN_IN	–	FLOW	Orofino	ORFI	13340000	FLOW
Cabine Gorge	CAB	–	FLOW-IN	–	PATW	12449950	FLOW
Cabinet Gorge	CAB	–	FLOW-OUT	–	PITW	14113000	FLOW
–	CASW	14243000	FLOW	–	PLNM	12389000	FLOW
–	CFMM	12363000	FLOW	Priest Rapids	PRD	12472800	FLOW
Chelan	CHL	–	FLOW-IN	–	PRII	13341570	FLOW
Chief Joseph	CHJ	–	FLOW-IN	Priest Lake	PSL	12395000	FLOW
Chief Joseph	CHJ	–	FLOW-OUT	Queens Bay	QBYB	–	FLOW-OUT
Chelan	CHL	–	FLOW-IN	Queens Bay	QBYB	–	FLOW-IN

Location Name	Location Identifier	USGS Gage Code	Data Type	Location Name	Location Identifier	USGS Gage Code	Data Type
Chelan	CHL	–	FLOW-OUT	Revelstoke	REVB	–	FLOW-OUT
Coeur D'Alene	COEI	–	FLOW	Revelstoke	REVB	–	FLOW
Duncan	DCDB	–	FLOW-OUT	Rock Island	RIS	–	FLOW-OUT
Duncan	DCDB	–	FLOW	Rock Island	RIS	–	FLOW-IN
Dworshak	DWR	–	FLOW-IN	Rocky Reach	RRH	–	FLOW-IN
Dworshak	DWR	–	FLOW-OUT	Rocky Reach	RRH	–	FLOW-OUT
Estacada	ESTO	14210000	FLOW	Spalding	SPDI	13342500	FLOW
–	FCFM	12355500	FLOW	–	SRGM	12354500	FLOW
–	FISM	12302055	FLOW	The Dalles	TDA	14105700	FLOW
Grand Coulee	GCL	–	FLOW-IN	The Dalles	TDA	–	FLOW-OUT
Grand Coulee	GCL	–	FLOW-OUT	Thomson	TOM	–	FLOW-OUT
Hells Canyon	HCD	–	FLOW-IN	Wanapum	WAN	–	FLOW-IN
Hells Canyon	HCD	–	FLOW-OUT	Wanapum	WAN	–	FLOW-OUT
Hungry Horse	HGH	–	FLOW-IN	Waneta	WANB	–	FLOW-OUT
Hungry Horse	HGH	–	FLOW-OUT	Wells	WEL	–	FLOW-IN
–	HODO	14120000	FLOW	Wells	WEL	–	FLOW-OUT
Ice Harbor	IHR	–	FLOW-IN	–	WGCM	12358500	FLOW
Ice Harbor	IHR	–	FLOW-OUT	–	–	12025000	FLOW
John Day	JDA	–	FLOW-IN	–	–	12310100	FLOW
John Day	JDA	–	FLOW-OUT	–	–	12321500	FLOW
Seli'Š Ksanka Qlispe'	KERM	–	FLOW-IN	–	–	12392155	FLOW
Seli'Š Ksanka Qlispe'	KERM	–	FLOW-OUT	–	–	13290450	FLOW
–	KIOW	12510500	FLOW	–	–	13317000	FLOW
–	LAUW	12404500	FLOW	–	–	13317660	FLOW
–	LEWIS	14222500	FLOW	–	–	14142500	FLOW
Little Goose	LGS	–	FLOW-IN	–	–	14190500	FLOW
Little Goose	LGS	–	FLOW-OUT	–	–	14202000	FLOW
Libby	LIB	–	FLOW-IN	–	–	14211010	FLOW
Libby	LIBBY	12301933	FLOW	–	–	14211500	FLOW
Lower Monumental	LMN	–	FLOW-IN	–	–	–	–

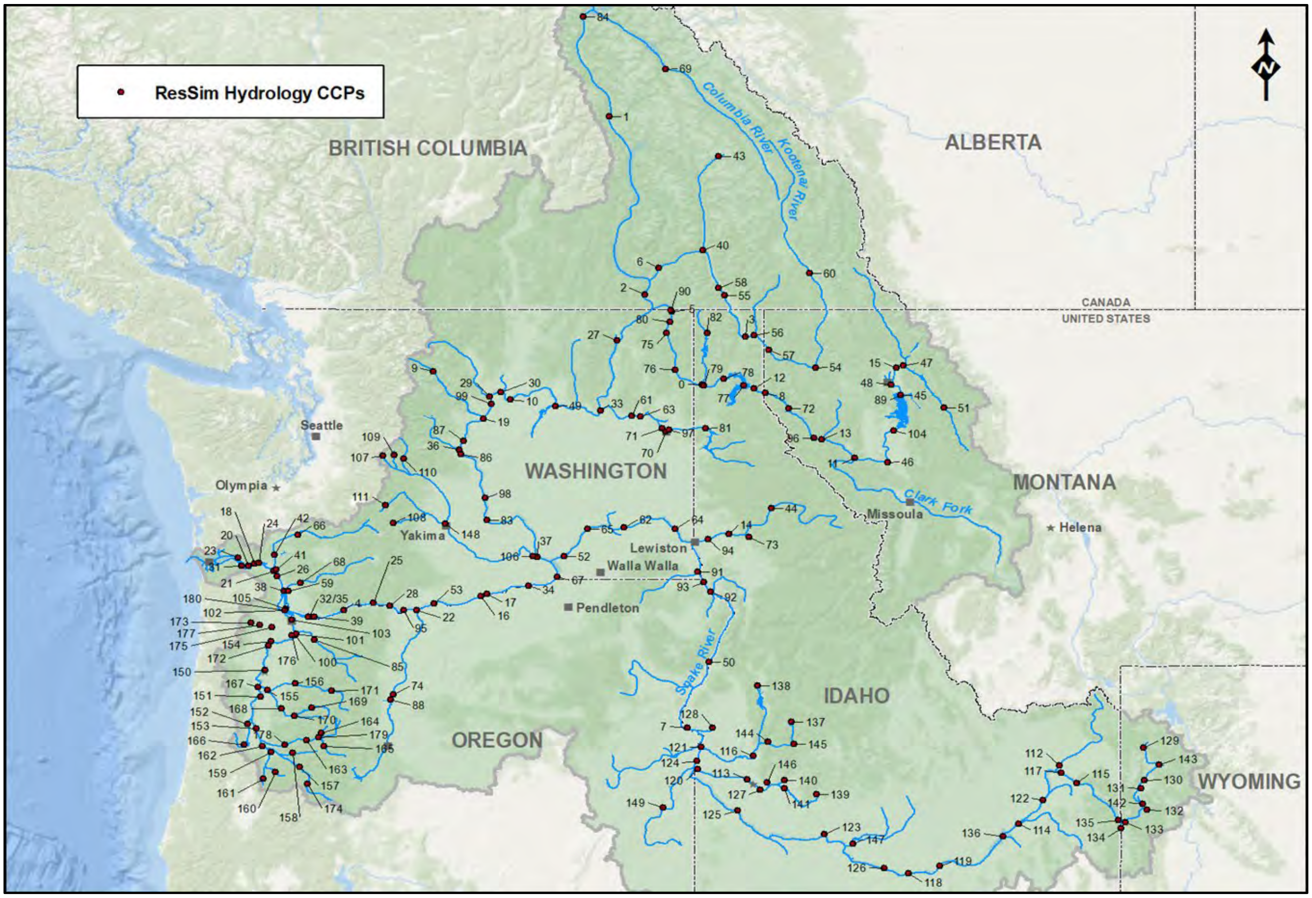


Figure B-1. Locations in the Columbia River System ResSim Model that require water inflow timeseries.

DRAFT COLUMBIA RIVER SYSTEM OPERATIONS ENVIRONMENTAL IMPACT STATEMENT

Appendix B, Part 6

Stage-Flow Transformation Documentation

Table of Contents

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ACRONYMS AND ABBREVIATIONS

AEP	annual exceedance probability
CCP	common computation point
CRSO	Columbia River System Operations
EIS	environmental impact statement
EM	engineering manual
FRA	flood risk assessment
FY	fiscal year
HEC-DSS	Hydrologic Engineering Center – Data Storage System
HEC-FIA	Hydrologic Engineering Center – Flood Impacts Analysis
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HEC-WAT	Hydrologic Engineering Center – Watershed Analysis Tool
Htabs	hydraulic tables parameters
k-NN	K-Nearest Neighbor
LOOCV	leave-one-out cross-validation
ResSim	Hydrologic Engineering Center – Reservoir Simulation
RM	river mile
SKQ	Seli'š Ksanka Qlispe'

CHAPTER 1 - INTRODUCTION

This technical appendix documents the stage-flow transformation used in the development of hydraulic data for the Columbia River System Operations (CRSO) Environmental Impact Statement (EIS), including the history of the hydraulic models, pre-processing and incorporation of hydrology inputs, theory and methodology of the stage-flow transformation tools, and post-processing of results for reporting and alternative evaluation.

Annual peak and daily average stage predictions are required for the CRSO analysis. These analyses need to be conducted throughout the Columbia River and its major tributaries, spanning a total of approximately 1,600 river miles divided into 24 river reaches. A Monte Carlo analysis involving 5,000 simulations will be used to characterize the impacts associated with various river management alternatives, requiring a computationally efficient and robust method to produce hydraulic depth predictions. The Hydrologic Engineering Center – River Analysis System (HEC-RAS) model, although very effective, would not be an ideal method to compute hydraulic stage for this stochastic analysis because of computation time and stability considerations. Consequently, stage-flow transformation tools were developed, based on a subset of HEC-RAS model results, and applied to the Monte Carlo analysis of the Columbia River Basin for CRSO purposes. The tools were developed to estimate hydraulic stage across the same domain as the HEC-RAS models, but to run in significantly less compute time and avoid the risk of unstable model results. The development of this tool required fitting a relationship between the HEC-RAS model boundary conditions and HEC-RAS results, akin to a rating curve, for every HEC-RAS cross section, or using an interpolation routine in portions with little variation between cross sections. This set of relationships can be applied to other alternatives evaluated in the Monte Carlo analysis that do not alter the physical conditions of the river. The following sections summarize the development and application of the relationships and the tools used to apply them.

CHAPTER 2 - HYDRAULIC MODEL HISTORY

In August 2012, Columbia River Basin reach-scale hydraulic models were constructed for multiple purposes to support a future assessment of the current level of flood risk and the flood risk impacts of the future changes in the Columbia River Basin.

The assessment required a method to predict how changes in operations will affect multiple purposes of the system. A series of hydraulic models was developed to understand the influence the physical characteristics of Columbia River Basin rivers have on local and system flood risk management. The hydraulic modeling effort was well documented. The 2012 models are referred to in this document hereafter as the Iteration 1 models.

Iteration 1 hydraulic modeling used the river routing software HEC-RAS and was completed for 1,860 river miles, initially divided into 30 individual reaches. Shortly after hydraulic development began, three reaches were eliminated, leaving 27 total reaches and 1,613 river miles. Each reach was built as a stand-alone model, with most extending from the tailwater of an upstream dam to the forebay of a downstream dam, though there are some downstream exceptions such as a confluence or the U.S.-Canada border. The reaches were numbered in ascending order from downstream to upstream. The HEC-RAS model reaches can be seen in Figure 2-1, numbered 1 to 30 with Reach 10 absorbed by Reach 9 and Reaches 11, 12, and 13 (located in the Hells Canyon Recreation Area on the Snake River) dropped for lack of flooding consequences.

River reaches within the HEC-RAS model study area were reviewed to determine whether individual reaches should be modeled using steady flow or unsteady flow components. The steady flow component uses the standard step method for the solution of steady, gradually varied flow. The unsteady flow component uses a numerical solution of the equations governing gradually varied unsteady flow in open channels, therefore taking into account the effects of in-channel and off-line storage in flow attenuation.

While the majority of the reaches in the system could be most effectively modeled using unsteady flow components, the benefits of using this approach were expected to be marginal considering the computational load added in building the flood risk assessment. It was therefore determined, for the purposes of Iteration 1, to only rely on unsteady flow modeling for reaches that either include levees for which failure modeling was required or for reaches where the variability of the water surface profile could not be sufficiently captured using a steady flow model. Seven of the 27 reaches (Reaches 1, 5, 9, 17, 24, 28, and 29, shown in Figure 2-1) were modeled using unsteady flow components. Table 2-1 outlines the boundaries of each reach.

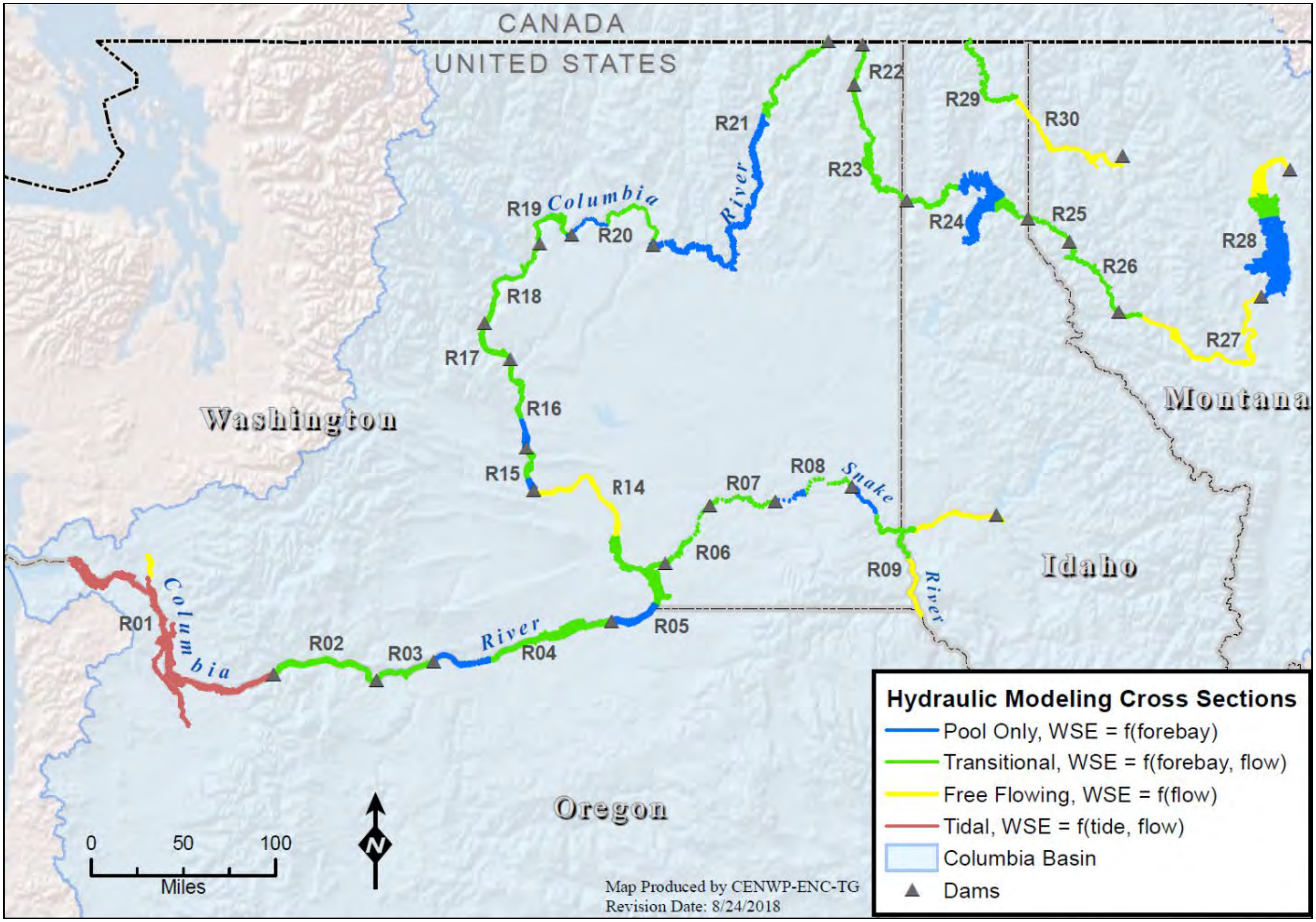


Figure 2-1. Columbia River Basin HEC-RAS Model Reaches as Used in 2012

Table 2-1. HEC-RAS Reach Boundaries for Iteration 1

Reach No.	Reach Name	River	CRT River Miles	Region	Model Type	District
1	Bonneville Dam to Pacific Ocean	Columbia	145.51 – 0.0	Lower Columbia	UNSTEADY	NWP
2	The Dalles Dam to Bonneville Dam	Columbia	191.95 – 145.71	Mainstem Columbia	STEADY	NWP
3	John Day Dam to The Dalles Dam	Columbia	216.5 – 191.98	Mainstem Columbia	STEADY	NWP
4	McNary Dam to John Day Dam	Columbia	291.14 – 216.58	Mainstem Columbia	STEADY	NWP
5	McNary Pool	Columbia	345.37 – 290.13	Mainstem Columbia	UNSTEADY	NWW
6	Lower Monumental Dam to Ice Harbor Dam	Snake	40.48 – 7.20	Lower Snake	STEADY	NWW
7	Little Goose Dam to Lower Monumental Dam	Snake	69.48 – 39.79	Lower Snake	STEADY	NWW
8	Lower Granite Dam to Little Goose Dam	Snake	106.62 – 68.85	Lower Snake	STEADY	NWW
9	Cochran Islands to Lower Granite Dam (Snake R.) and lower 7.8 miles of Clearwater River.	Snake/Clearwater	178.27 – 106.25 (Snake), 7.8 – 0 (Clearwater)	Lower Snake	UNSTEADY	NWW
10	Orofino to the Lower Granite Pool	Clearwater	45.51 – 8.22	Lower Snake	STEADY	NWW
14	Priest Rapids Dam to the McNary Pool	Columbia	396.33 – 342.39	Mainstem Columbia	STEADY	NWW
15	Wanapum Dam to Priest Rapids Dam	Columbia	415.13 – 397.14	Middle Columbia	STEADY	NWS
16	Rock Island Dam to Wanapum Dam	Columbia	453.54 – 415.27	Middle Columbia	STEADY	NWS
17	Rocky Reach Dam to Rock Island Dam	Columbia	473.84 – 453.59	Middle Columbia	UNSTEADY	NWS
18	Wells Dam to Rocky Reach Dam	Columbia	516.16 – 473.90	Middle Columbia	STEADY	NWS
19	Chief Joseph Dam to Wells Dam	Columbia	545.55-516.29	Middle Columbia	STEADY	NWS
20	Grand Coulee Dam to Chief Joseph Dam	Columbia	596.53 – 545.67	Middle Columbia	STEADY	NWS
21	International Border to Grand Coulee Dam	Columbia	748.22 – 596.63	Middle Columbia	STEADY	NWS
22	Box Canyon Dam to Boundary Dam	Pend Oreille	33.24 – 16.38	Kootenai-Pend Oreille-Spokane	STEADY	NWS
23	Albeni Falls Dam to Box Canyon Dam	Pend Oreille	89.03 – 33.26	Kootenai-Pend Oreille-Spokane	STEADY	NWS
24	Cabinet Gorge Dam to Albeni Falls Dam	Pend Oreille/ Clark Fork	Clark Fork 14.96 - Pend Oreille 89.22	Kootenai-Pend Oreille-Spokane	UNSTEADY	NWS
25	Noxon Rapids Dam to Cabinet Gorge Dam	Clark Fork	34.43 – 15.04	Kootenai-Pend Oreille-Spokane	STEADY	NWS
26	Thompson Falls Dam to Noxon Rapids Dam	Clark Fork	71.64 – 34.52	Kootenai-Pend Oreille-Spokane	STEADY	NWS
27	Kerr Dam to Thompson Falls Dam	Clark Fork / Flathead	Flathead 73.76 - Clark Fork 71.68	Kootenai-Pend Oreille-Spokane	STEADY	NWS
28	Hungry Horse Dam to Kerr Dam	Flathead / South Fork Flathead	South Fork Flathead 5.20 – Flathead 73.80	Kootenai-Pend Oreille-Spokane	UNSTEADY	NWS
29	Bonners Ferry to International Boundary	Kootenai	157.43 – 77.73	Kootenai-Pend Oreille-Spokane	UNSTEADY	NWS
30	Libby Dam to Bonners Ferry	Kootenai	219.23 – 157.87	Kootenai-Pend Oreille-Spokane	STEADY	NWS

Note: Kerr Dam in Reaches 27 and 28 is now Seli'š Ksanka Qlispe' (SKQ) Dam. NWP = Corps Portland District; NWS = Corps Seattle District; NWW = Corps Walla Walla District.

The Iteration 1 hydraulic models were developed to represent the river and the effect of existing hydropower and flood storage structures during high flows because high flow events were the focus of the flood risk assessment. These models were required to have the capability to determine relationships between water surface elevation (i.e., stage) and discharge, and to identify the extents, depths, and durations of flood inundation. Stage-discharge relationships are integral to the analysis of flood risk within the Columbia River Basin because they provide a means for assessing the failure risk of system components (e.g., levees, floodwalls, and gates) by comparing the water surface elevation to a top-of-protection elevation or to a levee fragility curve (i.e., the relationship between probability of failure and water surface elevation). The hydraulic models were also required to be able to calculate breach/overtopping hydrographs in the event that a system component fails, and the flooding depths and extents can be used as an input to estimate consequences.

The CRSO HEC-RAS reaches cover four major river systems: the Columbia River System, the Snake/Clearwater River System, the Clark Fork/Pend Oreille River System, and the Kootenai(y) River System. The hydraulic modeling team drew the lateral extent of the reaches, depicted by the extent of cross sections and storage areas, to encompass the maximum potential inundation boundary that would be expected from a wide range of operational alternatives. The location and extent of this area is based on mapping of floodplain areas and levee systems in the U.S. portion of the Columbia River Basin that are relevant to CRSO, and is approximately 3,000 square miles. The following paragraph describes the modeling process used in the Iteration 1 models to assess consequences within the basin.

Input hydrology datasets came from reservoir modeling within the HEC – Reservoir Simulation software (ResSim). Hydrology and forecasting are sampled stochastically as input to ResSim, which is run 5,000 or more times. Peak flow output from all the ResSim model runs is written at 87 common computation points (CCPs) within the basin that are associated with damage centers. HEC-RAS models simulate a large number of deterministic flow scenarios—106 separate year-long events—that range from extreme low to extreme high peaks. The hydraulic results—stage, flow, and inundation grids—are recorded at the same 87 CCPs. This approach for Iteration 1 was quick to compute but produced poor predictions in reaches where hydraulic conditions were a function of more variables than in-stream flow.

Two critical modifications discussed in the next two paragraphs were made to the HEC-RAS models shortly after completion of the Iteration 1 flood risk assessment: (1) more reaches were combined, and (2) all remaining steady-state reaches were converted to unsteady state reaches.

Reach 10 was absorbed by Reach 9. Reach 9 now begins on the Snake River at River Mile (RM) 178, ends at the forebay of Lower Granite Dam, and includes the Clearwater downstream from Orofino and the North Clearwater downstream of the Dworshak Dam tailwater. Reach 5 and Reach 14 were combined and the current Reach 5_14 (sometimes referred to simply as Reach 5) includes the Columbia River from the Priest Rapids Dam tailwater to the McNary Dam forebay and the Snake River from the Ice Harbor Dam tailwater to its confluence with the

Columbia. Lastly, Reaches 29 and 30 were combined to form Reach 29_30 (sometimes referred to simply as Reach 29), which is now a continuous model from the Libby Dam tailwater to Kootenay Lake in Canada.

By the end of fiscal year (FY) 2015, all remaining HEC-RAS models—24 total after the merging discussed above—were either already set up as unsteady flow models or converted to such. Unsteady flow models improve deterministic flood risk assessments, and they also provide information to assess the feasibility of the full unsteady stochastic analysis. The HEC-RAS model scheme adopted in FY 2015 has remained current and is what has been used in recent CRSO analysis. The current HEC-RAS model (all unsteady) reach names and boundaries are shown in Table 2-2.

Table 2-2 HEC- RAS Model Reach Names and Boundaries

Reach #	Reach Name	River(s)	Upstream Boundary (RM)	Dowsntream Boundary (RM)
1	Bonneville to Mouth	Columbia	145.86	0.15
2	The Dalles to Bonneville	Columbia	191.95	145.71
3	John Day to The Dalles	Columbia	216.529	191.98
4	McNary to John Day	Columbia	291.142	216.58
5-14	Priest Rapids to McNary	Columbia, Snake	395.6788 Columbia, 8.09 Snake	291.029
6	Lower Monumental to Ice Harbor	Snake	40.482	9.34
7	Little Goose to Lower Monumental	Snake	69.4768	40.9595
8	Lower Granite to Little Goose	Snake	106.6178	69.7715
9	Clearwater to Lower Granite	Snake, Clearwater	178.2715 Snake 45.502 Clearwater	106.87
15	Wanapum to Priest Rapids	Columbia	415.1	397.11
16	Rock Island to Wanapum	Columbia	453.47	415.19
17	Rocky Reach to Rock Island	Columbia	476.712	456.42
18	Wells to Rocky Reach	Columbia	515.4887	474.8522
19	Chief Jo to Wells	Columbia	545.5435	516.2935
20	Grand Coulee to Chief Jo	Columbia	597.3379	545.6679
21	Border to Grand Coulee	Columbia	748.216	596.635
22	Box Canyon to Boundary Dam	Pend Oreille	33.237	16.375
23	Albeni Falls to Box Canyon	Pend Oreille	89.02496	33.261
24	Cabinet Gorge to Albeni Falls	Pend Oreille, Clark Fork	14.96 Clark Fork	89.22
25	Noxon Rapids to Cabinet Gorge	Clark Fork	34.43	15.04
26	Thompson Falls to Noxon Rapids	Clark Fork	71.85271	34.5227
27	Kerr to Thompson Falls	Clark Fork, Flathead	73.762 Flathead, 110.134	71.676 Clark Fork
28	Hungry Horse to Kerr	Flathead	158.579	73.796
29-30	Libby to Canada	Kootenai	219.19	104.42 (Border)

Note: Kerr Dam in Reaches 27 and 28 is now SKQ Dam.

CHAPTER 3 - MODEL OPTIMIZATION AND STABILIZATION

The HEC – Watershed Analysis Tool (HEC-WAT) combines ResSim, HEC-RAS, and consequence models—as well as other tools—to build a sequence of calculations that, at a minimum and to fill a basic CRSO need, calculate basinwide hydraulic data for alternative comparisons. The HEC-RAS models were updated to unsteady flow models in FY 2015, but still needed advancements in stability, flexibility, and speed in order to fit within the WAT structure to build improved hydraulic datasets during a Monte Carlo compute consisting of many (5,000 or more) water-year-length simulations.

During the conversion of models from steady to unsteady state in FY 2015, the focus was on ensuring high quality calibration for each of the reaches. While standard modeling practices were followed, the models were not optimized for speed, stability and flexibility to boundary conditions. In order to develop comprehensive hydraulic data based on improved unsteady state models, each of the 24 HEC-RAS models must be run 100-plus times for two input hydrology scenarios (a testing set and a validation set). Further, the range of boundary conditions the models will run must equal or exceed the range expected in any future regulation scenario (so as to not cause model failure when the stochastically generated ResSim run results in extreme conditions). To achieve this large number of runs over such varying conditions, the models must be optimized for speed and stability while maintaining calibration. HEC-RAS Version 5.0.3 was used for this model optimization exercise, which included but was not limited to the following practices common to all reaches:

Step 1. Run simulation in subcritical flow, which sometimes entailed:

a) Adding cross sections
b) Softening the grade break if it is limited to one or two cross sections
c) Increasing Manning's n value at the critical sections
d) Adding an inline structure
e) Increasing minimum base flow if extreme low flow profiles are not required (non-navigation reaches)

Step 2. Optimize hydraulic tables parameters (Htabs) at bridges and cross sections by doing the following:

a) Start with 200 increments per cross section
b) Calculate incremental value by running extreme high event, adding 5 feet of buffer, and dividing channel-invert-to-water-surface elevation distance by 200 increments
Note: The hydraulic tables are calculated automatically by HEC-RAS after the first geometry pre-processor has been run (and they are used in place of the geometry pre-processor for simulations from that point on). However, manual adjustment as outlined above can speed simulation time by eliminating unnecessary lookup routines in the Htabs.

Step 3. Decrease computational run time:

  a) Eliminate warmup period
  b) Reduce iterations
  c) Eliminate initial conditions requirements

Step 4. Extend cross sections to ensure extreme event inundations extents are captured

Step 5. Use ineffective flow areas around bridges and other hydraulic features, as outlined in the HEC-RAS Hydraulic Reference Manual (Brunner 2016)

Step 6. Remove levee tool feature to eliminate straight-line disconnected gaps in inundation maps: Lateral structures, as opposed to levee tool, are used to model levees

Step 7. Update the existing Reach 1 HEC-RAS model to use the Tongue Point downstream boundary

The Hydraulics Team outlined an optimization quality control process, which included iterative reviews of calibration and mapping outputs as model features were adjusted. Most models ran a full year simulation in less than 1 minute, with more complex reaches like Reach 1 and Reach 29 taking 10 to 45 minutes.

The last step in model optimization was stress testing. The model stability and speed were generally set up and checked using one test year. ResSim generated HEC – Data Storage System (HEC-DSS) outputs based on a wide range of operational scenarios. The HEC-RAS models had to perform smoothly and accurately under all expected conditions within those scenarios. Model optimization and stress testing was a feasibility test for full unsteady stochastic analysis. If models could not be made robust and general, able to perform under all expected conditions, full stochastic analysis would not be feasible. The HEC-DSS files contained flow data for 106 separate year-long events, including 80 years of data similar to historical hydrographs (though this should not be confused with the period of record because project outflows are still based on non-historical operational scenarios) and 26 synthetic years representing varying degrees of extreme spring and winter flood flows. The operational scenario used to stress test the models—referred to hereafter as the training dataset—was the one most likely to produce the extreme high and low flows the HEC-RAS models would encounter in any other simulation. The training dataset was investigated and a sample dataset was pulled for stress testing. It was represented by 15 years of data: 5 each of low, typical, and high flood peaks. Those years, and corresponding peak flows, are shown in Table 3-1. The highlighted years are the events used for each strategic CCP labeled at the top.

Table 3-1. Training Dataset Years Used for Stress Testing of HEC-RAS Models

CCP	**Flathead + Stillwater**		**Clark Fork + Thompson**		**Pend Oreille + Priest**		**Kootenai + Yaak**		**Snake + Clearwater**		**Columbia @ Border**		**Columbia a+ Yakima**		**Columbia + Willamette (below)**		**Columbia + Willamette (above)**	
Reaches	**27,28**		**25,26**		**22,23,24**		**29-30**		**6,7,8,9**		**19,20,21**		**5-14,15,16,17,18**		**1**		**2,3,4**	
Year	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak
Historical High 1	1964	159047	1964	130641	1948	162456	1943	51490	1974	275849	1972	545909	1948	669975	1996	992356	3015	1,036,840
Historical High 2	1975	73696	1974	127125	1974	157941	1966	51288	1948	266199	1974	529562	1972	533087	1965	977839	3014	983,778
Historical High 3	1954	70931	1948	119258	1997	155351	1960	50682	1997	246554	1948	524804	1974	525921	1948	956770	3013	974,254
Synthetic High 1	3012	89992	3024	152850	3012	198711	3012	90867	3024	390331	3021	650805	3015	755077	3103	1284855	3021	972,428
Synthetic High 2	3024	84847	3012	152150	3015	181556	3024	57028	3023	349103	3020	633447	3014	719487	3108	1217983	3024	957,802
Synthetic High 3	3023	81078	3021	150476	3024	180325	3026	50673	3012	348567	3024	610859	3013	715522	3102	1173878	3020	937,097
Synthetic High 4	3028	80824	3023	148757	3014	179956	3027	49693	3022	336278	3019	606893	3021	708292	3107	1081746	3012	931,235
Synthetic High 5	3022	78886	3022	144657	3023	175525	3028	49491	3015	322378	3015	592754	3020	678817	3015	1078917	1948	912,103
	Year	Min	Year	Min	Year	Min	Year	Min	Year	Min	Year	Min	Year	Min	Year	Min	Year	Min
Historical Low 1	1929	2502	1931	4064	1940	4298	1998	2053	1934	11354	1936	16889	1936	34535	1992	64578	3101	14,677
Historical Low 2	1989	2509	1940	4597	1988	4370	1993	2495	1994	11370	1937	19442	1937	35518	1973	66812	1928	50,000
Historical Low 3	1988	2912	1992	4682	1931	4395	1979	2709	1937	11451	1931	21052	1929	35909	1987	67886	2005	50,000
Historical Low 4	1995	2913	1934	4710	1977	4790	1985	2872	1987	11626	1929	21325	1931	35913	1994	69039	3011	50,000
Historical Low 5	1937	2991	1988	4826	1992	4990	1989	3149	1938	11655	1930	21746	1939	36778	1985	75445	3014	50,000
Historical Low 6	1940	3015	1941	4855	1994	5168	1977	3261	1939	11821	1988	22087	1932	36820	1934	75871	3100	50,000
Historical Low 7	1980	3091	1977	4859	1952	5241	1980	3611	1935	11847	1977	22167	1953	37511	1935	75871	1992	53,988
Historical Low 8	1992	3096	1929	4874	1987	5580	1988	3676	1932	11967	1945	23674	1974	37561	1995	76650	1994	54,249
Historical Low 9	1930	3119	1987	5212	1941	5600	1987	3734	1931	11967	1939	23926	1973	37561	1993	76714	1957	54,725
Historical Low 10	1977	3129	1932	5305	1934	5808	1939	3958	1988	12037	1944	24291	1940	37659	1988	76838	2001	54,840
	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak	Year	Peak
Typical 1	1977	43615	1977	227733	1977	251596	1977	164423	1977	21837	1977	26012	1977	38372	1977	53334	1977	209,035
Typical 2	1997	114076	1997	479506	1997	796102	1997	486332	1997	64816	1997	44823	1997	155351	1997	246554	1997	658,522
Typical 3	1996	91161	1996	376326	1996	992356	1996	352712	1996	54552	1996	50378	1996	102105	1996	207552	1996	528,120
Typical 4	1972	116275	1972	545909	1972	740059	1972	533087	1972	60940	1972	41801	1972	141303	1972	211652	1972	734,002
Typical 5	1986	79142	1986	424974	1986	652583	1986	348001	1986	62115	1986	38841	1986	89933	1986	215878	1986	573,224

Note: Min = minimum.

CHAPTER 4 - INPUT HYDROLOGY

Input hydrology was developed for previous Columbia River Basin studies, based on the 80-year period of record in 2010 Level Modified Streamflows dataset and disaggregated to locations used by the HEC-ResSim and HEC-RAS models. This dataset was supplemented with 26 synthetic events, 17 of which were scaled during the spring freshets to the 1, 0.5, 0.2, and 0.1 percent annual exceedance probability (AEP) events for peak 60-day volume at The Dalles, Oregon, a regulation point for the Columbia River System (and the upstream boundary of Reach 2), and 9 of which were scaled for winter events to the 1, 0.5, 0.2, and 0.1 percent AEP for peak 1-day flow at the confluence of the Columbia and Willamette Rivers in Portland, Oregon. The events selected for scaling were several large historical events, selected for their variation of basin runoff patterns. The scaling procedure preserved the spatial pattern of the event, scaling across the basin proportionally until the desired AEP was met.

Two reservoir operations alternatives were used to develop regulated flows that were modeled in the HEC-RAS model described above. The first alternative was used for fitting the stage-flow relationships; it is not being used for further studies but represents a wide range of flow and stage conditions. The second alternative, modeling current reservoir operations, was used to validate the approach by assessing the performance of the stage-flow relationship tool against the HEC-RAS results. The HEC-RAS model was run for both alternatives over the entire water year on the 80 years in the period of record as well as each of the 26 synthetics. The stage-flow relationships were then developed on the training dataset alternative and tested against the validation alternative.

CHAPTER 5 - DETERMINISTIC RUN HEC-WAT SETUP

The CRSO Hydraulic Team used new tools capable of supporting risk-based assessments in a system context, unachievable with the limitations of some of the legacy modeling tools. The individual datasets and tools available for the CRSO study were integrated within a HEC-WAT modeling framework. HEC-WAT was chosen because it allows a study team to perform many of the necessary hydrologic, hydraulic, and planning analyses all orchestrated from a single interface within a common model framework.

HEC-WAT is an integrated system of software developed by the HEC to streamline the analytical and reporting processes of software commonly used by multidisciplinary teams for water resources studies. HEC-WAT is composed of a graphical user interface, data storage and management software, and tools for mapping, graphics, and reporting.

The HEC-WAT model for CRSO incorporated a basinwide reservoir model, using ResSim, and hydraulic models, using HEC-RAS, to calculate water surface profiles and identify levee breach locations. The HEC-RAS tool RASMapper was used to generate water depth grids. Depth grids generated by HEC-RAS were used to generate consequence thresholds. The suite of HEC-WAT models is able to share input and output data and run in a sequence for a single event. The HEC-WAT framework used in CRSO studies can be seen in Figure 5-1. Note that when the HEC-RAS Models were incorporated into the HEC-WAT, all models had been converted to unsteady state, so ResSim fed data to HEC-RAS and the HEC-RAS output (depth grids and water surface elevations at cross sections) was used for alternative analysis. Also note the HEC – Flood Impacts Analysis (HEC-FIA) step was removed from the HEC-WAT sequence for CRSO studies.

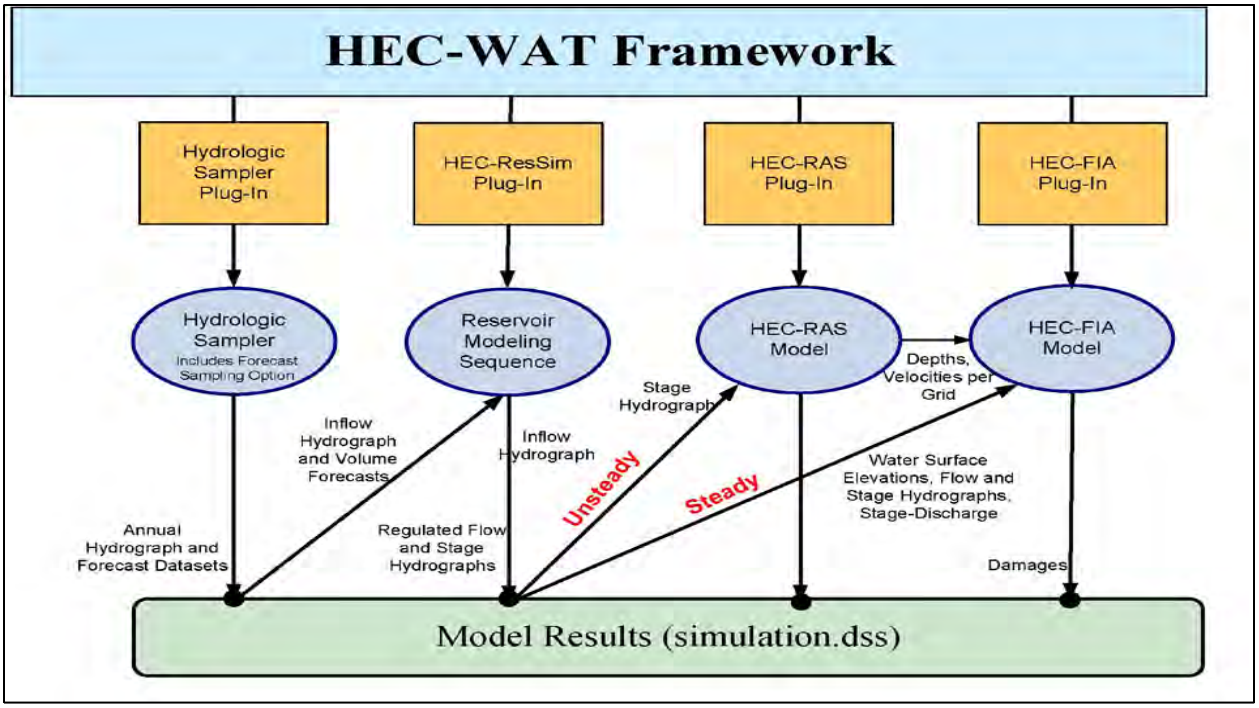


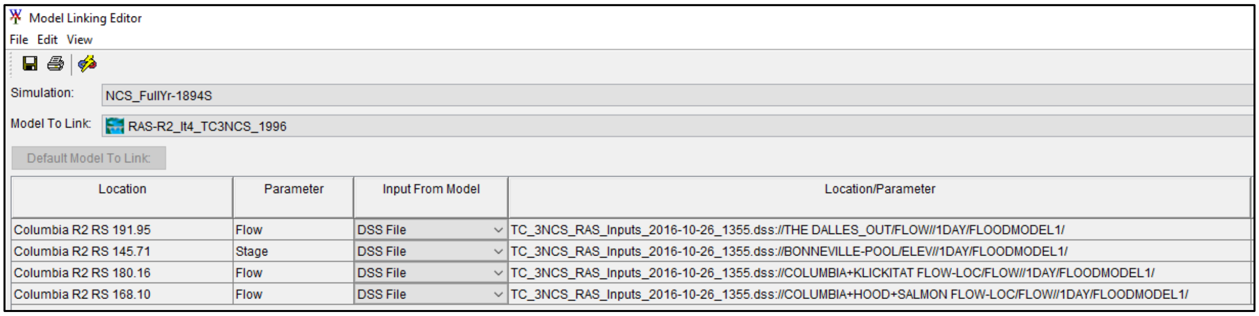
Figure 5-1. HEC-WAT Framework for CRSO Studies, Without the HEC-FIA Step

The CRSO Hydraulic Team discovered early in the HEC-WAT set-up that a full stochastic analysis would need an approach that accurately simulates water surface elevations to be used for alternative evaluation, but also one that runs exceedingly faster than the hydraulic models allowed at the time. Even after the optimization exercise, the basinwide runtime for all hydraulic models combined was roughly 1.5 hours. Additionally, the structure allocation to CCPs in order analyze consequence thresholds had a wide variance that needed improvement. With an eye on the computational and data storage demands coming out of the stochastic alternative analysis, the CRSO Hydraulic Team turned to using a multi-variate regression approach to predict water surface elevations that would then feed other models and provide RAS-like hydraulic data for alternative evaluation. The K-Nearest Neighbor (*k*-NN) regression algorithm is efficient and robust and uses existing model results as lookup tables in order to make predictions. It is used in this case as a stage-flow transformation tool, computing stage at cross sections based on a number of upstream flow inputs and downstream boundary conditions by looking back at previously computed HEC-RAS results for similar inputs and conditions. Basically, the approach was to use HEC-RAS results to build a multi-variate rating curve at every cross section or to use HEC-RAS results to build many thousands of map-book pages for flood events. Those most similar to a given condition were then averaged together.

The *k*-NN algorithm's theory and application are discussed in detail later in this document. The *k*-NN tool is critical to this section describing the HEC-WAT set-up because the primary factor affecting *k*-NN's capability is actually the deterministic HEC-RAS model results. This means an adequate sample of HEC-RAS results are needed to train the *k*-NN algorithm and effectively predict water surface elevations. Creating this training dataset was completed by setting up and running a deterministic HEC-WAT sequence. The process for building deterministic HEC-RAS results from the HEC-WAT is discussed in the following paragraphs.

The 24 HEC-RAS models were divided into four groups to make the HEC-WAT set-up and troubleshooting more manageable. The "LowerSnakeColumbia" group includes Reaches 2, 3, 4, 5_14, 6, 7, and 8. The "MidColumbia" group is Reaches 15, 16, 17, 18, 19, 20, and 21. The "NorthwestTribs" is Reaches 22, 23, 24, 25, 26, and 27. And the "Complex" group is Reaches 1, 9, 28, and 29_30. The input hydrology for the HEC-RAS models was in the form of a HEC-DSS file, which was the output from the training dataset scenario. This is the dataset that was used to build the deterministic HEC-RAS results and eventually train the *k*-NN tool.

As previously discussed, there are 106 years of hydrology data in the training dataset: 80 years from the modified flows dataset with reasonably extreme operations applied, and 26 years of synthetic events derived by scaling selected years to 1, 0.5, 0.2, and 0.1 percent AEP events at The Dalles, Oregon, for spring floods, and 1, 0.5, 0.2, and 0.1 percent AEP events at Vancouver, Washington, for winter floods. All 106 events were included in the deterministic HEC-WAT run. The sequence reads data from the HEC-DSS file output by the deterministic HEC-WAT reservoir operations compute and feeds it into the HEC-RAS model to generate stages and depth grids. The user links the models together using the model linking editor inside the HEC-WAT. The HEC-RAS model is linked to the HEC-DSS hydrology file by the boundary conditions. Figure 5-2 shows an example of the linking editor for Reach 2, where four locations within the HEC-RAS model are linked to the hydrology inputs from the training dataset HEC-DSS file.



Simulation: NCS_FullYr-1894S

Model To Link: RAS-R2_It4_TC3NCS_1996

Location	Parameter	Input From Model	Location/Parameter
Columbia R2 RS 191.95	Flow	DSS File	TC_3NCS_RAS_Inputs_2016-10-26_1355.dss://THE DALLES_OUT/FLOW//1DAY/FLOODMODEL1/
Columbia R2 RS 145.71	Stage	DSS File	TC_3NCS_RAS_Inputs_2016-10-26_1355.dss://BONNEVILLE-POOL/ELEV//1DAY/FLOODMODEL1/
Columbia R2 RS 180.16	Flow	DSS File	TC_3NCS_RAS_Inputs_2016-10-26_1355.dss://COLUMBIA+KLICKITAT FLOW-LOC/FLOW//1DAY/FLOODMODEL1/
Columbia R2 RS 168.10	Flow	DSS File	TC_3NCS_RAS_Inputs_2016-10-26_1355.dss://COLUMBIA+HOOD+SALMON FLOW-LOC/FLOW//1DAY/FLOODMODEL1/

Figure 5-2. Reach 2 Model Linking Between Training Dataset HEC-DSS file and HEC-RAS model

Similarly, the HEC-RAS model would be linked to the HEC-FIA model to pass the water surface elevations to HEC-FIA at every cross section if structure damages were desired. The HEC-FIA step was turned off in the CRSO analysis.

There are at least a half-dozen steps in the HEC-WAT set-up that will be excluded from this document because they are outlined in other CRSO documentation. Setting up the HEC-RAS models for HEC-WAT computations, creating the analysis periods, lining up the program order, and building the alternative/simulation are critical steps in constructing the deterministic HEC-WAT model, but they are common to most HEC-WAT runs and will not be covered here.

A compute in HEC-WAT with the training dataset yields output HEC-DSS files for each event with stage and flow at every cross section. In addition to the modeled downstream pool conditions attached to the training dataset, the CRSO Hydraulic Team found the need to run a wider range of downstream boundaries. In general, the training alternative’s flow dataset was run for up to four additional pool conditions—depending on the operating range within each reservoir—which fixed the pool elevation at a given elevation. The elevations were chosen to span the range of possible operations, while the HEC-RAS model and inflows remained the same as before. It was expected that multi-parameter lookup tables based on a range of pool elevations would alleviate some of the observed cloudiness in deterministic hydraulic data as well as provide additional points for the *k*-NN tables to use outside of existing reservoir operations. Even with building additional result sets from pool condition alternatives, there is a theoretical basis for expecting some variance in the curves due to timing of floods at confluences and the overall lack of interior drainage modeling within the system. The team viewed this as an acceptable limitation given the benefits of the *k*-NN tool. A more detailed discussion on *k*-NN accuracy and limitations is provided in Chapter 10.

The combination of the training dataset alternative with varying pool conditions provided a sufficient range of data to train the *k*-NN model. Another system operations alternative—with operations close to current conditions—was set up in the HEC-WAT to validate the *k*-NN results by comparing performance of *k*-NN and HEC-RAS on boundary condition data (validation dataset) that was not used to fit the model (training dataset). The lookup tables built by *k*-NN were finalized based on the performance measured for the training and validation alternatives.

Finally, the *k*-NN model was added into the HEC-WAT sequence in place of HEC-RAS, taking inputs from ResSim and producing stages in HEC-RAS-like output for use in alternative evaluation and other stage-dependent models.

CHAPTER 6 - DEPTH GRID BENCHMARK MODELS

The discussion to this point in the document has referenced HEC-RAS or *k*-NN models producing data at each cross section, then applying that data to features connected to each cross section, like a structure, levee, or storage area. Part of the quality control and review of the *k*-NN tool was to compare water surface elevations between *k*-NN and HEC-RAS. The most accurate representation of flood consequences currently at our disposal would be built on ResSim handing flow inputs to unsteady HEC-RAS models, computing maximum depth grids in RASMapper, and evaluating hydraulic data and consequences based on those depth grids.

The sequence described above was built into HEC-WAT and deemed the benchmark model for each run. All validation dataset deterministic runs (80 period of record events, 26 synthetic events by 24 reaches) were computed using the benchmark models and recorded for consequences. Those consequences were compared to those obtained using *k*-NN to provide quality control of a novel regression-based scheme versus the best available representation of the basin.

CHAPTER 7 - STAGE-FLOW TRANSFORMATION THEORY

The *k*-NN algorithm was selected to compute hydraulic depths because it is robust and balances a minimal effort of fitting the model with adequate speed of producing predictions. By the very nature of the algorithm, *k*-NN will always have less accurate predictions than the HEC-RAS results. However, inaccuracies can be reduced by using a robust training dataset and the *k*-NN algorithm will compute faster and not become unstable, which is a major limitation with HEC-RAS.

The *k*-NN algorithm uses observed data (i.e., lookup tables) to make predictions. The primary factor affecting the *k*-NN algorithm's capability is actually the observed data, and it is therefore considered a large component of calibration. Additional factors affecting *k*-NN accuracy are the *k* values, determining the number of similar observed data points to use for a prediction, and other parameters associated with the way distance metrics are computed to inform similarity of observed values to those being predicted.

7.1 BASIC PRINCIPLES OF THE K-NN ALGORITHM

The *k*-NN algorithm uses observed data to inform predictions. Figure 7-1 shows a surface of scatterplot of two independent variables (x_1, x_2), and one dependent variable (z). The gridded average response surface is also shown in Part C of Figure 7-1 in gray for visual clarity.

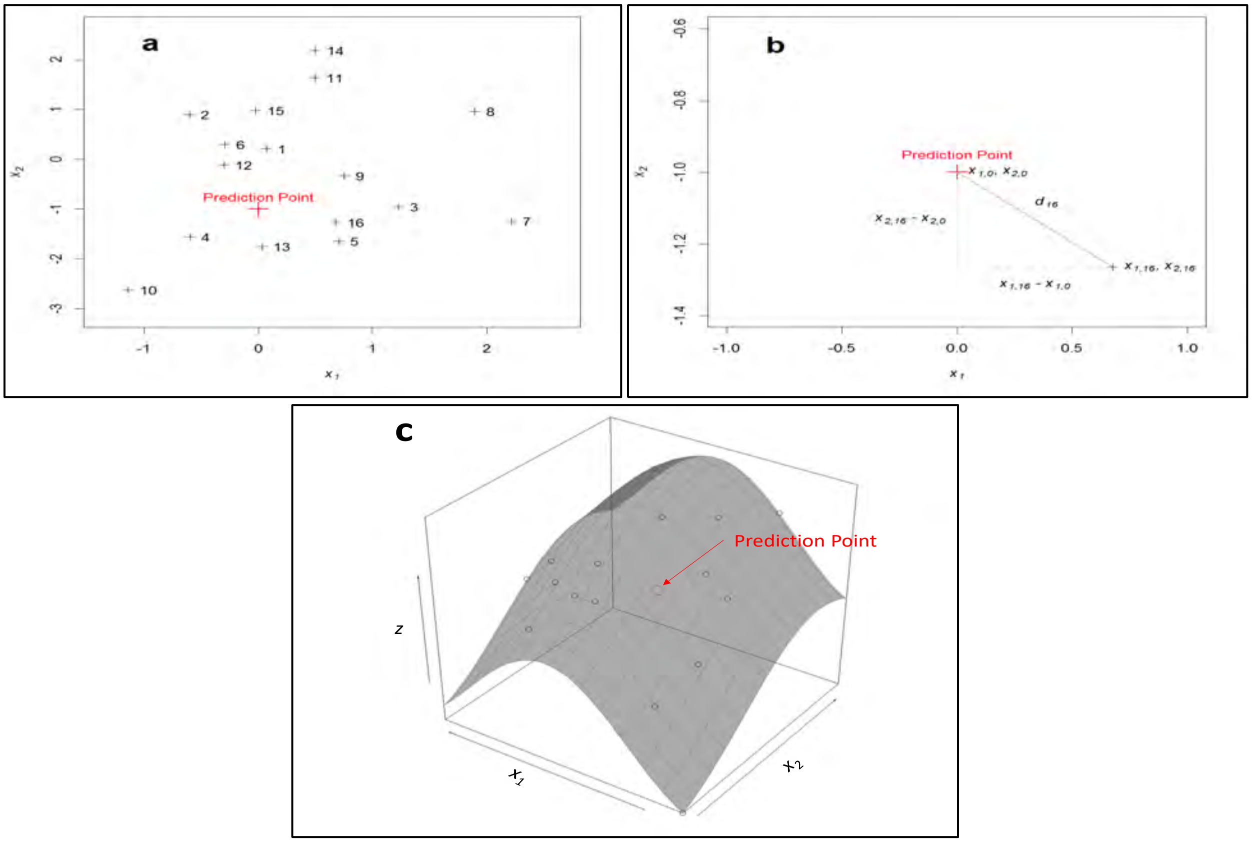


Figure 7-1. Computing the Euclidian Distance Metric for Two Independent Variables, x_1 and x_2: a) Overview of Data, b) Zoomed View of Distance Calculations, and c) 3D Perspective of Points and Average Response Surface

First, the z-scores of independent variables are computed to normalize the data. In the example dataset, the *z*-scores of data are already being used as the x_1 and x_2 variables. However, without this step, distance metrics can be completely dominated by one variable with the largest range (e.g., flow variables on the order of 100,000 cfs will have a much greater effect on Euclidian distance than forebay elevations on the order of 100 feet). Distances are then computed between the predictor data point and the observed (a.k.a., training) dataset. The distance is derived from the differences between the *z*-scores of the independent variables.

Equation 1:

$$d_j = \left\{\sum_{i=1}^{n}\left[b_i\,(x_{ij} - x_{i0})\right]^q\right\}^{1/q}$$

Where

d_j = distance to point j

b_i = weight associated with the i^{th} independent variable

x_{ij} = z-score value associated with the j^{th} point of the i^{th} independent variable; x_{i0} is the value associated with the predictor point for the i^{th} independent variable

q = distance exponent; $q = 2$ for Euclidian distance, $q = 1$ for Manhattan distance

For every value of *j* in *X*, there is a corresponding dependent value in *z*. There may also be multiple dependent variables, *Z* (different than *z* found in the equations that follow). The weight component, b_i, may be one if all independent variables are to be considered equally influential. b_i may also be the correlation of the independent variable to the dependent variable or some other specified value. Figure 7-1 demonstrates the Euclidian distance computation when there are two independent variables, and b_i is one for both independent variables.

Once the distances are computed, the values of the independent variables from the top *k* smallest-distances are used to make the new prediction. The index *l* is now used to indicate the rank, in ascending order, of the distances associated with data points. In this example the *k* parameter is set to 5. Thus, the five closest points to the prediction point are used to compute the new value. In Table 7-1, the rows of the five nearest neighbor points are highlighted in yellow.

Note that for the purposes of the CRSO, some modifications were applied to the basic *k*-NN algorithm to improve performance:

- Weight Exponent – *a* variable in Equation 2 description that follows
- Weight Calculation Method – inverse distance method in Equation 2 description below

Table 7-1. Tabulation of k-NN Distances and Rankings

j	x_1	x_2	d	l	z
1	0.07	0.21	1.21	7	1.01
2	-0.60	0.89	1.99	12	0.86
3	1.23	-0.95	1.23	8	1.22
4	-0.60	-1.55	0.82	**3**	0.83
5	0.71	-1.64	0.96	**5**	1.09
6	-0.29	0.29	1.32	9	0.94
7	2.22	-1.24	2.23	13	1.40
8	1.90	0.96	2.72	15	1.35
9	0.75	-0.34	1.00	6	1.15
10	-1.14	-2.62	1.98	11	0.64
11	0.50	1.63	2.67	14	1.05
12	-0.30	-0.12	0.93	**4**	0.94
13	0.03	-1.75	0.75	**2**	0.95
14	0.50	2.18	3.22	16	1.01
15	-0.02	0.97	1.97	10	0.98
16	0.68	-1.26	0.73	**1**	1.10

The *k-NN* prediction of the new point is computed using:

Equation 2:

$$\boldsymbol{z_0 = \frac{\sum_{l=1}^{k} w_l z_l}{\sum_{l=1}^{k} w_l}}$$

Where

z_0 = prediction of dependent variable

w_l = weight associated with the l^{th} point

$$= \begin{cases} (1/\mathrm{d_l})^{\mathrm{a}} & ;\ \textit{inverse distance weighting} \\ 1 & ;\textit{no weightingw} \end{cases}$$

a = weighting exponent, $a \geq 1$

z_l = dependent variable value associated with the l^{th} data point

For this example, the final prediction is thus:

$$\boldsymbol{z_0 = \frac{1.10+0.95+0.83+0.94+1.09}{5}} = \mathbf{0.98}$$

CHAPTER 8 - STATE-FLOW TRANSFORMATION METHODOLOGY

Development of *k*-NN tables and parameters for use in predicting river stage involves many separate processes, which are outlined in Figure 8-1. First, raw data are needed to develop regression and validation datasets (Step 1). The data then need to be appropriately extracted and formatted (Step 2). The datasets are filtered to a subset that is appropriate for the desired purpose of the *k*-NN lookup table (Step 3). The lookup table is then validated using either a leave-one-out cross-validation (LOOCV) or some other cross-validation methodology (Step 4). Lastly, the prediction error and other error metrics are computed to determine if the lookup table and parameters produce the desired precision (Step 5). If adjustments to either the table or fitting parameters are required, the process is repeated from Step 3.

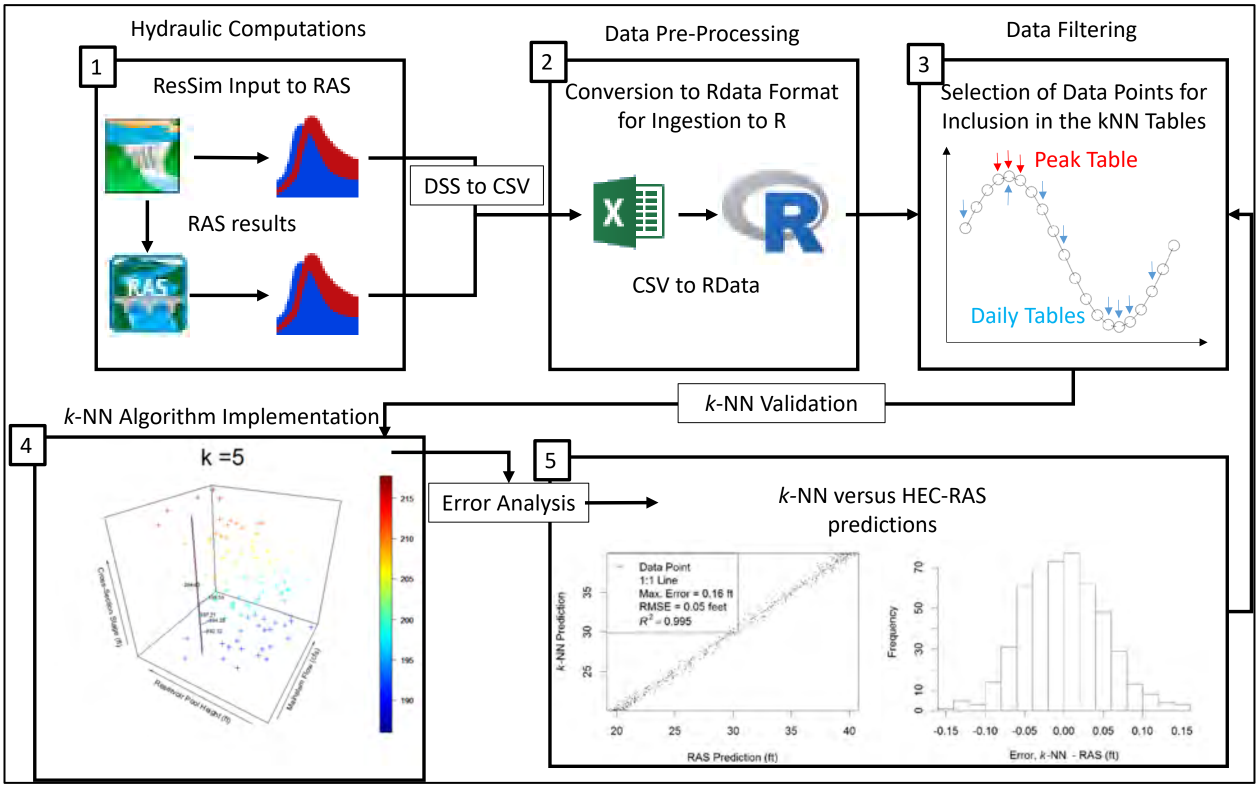


Figure 8-1 Workflow Process for the Development of k-NN Table

Table 8-1 is a brief summary of hydraulic phenomena. The following list provides corresponding accommodation of these phenomena (how they were accounted for) within the *k*-NN algorithm.

- Hysteresis – flow derivative as predictor
- Large lake – pool elevation as predictor or use internal boundary in HEC-RAS
- Large tributary – total flows as predictors
- Large pool variations – predict based on stage minus forebay elevation
- Channel constriction – flow derivative as predictor
- Tidal conditions – tide as predictor

Table 8-1. Hydraulic phenomena tabulated by RAS reach

	Bonneville - Ocean	Lower Columbia			McNary Pool	Snake River			Snake-Clearwater Confluence	Mid-Columbia						Grand Coulee Pool	Pend Oreille		Lake Pend Oreille	Clark Fork		Clark Fork/Flathead	Flathead Lake	Corra Linn Pool
Hydraulic Phenomena	**R01**	**R02**	**R03**	**R04**	**R05**	**R06**	**R07**	**R08**	**R09**	**R15**	**R16**	**R17**	**R18**	**R19**	**R20**	**R21**	**R22**	**R23**	**R24**	**R25**	**R26**	**R27**	**R28**	**R29**
Hysteresis	x																	x				x		
Large lake																			x				x	
Large tributary	x				x				x													x	x	
Large pool variations				x												x								
Channel constriction																		x						
Tidal conditions	x																							

CHAPTER 9 - CROSS SECTION CULLING

9.1 OVERVIEW

Water surface elevations are calculated at each cross section in the HEC-RAS models and are used to build water surface profiles needed for flood mapping. Water surface profiles are used to create inundated area maps and depth grids during high water conditions (50 to 0.5 percent AEP). Water surface profiles during low flow are also used as an aid to interpreting changes in water levels at discrete locations; however, low flow conditions are not mapped.

There are roughly 6,000 cross sections in the suite of HEC-RAS hydraulic models used for alternative analysis in CRSO. To decrease development time, reduce output file size, and reduce compute time required (to translate ResSim output to water surface elevations through the basin), the total number of cross sections was reduced by culling cross sections that are not needed to adequately represent the water surface profile. The following paragraphs detail the culling methodology.

9.2 METHODS

A preliminary assessment of the hydraulic models was performed to determine suitability and priority for culling. Factors that contributed to overall suitability included average slope, cross-section spacing, consequences, and the likely error post-culling. Models were broken into subreaches and each was assigned an overall grade. Some reaches were not culled if a combination of several factors applied, or if the reaches were generally considered low priority due to minimal returns on effort.

Maximum water surface profiles from two simulations were used to identify critical cross sections in a given reach and to assess error resulting from culling. The simulations were based on the training dataset hydrology and included one very large flood year and one non-flood year. The high and low flow simulations used for each HEC-RAS model are not intended to be extremes that fully bracket the range of potential flow conditions, but instead were chosen to identify potential differences in water surface profile that may occur during different flow and downstream stage regimes. Verification was performed using a moderate flow simulation, and error quantification was performed on all three (high, moderate, and low flow). Microsoft Excel spreadsheets were created for each reach to document the culling, define the final list of cross sections for *k*-NN, and calculate the error associated with the simplified profiles. Figure 9-1 shows an example of a spreadsheet used for culling.

For each reach, water surface and energy grade results from the two HEC-RAS simulations were imported into Excel along with the downstream distance data (reach lengths) at each cross section. Water surface and energy grade profile plots were recreated in Excel using cumulative downstream distance. A culled profile series was created and added to the profile charts. The culled profile uses only selected points from the original RAS profiles, linearly interpolating between consecutive ordinates. Initial culled cross sections were chosen randomly at first, and then adjusted to achieve the following criteria:

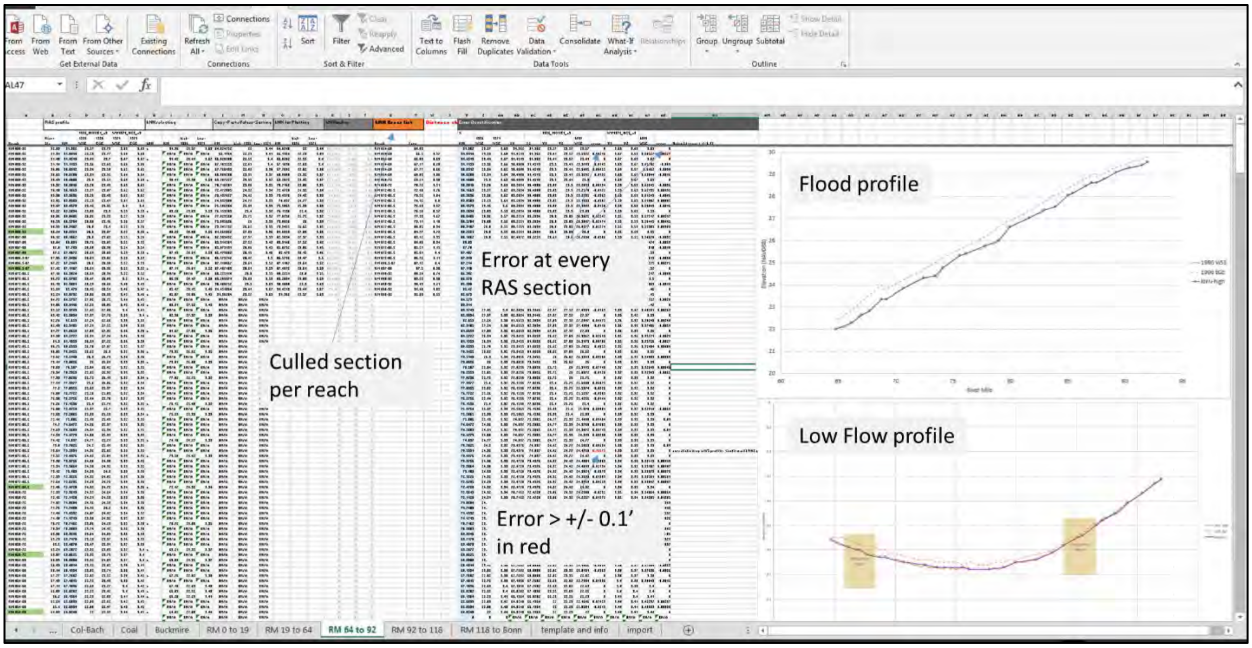


Figure 9-1. Culling Spreadsheet Example

- Difference between culled profile and RAS profile should be less than 0.1 feet, on average.
- Maximum spacing should be 2 miles, with the exception of 5-mile spacing for large reservoirs.

9.3 RESULTS

The *k*-NN culling resulted in a reduction of 2,965 cross sections, approximately 55 percent of the nearly 5,400 cross sections remaining after excluding non-modeled portions of the basin (Table 9-1).

Table 9-1. List of Culled Reaches, Number, and Percent of Cross Sections Removed and/or Interpolated Through Culling

Model	River	River Section	Removed	% Removed
R01	Columbia	RM 23–64	69	65%
R01	Columbia	RM 64–92	65	72%
R01	Columbia	RM 92–118	53	65%
R01	Columbia	RM 118–145	44	60%
R01	Willamette	Willamette	89	76%
R01	Multnomah Channel	Multnomah Channel	65	79%
R01	Lewis	Lewis	24	60%
R01	Cowlitz	Cowlitz below 7.08	21	81%
R01	All minor reaches	All minor reaches	216	88%
R01	All side channels	All side channels	153	74%
R02	Columbia	RM 145–192	211	81%

Model	River	River Section	Removed	% Removed
R03	Columbia	RM 190–216	105	78%
R04	Columbia	RM 216–291	157	77%
R05	Columbia	RM 291–345	150	71%
R05	Yakima	RM 0–6	26	51%
R05	Snake	RM 0–8	16	38%
R09	Snake	RM 107–138	202	96%
R09	Snake	RM 139–148	99	77%
R09	Clearwater	RM 0–8	79	72%
R16	Columbia	RM 415–453	80	71%
R19	Columbia	RM 516–545	69	70%
R21	Columbia	RM 596–711	167	84%
R21	Columbia	RM 711–731	87	78%
R21	Columbia	RM 731–748	71	65%
R22	Pend Oreille	RM 16–26	138	91%
R22	Pend Oreille	RM 26–33	72	74%
R23	Pend Oreille	RM 33–89	169	77%
R24	Pend Oreille	RM 89–120	44	56%
R24	Pend Oreille	RM 120–159	64	88%
R28	Flathead	RM 78–110	59	88%
R28	Flathead	RM 110–129	12	38%
R29	Kootenai	RM 48–151	89	55%

In most cases, the *k*-NN profile reproduces the HEC-RAS profile within 0.01 foot at every cross section in a given reach, well below the 0.1-foot accuracy target; however, there are several instances where this criteria was not achieved. In steeper, high-energy reaches, more erratic profiles are not uncommon and maintaining the 0.1-foot difference is not possible without including nearly all cross sections. Considering the erratic water surface profile may often be an artifact of model resolution and not necessarily reflective of the actual water surface profile, culled profiles conservatively follow the slope of the energy grade line with sections skipping over a local drop in water surface at a single cross section. The upper Willamette River, shown in Figure 9-2, is a good example of a culled reach that disregards local drops in the water surface.

Table 9-2 summarizes the count of sections removed and other error statistics for the reaches where culling was performed. The table shows three sets of error statistics, one for the maximum water surface from a very large flood event (high), one for a moderate water year (mod), and one for the annual maximum water surface profile from a low water year simulation (low).

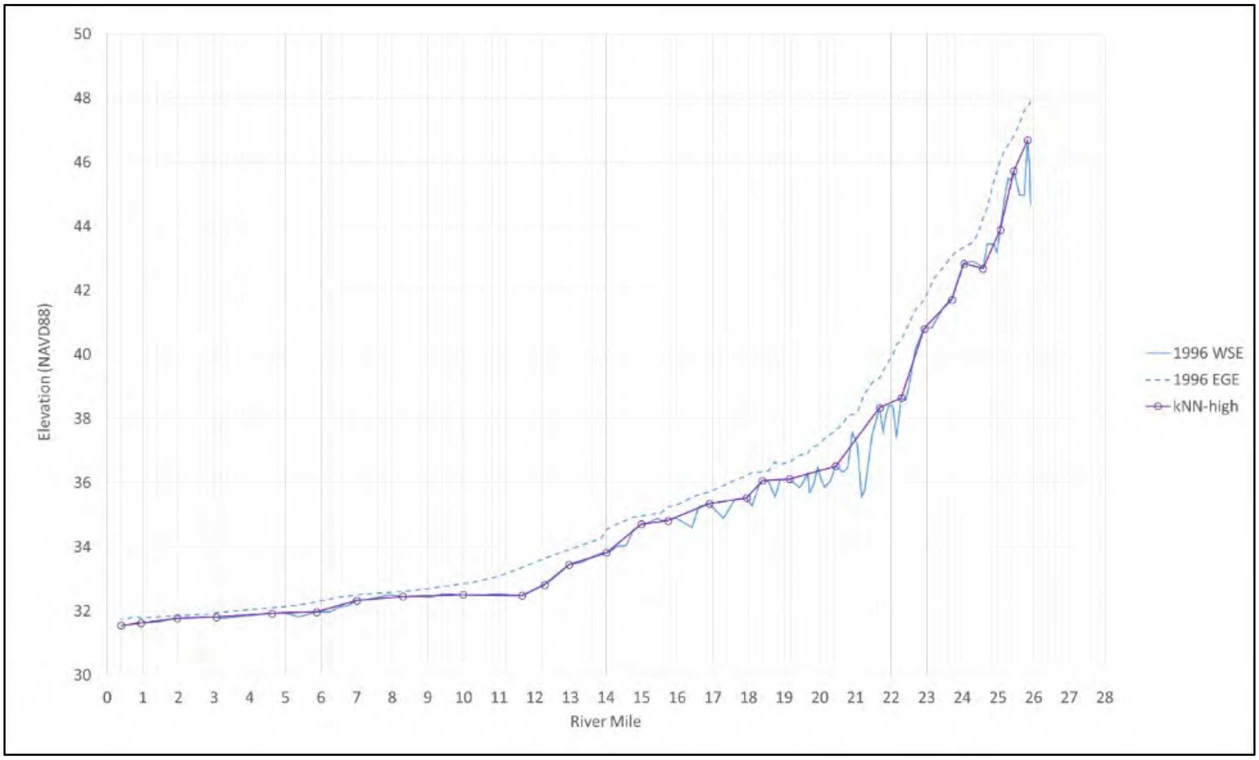


Figure 9-2. Willamette Example of Culled Cross Sections Within Erratic HEC-RAS Profile

Table 9-2. Median Absolute Error and Maximum Error for the Culled Reaches (feet)

Model	River	River Section	Count	Maximum Absolute Error High	Maximum Absolute Error Mod.	Maximum Absolute Error Low	Median Absolute Error High	Median Absolute Error Mod.	Median Absolute Error Low
R01	Columbia	RM 23–64	57	0.12	0.14	0.04	0.03	0.02	0.01
R01	Columbia	RM 64–92	59	0.18	0.18	0.08	0.03	0.02	0.02
R01	Columbia	RM 92–118	46	0.12	0.08	0.05	0.02	0.01	0.02
R01	Columbia	RM 118–145	40	3.46	0.86	1.75	0.04	0.01	0.02
R01	Willamette	RM 0–26	83	0.60	2.40	1.16	0.00	0.12	0.07
R01	Multnomah Channel	RM 0–22	63	0.05	0.06	0.03	0.02	0.02	0.01
R01	Lewis	RM 0–9	23	0.01	0.16	0.17	0.00	0.07	0.02
R01	Cowlitz	RM 0–7.08	20	0.03	0.32	0.50	0.01	0.09	0.08
R01	All minor reaches		206	1.10	1.30	0.18	0.00	0.00	0.00
R01	All side channels		124	0.27	0.38	0.73	0.02	0.01	0.01
R02	Columbia	RM 145–192	211	2.06	0.80	0.15	0.04	0.03	0.01
R03	Columbia	RM 190–216	105	0.64	0.26	0.06	0.07	0.04	0.01
R04	Columbia	RM 216–291	157	0.36	0.12	0.02	0.01	0.00	0.00
R05	Columbia	RM 291–345	149	0.83	0.24	0.06	0.02	0.01	0.00
R05	Yakima	RM 0–6	25	0.13	0.14	0.12	0.02	0.06	0.03
R05	Snake	RM 0–8	15	0.08	0.05	0.03	0.01	0.02	0.00

Model	River	River Section	Count	Maximum Absolute Error			Median Absolute Error		
				High	Mod.	Low	High	Mod.	Low
R09	Snake	RM 107–138	202	0.01	0.01	0.01	0.00	0.00	0.00
R09	Snake	RM 139–148	99	0.58	0.44	0.06	0.04	0.02	0.00
R09	Clearwater	RM 0–8	79	0.52	0.36	0.23	0.03	0.02	0.02
R16	Columbia	RM 415–453	80	0.68	0.00	0.27	0.05		0.01
R19	Columbia	RM 516–545	69	0.89	0.00	0.14	0.10		0.01
R21	Columbia	RM 596–711	167	0.46	0.15	0.01	0.00	0.00	0.00
R21	Columbia	RM 711–731	87	0.85	0.37	0.03	0.03	0.01	0.00
R21	Columbia	RM 731–748	71	0.59	0.42	0.45	0.09	0.07	0.04
R22	Pend Oreille	RM 16–26	138	2.19	0.00	0.23	0.04		0.00
R22	Pend Oreille	RM 26–33	72	0.86	0.00	0.20	0.04		0.02
R23	Pend Oreille	RM 33–89	169	2.62	0.00	0.24	0.02		0.01
R24	Pend Oreille	RM 89–120	44	0.15	0.12	0.01	0.01	0.01	0.00
R24	Pend Oreille	RM 120–159	64	0.00	0.01	0.00	0.00	0.00	0.00
R28	Flathead	RM 78–110	59	0.01	0.00	0.00	0.00	0.00	0.00
R28	Flathead	RM 110–129	12	0.06	0.05	0.01	0.03	0.01	0.00
R29	Kootenai	RM 48–151	89	0.25	0.31	0.17	0.01	0.02	0.01

Note: Mod. = moderate.

The median absolute error for a culled reach ranges from 0.0 to 0.1 foot for the high profile, to 0.0 to 0.08 foot for the low profile, averaging 0.03 and 0.01 foot, respectively. Maximum errors could be quite high for steep reaches and reaches with jagged profiles or with sharp drops in the water surface profile. Maximum errors can be as high as 5 feet, although the reasonableness of the HEC-RAS profile is questionable at these specific locations. Maximum errors often occur at sharp drops in the water surface profile at a single location.

The median error can be used to assess general bias in the water surface profile. In several cases, a conservative profile was drawn by skipping cross sections; however, the goal was to not introduce bias, high or low, but to replicate the HEC-RAS profile as accurately as possible. Table 9-3 shows the mean error for the same high and low scenarios for all of the culled reaches.

Table 9-3. Mean Error of the Culled Reaches, Used as a Proxy to Identify Bias (feet)

Model	River	River Section	Count	Mean		
				High	Mod.	Low
R01	Columbia	RM 23–64	57	0.01	0.01	0.00
R01	Columbia	RM 64–92	59	0.02	0.01	0.01
R01	Columbia	RM 92–118	46	0.00	0.00	0.00
R01	Columbia	RM 118–145	40	0.16	0.04	0.07
R01	Willamette	RM 0–26	83	0.03	0.25	0.15
R01	Multnomah Channel	RM 0–22	63	0.01	0.01	0.00

Model	River	River Section	Count	Mean		
				High	Mod.	Low
R01	Lewis	RM 0–9	23	0.00	0.00	0.00
R01	Cowlitz	RM 0–7.08	20	0.01	0.03	0.05
R01	All minor reaches		206	0.00	0.00	0.00
R01	All side channels		124	0.00	0.00	0.01
R02	Columbia	RM 145–192	211	0.01	0.01	0.00
R03	Columbia	RM 190–216	105	0.04	0.02	0.00
R04	Columbia	RM 216–291	157	0.01	0.00	0.00
R05	Columbia	RM 291–345	149	0.01	0.00	0.00
R05	Yakima	RM 0–6	25	0.00	-0.01	-0.01
R05	Snake	RM 0–8	15	0.00	0.00	0.01
R09	Snake	RM 107–138	202	0.00	0.00	0.00
R09	Snake	RM 139–148	99	0.02	0.02	0.00
R09	Clearwater	RM 0–8	79	0.00	0.01	0.01
R16	Columbia	RM 415–453	80	-0.04		-0.01
R19	Columbia	RM 516–545	69	0.05		0.01
R21	Columbia	RM 596–711	167	0.01	0.00	0.00
R21	Columbia	RM 711–731	87	-0.04	-0.02	0.00
R21	Columbia	RM 731–748	71	-0.08	-0.08	-0.09
R22	Pend Oreille	RM 16–26	138	0.06		0.00
R22	Pend Oreille	RM 26–33	72	0.09		0.02
R23	Pend Oreille	RM 33–89	169	-0.11		0.00
R24	Pend Oreille	RM 89–120	44	0.01	0.01	0.00
R24	Pend Oreille	RM 120–159	64	0.00	0.00	0.00
R28	Flathead	RM 78–110	59	0.00	0.00	0.00
R28	Flathead	RM 110–129	12	0.00	0.01	0.00
R29	Kootenai	RM 48–151	89	0.02	0.02	0.01

For the high scenario, 22 of the 31 culled reaches have a mean error within 0.01 foot of zero, as do 28 for the low scenario. Those outside of the 0.01-foot bias are typically short and steep reaches. Detailed notes on the errors are compiled in the previously mentioned Excel spreadsheets.

9.4 ADDITIONAL CONSIDERATIONS

The result of skipping over sharp drops in the profile is that in several locations the interpolated water surface profile using a *k*-NN cross section and the inundation map it produces will have higher water surface elevations than what would be produced in HEC-RAS and RASMapper. This will ultimately result in higher damages since structures are all along the upper Willamette, regardless if the culled profile is more realistic or not.

Water level estimates for HEC-RAS storage areas are based on cross sections nearest a breach location and/or the low point of a lateral structure. The cross section culling did not consider specific locations but instead focused solely on adequate profile representation; therefore, interpolation to a specific location is required prior to calculating water levels in some storage areas.

CHAPTER 10 - DISCUSSION OF STAGE-FLOW TRANSFORMATION ACCURACY

At the start of this effort, the CRSO Hydraulic Team discussed the required accuracy of the *k*-NN model for estimating stages that would be output from an equivalent HEC-RAS model. It was decided to use the *k*-NN results for the training dataset alternative to train the models, as this alternative has a wider range of flows than the other alternatives running close-to-current operations, which were used for validation of the *k*-NN model. The validation model is more similar to current operating conditions. The HEC-RAS model was run for the 80 years in the modified flows period of record, as well as for the additional 26 scaled synthetic event hydrographs. The 106 total years of validation data covered up to a 0.1 percent annual chance exceedance event at The Dalles for spring events and at Vancouver for winter events. By running both the *k*-NN and HEC-RAS models for the validation alternative, with *k*-NN using the tables fit on the training dataset alternative's HEC-RAS output, we can assess how well *k*-NN is able to reproduce the stages that the HEC-RAS model would have output. The training dataset alternative results were used to generate the *k*-NN stage-flow relationships and fit the appropriate parameters, while the validation alternative results were used for validation of the *k*-NN stage-flow relationships' predictive ability.

10.1 COMPARISON OF K-NN MODEL RESULTS AGAINST HEC-RAS MODEL OUTPUT

The initial goal for *k*-NN performance was to match the performance of HEC-RAS results against observed data. As the HEC-RAS models were primarily calibrated to a sparse set of gages (besides the reservoir forebay elevations that are used as a boundary condition to the model), it was deemed more appropriate to look at general performance of HEC-RAS models in ungaged locations. If the *k*-NN method produces error in the same range as the HEC-RAS model for these locations, with minimal bias in the estimates, it should be considered an acceptable manner of approximating the HEC-RAS model output.

For estimates of uncertainty in HEC-RAS models, Engineering Manual (EM) 1110-2-1619, Chapter 5: Uncertainty of Stage-Discharge Function provided guidance. Figure 5-3 in the EM shows a range of standard deviations for stage-discharge relationships as a function of channel slope as read from 7.5-minute US. Geological Survey quadrangles. For the steepest channels, the estimate of standard deviation is 0.7 foot. For the flattest of channels, the standard deviation can be as high as 2.75 feet. Table 5-2 in the EM provides a range of standard deviations based on the reliability of Manning's *n* value used and the method of survey for the cross-section profiles. The best case from this table has a standard deviation of 0.3 foot. From these estimates, our criteria for the model fitting and validation error of 0.75 foot seems reasonable.

10.2 FITTING

During the fitting process, a cross-validation approach was used, by which the event that was being predicted would be excluded from the *k*-NN table (i.e., LOOCV). This cross-validation gave an early estimate of the predictive ability of the *k*-NN method. Some issues with the HEC-RAS modeling, such as model instabilities and sensitivity to starting conditions, were identified during this step. In these cases, the results from the HEC-RAS model were culled from the *k*-NN stage-flow relationship. Table 10-1 shows the tabulated error metrics for each reach. The value in each cell is the minimum, mean, or maximum error metric for all cross sections in the specified reach.

10.3 VALIDATION

Validation was performed to ensure that the *k*-NN results from one reservoir operations alternative run through HEC-RAS were appropriate to apply to other reservoir operations alternatives. The validation was performed by computing the *k*-NN based stage-flow relationships that had been created in the fitting process on the validation reservoir operations output and comparing to the HEC-RAS model run against the same reservoir operations output. During the validation step, one issue identified was the handling of the tidal boundary condition in Reach 1 and the effect of monthly inflows used as a predictor. Additionally, there was a need to adjust the time window for running the peaks as the *k*-NN code was missing peaks due to large tributary inflow contributions (outside the time window) such as the 1964 event in Reach 28.

Table 10-1. k-NN Fitting Error Metrics by Reach (in feet)

Error Metric		Reach Name																							
		R01	**R02**	**R03**	**R04**	**R05**	**R06**	**R07**	**R08**	**R09**	**R15**	**R16**	**R17**	**R18**	**R19**	**R20**	**R21**	**R22**	**R23**	**R24**	**R25**	**R26**	**R27**	**R28**	**R29**
RMSE	Minimum	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01
	Mean	0.42	0.14	0.04	0.05	0.21	0.02	0.02	0.03	0.14	0.10	0.02	0.02	0.05	0.06	0.21	0.14	0.09	0.30	0.11	0.02	0.05	0.10	0.12	0.26
	Maximum	0.96	0.17	0.08	0.12	0.60	0.08	0.11	0.08	0.25	0.25	0.06	0.10	0.11	0.17	0.88	0.24	0.14	0.35	0.15	0.08	0.14	0.22	0.74	1.14
MAE	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	Mean	0.29	0.06	0.02	0.04	0.14	0.00	0.01	0.01	0.07	0.03	0.02	0.01	0.03	0.04	0.07	0.09	0.05	0.19	0.05	0.01	0.03	0.06	0.07	0.17
	Maximum	0.74	0.07	0.03	0.09	0.45	0.02	0.06	0.02	0.17	0.08	0.04	0.06	0.07	0.10	0.26	0.16	0.09	0.22	0.08	0.04	0.08	0.14	0.43	0.49
Absolute Error	Maximum	4.75	2.12	1.01	0.80	2.93	1.80	1.60	1.59	4.36	3.04	0.45	1.82	0.61	0.68	6.25	3.28	3.18	3.21	1.30	1.16	1.52	2.93	8.01	6.13

Note: MAE = mean absolute error; RMSE = root mean squared error.

10.3.1 Summary of Accuracy

In most locations, the *k*-NN model is well within the acceptable range of errors for the *k*-NN data. The locations that show the most error relative to the HEC-RAS model are those in the transition zone between riverine and flat reservoir pools.

The least accuracy is found in the following conditions:

- Instances of an extreme stage that has rarely been observed (e.g., 1964 event on Reach 28)
- Reach 1 with large flashy events like winter floods that have few similar points
- Reach 1 in the tidal transition zone

k-NN is limited to the range of values for which it is fit. The *k*-NN model outputs errors when it encounters a boundary condition value outside of the values found in the stage-flow relationship table (based on the deterministic runs detailed in Chapter 4). This limitation should be considered when applying *k*-NN lookup tables to new reservoir operations alternatives, particularly those that change the downstream pool elevation to operate outside of the authorized limits (described in Chapter 4 as the range of pool conditions for the training dataset). *k*-NN is a statistical model without a mass balance, and should not be used to drive other physical models as a boundary condition without careful consideration.

CHAPTER 11 - DIFFERENCES IN PEAK AND DAILY STAGE-FLOW TRANSFORMATION

As the *k-NN* fitting process was being developed for peak stages, it showed enough promise to adapt the approach to compute daily stages. In order to adapt the process to computing daily stages, a new dataset from the hydraulic models was developed for year-round flows (not just catching the peaks with a time window), which were aggregated into daily average values to match the ResSim output's daily timestep.

The flow-stage lookup tables used for computing daily stages were derived similarly to those used for peak stages, with two exceptions: the statistical measure used to convert the hourly stage data produced by HEC-RAS back into daily data was included, and the range of values over which the tables were fit was increased. Daily stages were computed by taking the mean value on a daily basis, while peak stages were computed by taking the daily maximum stage for each 24-hour window. This was done to better capture the parameter of interest. The peaks data should be used where the water surface profile and the annual chance of inundation by stage at a given station on the river is desired. For analyses where the variable of interest is the frequency at which a certain depth of water is present throughout the year, the daily averages are more appropriate. The tables used for computing peaks were limited to higher flows and higher downstream forebay elevations in order to better estimate those larger events.

Using separate tables for peak stage and daily stage introduced a possibility that the stage estimation process could produce a daily stage greater than the peak stage for the year. Using similar parameter groupings and predicting daily-average stages from the same dataset instead of daily maximums minimized the likelihood of this situation from occurring. The same parameter groupings picked up the same events from the HEC-RAS dataset, and the daily average will always be less than the daily maximums used to fit the peak tables. If the situation were to occur because of differences in the predictors used, the daily stage should then be capped at the peak stage predicted.

CHAPTER 12 - STAGE-FLOW TRANSFORMATION APPLIED IN MONTE CARLO COMPUTES

The *k*-NN stage-flow relationship is used in the HEC-WAT Monte Carlo compute method to provide estimates of peak stages and daily average stages. A post-processor script attached to the reservoir operations model is used to estimate stages from the flows and reservoir forebay elevations output by the model. The resulting time series of stages is made available to the later models in the sequence, in particular to establish consequence thresholds, or can be retrieved at a later time from the output files.

The *k*-NN relationship is computed for the entire water year when applied to the daily average stage; for the annual peaks it is only run during the flood season on a small time window around the peak of each of the significant predictors. The time window is used to limit the number of timesteps for which the stage estimation is run, which decreases model compute time. In order to capture the peak stage event where the peak stage occurs from a combination of flows and downstream stages that are not at the maximum value of either, the predictor variables typically used include the downstream pool elevation and reservoir total inflow. Reservoir total inflow, as opposed to a reach's most upstream inflow and tributary inflow is used, as this single variable should capture peak flows for both. For lengthy reaches with significant tributaries, the tributary and upstream inflow flows may also be used. The time window around the maximums of these predictors is typically set to be from 7 days prior to the peak until 7 days after. Through testing of the *k*-NN model, it was found that the peak stage was often found within this window as a result of combined high flow and high downstream pool elevations.

For each day within the time window or over the entire water year, the flow and reservoir forebay elevation output from ResSim is fed through the *k*-NN stage-flow relationships to create a time series of stages. These are saved to the model results file using a similar naming scheme as that used by the HEC-RAS model to ensure that data could be passed to other HEC programs as needed.

12.1 EFFECTS OF LOCAL HYDROLOGY AND FIXED VALUE REGULATION IN MONTE CARLO MODEL OUTPUT

Local inflows and reservoir regulation that occurs at extreme values will cause *k*-NN to predict identical values to other events (within the 5,000 simulations) where the same water year (of the 106) is sampled. This will occur at sites downstream of unregulated inflows or when an upstream reservoir is operating to a limitation that is not a function of a water supply forecast. This limitation of the Monte Carlo sampling and *k*-NN stage-flow estimates should be kept in mind while interpreting the resulting stage-frequency plots and water surface profiles for reaches where this condition occurs. The results will show identical values whenever this condition occurs, which will show up on a frequency curve of the Monte Carlo results as multiple repeated values of the same stage. This behavior is not specific to the *k*-NN process and would appear with other stage-discharge relationship methods. For distance-weighted *k*-NN relationships, these conditions may result in *k*-NN heavily trending towards a single HEC-RAS output instead of the average of multiple points.

CHAPTER 13 - POST-PROCESSING OF STAGE DATA PRODUCED IN MONTE CARLO COMPUTE

The output in the Monte Carlo analysis is post-processed with the flood risk assessment (FRA) extract tool, a script developed for previous studies, to take the set of 5,000 time series generated for a given location and parameter, e.g., stage at a given point in the river, and transform it into annual statistics by site, such as annual or seasonal maximums, average, or time above and below a threshold. The resulting table of 5,000 values can be compared against results from other alternatives in a paired manner, as the Monte Carlo model sampling ensures that the inputs to the reservoir operations model are identical between runs, or can be used to generate frequency curves and probabilistic results.

In the case of peak flows, an annual peak is retrieved at every location for which the *k*-NN stage-flow relationship is computed. These annual peaks across every reach are ranked and assigned a probability in order to create a profile of AEPs for a given stage at every point for which the stage-flow relationship was computed. It is critical to reiterate that the AEP profile developed within the *k*-NN compute is a summation of singular AEP points along the reach, and not based on a simulated profile ranked by flow and plotted as a deterministic flood event. Each cross section has its own AEP stage, computed individually from 5,000 simulations, and when the stages at each cross section are connected together a reach scale profile is realized. This AEP profile can be compared with those from other alternatives to detect impacts from changes in operations.

The major advantage of having AEP profiles generated from the output of the hydraulic models (HEC-RAS and *k*-NN), instead of running a single event of inputs derived from a joint probability distribution is the ability to correctly compute AEP at each location along the river without running a separate model for each. This depends on the Monte Carlo sampling and regulated flows resulting from reservoir operations having the correct probabilities. The other advantage is that with the larger number of events run through the model and stage estimation script, uncertainty of a given AEP can be estimated for every location along the river.

The portion of an AEP profile in the reservoir is driven more by downstream stage, while the riverine portion upstream is driven by discharge. In the transition zone between riverine and reservoir conditions, the AEP profile will be the result of a combination of both drivers, especially for reservoirs without a fixed pool elevation. Changes in AEP profiles are a metric in identifying and communicating changes in hydraulics occurring with a given alternative.

Other analyses can be performed on the daily stage hydrograph output, such as generating duration curves and summary stage hydrographs at locations other than the reservoir forebay. The FRA extract tool can also produce more complex summary statistics by year, such as number of days in an event where a given stage is exceeded or not. This may be useful for analysis of how frequently a resource connected to the river is available, for resources such as recreation sites, ferry crossings, or pump intakes.

CHAPTER 14 - SUMMARY

This document summarizes why and how a stage-flow transformation tool, *k*-NN, was used in the development of hydraulic data for the CRSO study. Twenty-four unsteady HEC-RAS models were constructed by the end of FY 2015. They were optimized for stability, flexibility, and speed in preparation for building annual peak stage predictions and other hydraulic datasets for the Columbia River Basin. The CRSO Hydraulics Team developed new tools capable of supporting risk-based assessments in a system context, integrating the individual datasets and tools within a HEC-WAT modeling framework.

HEC-RAS, although very effective, was not an ideal method for computing hydraulic stage for the Monte Carlo stochastic analysis involving 5,000 simulations. The HEC-RAS models were built into the HEC-WAT with a training dataset of 106 years of deterministic simulations. The deterministic results were used to develop *k*-NN, a stage-flow transformation tool based on a subset of HEC-RAS model results and capable of stochastically analyzing the Columbia River Basin for peak and daily flow and stage.

The *k*-NN algorithm, though a less accurate predictive model than HEC-RAS, was selected to compute hydraulic depths because it is robust with fast compute times and no stability issues. The *k*-NN algorithm uses observed data (i.e., lookup tables) to make predictions. A training dataset, with a wide range of flows and boundary conditions, was used to generate the *k*-NN stage-flow relationships and fitting parameters, while a validation dataset, running close-to-current operations, was used for verification of the *k*-NN model's predictive ability. Flows, stages, and consequences coming out of the *k*-NN model were compared to the benchmark model for each reach. The benchmark model was built on a sequence of ResSim flows, unsteady HEC-RAS model stages, and RASMapper depth grids. It is the best representation of those parameters available and was used to perform quality control checks on the *k*-NN model results.

The *k*-NN model produces water surface elevations at each cross section in the HEC-RAS models to build water surface profiles needed for flood mapping. Water surface profiles are used to create inundated area maps and depth grids during high water conditions (50 to 0.5 percent AEP). The *k*-NN fitting process was adapted to compute daily stages as well, using a new training dataset for year-round flows, which were aggregated into daily average values to match the ResSim output's daily timestep.

The output in the Monte Carlo analysis is post-processed with the FRA extract tool to take the set of 5,000 time series generated for a given location and parameter, e.g., stage at a given point in the river, and transform it into annual statistics by site, such as annual or seasonal maximums, average, or time above and below a threshold. The mostly-automated process generates AEP profiles in a tabular format as an XML document.

The replacement of HEC-RAS in the Monte Carlo modeling with *k*-NN lookup tables meets the needs of the CRSO study. However, the capability of *k*-NN is limited to the range of values to which it is fitted. The *k*-NN model outputs errors when it encounters a boundary condition value outside of the values found in the stage-flow relationships. This limitation should be considered when applying *k*-NN lookup tables to new reservoir operations alternatives, particularly those that change the downstream pool elevation to operate outside of the authorized limits.

CHAPTER 15 - REFERENCES

Brunner, Gary W. 2016. HEC-RAS, River Analysis System Hydraulic Reference Manual. Version 5.0. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Reference%20Manual.pdf. U.S. Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center. Davis, CA.

Draft Columbia River System Operations Environmental Impact Statement

Appendix B, Part 7

Grand Coulee Upstream Storage Correction Method Sensitivity Documentation

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ACRONYMS AND ABBREVIATIONS

CRS	Columbia River System
CRSO	Columbia River System Operations
Current Method	current upstream storage correction methodology
EIS	environmental impact statement
FRM	flood risk management
kaf	thousand acre-feet
Maf	million acre-feet
NGVD29	National Geodetic Vertical Datum of 1929
Proposed Method	measure referred to as the “Upstream Storage Corrections Method as applied to the Grand Coulee Storage Reservation Diagram”
SRD	Storage Reservation Diagram
TDA forecast	corrected April through August The Dalles unregulated flow forecast

CHAPTER 1 - INTRODUCTION AND PURPOSE

The purpose of this appendix is to examine the potential sensitivities of Grand Coulee Dam flood risk draft requirements to upstream U.S. Columbia River System (CRS) reservoir trapped storage[1] for the Current Method of calculating the Grand Coulee upstream storage correction (referred to as the Current Method) and the Proposed Upstream Corrections Method as applied to the Grand Coulee Storage Reservation Diagram (SRD) (referred to as the Proposed Method). The Proposed Method would change the way end-of-month target flood space elevation of Lake Roosevelt at Grand Coulee project ("project" is used to collectively refer to a given dam and its associated reservoir) is calculated. This measure is not intended to increase or decrease the current level of CRS flood risk but rather to ensure the upstream storage correction reflects the relationship between the geographic and hydrologic location of storage and the project's ability to manage flooding within the basin.

Review of historical records has found infrequent instances of CRS trapped storage. The simulation modeling of the Columbia River System Operations (CRSO) Multiple Objective Alternatives also shows infrequent occurrence of trapped storage. Of the historic instances of CRS trapped storage, most totaled less than 500 thousand acre-feet (kaf), and all were less than 1,000 kaf. Because trapped storage is not considered in the environmental impact statement (EIS), the potential difference in Grand Coulee flood risk management (FRM) drafts under the Proposed Method versus the Current Method is not evident. This sensitivity analysis explores this potential difference.

The Proposed Method differs from the Current Method in the way in which trapped storage in upstream CRS reservoirs is accounted for in the computation of monthly Grand Coulee FRM requirements. This measure allows the Grand Coulee project to reciprocally respond to un-anticipated trapped storage in an upstream CRS reservoir.

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[1] Trapped storage describes the volume of water projected to be in an upstream CRS reservoir in excess of that reservoir's April 30 FRM allowable storage.

CHAPTER 2 - DESCRIPTION OF GRAND COULEE CURRENT AND PROPOSED UPSTREAM STORAGE CORRECTION METHODOLOGIES

Chapter 2 describes the general procedure for computing the April 30 Grand Coulee FRM draft requirements under both the Current Method and the Proposed Method. Examples are provided to demonstrate the computation procedure and how trapped storage affects the April 30 FRM draft requirement under both methods. This section also introduces some concepts necessary for understanding the results and conclusions provided in this analysis.

2.1 CURRENT GRAND COULEE UPSTREAM STORAGE CORRECTION METHODOLOGY

Under the Current Method, the Grand Coulee April 30 draft requirement is determined from a relationship between the corrected April through August The Dalles unregulated flow forecast (TDA forecast) and the April 30 draft requirement. This relationship is shown in Figure 2-1. The forecast correction is the summation of all usable FRM storage space projected to be available as of April 30 by upstream CRS reservoirs. Usable FRM storage space for each reservoir is the lesser of the projected April 30 draft or the creditable refill of that reservoir. Creditable refill is defined as the volume of reservoir inflow minus the minimum reservoir outflow during the refill period (May through July). This correction is subtracted from the official TDA forecast to obtain the X-axis parameter (corrected TDA forecast) for use with the relationship shown in Figure 2-1.

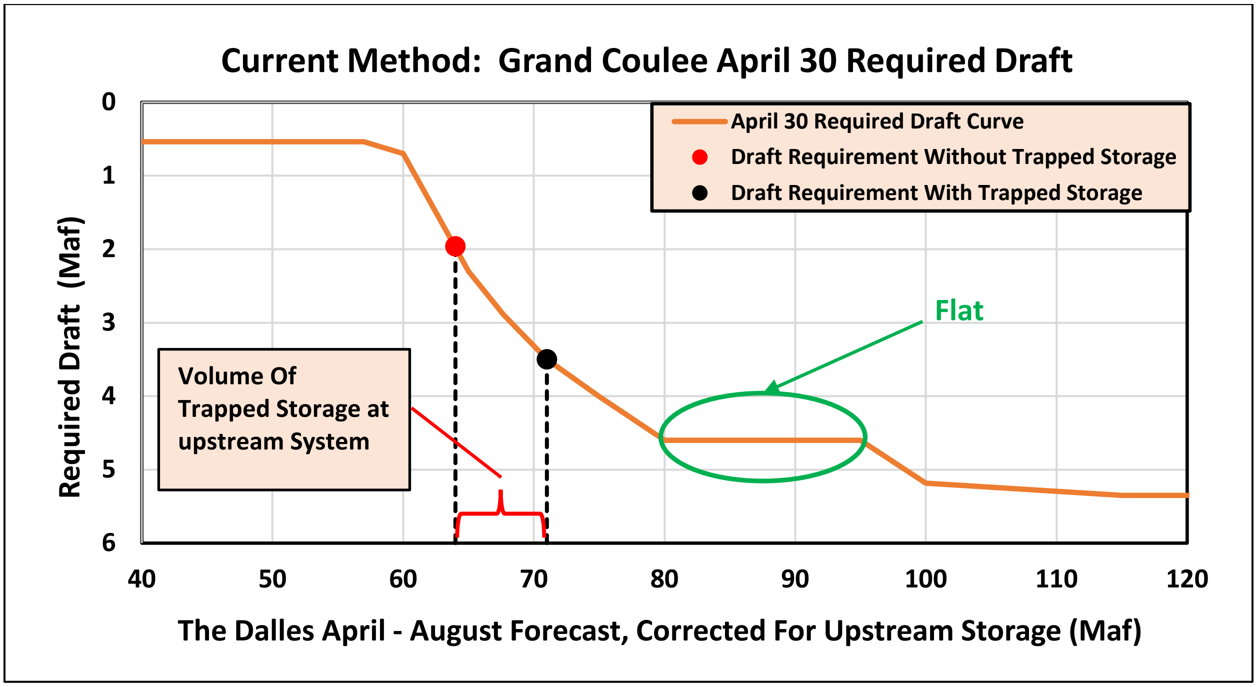


Figure 2-1. Current Method Grand Coulee April 30 Required Draft Curve Illustrating Adjustment for Trapped Storage in Upstream Columbia River System Reservoirs

As an example, assume that the official TDA forecast is 80 million acre-feet (Maf) and that the summation of all usable upstream FRM storage space is 16 Maf. Therefore, the TDA forecast corrected for upstream storage is 64 Maf (80 – 16 Maf). Using the relationship shown in Figure 2-1, the April 30 Grand Coulee FRM draft requirement is 2 Maf.

To understand how the Current Method treats upstream trapped storage in the determination of Grand Coulee April 30 draft requirements, the preceding example will be expanded. Assume that the original 16 Maf of usable upstream FRM storage space is reduced to 9 Maf due to 7 Maf of trapped storage in upstream CRS reservoirs. Now, the TDA forecast corrected for upstream storage is 71 Maf (80 – 9 Maf). Using the relationship shown in Figure 2-1, the April 30 Grand Coulee FRM draft requirement is now 3.5 Maf.

In this example, 7 Maf of trapped storage in upstream CRS reservoirs resulted in an increased April 30 draft requirement from 2 Maf to 3.5 Maf. As can be seen from Figure 2-1, the April 30 draft requirement relationship is non-linear. Therefore, the effects of trapped storage on April 30 draft requirements are highly dependent on the TDA forecast. For example, if the TDA forecast corrected for upstream storage falls in the 80 to 95 Maf range, trapped storage will have no effect on the April 30 draft requirement. This 80 to 95 Maf portion of the April 30 draft requirement curve is known as the “flat spot.”

The flat spot in the Grand Coulee SRD at elevation 1,222.7 feet (National Geodetic Vertical Datum of 1929 [NGVD29]) is an operating constraint established to address concerns with pumping from the John Keys Pump Generating Plant to Banks Lake (pump restarts and pumping efficiency) at low Lake Roosevelt Lake elevations.

2.2 PROPOSED GRAND COULEE UPSTREAM STORAGE CORRECTION METHODOLOGY

Similar to the Current Method, the Grand Coulee April 30 draft requirement under the Proposed Method is determined from a relationship between the TDA forecast and the Grand Coulee April 30 draft requirement. Unlike the Current Method, the Proposed Method relies on the official TDA forecast without the correction for upstream storage as its X-axis parameter. This relationship is shown in Figure 2-2. Note that the Current Method’s flat spot has been removed from the Proposed Method’s April 30 required draft curve in this analysis. This relationship assumes no trapped storage in upstream CRS reservoirs. If trapped storage does exist in any of the upstream CRS reservoirs, the Grand Coulee April 30 draft requirement is increased to offset the trapped storage induced reduction in CRS FRM space.

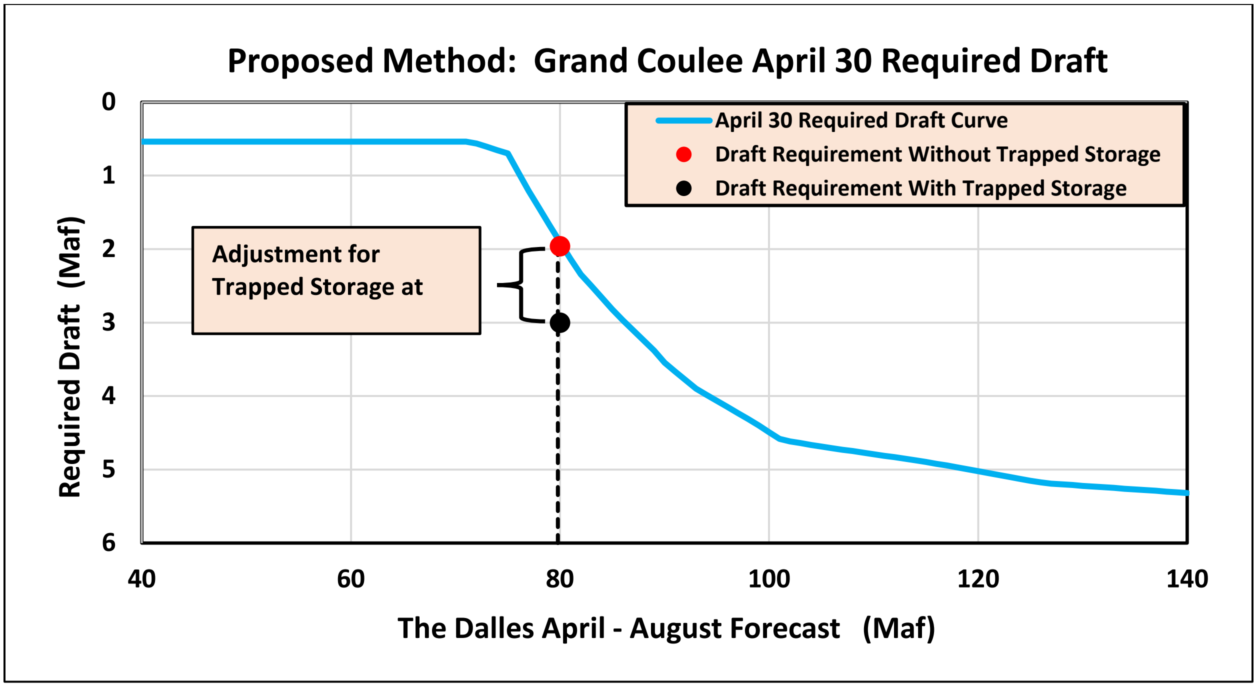


Figure 2-2. Proposed Method Grand Coulee April 30 Required Draft Curve Illustrating Adjustment for Trapped Storage in Upstream Columbia System Reservoirs

Unlike the adjustment to Grand Coulee April 30 draft requirement for trapped storage under the Current Method, the Proposed Method depends on which specific reservoir(s) has trapped storage, the volume of trapped storage in the reservoir(s), and the TDA forecast. To understand the computation of the adjustment for trapped storage under the Proposed Method, the concepts of Base Draft and Reservoir-Specific weighting factors need to be introduced.

Base Draft: For each U.S. CRS reservoir, the Base Draft is defined as the required April 30 draft for its respective system or local forecast. These drafts were designed to minimize CRS flood risk while still supporting reservoir refill. The reservoir base drafts are intended to be changeable to accommodate changes to an individual reservoir's operating requirements, hydrology, and CRS FRM operations.

Reservoir-Specific Weighting Factor Curves: Unlike the Current Method, which treats available FRM space in all CRS reservoirs as having the same relative benefit to CRS FRM, the Proposed Method recognizes that individual CRS reservoirs have differing CRS FRM benefits due to geographic location and hydrology. The Proposed Method uses Reservoir-Specific weighting factors, which are functions of the TDA forecast (shown in Figure 2-3). The Current Method implicitly incorporates reservoir weighting factors through the design of the April 30 draft requirement curve shown in Figure 2-1. Those implicit weighting factors are the same for all reservoirs and vary from 0 acre-feet per acre-foot of Grand Coulee space to 0.32 acre-foot per acre-foot of Grand Coulee space depending on the TDA forecast. For comparison, the Current Method's implicit weighting factors are also shown in Figure 2-3.

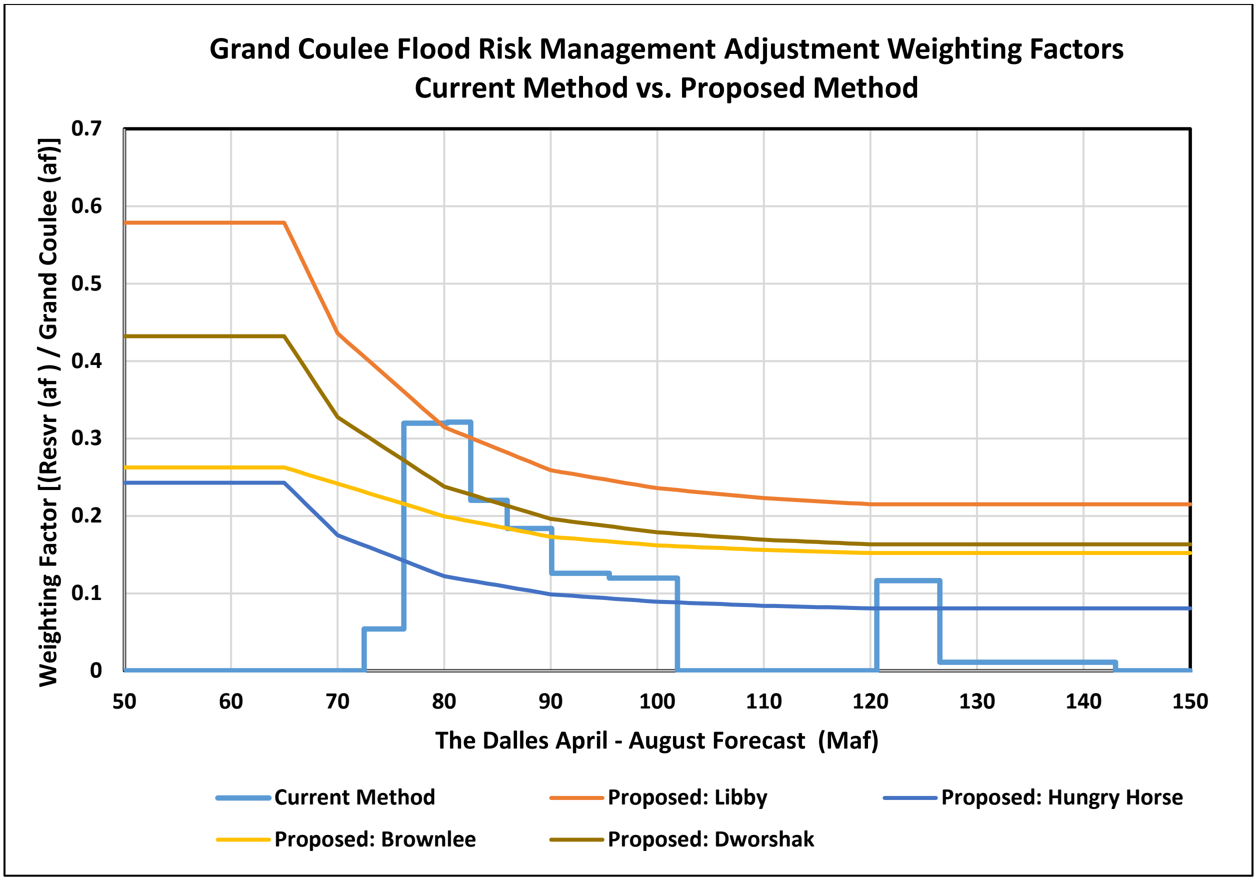


Figure 2-3. Comparison of Current Method and Proposed Method Weighting Factors

Determination of Grand Coulee April 30 draft requirements with and without trapped storage in upstream CRS reservoir(s) will be demonstrated through example using Figure 2-2 and Figure 2-3. Assume that the official TDA forecast is 80 Maf and that there is no trapped storage in any of the upstream CRS reservoirs. From the Grand Coulee April 30 draft requirement curve shown in Figure 2-2, for a TDA forecast of 80 Maf, the Grand Coulee April 30 draft requirement is 2 Maf.

To continue with the example by including trapped storage, assume that Base Draft (April 30 FRM draft requirements) for Libby, Hungry Horse, Dworshak, and Brownlee are as provided in Column (1) of Table 2-1 as determined from their respective local water supply forecasts. Further assume that the projections of the April 30 draft are as provided in Column (2). Trapped storage (3) is computed for each reservoir as the difference between the Base Draft (1) and projected April 30 draft (2). The reservoir-specific weighting factors (4) are determined from the reservoir-specific curves provided in Figure 2-3 for an 80 Maf TDA forecast. The adjustment due to trapped storage in each reservoir (5) is computed as the trapped storage in that reservoir (3) multiplied by that reservoir’s weighting factor (4). The total increase in Grand Coulee April 30 required draft for trapped storage in upstream CRS reservoirs is the summation of the individual reservoir adjustments, or 1.0 Maf. In this example, the final Grand Coulee FRM April 30 draft requirement is the 2.0 Maf requirement assuming no trapped storage plus the 1.0 Maf adjustment for trapped storage, or 3.0 Maf. In this example, the Grand Coulee April 30 FRM draft requirement was increased 1.0 Maf for a total of 4.6 Maf of trapped storage in upstream CRS reservoirs.

Table 2-1. Example Computation of Proposed Method Adjustment for Upstream Columbia River System Reservoir Trapped Storage

Column (Number)	(1)	(2)	(3) = (1) – (2)	(4)	(5) = (3) * (4)
Reservoir	**Base Draft (April 30 Required Draft) (Maf)**	**Projected April 30 Draft (Maf)**	**Trapped Storage (Maf)**	**Weighting Factor**	**Adjustment for Trapped Storage (Maf)**
Libby	4.0	1.9	2.1	0.32	0.66
Hungry Horse	2.0	0.6	1.4	0.12	0.17
Dworshak	1.5	0.8	0.7	0.13	0.09
Brownlee	0.8	0.4	0.4	0.20	0.08
Total	–	–	4.6	–	1.00

CHAPTER 3 - RESERVOIR MODELING APPROACH

Chapter 3 discusses the scope of analysis and modeling methods employed to demonstrate the sensitivity of operations at Grand Coulee resulting from trapped storage at upstream CRS reservoirs using both the Current and Proposed Methods.

3.1 SCOPE OF ANALYSIS

The CRS Model (HEC-WAT and ResSim) is used to simulate operations at Grand Coulee with trapped storage conditions at Brownlee, Libby, and Hungry Horse under the Proposed Method and Current Method for a series of forced trapped storage scenarios. To the extent possible, the forced trapped storage is apportioned to each of the three reservoirs in proportion to the maximum draft of each reservoir.

To demonstrate the sensitivity of changing the Grand Coulee SRD computation methodology to upstream trapped storage, reservoir operations consistent with the No Action Alternative (which includes the Current Method) are simulated under three target upstream trapped storage volumes. Also, reservoir operations consistent with the No Action Alternative (and updated to include the Proposed Method) are simulated for the same three volumes of total upstream trapped storage. Each simulation consists of 80 years of operations under the same historical (1928 to 2008) streamflow and forecast conditions. Table 3-1 summarizes the operational conditions and includes unique names (in bold) for each simulation.

Table 3-1. Summary of Simulations Performed

Upstream Trapped Storage (Increase from No Action)	No Action Alternative (Current Method)	No Action Alternative (Proposed Method)
None	NAA-C-0	NAA-P-0
500 kaf	NAA-C-500	NAA-P-500
1,000 kaf	NAA-C-1000	NAA-P-1000

3.2 MODEL IMPLEMENTATION

For the Proposed Method analysis, trapped storage is simulated by modifying the Proposed Method’s Base Draft requirements for Libby, Hungry Horse, and Brownlee. The Base Draft modifications are, to the extent possible, made in proportion to the maximum draft of the respective reservoirs. By increasing the respective Base Draft requirements to be deeper than the April 30 SRD value for each reservoir, the Proposed Method computes a volume stored above the Base Draft and considers it trapped storage. The model increases the Grand Coulee required draft to offset the computed trapped storage.

To provide a comparable analysis for the Current Method, the computation of the Grand Coulee upstream storage correction is modified so that it accounts for the same amount of upstream storage that is simulated in the Proposed Method. While keeping trapped storage consistent between simulations with the same target trapped storage, this approach effectively shows the change in Grand Coulee's April 30 FRM draft requirements and water surface elevations resulting only from the difference in computation methods.

3.2.1 No Increased Trapped Storage Scenario (NAA-C-0 and NAA-P-0)

The 0 kaf of CRS trapped storage using the Current Method is the No Action Alternative run renamed NAA-C-0 for this analysis. The 0-kaf CRS trapped storage Proposed Method (NAA-P-0) is identical to the No Action Alternative, but it employs the Proposed Method.

3.2.2 500-kaf Increased Trapped Storage Scenario (NAA-C-500 and NAA-P-500)

To simulate 500 kaf of CRS trapped storage with the No Action Alternative run (NAA-P-0), the Libby, Hungry Horse, and Brownlee Base Drafts were increased (deepened). The amount of Base Draft was determined by apportioning 500 kaf to each of the three reservoirs in proportion to their respective maximum FRM drafts. Table 3-2 shows the computation of the apportionment of 500 kaf among the three reservoirs.

Table 3-2. Apportionment of 500-kaf Trapped Storage

Project	Maximum FRM Draft (Maf)	Percent of Total Maximum FRM Draft (%)	500-kaf Trapped Storage Apportionment (kaf)
Libby	4.980	56%	279
Hungry Horse	2.981	33%	167
Brownlee	0.975	11%	55
Total	8.936	100%	500

For drier years, the reservoirs' April 30 draft requirements are less than the apportioned trapped storage. Because trapped storage cannot exceed each reservoir's required draft, the increase in Base Draft (and therefore trapped storage) was limited to the volume of the April 30 required draft for those drier years. For example, for years with TDA forecasts less than 62 Maf, the Libby April 30 required FRM draft is only 100 kaf. Therefore, trapped storage at Libby in those years was limited to 100 kaf, rather than the apportioned 279 kaf.

In some years, the trapped storage apportionment was allowed to exceed its computed apportionment to get as close as possible to the desired 500 kaf CRS trapped storage. For example, the Hungry Horse April 30 required draft for drier years is 345 kaf, which is much larger than its apportionment of 167 kaf. This additional 178 kaf capacity for trapped storage at Hungry Horse (178 kaf = 345 – 167 kaf) was used to offset the lack of trapped storage capacity at Libby and Brownlee for years in which the TDA forecast was less than 76 Maf.

Figure 3-1 shows the final apportionment of additional trapped storage for the 500-kaf scenario. Note that the total CRS additional trapped storage is less than the desired 500 kaf for years with The Dalles April to August forecasts of 66 Maf or less and does not meet the computed apportionments until years with forecasts of 85 Maf or greater.

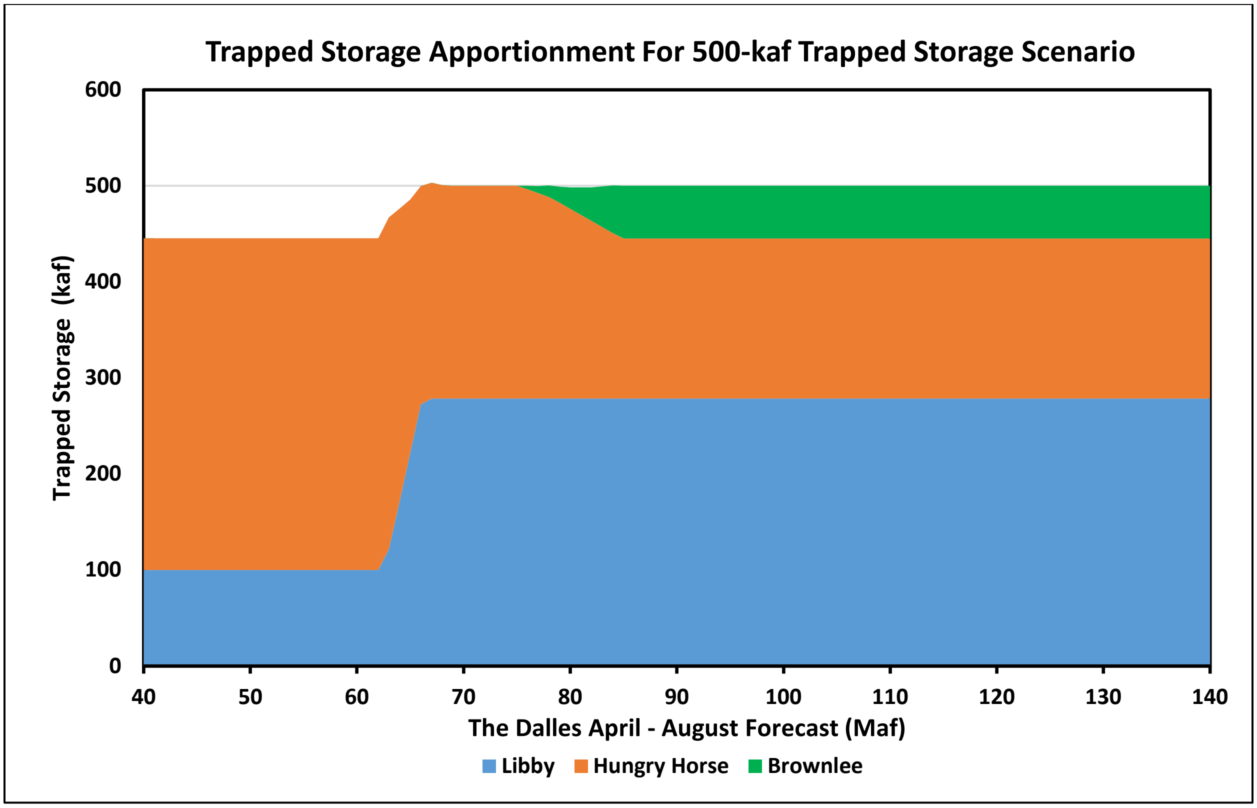


Figure 3-1. Apportionment of Trapped Storage for the 500-kaf Scenario

As described in Section 3.2, to provide a comparable 500 kaf trapped storage Current Method simulation (NAA-C-500), the corrected TDA forecast (parameter) is modified to account for the same amount of upstream storage that is simulated in the Proposed Method.

3.2.3 1,000-kaf Increased Trapped Storage Scenario (NAA-C-1000 and NAA-P-1000)

To simulate 1,000 kaf of CRS trapped storage with the No Action Alternative run (NAA-P-0), the Libby, Hungry Horse, and Brownlee Base Drafts were increased (deepened). The amount of Base Draft was determined by apportioning the 1,000 kaf to each of the three reservoirs in proportion to their respective maximum FRM drafts. Table 3-3 shows the computation of the apportionment of the 1,000 kaf among the three reservoirs.

Table 3-3. Apportionment of 1,000-kaf Trapped Storage

Project	Maximum FRM Draft (Maf)	Percent of Total Maximum FRM Draft (%)	1,000-kaf Trapped Storage Apportionment (kaf)
Libby	4.980	56%	557
Hungry Horse	2.981	33%	334
Brownlee	0.975	11%	109
Total	8.936	100%	1,000

As with the 500-kaf additional trapped storage scenario, the maximum potential for CRS trapped storage was less than the desired 1,000 kaf in drier years. For those drier years, the apportionment was modified, as described in Section 3.2.2, to come as close to the desired 1,000 kaf of additional trapped storage as possible. Figure 3-2 shows the final apportionment of additional trapped storage for the 1,000-kaf scenario. Note that the total CRS additional trapped storage is less than the desired 1,000 kaf for years with The Dalles April to August forecasts of 74 Maf or less and does not meet the computed apportionments until years with forecasts of 85 Maf or greater.

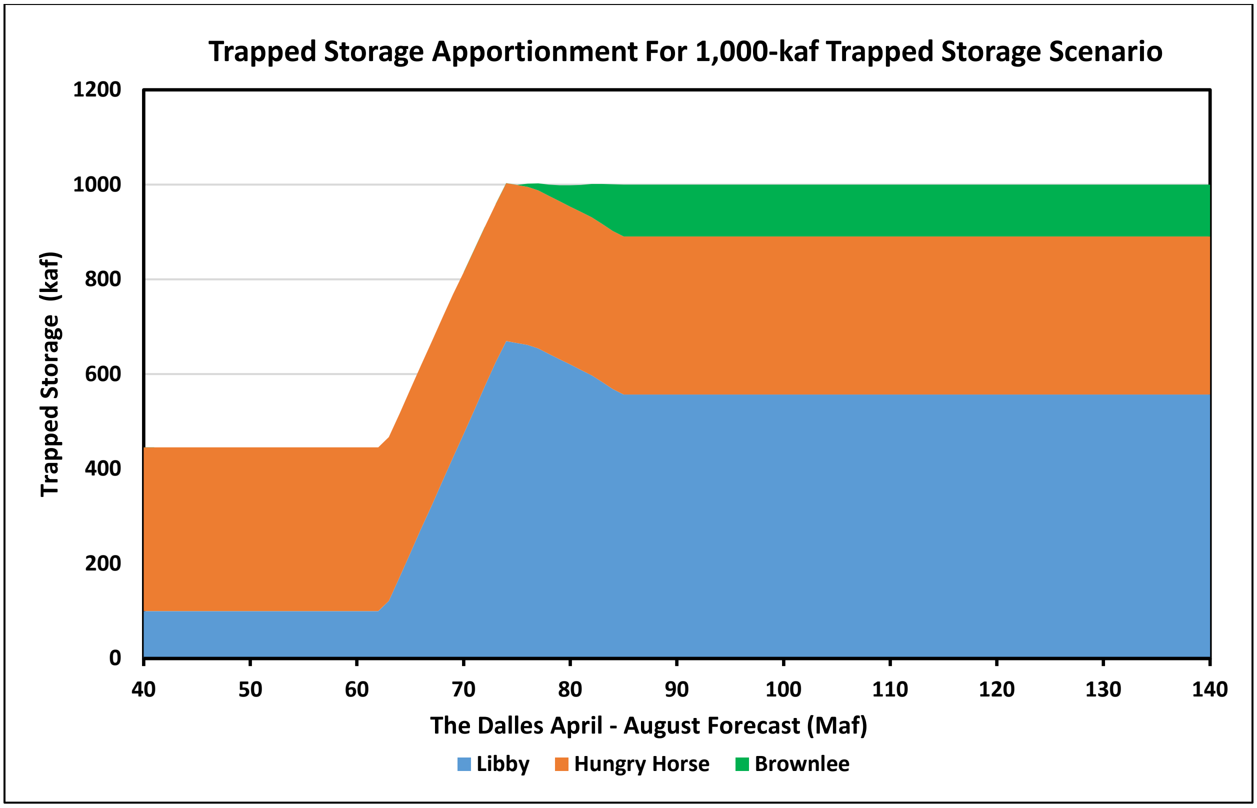


Figure 3-2. Apportionment of Trapped Storage for the 1,000-kaf Scenario

3.3 ASSUMPTIONS AND LIMITATIONS

Because the analysis was designed to describe changes to the operation at Grand Coulee only, implementation of trapped storage impacts for both the Proposed Method and the Current Method does not actually result in additional storage modeled at any reservoir or change the operation of that reservoir. It merely informs the upstream storage correction computation that there is trapped storage to provoke a deeper draft computation for Grand Coulee. Therefore, these model results may only be used to characterize impacts to Grand Coulee and cannot be used to characterize CRS-wide impacts to various resources.

This analysis assumes that, in any year, the amount of trapped storage that is physically possible is limited to the space required by the reservoir’s SRD (assuming the reservoir is at full pool). Therefore, in years when forecasts are low and little space is required by the SRD, the trapped storage used to inform the upstream storage correction computation must be less than the target values of 500 kaf and 1,000 kaf.

Consistent with the CRSO EIS Impact Analysis study approach, reservoir operations outside the United States and the resulting daily streamflow across the U.S.-Canada border and into the United States is held constant for all simulations.

As currently designed, the Proposed Method includes a provision that modifies the Dworshak Base Draft to reflect its ability to achieve refill. This provision does not allow the Dworshak Base Draft to be defined as a simple relationship between inflow forecast and required April 30 FRM draft. Therefore, the development of a Dworshak Base Draft that includes the appropriate proportion of a fixed CRS trapped storage would require significant effort and require additional variables to be considered during results analysis. For this reason, trapped storage at Dworshak was not included in this analysis.

CHAPTER 4 - DESCRIPTION OF RESULTS

4.1 YEAR-TYPE DEFINITION

To provide a more refined analysis of the effects of trapped storage on Grand Coulee April 30 water surface elevations, a set of year-type designations was defined. These year types were defined to match specific breakpoints in the Proposed Method's Grand Coulee April 30 required draft curve (see Figure 2-2) and to provide approximately the same number of years in each type. The year-type definitions were provided in Table 3-3.

The analysis revealed inconsistencies in drum gate maintenance years, with the Current Method requiring the maintenance operations more frequently than the Proposed Method, particularly in dry years. It was found that that the dry year inconsistencies in drum gate maintenance occurrences was due to modeling simplifications rather than a result of the change from the Current Method to the Proposed Method. The modeling simplification biases the Current Method to require drum gate maintenance more frequently in dry years. For this reason, it was decided to exclude all years with inconsistent drum gate maintenance operations from the analysis comparing the two methods. Table 4-1 shows the number of years of the 80-year model run that were defined as specific year types and used in this analysis.

Table 4-1. Water Year Type Definitions

Year Type	April 1 The Dalles April–August Forecast Range (Maf)	Total Number of Years	Number of Years (*excluding inconsistent drum gate years)*
Dry	0–76.2	22	17
Below Normal	76.3–90	21	20
Above Normal	90.1–101.9	22	21
Wet	102–200	15	15

Note: These year-type designations are specific to this analysis and are based on the April 1 TDA forecast.

4.2 COMPARISON OF CURRENT METHOD AND PROPOSED METHOD SENSITIVITY

This section uses the results of all six simulations to compare the Grand Coulee water surface elevation sensitivity between methods. CRS trapped storage weighting factors were found to be a significant factor in the sensitivity of each Method to trapped storage. The Current Method weighting factor and composites of the Proposed Method's Libby, Hungry Horse, and Brownlee weighting factors are provided in Figure 4-1. These composite weighting factors are a combination of the three reservoirs' individual weighting factors based on the relative amounts of trapped storage in each scenario. The composites are not actually used in the modeling but are provided here for simplification to assist in illustrating the differences between method sensitivity.

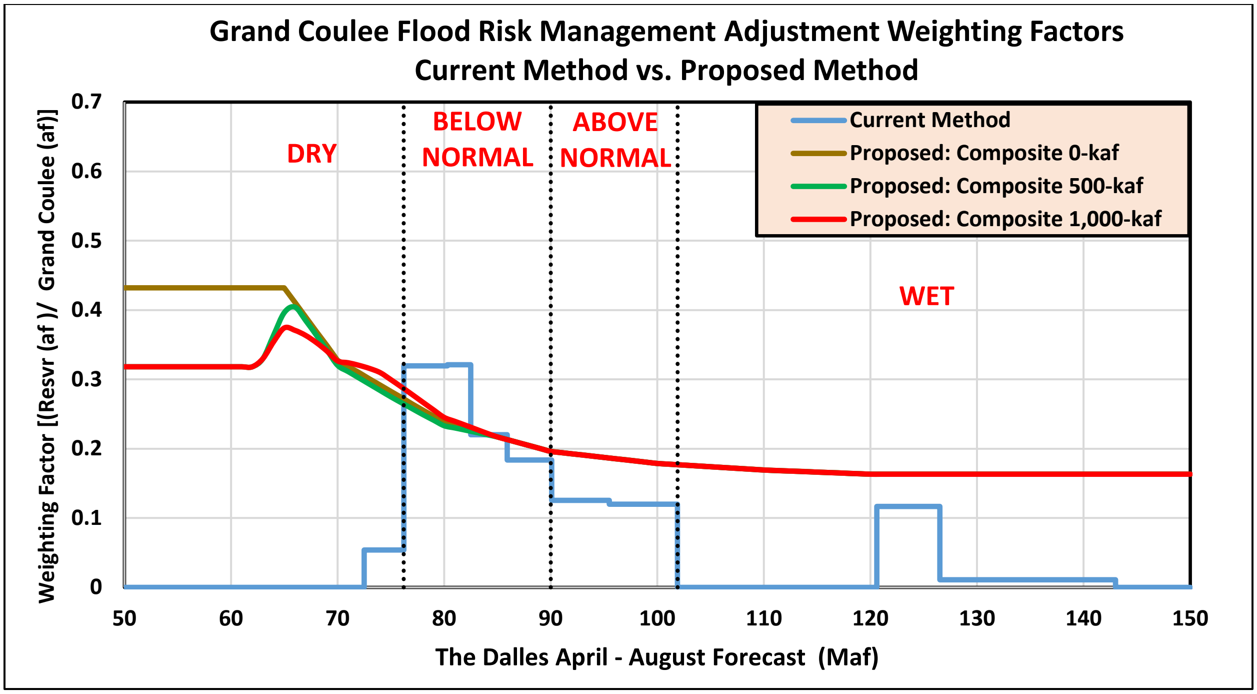


Figure 4-1. Current and Proposed Method Weighting Factors

The following series of eight graphs (Figure 4-2 to Figure 4-9) provide a comparison of the sensitivity of Grand Coulee April 30 water surface elevations to trapped storage in CRS reservoirs between the Current and Proposed Methods. Because this sensitivity varies with the relative wetness of the year as defined by the TDA forecast, comparisons of sensitivity will be performed for each of the four year types defined in this analysis. For each year type, there is a set of two graphs. The first graph of each set (e.g., Figure 4-2) provides box and whisker plots comparing the water surface elevations between the Current and Proposed Methods for each of the three trapped storage scenarios. The purpose of this graph is to show the range of water surface elevations for that water year type resulting from the three sets of trapped storage scenarios. The boxes of each plot define the 20 percent to 80 percent exceedance range of the data, and the whiskers define the 5 percent and 95 percent exceedance values.

The second graph of each water year set (e.g., Figure 4-3) provides two comparisons with box and whisker plots. The purpose of the left-most set of box plots is to illustrate the sensitivity of the Grand Coulee water surface elevation to 500 kaf of trapped storage under the Current Method, the sensitivity of the Grand Coulee water surface elevation to 500 kaf of trapped storage under the Proposed Method, and then to compare the Current Method sensitivity to the Proposed Method sensitivity. The first of the two box plots is the distribution of the differences between Grand Coulee water surface elevations between the Current Method 500-kaf trapped storage scenario (NAA-C-500) and the Current Method 0-kaf trapped storage scenario (NAA-C-0), while the second of the two box plots is the distribution of the differences between Grand Coulee water surface elevations between the Proposed Method 500-kaf trapped storage scenario (NAA-P-500) and the Proposed Method 0-kaf trapped storage scenario (NAA-P-0). The right-most set of two box plots provide those same comparisons for the imposition of 1,000 kaf of trapped storage.

In dry years (Figure 4-2), Grand Coulee April 30 water surface elevations average about 1,260 feet NGVD29 and generally range between 1,247 and 1,273 feet NGVD29 for all trapped storage scenarios under both the Current and Proposed Methods. This implies little sensitivity to trapped storage under either method. Figure 4-3 shows that water surface elevations are not sensitive at all to trapped storage under the Current Method and only slightly sensitive under the Proposed Method. The lack of Current Method sensitivity is due to the zero weighting factor in dry years under the Current Method (Figure 4-1) and non-FRM drivers controlling Grand Coulee operations. The slight Proposed Method sensitivity (<1.0 foot for both 500-kaf and 1,000-kaf trapped storage scenarios) is due to the relatively large dry year weighting factors applied to trapped storage in the Proposed Method. However, as with the Current Method, non-FRM operational drivers tend to control Grand Coulee operations in dry years.

In below-normal years (Figure 4-4), Grand Coulee April 30 water surface elevations average about 1,248 feet NGVD29 and generally range between 1,244 and 1,254 feet NGVD29 for all trapped storage scenarios under both the Current and Proposed Methods. In fact, the median water surface elevation is slightly higher under the Proposed Method than under the Current Method for all three trapped storage scenarios. Figure 4-5 shows that water surface elevations are relatively insensitive to trapped storage of 500 kaf under both methods (80 percent of differences < 0.82 foot). Both methods are more sensitive to the larger 1,000-kaf trapped storage, with differences in methods being similar. The similarity in sensitivity for below-normal years is due to the similarity in method weighting factors as shown in Figure 4-1. In addition, below-normal years are a transitional zone in which Grand Coulee operations are controlled by FRM requirements in some years and non-FRM operational drivers in others.

In above-normal water years (Figure 4-6), Grand Coulee April 30 water surface elevations generally range between 1,225 and 1,239 feet NGVD29 for all trapped storage scenarios under both the Current and Proposed Methods. In fact, the median water surface elevation is slightly higher under the Proposed Method than under the Current Method for all three trapped storage scenarios. Figure 4-7 shows that Grand Coulee water surface elevations are more sensitive to trapped storage under the Proposed Method than the Current Method for both the 500-kaf and 1,000-kaf trapped storage scenarios. Because Grand Coulee water surface elevations in above-normal years are almost entirely driven by FRM requirements, the increased sensitivity under the Proposed Method is due to the larger weighting factors of the Proposed Method in this water year category (approx. 0.18 acre-feet/acre-foot versus 0.12 acre-feet/acre-foot). The 50-percent-larger weighting factor applied in the Proposed Method manifests itself in approximately a 50-percent-larger draft requirement adjustment than the Current Method’s draft requirement adjustment.

In wet years (Figure 4-8), Grand Coulee April 30 water surface elevations generally range between fully drafted (1,208 feet NGVD29) and 1,236 feet NGVD29 for all trapped storage scenarios under both the Current and Proposed Methods. Median water surface elevations under all three trapped storage scenarios are significantly deeper (~10 feet) under the Proposed Method. The deeper water surface elevations are due to the removal of the flat spot from the April 30 Grand Coulee unadjusted draft requirement curve in the Proposed Method. Figure 4-9 further shows that water surface elevations are insensitive to trapped storage under the Current Method and very sensitive under the Proposed Method. This difference in sensitivity is entirely attributable to the difference in method weighting factors. Figure 4-1 showed that in the range of TDA forecasts of 101.9 to 120.6 Maf, the Current Method weighting factor is zero, whereas the composite Proposed Method weighting factor is approximately 0.18 acre-feet per acre-foot. In water years with TDA forecasts greater than 120.6 Maf, the on-call provision requires full draft of Grand Coulee regardless of trapped storage in CRS reservoirs.

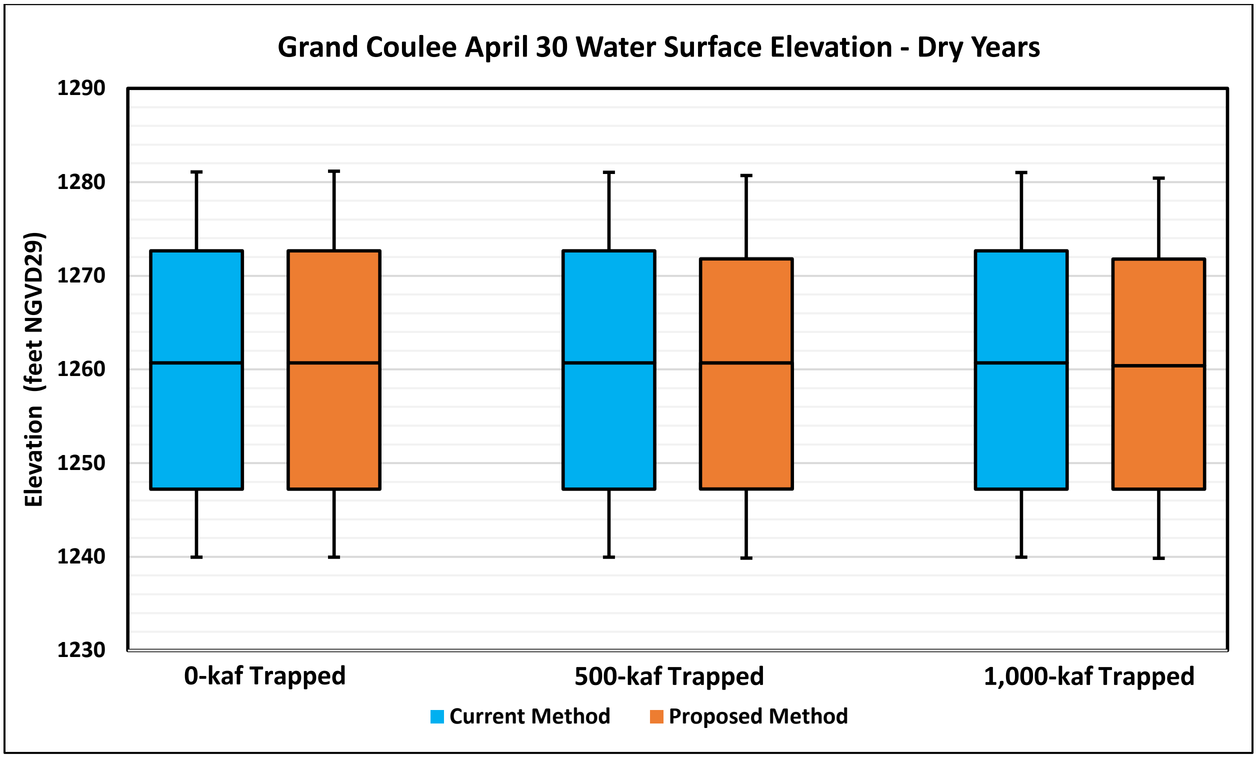
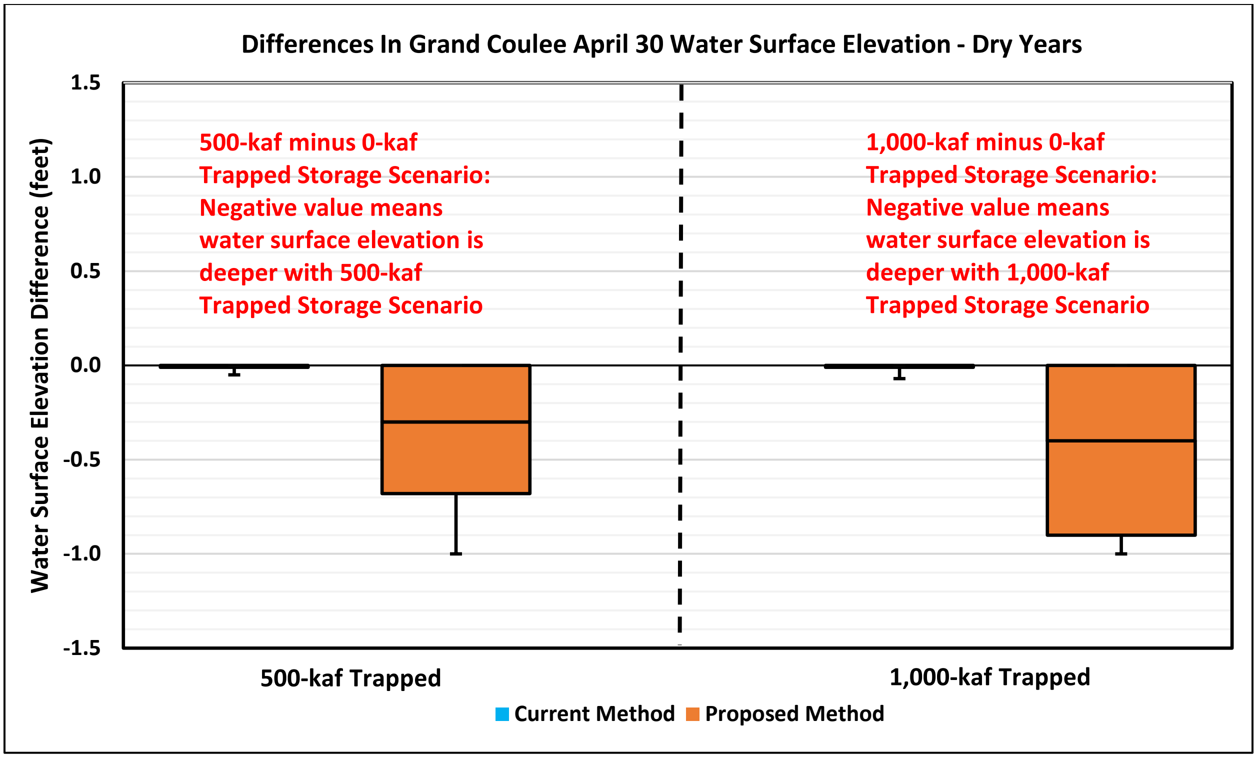


Figure 4-2. Dry Year Type Grand Coulee Water Surface Elevations



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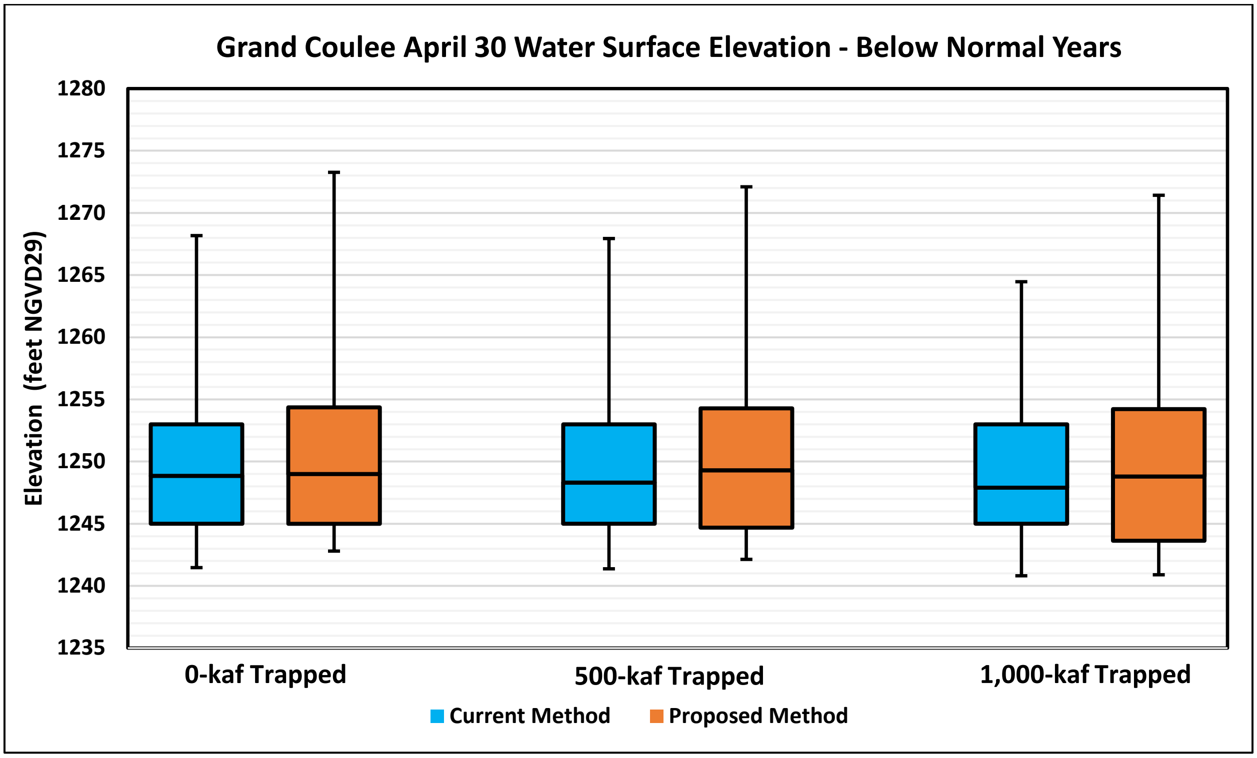
391 **Figure 4-3. Differences in Dry Year Type Grand Coulee Water Surface Elevations**



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393 **Figure 4-4. Below Normal Year Type Grand Coulee Water Surface Elevations**

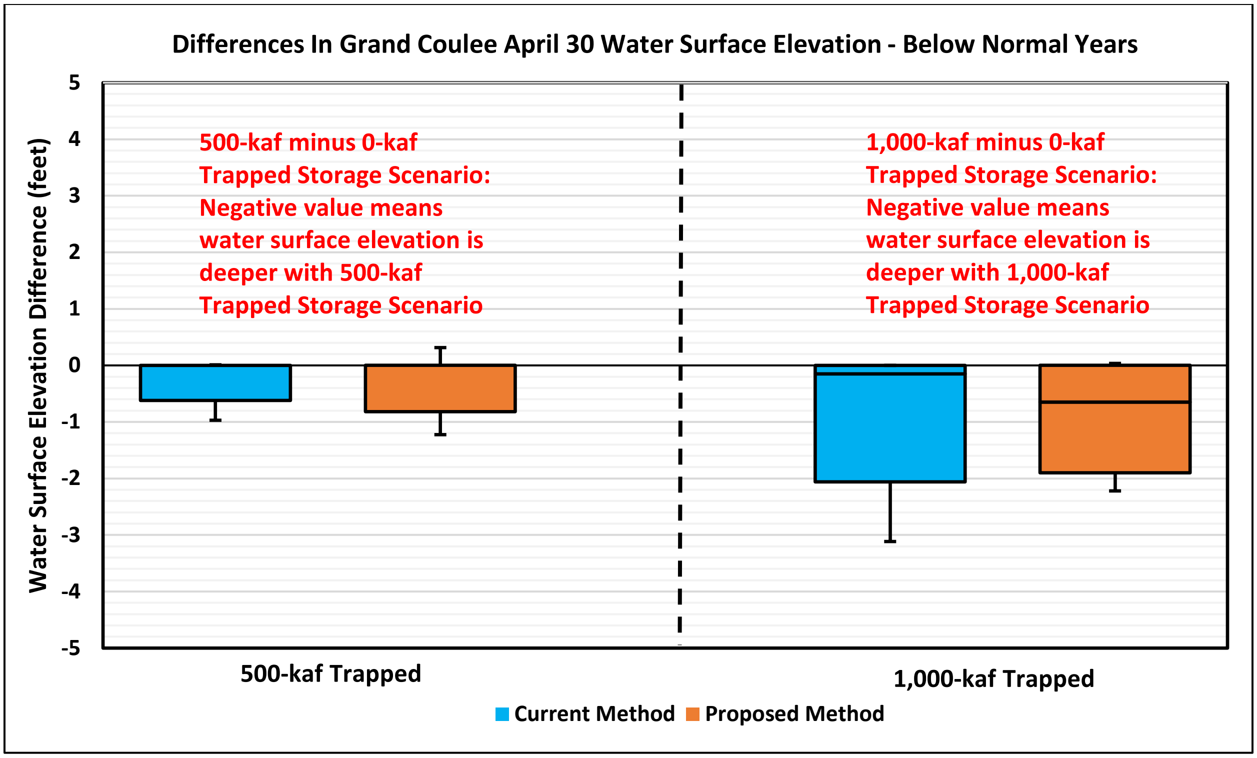

Figure 4-5. Differences in Below Normal Year Type Grand Coulee Water Surface Elevations

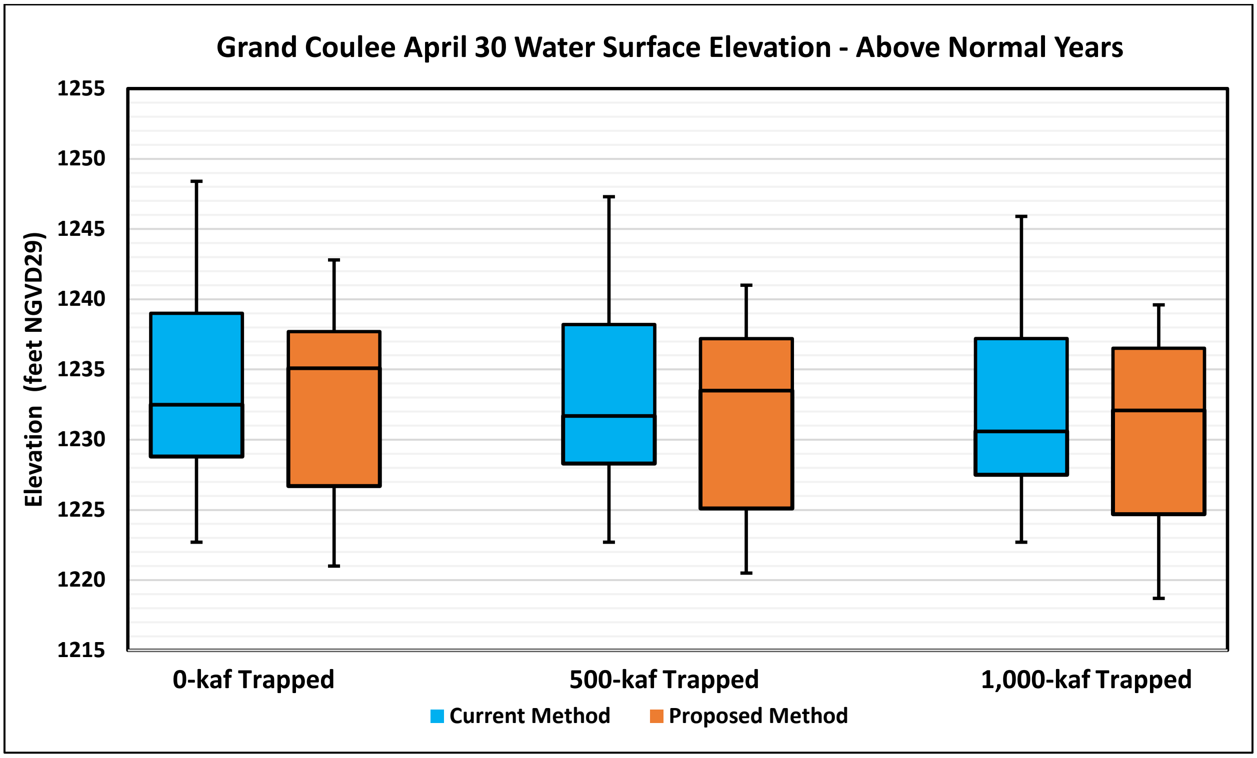

Figure 4-6. Above Normal Year Type Grand Coulee Water Surface Elevations

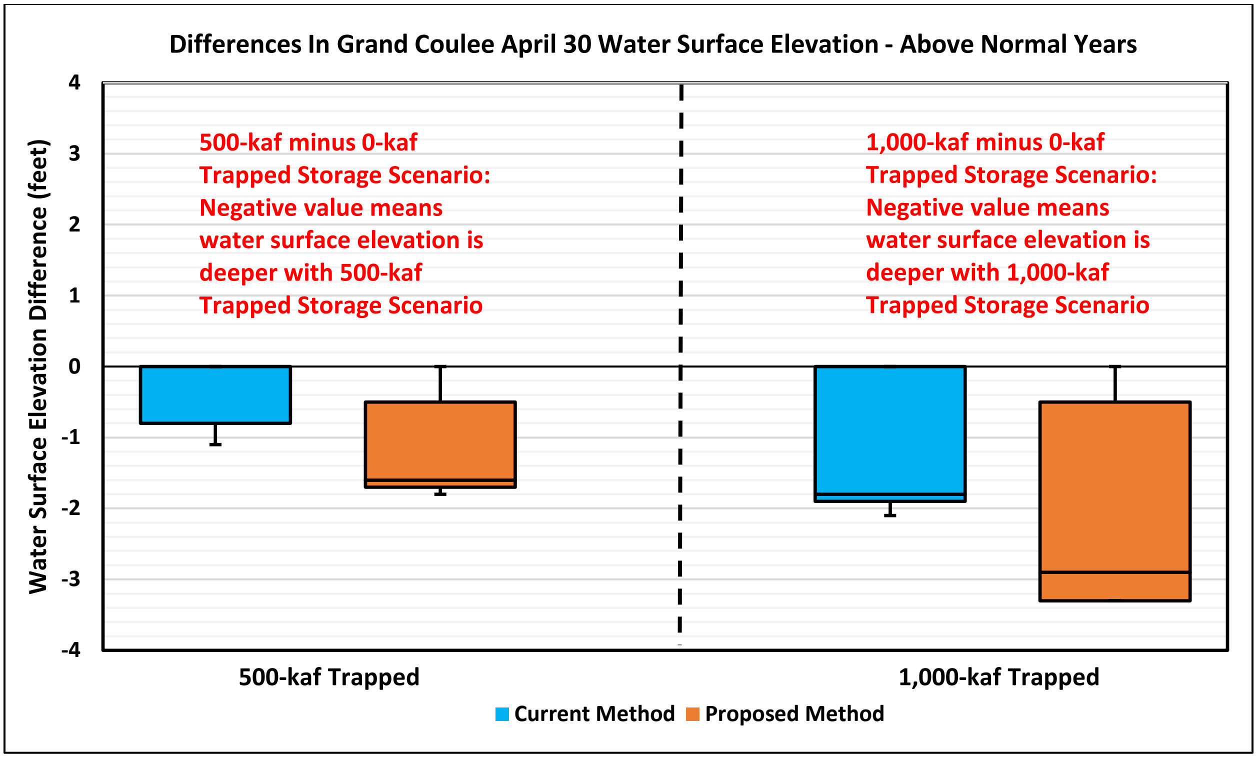

Figure 4-7. Differences in Above Normal Year Type Grand Coulee Water Surface Elevations

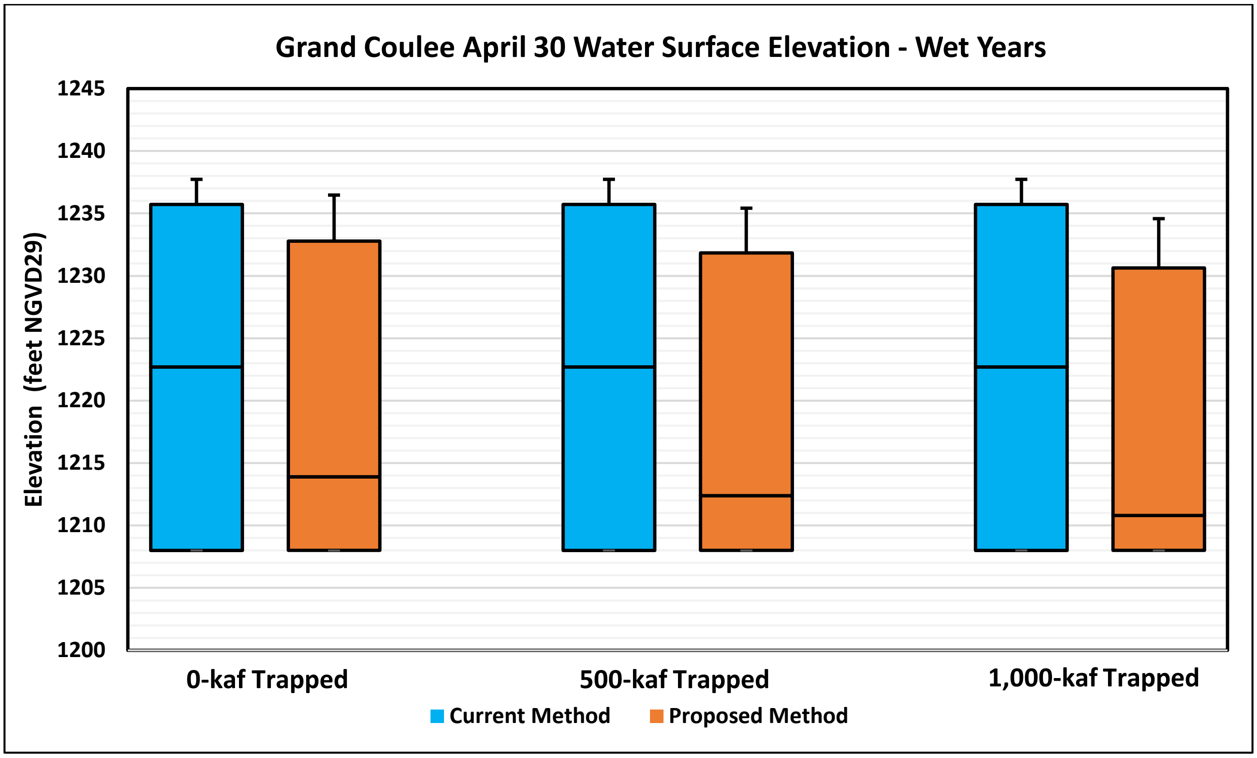

Figure 4-8. Wet Year Type Grand Coulee Water Surface Elevations.

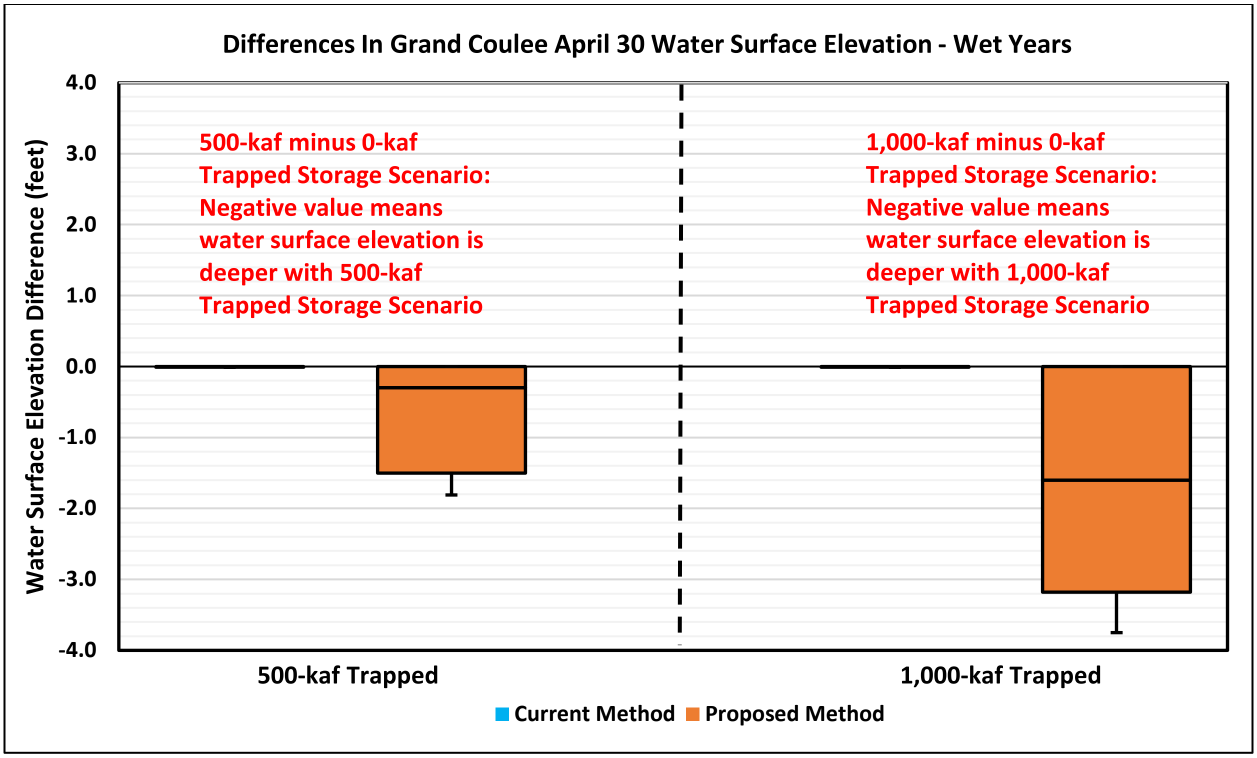

Figure 4-9. Differences in Wet Year Type Grand Coulee Water Surface Elevations

CHAPTER 5 - CONCLUSIONS

5.1 CONCLUSIONS

The Current and Proposed Methods of computing Grand Coulee FRM draft requirements both account for system reservoir trapped storage. The purpose of this analysis is to examine the sensitivity of Grand Coulee April 30 water surface elevations to trapped storage in upstream CRS reservoirs under the Current and Proposed Methods.

The sensitivity of Grand Coulee April 30 water surface elevations to trapped storage in CRS reservoirs is a function of two primary factors. First, both the Current and Proposed Methods employ weighting factors in the computation of Grand Coulee FRM draft requirements. The weighting factors, combined with the volume of CRS reservoir trapped storage, determine the volume of additional draft required at Grand Coulee to offset the CRS trapped storage for FRM purposes.

The second factor influencing sensitivity to trapped storage is Grand Coulee operational drivers. CRS reservoir trapped storage influences the computation of the Grand Coulee FRM draft requirements. These draft requirements place an upper limit on Grand Coulee water surface elevations. However, in many drier years, Grand Coulee’s operations for non-FRM purposes result in deeper drafts than the FRM draft requirements. In these instances, CRS reservoir trapped storage would have little to no effect on Grand Coulee water surface elevations.

The analysis of CRS reservoir trapped storage scenarios showed that Grand Coulee water surface elevations are insensitive to the tested trapped storage volumes under both the Current and Proposed Methods in dry years (TDA forecast < 76.5 Maf). In dry years, Grand Coulee drafts are almost always controlled by non-FRM drivers, negating any effects of increased FRM requirements on water surface elevations. Because the Proposed Method’s dry year weighting factors are large, it is possible that system trapped storage larger than the 1,000 kaf modeled for this analysis could begin to affect Grand Coulee water surface elevations. However, because system reservoir FRM draft requirements in dry years are minimal, there is a real limit to the amount of system trapped storage that could occur in dry years.

The Grand Coulee water surface elevation sensitivity to trapped storage in below-normal water year types (76.5 Maf < TDA forecast < 90 Maf) is very similar between the Current and Proposed Methods. Under both methods, the below-normal water year category is a transitional zone with respect to Grand Coulee water surface elevation sensitivity to trapped storage. Grand Coulee water surface elevations are driven by FRM requirements in some below-normal years and non-FRM operational requirements in others. In the years driven by FRM requirements, the water surface elevation sensitivity under both methods is dependent upon their respective weighting factors. Because the methods’ weighting factors are quite similar for below-normal water years, there is similar water surface elevation sensitivity. Due to the similarity in weighting factors, it is expected that the two methods would maintain similar water surface elevation sensitivity even with system trapped storage in excess of the modeled 1,000 kaf in below-normal year types.

In above-normal water years (90 Maf < TDA forecast < 101.9 Maf), Grand Coulee water surface elevations are more sensitive to trapped storage under the Proposed Method than under the Current Method. Because Grand Coulee water surface elevations in this year type are almost entirely driven by FRM requirements, the increased sensitivity under the Proposed Method is due to the larger weighting factors of the Proposed Method in this water year category (approximately 0.18 acre-feet/acre-foot versus 0.12 acre-feet/acre-foot). The 50 percent larger weighting factor applied in the Proposed Method manifests itself in approximately a 50 percent larger draft requirement adjustment than the Current Method's draft requirement adjustment.

The difference in Grand Coulee water surface elevation sensitivity between the Current and Proposed Method is most pronounced in wet year types (101.9 Maf < TDA forecast). The wet year TDA forecast range includes the Current Method's flat spot, resulting in a zero weighting factor being applied to system trapped storage under the Current Method in wet years. Therefore, Grand Coulee water surface elevation exhibits no sensitivity to trapped storage under the Current Method. In contrast, the composite weighting factor for the trapped storage scenarios in this analysis is approximately 0.18 acre-feet per acre-foot under the Proposed Method. Because Grand Coulee water surface elevations in wet years are almost entirely driven by FRM requirements, increases of system trapped storage directly affect water surface elevations under the Proposed Method.

It is important to recognize that this analysis uses a fixed apportionment of trapped storage between CRS reservoirs in determining Grand Coulee FRM draft requirement adjustments. While the Current Method treats trapped storage the same for all CRS reservoirs, the Proposed Method uses reservoir-specific weighting factors. As a result, the Proposed Method will likely exhibit greater Grand Coulee water surface elevation sensitivity than described in this analysis when CRS reservoir trapped storage occurs in the more heavily weighted CRS reservoirs.

Larger volumes (>1,000 kaf) of CRS reservoir trapped storage are also likely to affect the sensitivity of Grand Coulee water surface elevations under the Proposed Method more than under the Current Method. The larger magnitude adjustments would increase the Grand Coulee FRM draft and begin to overwhelm the non-FRM operational drivers that had been controlling Grand Coulee water surface elevations in the below-normal and dry water years.