Draft Columbia River System Operations Environmental Impact Statement

Appendix C
River Mechanics

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ACRONYMS AND ABBREVIATIONS

AdH	adaptive hydraulics model
Abv	above
Blw	below
Btw	between
Cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CR FNC	Columbia River FNC
CRM	Columbia River Mile(s)
CRS	Columbia River System
CRSO	Columbia River System Operations
EIS	Environmental Impact Statement
FCRPS	Federal Columbia River Power System
FNC	Federal Navigation Channel
FRM	flood risk management
H&H	hydrology and hydraulics
HG	hydrogeomorphic
LCR FNC	Lower Columbia River FNC
LWR FNC	Lower Willamette River (LWR) FNC
Mcy	million cubic yards
Mg/L	milligrams per liter
MO	Multiple Objective Alternative(s)
MO1	Multiple Objective Alternative 1
MO2	Multiple Objective Alternative 2
MO3	Multiple Objective Alternative 3
MO4	Multiple Objective Alternative 4
Mton	millions of tons
NAA	No Action Alternative
O&M	operations and maintenance
PA	Preferred Alternative
PSMP	2014 Lower Snake River Programmatic Sediment Management Plan
PTM	Particle Tracking Model
RM	River Mile
SKQ	Seli’š Ksanka Qlispe’ Dam
USGS	U.S. Geological Survey
VTD FNC	Vancouver, Washington, to The Dalles, Oregon, FNC
W/D	width-to-depth ratio

CHAPTER 1 - INTRODUCTION

This appendix is intended serve multiple purposes including providing an overview of the river mechanics analysis approach, documenting No Action Alternative results in greater detail than was provided in the main Environmental Impact Statement (EIS), and presenting the alternatives analyses, which compares the geomorphology and sediment transport condition metrics to those of the No Action Alternative. Additional detail on analysis assumptions, limitations, anomalies, and differences between quantitative results and changes to expected conditions is noted, as are discussions of non-quantitative factors that could potentially impact river mechanics conditions.

This appendix is composed of several parts. It includes (1) discussion of the methodology and river mechanics metrics, (2) a description of the study area and the baseline sediment transport and geomorphologic conditions based on stochastic hydroregulation modeling of the No Action Alternative, (3) a summary of quantitative metric results highlighting the changes in river mechanics conditions, and (4) an estimate of the potential impacts to river mechanics metrics under the No Action Alternative (NAA) and four Multiple Objective Alternatives (MO). Relative impacts are then compared between the MO and NAA. See Chapter 7 for a description of impacts to river mechanics as a result of implementing the draft preferred alternative.

CHAPTER 2 - METHODOLOGY

2.1 OVERVIEW

The general approach for evaluating river mechanics response in the system was to leverage the 5,000 years of stochastic daily flow and stage output from the quantitative hydroregulation planning models (see Appendix A) across the study area as inputs to a suite of quantitative river mechanics metrics. Discrete metrics were developed for storage projects, run-of-river reservoirs and free-flowing reaches as detailed in Chapter 2.3 below. Quantitative river mechanics metrics were limited to evaluating annual effects across operational hydroperiods representative of each multiple objective alternative and did not include seasonality effects. In addition, because the river mechanics quantitative metrics directly leveraged the hydroregulation planning models, they are subject to the baseline limitations and caveats of those models, including real-time management deviations, sub-daily variability resulting from power operations, and other irregular events such as equipment servicing and fisheries demands (see Appendix A.3.4).

2.2 STUDY AREA

While the Columbia River System (CRS) study is focused on operational or structural changes at specific hydroregulation projects and reaches, the interdependencies of water supply and flow routing required that the entire Columbia River Basin be represented in the quantitative hydroregulation planning models. Similar to the hydrology and hydraulics (H&H) analysis, the study area for the river mechanics metrics was also organized into four physiographic regions (Table 2-1; Figure 2-1). To develop representative summaries of river mechanics metric responses within the four regions, they were further discretized into major/minor reaches and subreaches. Major and minor reaches are primarily organized Federal Columbia River Power System (FCRPS) projects and stream network segments. Subreaches represent the finest resolution for grouping model/metric outputs and were selected based on localized details including valley type, tributary interactions, geomorphic context, and gradient. River mechanics metrics were computed across the CRS study area for all cross-sections of the H&H hydraulic model and subsequently aggregated by subreach into representative metric distributions as detailed herein.

Table 2-1. River Mechanics Study Area Regions

CRSO Region	River Basins
A	Kootenai, Flathead, and Pend Oreille Rivers
B	Middle Columbia River
C	Clearwater and lower Snake Rivers
D	Lower Columbia River

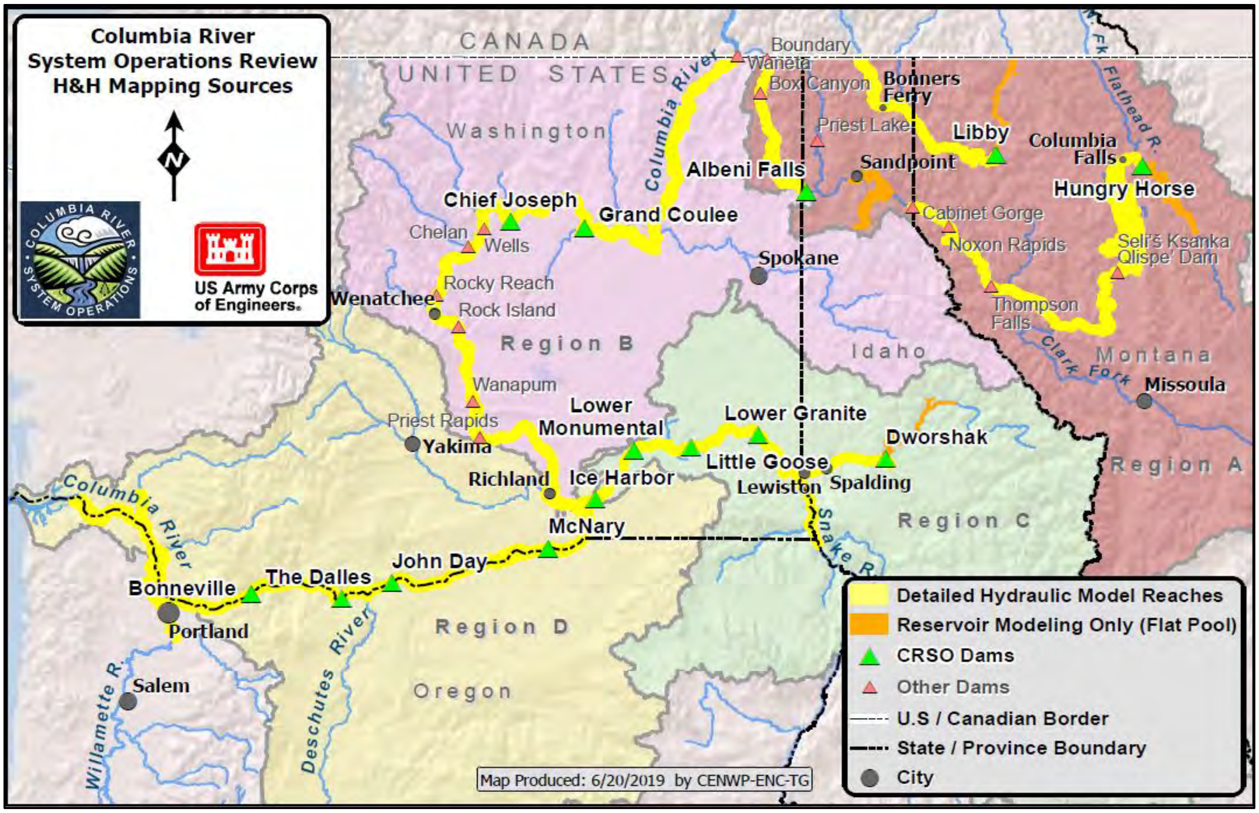


Figure 2-1. Overview Map of Study Area Regions Used for River Mechanics Assessment

2.2.1 Region A: Kootenai, Flathead, and Pend Oreille Basins

Region A includes the Kootenai, Flathead, and Pend Oreille Basins (Figure 2-2). There are nine hydroregulation projects located within Region A as listed in Table 2-2. Only three of the projects are operated for storage (Libby Dam, Hungry Horse, and Albeni Falls). The remaining six projects are not part of the CRS but were included in the hydroregulation planning model to quantify potential departure in metrics that could result due to operational changes between the upper basin storage projects and the Columbia River.

Table 2-2. Region A Hydroregulation Projects

Project Name	Project ID	River Name	Project Type	CRS EIS	CRM Location
Libby[1/]	LIB	Kootenai	Storage	Yes	1,119.2
Hungry Horse[1/]	HGH	Flathead	Storage	Yes	1,172.3
Seli'š Ksanka Qlispe'	SKQ	Flathead	Storage	No	1087.5
Thompson Falls	TOM	Clark Fork	Run-of-river	No	976.5
Noxon Rapids	NOX	Clark Fork	Run-of-river	No	939.3
Cabinet Gorge	CAB	Clark Fork	Run-of-river	No	919.9
Albeni Falls	ALF	Pend Oreille	Storage	Yes	859.2
Box Canyon	BOX	Pend Oreille	Run-of-river	No	803.3
Boundary	BND	Pend Oreille	Run-of-river	No	786.4

1/ Operated for storage.

Note: CRM = Columbia River Miles.

The Kootenai River Basin study area spans approximately 115 river miles from the Libby Dam storage project upstream in northwestern Montana to the U.S.-Canada border downstream at Porthill, Idaho (Table 2-3). Inflow to the Kootenai River study reach includes Libby Dam outflows and several tributaries, including the Fisher, Yaak, and Moyie Rivers. The upper approximately 70 miles of the reach are free flowing, and the downstream subreaches transition to run-of-river near Bonner's Ferry, Idaho, due to the backwater influence from Kootenay Lake downstream in Canada.

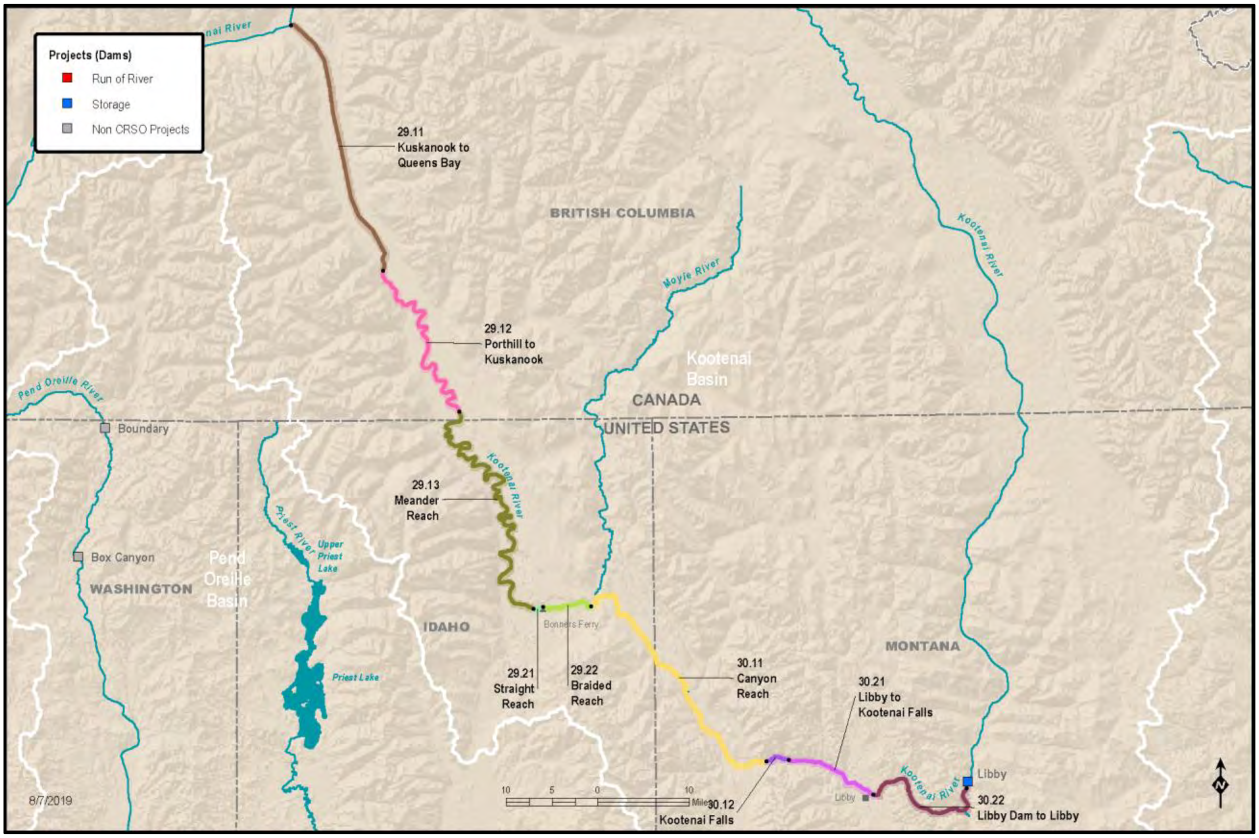


Figure 2-2. Region A1 Kootenai River Subreaches between Libby Dam and the U.S.-Canada Border

Table 2-3. Kootenai River Subreaches between Libby Dam and the U.S.-Canada Border

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
30.22	Libby Dam to Libby	Free flowing	15.9	1,103.29	1,119.19	4.5
30.21	Libby to Kootenai Falls	Free flowing	9.69	1,093.31	1,103.00	6.9
30.12	Kootenai Falls	Free flowing	2.97	1,089.83	1,092.80	19.0
30.11	Canyon Reach	Free flowing	32.52	1,056.86	1,089.38	4.5
29.22	Braided Reach above Bonner's Ferry	Free flowing and run-of-river	5.96	1,050.58	1,056.54	2.7

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
29.21	Straight Reach below Bonner's Ferry	Run-of-river	1.13	1,049.40	1,050.53	1.0
29.13	Meander Reach above U.S-Canada border	Run-of-river	45.3	1,004.07	1,049.37	0.06

The Flathead River Basin study area extends approximately 158 river miles between Hungry Horse Dam upstream and the Clark Fork River confluence downstream (Figure 2-3; Table 2-4). Seli'š Ksanka Qlispe' Dam (SKQ) located downstream of Flathead Lake subdivides the upper and lower Flathead River reaches. Inflow to the upper Flathead River reach includes Hungry Horse Dam outflows on the South Fork Flathead River, the unregulated Middle and North Forks of the Flathead River, and smaller Flathead Valley tributaries including the Whitefish and Stillwater Rivers. Inflows to the lower Flathead River reach include SKQ outflows and the Jocko River.

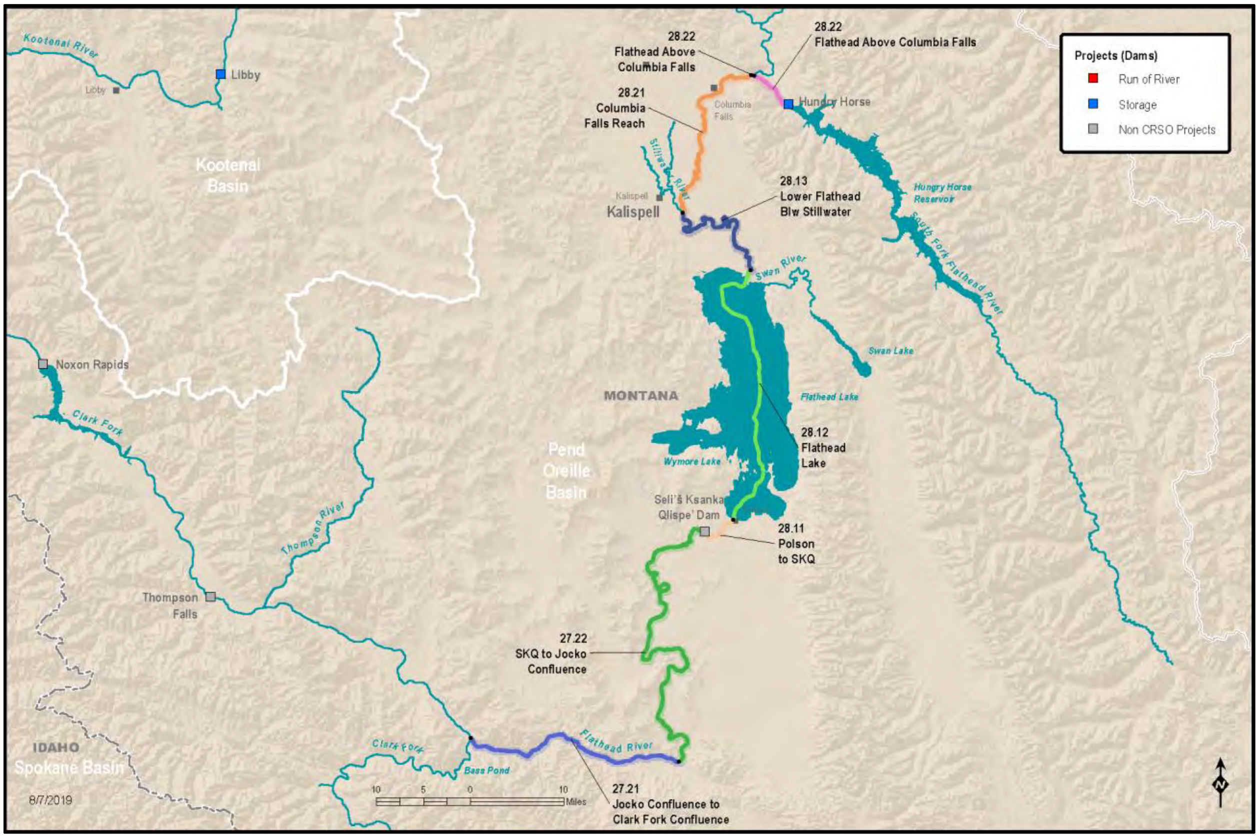


Figure 2-3. Flathead River Subreaches between Hungry Horse Dam and the Clark Fork River Confluence

Table 2-4. Flathead River Subreaches between Hungry Horse Dam and the Clark Fork River Confluence

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
28.22	Hungry Horse Dam to Columbia Falls	Free flowing	4.79	1,167.498	1,172.286	6.5
28.21	Columbia Falls Reach	Free flowing	22.96	1,143.811	1,166.769	6.1
28.13	Lower Flathead River below Stillwater	Run-of-river	19.11	1,124.297	1,143.407	0.04
28.12	Flathead Lake	Storage reservoir	31.22	1,092.521	1,123.737	8.8E-05
28.11	Polson to SKQ	Run-of-river	4.54	1,087.503	1,092.043	0.12
27.22	SKQ to Jocko River Confluence	Free flowing	47.15	1,040.317	1,087.469	10.0
27.21	Jocko River Confluence to Clark Fork River Confluence	Free flowing	25.13	1,014.397	1,039.525	0.99

Within the study area, the Pend Oreille Reach spans approximately 227 river miles and includes both the lower Clark Fork River (below its confluence with the Flathead River) and the Pend Oreille River upstream of the U.S.-Canada border (Figure 2-4).

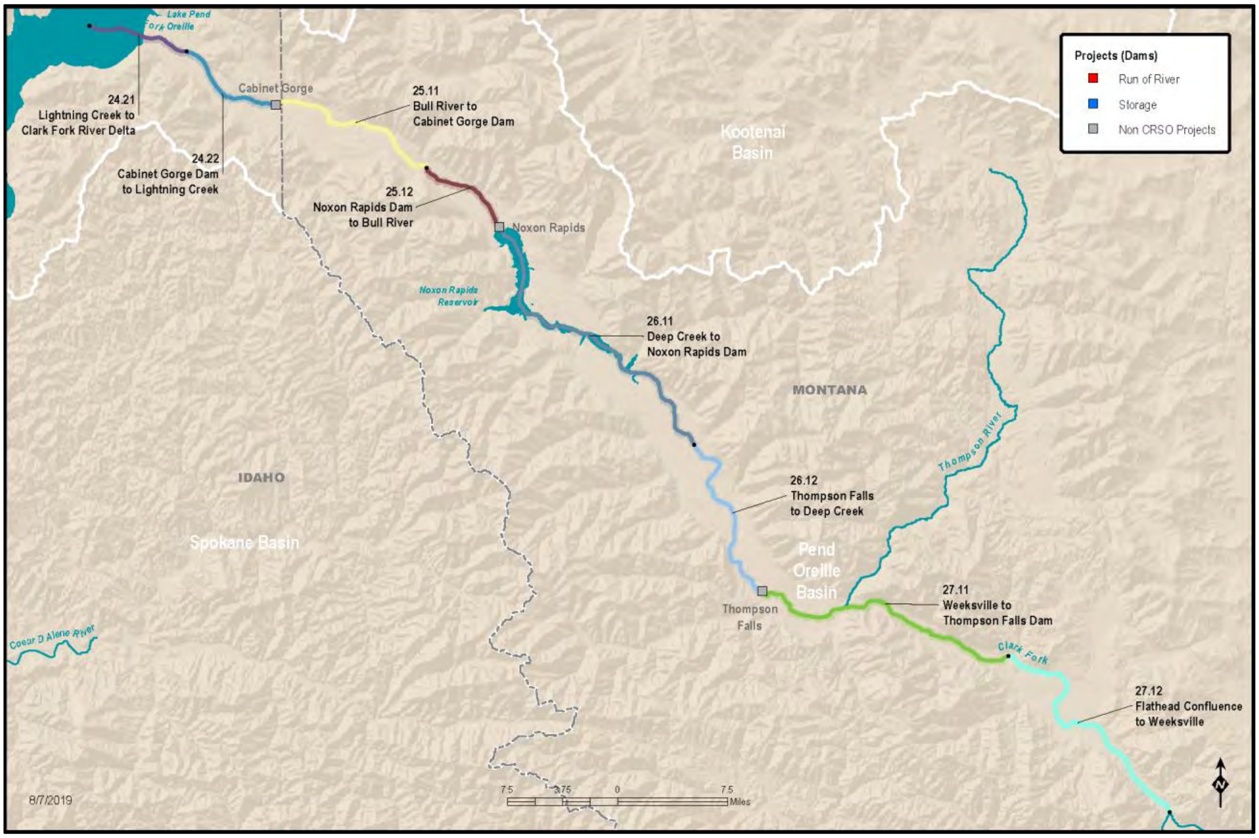


Figure 2-4. Lower Clark Fork Subreaches between the Flathead River Confluence and Lake Pend Oreille

The Lower Clark Fork River subreach extends approximately 109 river miles from the Flathead River confluence upstream to Lake Pend Oreille downstream. There are three non CRSO run-of-river projects within the subreach: Thompson Falls, Noxon Rapids, and Cabinet Gorge which can locally influence Clark Fork River hydraulics. Inflows to the Lower Clark Fork River subreach include outflow from the Flathead River reach noted above, contributions from the Upper Clark Fork River basin outside of the study area, and other lateral tributary inputs including the Thompson River, Bull River, and Lightning Creek (Table 2-5).

Table 2-5. Lower Clark Fork River Subreaches between Flathead River Confluence and Lake Pend Oreille

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
27.12	Flathead Confluence to Weeksville	Free flowing	17.68	996.030	1,013.707	3.04
27.11	Weeksville to Thompson Falls Dam	Run-of-river	19.04	976.482	995.517	0.81
26.12	Thompson Falls to Deep Creek	Run-of-river	13.31	963.349	976.659	1.05
26.11	Deep Creek to Noxon Rapids Dam	Run-of-river	23.06	939.329	962.389	1.05
25.12	Noxon Rapids Dam to Bull River	Run-of-river	6.85	932.386	939.236	0.23
25.11	Bull River to Cabinet Gorge Dam	Run-of-river	12.52	919.846	932.366	0.008
24.22	Cabinet Gorge Dam to Lightning Creek	Run-of-river	7.84	911.930	919.766	1.34
24.21	Lightning Creek to Clark Fork River Delta	Run-of-river	6.29	905.034	911.324	0.58

The Pend Oreille River subreach spans approximately 118 river miles between the Clark Fork River Delta on Lake Pend Oreille upstream to Boundary Dam downstream at the U.S.-Canada border in northeast Washington (Figure 2-5; Table 2-6). There is one CRSO storage project (Albeni Falls) and two non-CRSO run-of-river projects (Box Canyon and Boundary) that influence hydraulic response within the reach. Inflows to the Pend Oreille River include outflows from the Albeni Falls storage project (which includes notable volume from the Priest River) and minor tributaries including Calispell and Sullivan Creeks (which do not appreciably influence flow rates). Downstream of Boundary Dam, the Pend Oreille River flows north into Canada where it joins the Columbia River approximately 17 miles downstream near Waneta Dam, BC.

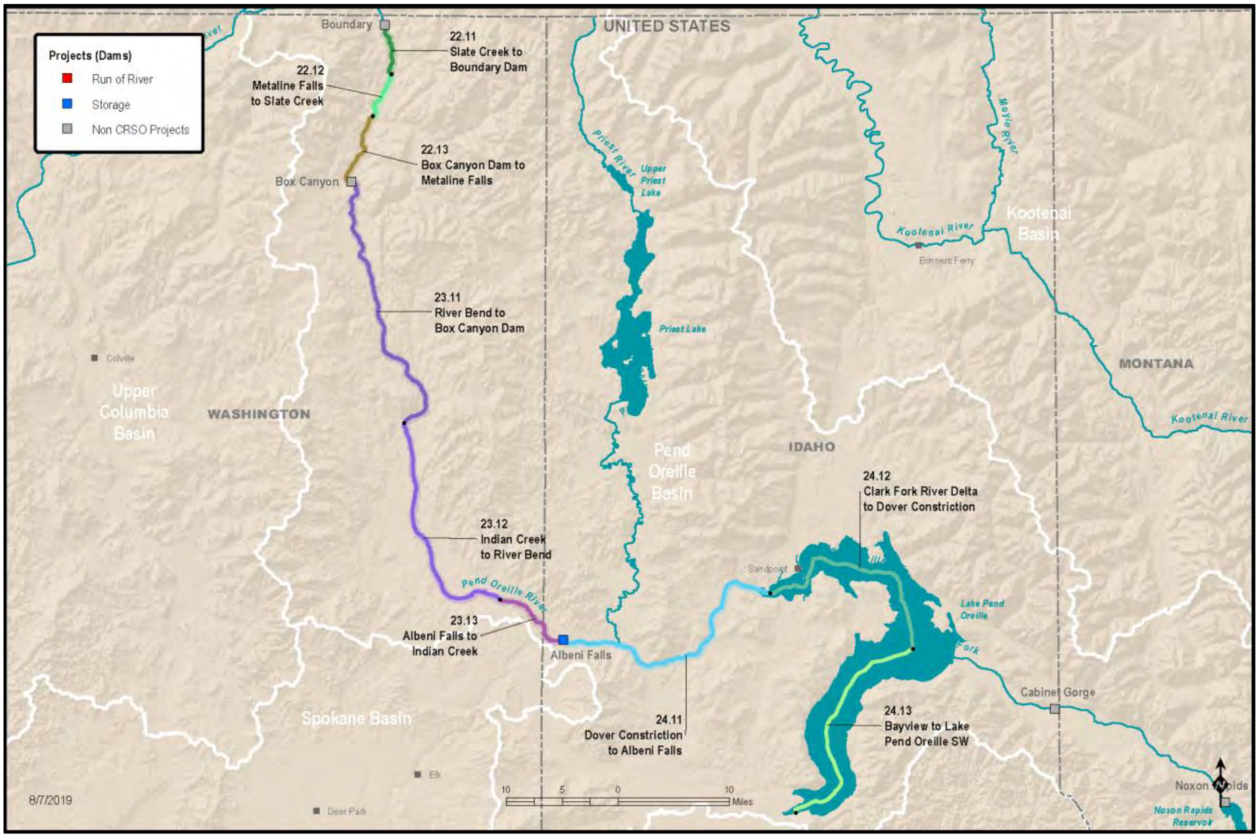


Figure 2-5. Lower Clark Fork and Pend Oreille River Subreaches between Flathead River Confluence and U.S.-Canada Border

Table 2-6. Pend Oreille River Subreaches between Lake Pend Oreille and Boundary Dam

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
24.13	Bayview to Lake Pend Oreille SW	Storage project	21.44	905.151	926.586	5.3E-06
24.12	Clark Fork River Delta to Dover Constriction	Run-of-river reservoir	20.39	884.41	904.806	0.001
24.11	Dover Constriction to Albeni Falls	Run-of-river	24.65	859.22	883.873	0.03
23.13	Albeni Falls to Indian Creek	Run-of-river	7.52	851.505	859.025	0.18
23.12	Indian Creek to River Bend	Run-of-river	21.23	829.751	850.985	0.05
23.11	River Bend to Box Canyon Dam	Run-of-river	26.22	803.261	829.481	0.05
22.13	Box Canyon Dam to Metaline Falls	Run-of-river	7.26	795.981	803.237	0.33
22.12	Metaline Falls to Slate Creek	Run-of-river	4.48	791.487	795.964	0.71
22.11	Slate Creek to Boundary Dam	Run-of-river	5.06	786.375	791.432	0.008

2.2.2 Region B: Middle Columbia

Region B includes the middle Columbia River Basin as it enters the United States from Canada. There are seven hydroregulation projects located within Region B as listed in Table 2-7. Only one of the projects (Grand Coulee) is operated for storage; two of the projects (Grand Coulee and Chief Joseph) have modified operational measures under the CRSO EIS. The remaining five projects downstream of Chief Joseph are all run-of-river and are not part of the CRS; however, they were included in the hydroregulation planning model to quantify potential departure in metrics that could result due to operational changes between Lake Roosevelt upstream and the lower Columbia River downstream.

Table 2-7. Region B Hydroregulation Projects

Project Name	Project ID	River Name	Project Type	CRSO Project	CRM Location
Grand Coulee[1/]	GCH	Columbia	Storage	Yes	596.6
Chief Joseph	CHJ	Columbia	Run-of-river	Yes	545.7
Wells	WEL	Columbia	Run-of-river	No	516.3
Rocky Reach	RRH	Columbia	Run-of-river	No	474.9
Rock Island	RIS	Columbia	Run-of-river	No	453.9
Wanapum	WAN	Columbia	Run-of-river	No	415.2
Priest Rapids	PRD	Columbia	Run-of-river	No	397.1

1/ Operated for storage.

The middle Columbia River Basin study reach spans approximately 413 river miles from the U.S.-Canada border upstream in northeastern Washington to Richland, Washington, downstream near the Yakima River confluence (Figure 2-6 and Figure 2-7; Table 2-8). Inflow contributions to the mainstem Columbia River in this study reach are predominately from 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. Tributary inflows to the Columbia River within this study reach include the Spokane, Chelan, Wenatchee, and Yakima Rivers.

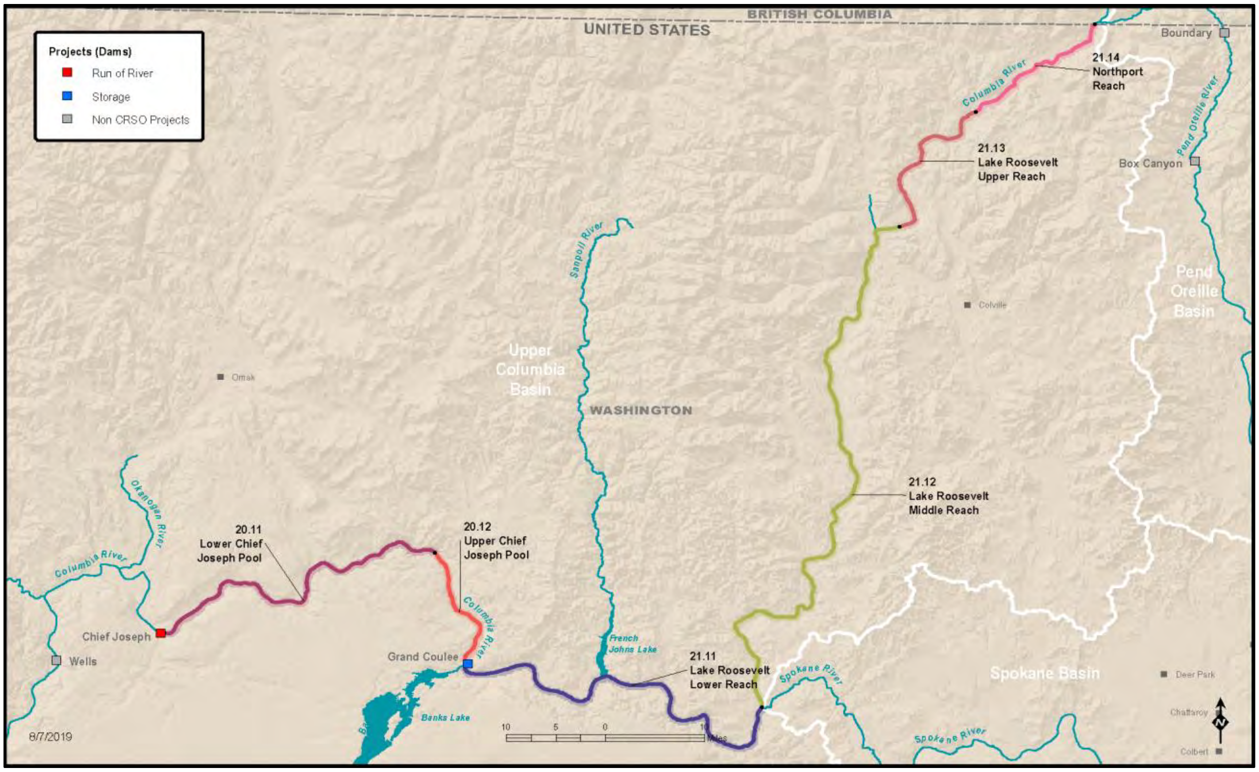


Figure 2-6. Middle Columbia River Subreaches between the U.S.-Canada Border and Chief Joseph Dam

Figure 2-7. Middle Columbia River Subreaches between Chief Joseph Dam and Richland, Washington

Table 2-8. Middle Columbia River Subreaches between the U.S.-Canada Border and Richland, Washington

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
21.14	Northport Reach	Storage	17.11	731.110	748.216	1.32
21.13	Lake Roosevelt Upper Reach	Storage	19.56	711.482	731.045	0.17
21.12	Lake Roosevelt Middle Reach	Storage	70.02	640.716	710.738	0.003
21.11	Lake Roosevelt Lower Reach	Storage	43.46	596.635	640.094	1.3E-04
20.12	Upper Chief Joseph Pool	Run-of-river	14.65	582.688	597.338	0.44
20.11	Lower Chief Joseph Pool	Run-of-river	36.09	545.668	581.758	0.01
19.12	Upper Wells Pool	Run-of-river	15.16	530.384	545.544	0.21
19.11	Lower Wells Pool	Run-of-river	14.07	516.294	530.3635	0.78
18.12	Upper Rocky Reach Pool	Run-of-river	11.97	503.522	515.489	1.63
18.11	Lower Rocky Reach Pool	Run-of-river	28.24	474.852	503.095	1.18
17.12	Upper Rock Island Pool	Run-of-river	5.13	469.080	474.212	0.53
17.11	Lower Rock Island Pool	Run-of-river	14.57	453.920	468.490	0.11
16.12	Upper Wanapum Pool	Run-of-river	19.63	433.840	453.470	0.26
16.11	Lower Wanapum Pool	Run-of-river	17.29	415.190	432.480	0.005
15.11	Priest Rapids Pool	Run-of-river	17.99	397.110	415.100	0.32
14.12	Hanford Reach below Priest Rapids	Free flowing	49.44	346.237	395.679	1.49
14.11	Richland Reach above Yakima River confluence	Run-of-river	10.84	335.029	345.871	0.24

2.2.3 Region C: Clearwater and Lower Snake River Basin

Region C includes the Clearwater and lower Snake River Basins in Western Idaho and Eastern Washington. There are five hydroregulation projects located within Region C that have modified operational measures under the CRSO EIS as listed in Table 2-9. Only one of the projects (Dworshak) on the Clearwater River is operated for storage, while the remaining four on the lower Snake River below Lewiston, Idaho, are run-of-river projects.

Table 2-9. Region C Hydroregulation Projects

Project Name	Project ID	River Name	Project Type	CRSO Project	CRM Location
Dworshak	DWR	Clearwater	Storage	Yes	505.0
Lower Granite	LWG	Snake	Run-of-river	Yes	430.9
Little Goose	LGS	Snake	Run-of-river	Yes	393.8
Lower Monumental	LMN	Snake	Run-of-river	Yes	365.0
Ice Harbor	IHR	Snake	Run-of-river	Yes	333.4

The Clearwater River and lower Snake River study reaches extend approximately 180 river miles from Dworshak reservoir upstream in Western Idaho to the confluence of the Snake and Columbia Rivers downstream near Pasco, Washington (Figure 2-8 and Figure 2-9).

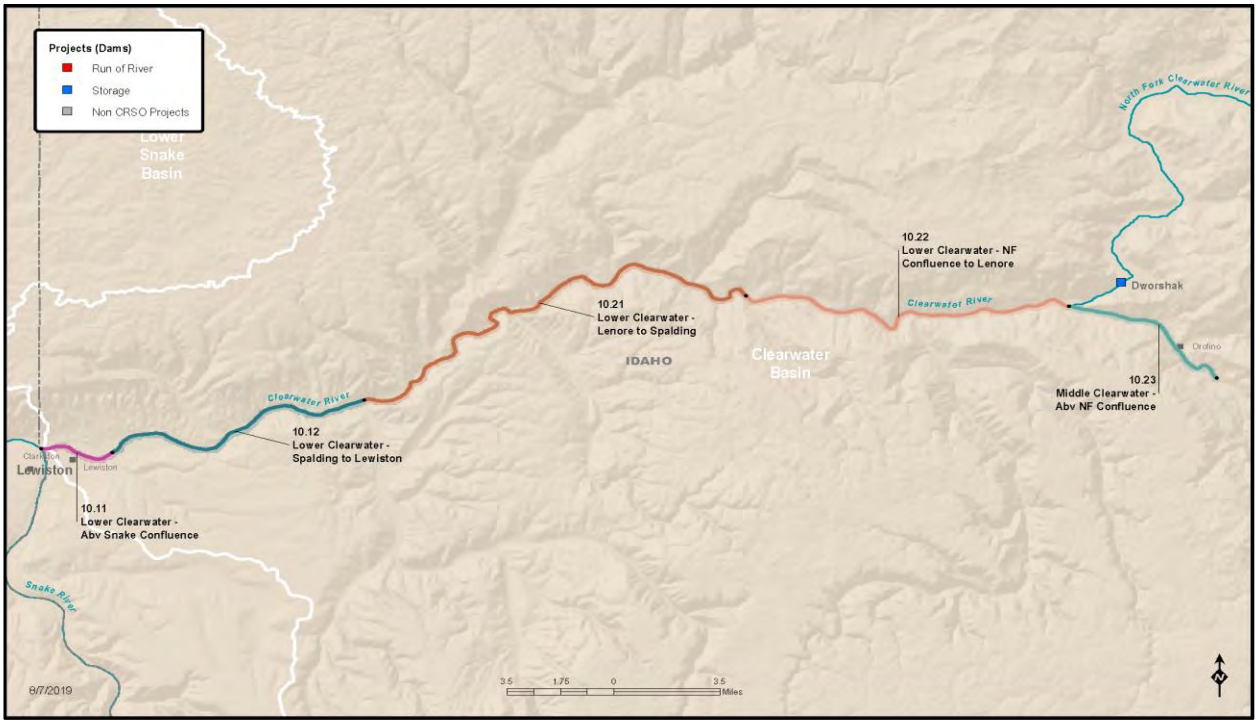


Figure 2-8. Clearwater River Subreaches between Dworshak Dam and the Snake River Confluence

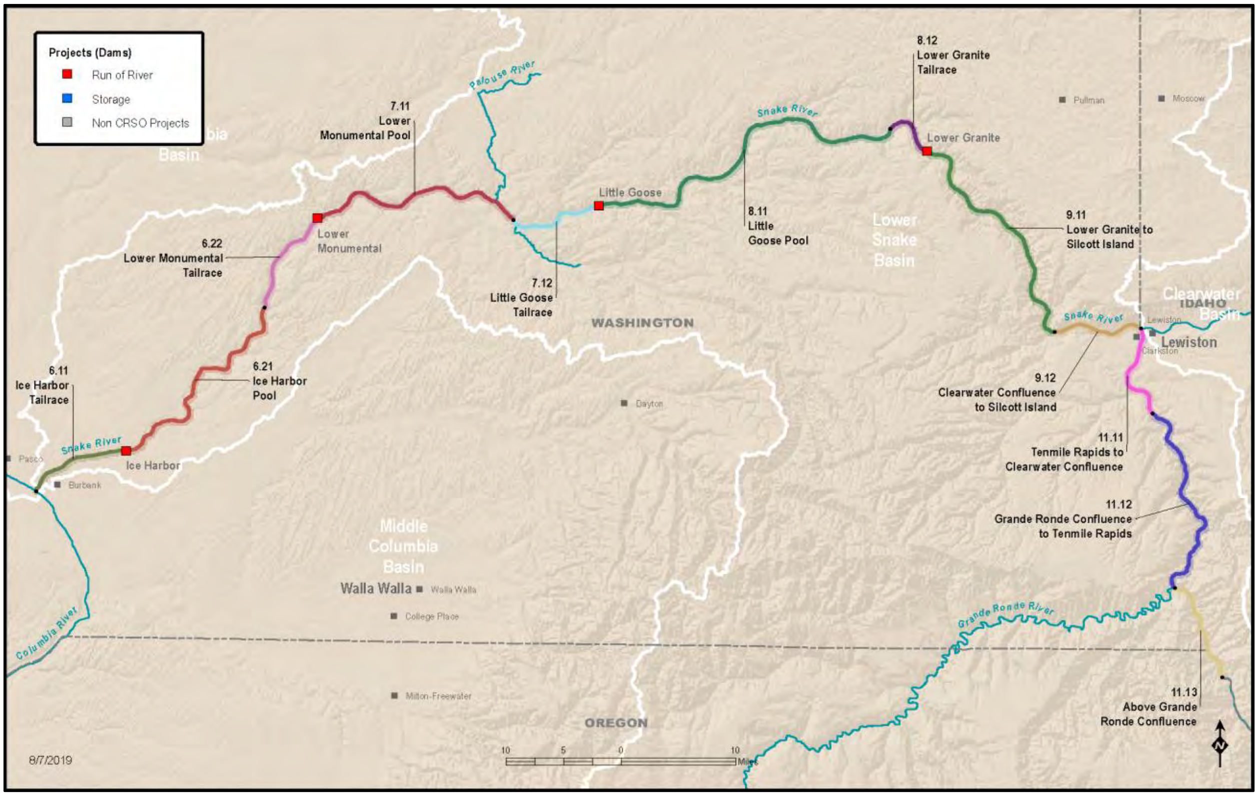


Figure 2-9. Snake River Subreaches between Grande Ronde Confluence and Columbia River Confluence

The Clearwater River study reach spans approximately 42 river miles from Dworshak Dam to the confluence with the Snake River near Lewiston, Idaho (Table 2-10). Inflow contributions for the Clearwater River include outflow from Dworshak Dam on the North Fork Clearwater River and unregulated flows on the South Fork Clearwater River. Tributary inflows to the Clearwater River subreach are limited and include the Potlatch and Lapwai Rivers.

Table 2-10. Clearwater River Subreaches above Snake River Confluence

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
10.23	Middle Clearwater - Abv NF Confluence	Free flowing	4.53	503.3580	507.8930	8.23
10.22	Lower Clearwater - NF Confluence to Lenore	Free flowing	12.38	490.6701	503.0490	7.94
10.21	Lower Clearwater - Lenore to Spalding	Free flowing	16.65	473.9047	490.5521	7.47
10.12	Lower Clearwater - Spalding to Lewiston	Free flowing	8.7	464.9596	473.6599	5.20
10.11	Lower Clearwater - Abv Snake Confluence	Run-of-river	2.29	462.6080	464.8953	0.054

The lower Snake River study reach extends approximately 178 river miles between Cache Creek (upstream of the Grande Ronde confluence) through the Clearwater River confluence near Lewiston, Idaho, and down to the Columbia River confluence downstream near Pasco, Washington (Table 2-11). There are four run-of-river hydroregulation projects on the lower Snake River with operational alternatives evaluated within the CRSO EIS analysis. Inflow contributions to the Snake River study reach are composed of regulated outflows from the upper Snake River Basin (downstream of Hells Canyon Dam), and unregulated flows from the Salmon, Grande Ronde, and Imnaha Rivers. Tributary inflows downstream of the Snake and Clearwater confluence are fairly limited and include the Tuccanon and Palouse Rivers.

Table 2-11. Lower Snake River Subreaches between Cache Creek and Columbia River Confluence

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
11.13	Above Grande Ronde Confluence	Free flowing	10.19	492.1017	502.2925	6.00
11.12	Grande Ronde Confluence to Tenmile Rapids	Free flowing	18.73	472.8699	491.6044	4.42
11.11	Tenmile Rapids to Clearwater Confluence	Run-of-river	9.35	462.5210	471.8710	0.63
9.12	Clearwater Confluence to Silcott Island	Run-of-river	7.94	454.4480	462.3910	0.0179
9.11	Lower Granite to Silcott Island	Run-of-river	23.38	430.8910	454.2750	2.49E-03
8.12	Lower Granite Tailrace	Run-of-river	4.91	425.7261	430.6388	0.080
8.11	Little Goose Pool	Run-of-river	31.2	393.7925	424.9938	5.66E-03

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (feet/mile)
7.12	Little Goose Tailrace	Run-of-river	7.78	385.7185	393.4978	0.036
7.11	Lower Monumental Pool	Run-of-river	20.27	364.9805	385.2482	3.21E-03
6.22	Lower Monumental Tailrace	Run-of-river	8.4	356.1071	364.5030	0.118
6.21	Ice Harbor Pool	Run-of-river	21.45	333.3618	354.8083	5.92E-03
6.11	Ice Harbor Tailrace to Columbia River	Run-of-river	7.93	324.1810	332.1110	0.33

2.2.4 Region D: Lower Columbia River

Region D includes the Columbia River below Richland, Washington. There are four hydroregulation projects located within Region D that have modified operational measures under the CRSO EIS as listed in Table 2-12. These projects generally operate as run-of-river projects, even though there is a small amount of storage at John Day Dam.

Table 2-12. Region D Hydroregulation Projects

Project Name	Project ID	River Name	Project Type	CRSO Project	CRM Location
McNary	MCN	Columbia	Run-of-river	Yes	291.0
John Day*	JDA	Columbia	Run-of-river*	Yes	216.6
The Dalles	TDA	Columbia	Run-of-river	Yes	192.0
Bonneville Dam	BON	Columbia	Run-of-river	Yes	145.7

* JDA has a small amount of storage, but is generally operated as a run-of-river project.

The lower Columbia River study reach extends approximately 316 river miles from the Yakima River confluence upstream to the mouth of the Columbia River downstream near Astoria, Oregon (Figure 2-10 and Figure 2-11; Table 2-13). Inflow contributions to the lower Columbia River in this study reach upstream of McNary Dam are predominately from Columbia River flows leaving upstream Region B below (Priest Rapids outflows), the Yakima River, and the Snake River. Notable tributary inflows to the lower Columbia River within this study reach include the Walla Walla, Umatilla, John Day, Deschutes, Klickitat, Hood, Salmon, Willamette, and Cowlitz Rivers.

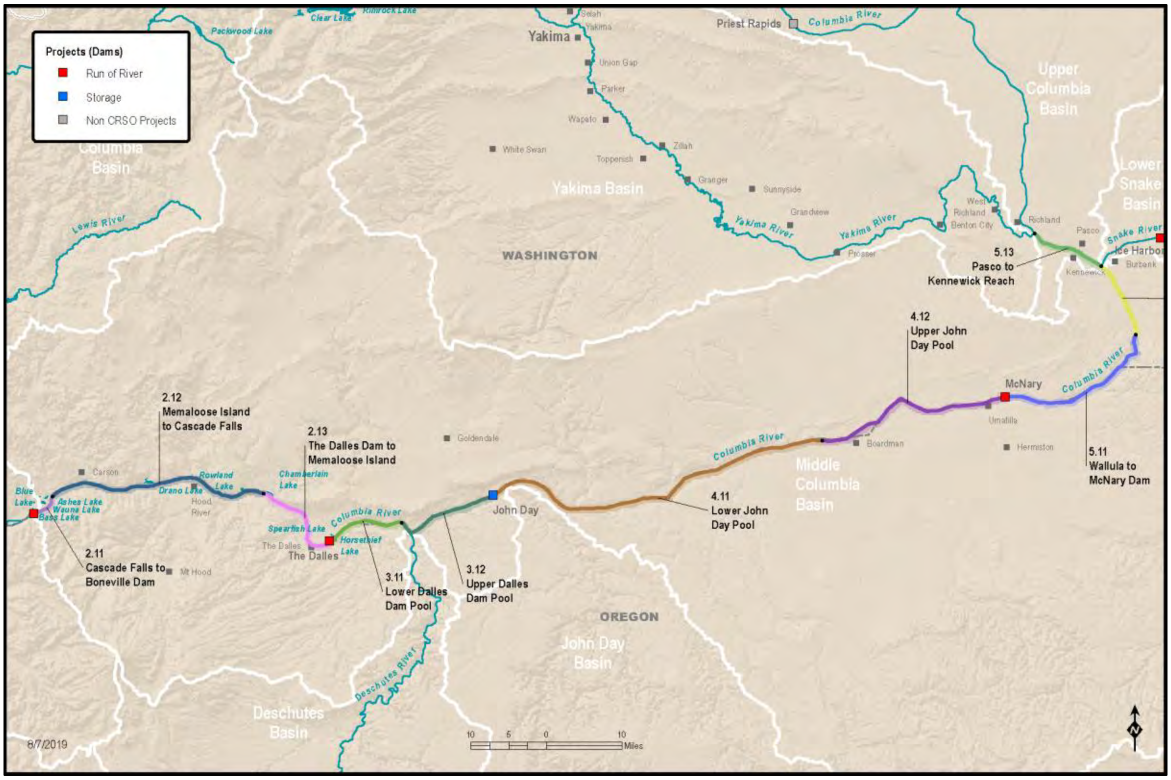


Figure 2-10. Lower Columbia River Subreaches between Richland, Washington, and Bonneville Dam

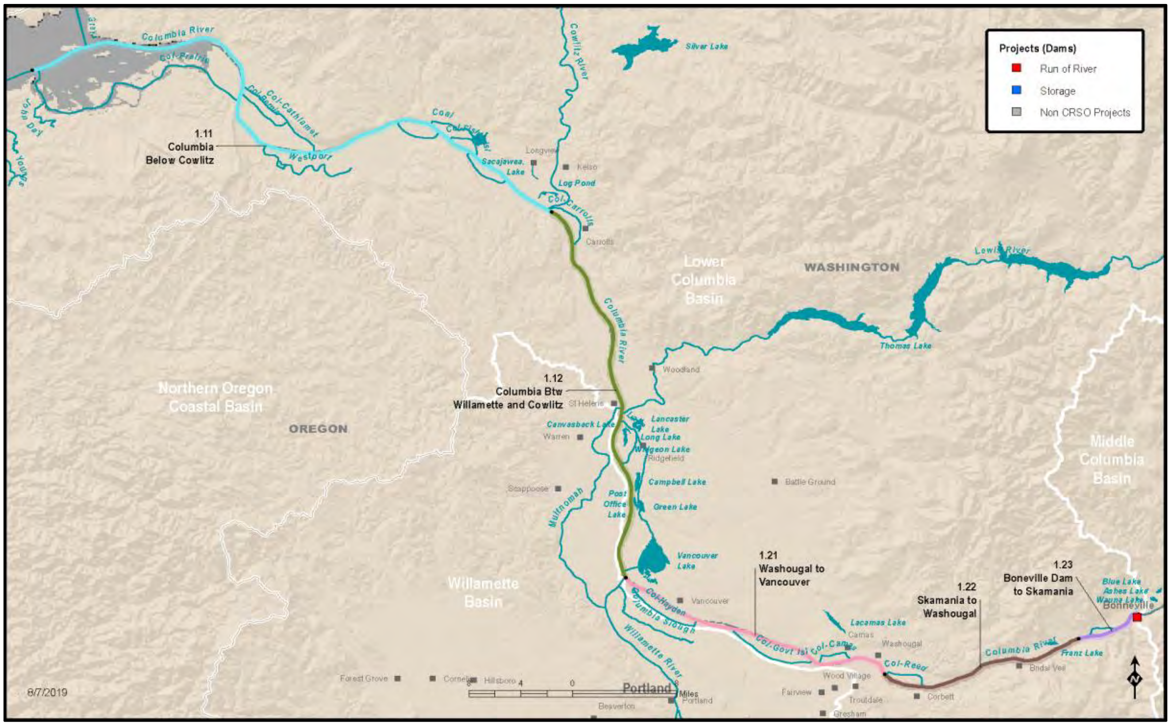


Figure 2-11. Lower Columbia River Subreaches between Bonneville Dam and Astoria, Oregon

Table 2-13. Lower Columbia River Subreaches between Richland, Washington, and Astoria, Oregon

ID	Subreach Name	Type	CRM Length	CRM Downstream	CRM Upstream	Average Slope (ft/mile)
5.13	Pasco to Kennewick Reach	Run-of-river	10.52	324.31	334.83	0.07
5.12	Snake River Confluence to Wallula	Run-of-river	10.44	313.59	324.02	0.03
5.11	Wallula to McNary Dam	Run-of-river	22.26	291.03	313.29	0.003
4.12	Upper John Day Pool	Run-of-river	26.83	264.31	291.14	0.07
4.11	Lower John Day Pool	Run-of-river	47.37	216.58	263.95	0.003
3.12	Upper Dalles Dam Pool	Run-of-river	13.92	202.61	216.53	0.15
3.11	Lower Dalles Dam Pool	Run-of-river	10.34	191.98	202.32	0.03
2.13	The Dalles Dam to Memaloose Island	Run-of-river	13.95	178.00	191.95	0.05
2.12	Memaloose Island to Cascade Falls	Run-of-river	28.84	149.03	177.87	0.04
2.11	Cascade Falls to Bonneville Dam	Run-of-river	3.21	145.71	148.92	0.17
1.23	Bonneville Dam to Skamania	Run-of-river	5.32	140.54	145.86	0.83
1.22	Skamania to Washougal	Run-of-river	15.68	124.49	140.17	0.11
1.21	Washougal to Vancouver	Run-of-river	22.58	101.86	124.44	0.17
1.12	Columbia Btw Willamette and Cowlitz	Run-of-river	32.62	69.21	101.83	0.08
1.11	Columbia Below Cowlitz	Run-of-river	50.42	18.65	69.07	0.06

2.3 ANALYSIS METRICS SUMMARY

Both quantitative and qualitative assessment methods were used to assess relative potential changes to river mechanics (sediment transport and geomorphology) for each EIS alternative. Seven quantitative metrics were developed to represent various physical characteristics and processes that could affect storage reservoirs, run-of-river reservoirs, and free-flowing reaches as enumerated below:

- Storage project metrics
    - Head-of-Reservoir Sediment Mobilization
    - Sediment Trap Efficiency
    - Shoreline Exposure
- Run-of-river reservoirs and free-flowing reach metrics
    - Potential for Sediment Passing Reservoirs and Reaches
    - Potential for Bed Material Change
    - Potential Change to Width to Depth Ratio
    - Potential Changes to Navigation Channel Dredging Volumes

These seven scalar metrics are derived as deterministic calculations based on the H&H planning models (see Appendix A) which established stochastic datasets that represent the daily average system state of hydrology, hydroregulation, and riverine hydraulics. While dimensionally consistent, the geomorphic and sediment transport metrics are intended to provide a measure of relative change between a single Multiple Objective Alternative (MO) and the baseline No Action Alternative insofar as it relates to trends in hydraulic departure for a select MO. It is also important to note that the stochastic hydrology for the NAA (see Chapter 3.2) was derived assuming climactic stationarity (i.e. without climate change). A discussion of sediment and geomorphology for NAA under a future with climate change is presented separately in Chapter 4.

Due to the large size of the study area, the spatiotemporal variability of supporting calibration data (e.g., bed material gradation and sediment supply), and limitations of the base input planning models, the scalar magnitude of a select metric at a discrete location and time may not necessarily represent actualized conditions. More specifically, the daily average resolution of H&H results are limited in that sub-daily variability is not represented. The most sensitive parameter to sub-daily variability is expected to be reservoir operational stage which is used to compute energy grade slope and subsequently boundary shear stress, one of the primary inputs for sediment transport metrics. Nonetheless, considering the size of the CRS study area, and the stochastic methodology used, the NAA and MO results were deemed sufficiently representative to adequately describe the hydrology and hydraulics as required to establish a general baseline of the study area for trend and departure analysis. The quantitative metrics were interpreted within a subreach context to estimate qualitative trends for anticipated impacts at various locations within the study area. In addition, for the Environmental Consequences assessment of the *Breach Snake Embankments* measure under MO3, a numerical mobile bed riverine hydraulic model was developed as described in Chapter 3.4.

2.4 STORAGE PROJECT METRICS

Three storage project metrics were developed to investigate potential for changes in sediment processes at the six CRS storage projects in the study area (Libby, Hungry Horse, Albeni Falls, Grand Coulee, Dworshak, and John Day). Development and impact threshold determination for the storage project metrics is described in this section.

2.4.1 Head-of-Reservoir Sediment Mobilization

The head-of-reservoir sediment mobilization metric is designed to indicate the potential for changes in sediment scour and deposition patterns in the most upstream portion of storage reservoirs. In dams that use large amounts of storage volume and operate over a wide range of elevations throughout the year, the transition from riverine to reservoir conditions can shift upstream and downstream considerable distances. If reservoir drawdown leaves the delta exposed during high-flow periods, the upper layers of delta will be eroded and transported farther into the reservoir, potentially increasing turbidity and downstream sediment deposit thickness. Changes in storage project elevations or changes to the flow of water and sediment into the reservoir can result in changes to the head-of-reservoir erosion and deposition patterns. This metric compares the paired relationships of flow and stage over time to indicate the potential for change in sediment mobilization at the head-of-reservoir for each alternative. Changes in delta sediment mobilization could alter the sediment load farther downstream within the reservoir and potentially the amount of sediment passing a dam, particularly during high-flow periods.

The Sediment Transport Potential calculation was computed using output data from the hydroregulation operations modeling and provides the basis for the head-of-reservoir sediment mobilization metric. This calculation, along with development of the head-of-reservoir sediment mobilization metric and threshold, are described below.

2.4.1.1 Sediment Transport Potential Calculation

Frequently, Lane's Balance is used to analyze the qualitative relationship between sediment transport rates (Q_s), bed material size (d_{50}), flow (Q), and water surface slope (S). It can be written as:

$$Q_s d_{50} \sim QS$$

Where the symbol ~ is generally taken to mean "is related to." A similar relationship can be derived from principles proposed in Henderson (1966) and used in Schmidt and Wilcock (2008) to analyze the effect of dams:

$$\frac{q_s}{{d_{50}}^{1.5}} \propto \left(\frac{\tau}{d_{50}}\right)^3$$

Where τ is the bed shear stress and the symbol ∝ means "is proportional to." Using Manning's equation, flow continuity, and assuming bed material size is fixed, the relationship can be rewritten as:

$$q_s \propto q^{1.8} S^{2.1}$$

In the riverine reaches, the river slope will be essentially unaffected by reservoir operations, but in the reservoir reaches, the slope increases when the reservoir elevation is low. The metric assumes the slope in the reservoir reach at any given day is the ratio of reservoir drawdown relative to full pool (ΔH) to the length of reservoir (L). The transport indicator variable can be written as:

$$Q_s \propto Q^{1.8} \left(\frac{\Delta H}{L}\right)^{2.1}$$

The value of ΔH is assumed to vary according to the daily average reservoir elevation, but the length (L) is assumed to be constant and equal to the square root of the reservoir area at full pool. The analysis is limited to comparing the relative value of this indicator between alternatives, and therefore the value of L will not change the alternative comparison. The metric is not intended to provide a comparison between reservoirs. A sediment transport duration curve could be constructed from this equation. An indicator of changes to sediment transport in the upper portion of the reservoirs is, therefore, the change to Q_s. A schematic of various reservoir pool elevation and the upper portion of the reservoir is given in Figure 2-12.

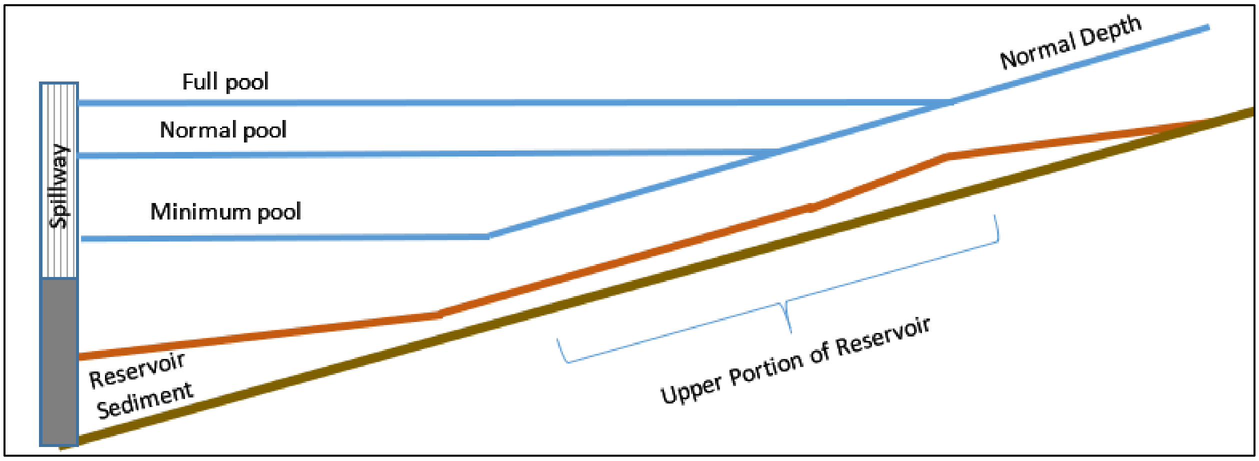


Figure 2-12. Schematic Showing Definition of Reservoir Pools and Idealized Sediment Deposit

2.4.1.2 Head-of-Reservoir Metric

Sediment transport duration curves used in this metric are developed from daily average data extracted from the 5,000-year stochastic reservoir operation model. Curves were developed for each of the major tributaries to the CRSO storage projects. The curves are integrated to calculate an average that is compared with the No Action Alternative using the following formula.

$$\frac{\overline{Qs}alt}{\overline{Qs}NA} - 1$$

Where:
$\overline{Qs}alt$ is the average of the sediment transport duration curve of the alternative being analyzed.
$\overline{Qs}NA$ is the average of the sediment transport duration curve of the No Action Alternative.

The metric can also be informed by changes in critical sediment diameter where hydraulics models are available.

The metric calculates a percent change in sediment transport potential relative to the No Action Alternative due to changes in paired inflow and reservoir elevation. Without a change in reservoir operational range, the ultimate erosion and deposition patterns of head-of-reservoir bed materials is likely unchanged between alternatives and will be related to the lowest drawdown elevation at the reservoir. Change identified by this metric may only be temporary in nature as sediment deposits can be remobilized when the reservoir elevation drops in subsequent seasons or years.

2.4.1.3 Head-of-Reservoir Impact Thresholds

A less than 10 percent change in sediment transport potential at the head-of-reservoir is considered likely unmeasurable with any confidence and negligible. A 10 percent to 50 percent increase or decrease would be a measurable but small change. A 100 percent or greater change in sediment transport potential would be considered a large change at the head-of-reservoir (**Table** 2-14).

Table 2-14. Magnitude of Effects: Head of Reservoir Sediment Mobilization

Sediment Transport Potential Change	Impact Threshold
$\|\Delta x\| = 0\%$	No Effect
$0\% < \|\Delta x\| < 10\%$	Negligible Effect
$10\% < \|\Delta x\| < 50\%$	Minor Effect
$50\% < \|\Delta x\| < 100\%$	Moderate Effect
$\|\Delta x\| > 100\%$	Major Effect

2.4.2 Sediment Trap Efficiency

The sediment trap efficiency metric estimates the potential for changes in the amount of sediment that can deposit within or pass through the storage reservoirs. Trap efficiency is the proportion of inflowing sediment deposited in the reservoir relative to the total incoming sediment load. The trap efficiency is computed based on the ratio of reservoir storage volume to annual inflow. Because the volume of water stored at any given time in the storage projects can vary between alternatives, there is potential for the amount of material being deposited in the reservoir to change between alternatives. This metric compares the paired relationship of flow and reservoir storage to indicate the potential for changes in the amount of sediment being trapped by the storage projects for each alternative relative to the NAA baseline. The actual amount of sediment trapped is dependent not only on trap efficiency but also the incoming sediment load. Qualitative inferences are discussed on potential trap efficiency changes using sediment source documentation where available in the affected environment section of Chapter 3.3.2.

2.4.2.1 Sediment Trap Efficiency Calculation

The Brune Curve (Brune 1953) is an empirical function used to determine the fraction of sediment trapped within a reservoir and is a function of the reservoir volume and incoming flow (Figure 2-13). The ratio is computed for each day of the 5,000 -year stochastic reservoir operation model outputs (annual hydrographs) and then analyzed based on comparing exceedance potential among all possible daily output (e.g. 30 percent, 50 percent, 90 percent). Changes to the estimated trap efficiency would indicate changes to the amount of sediment moved through the reservoir. The lower the trap efficiency, the more sediment that will pass through the reservoir.

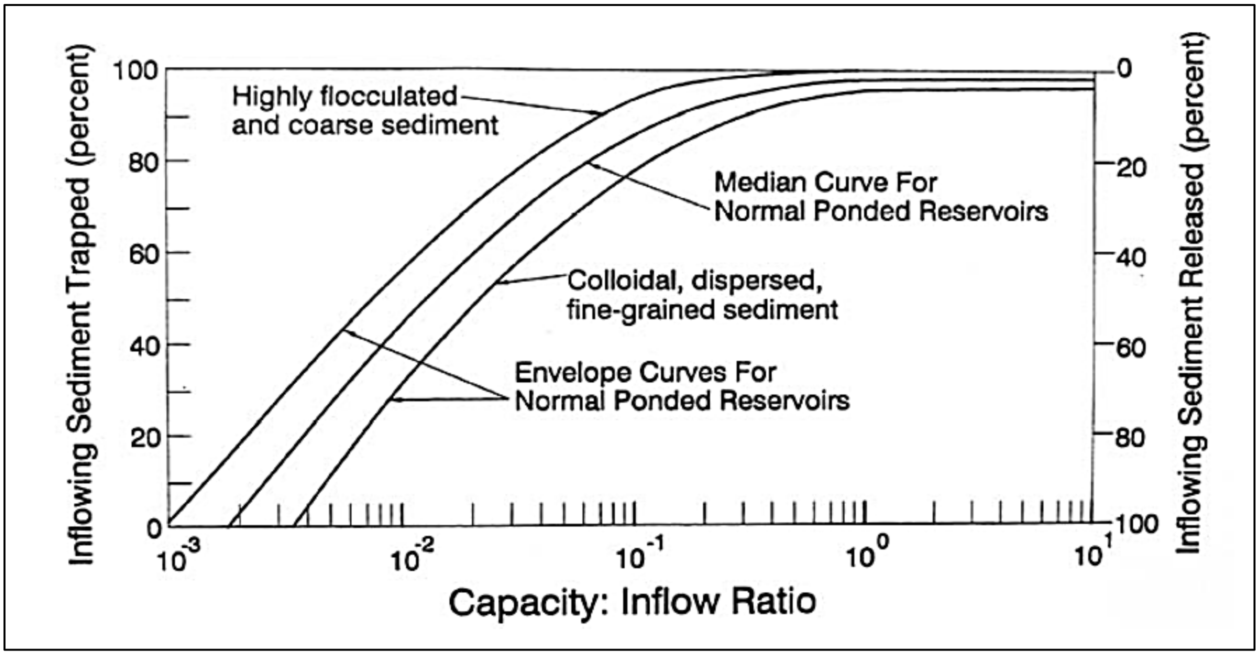


Figure 2-13. Brune Curve Used in Alternative Assessment for Trap Efficiency

Source: Adapted from Brune 1953

2.4.2.2 Sediment Trap Efficiency Metric (Fine-Grained Sediment Only)

Trap efficiency-duration curves used in this metric are developed from daily average data extracted from the 5,000-year stochastic reservoir operation model. The curves are integrated to calculate an average that is compared with the No Action Alternative using the following formula. The metric estimates a percent change in the amount of sediment passing the project.

$$\frac{1-\overline{TE}alt}{1-\overline{TE}na}-1$$

Where:

$\overline{TE}alt$ is the average trap efficiency of the alternative being analyzed

$\overline{TE}na$ is the average trap efficiency of the No Action Alternative

2.4.2.3 Sediment Trap Efficiency Impact Thresholds

A less than 10 percent change in sediment passing a project is considered likely unmeasurable with any confidence and negligible. A 10 percent to 50 percent increase or decrease would be a measurable but small change. A 100 percent or greater change in sediment passing a project would be considered large change in trapping efficiency. With high trapping efficiencies in most of the CRSO projects, a change in sediment passing (such as doubling) may only increase the depositional rate by a few percentage points (Table 2-15).

Table 2-15. Magnitude of Effects: Sediment Trap Efficiency

Sediment Trap Efficiency Change	Impact Threshold
$\lvert\Delta x\rvert = 0\%$	No Effect
$0\% < \lvert\Delta x\rvert < 10\%$	Negligible Effect
$10\% < \lvert\Delta x\rvert < 50\%$	Minor Effect
$50\% < \lvert\Delta x\rvert < 100\%$	Moderate Effect
$\lvert\Delta x\rvert > 100\%$	Major Effect

2.4.3 Shoreline Exposure

Shoreline erosion of bank sediments along reservoir margins is a complex process that is influenced by the cumulative effects of: wave erosion, reservoir currents, precipitation runoff, freeze-thaw, soil properties, exposure, vegetation density and type. One commonly observed process is that during times of extended reservoir drawdown, exposed un-vegetated shoreline soils that were previously saturated are prone to erosion and slumping. The shoreline exposure metric was developed as a surrogate for shoreline erosion processes. This metric compares the amount of days that the reservoir water surface spends at any elevation to identify change in shoreline exposure and indicate the potential for change in shoreline erosion in the CRS storage projects.

The simplest metric is a reservoir elevation exceedance percentage analysis. Comparison of the reservoir elevation exceedance percentage between alternatives will demonstrate the range of reservoir operations. If the range and duration of the reservoir elevations changes, there is a potential that the shoreline erosion rates or patterns may change. While the shoreline exposure metric does not directly consider reservoir draft rate, it does represent the duration effects that could result from draft rate operational measures. An additional metric for shoreline erosion was developed to evaluate potential impacts to cultural resources. This metric considered draft frequency and amplitude and is detailed in Chapter 3.16.3.

2.4.3.1 Shoreline Exposure Metric

Elevation-duration curves used in this metric are developed from daily average data extracted from the 5,000-year stochastic hydroregulation operations model. The curves are integrated to calculate an average and are compared with the No Action Alternative using the following formula:

$$AVE_{alt} – AVE_{na}$$

Where:

AVE_{alt} is the average reservoir elevation of the alternative being analyzed

AVE_{na} is the average reservoir elevation of the No Action Alternative

2.4.3.2 Shoreline Exposure Impact Thresholds

Average differences less than ±5 feet are likely not discernable within the reservoir due to sub-daily power fluctuation and other processes such as waves, which occur within a similar range. A ±5- to ±10-foot difference is estimated to be the threshold when shoreline effects would be observable on the landscape and are considered small changes in shoreline exposure. Differences greater than ±10 feet would be observable and would result in moderate changes in shoreline exposure. A modification in the operational range of the project would be required to have large changes in shoreline exposure with new lands becoming inundated or existing shoreline becoming permanently submerged (Table 2-16). However, none of the analyzed MO operational measures changed the operational range at the CRS storage projects.

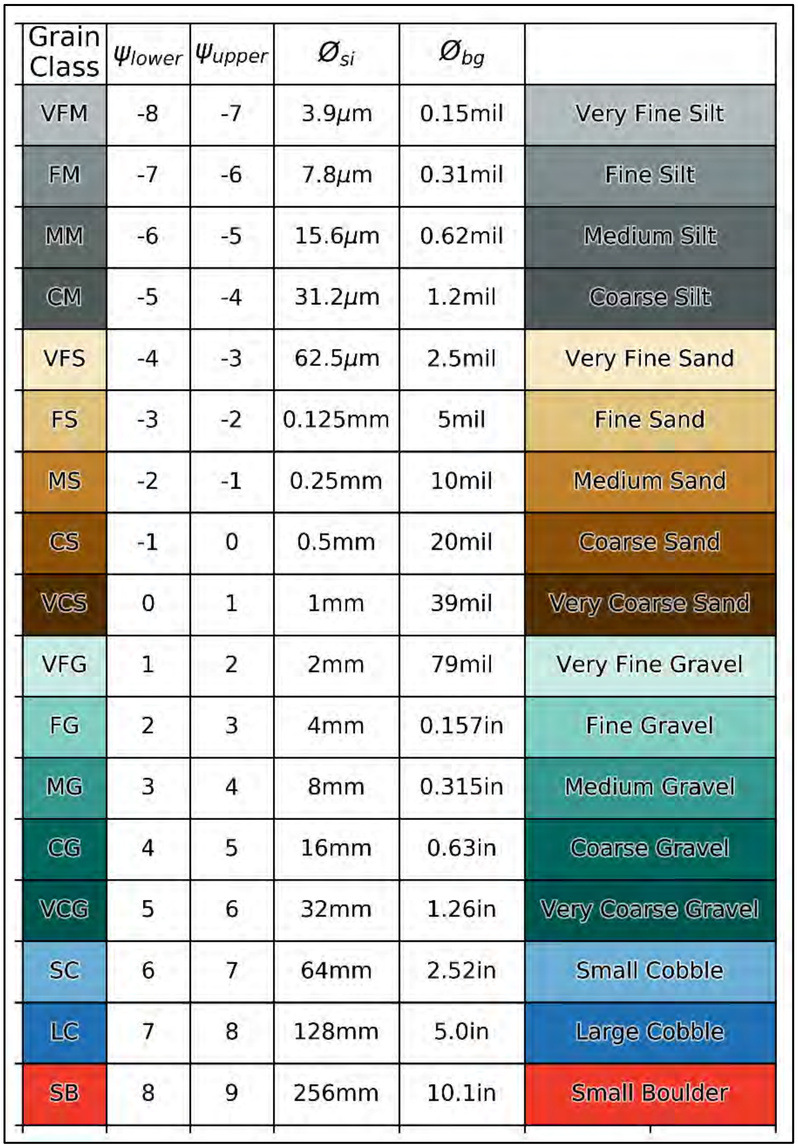
Table 2-16. Magnitude of Effects: Shoreline Exposure

Shoreline Exposure Change	Impact Threshold
$\lvert\Delta x\rvert = 0$ feet	No Effect
0 feet < $\lvert\Delta x\rvert$ <5 feet	Negligible Effect
5 feet < $\lvert\Delta x\rvert$ <10 feet	Minor Effect
$\lvert\Delta x\rvert$ >10 feet	Moderate Effect
Change in operational range	Major Effect

2.5 RUN-OF-RIVER RESERVOIR AND FREE-FLOWING REACH METRICS

Run-of-river reservoirs and free-flowing reaches include all the river reaches downstream of CRSO storage projects. Run-of-river reservoirs are formed by dams that are operated to discharge water downstream at rates that generally match the upstream inflows. Bonneville Dam is an example of a run-of-river project that operates in a small range of pool elevations for daily or weekly hydropower purposes but does not attempt to store water for release in later seasons. Free-flowing reaches are portions of the river that are not influenced by the backwater of a downstream reservoir. The Flathead River downstream of Hungry Horse Dam and upstream of Flathead Lake is an example of a free-flowing reach.

Many of the run-of-river reservoir and free-flow reach metrics are expressed in grain sizes or changes in a grain-size class. Figure 2-14 shows the grain size in psi ($\log_2$) scale (ψ), upper and lower size bounds and common naming notation for these metrics.



Grain Class	ψ_{lower}	ψ_{upper}	$\varnothing_{si}$	$\varnothing_{bg}$	
VFM	-8	-7	3.9μm	0.15mil	Very Fine Silt
FM	-7	-6	7.8μm	0.31mil	Fine Silt
MM	-6	-5	15.6μm	0.62mil	Medium Silt
CM	-5	-4	31.2μm	1.2mil	Coarse Silt
VFS	-4	-3	62.5μm	2.5mil	Very Fine Sand
FS	-3	-2	0.125mm	5mil	Fine Sand
MS	-2	-1	0.25mm	10mil	Medium Sand
CS	-1	0	0.5mm	20mil	Coarse Sand
VCS	0	1	1mm	39mil	Very Coarse Sand
VFG	1	2	2mm	79mil	Very Fine Gravel
FG	2	3	4mm	0.157in	Fine Gravel
MG	3	4	8mm	0.315in	Medium Gravel
CG	4	5	16mm	0.63in	Coarse Gravel
VCG	5	6	32mm	1.26in	Very Coarse Gravel
SC	6	7	64mm	2.52in	Small Cobble
LC	7	8	128mm	5.0in	Large Cobble
SB	8	9	256mm	10.1in	Small Boulder

Figure 2-14. Log$_2$ Based Grain-Size Classes Used in this Appendix

2.5.1 Potential for Sediment Passing Reservoirs and Reaches

This metric estimates the size of material that can be held in suspension in the water column through each run-of-river reservoir and free-flowing reach due to operations of CRSO projects. Water flowing in nature is predominately turbulent with chaotic changes in flow intensity and direction occurring at many scales internal to the overall downstream movement of the water. These turbulent forces can be strong enough to hold small sediment particles in suspension in the water column. The more energetic the turbulent forces, the larger the particle that can be suspended. Changes in the hydraulic conditions within the run-of-river reservoirs and reaches can change the ability of the river to transport sediment high in the water column. This metric calculates the grain size that can be held with 100 percent of its transporting mass in suspension for a given hydraulic condition using the Rouse profile (Rouse, 1937). Comparison of the suspended sediment size between alternatives as well as upstream and downstream in a single alternative can inform managers whether there is potential for changes in material passing through or settling in a run-of-river reservoir or free-flowing reach.

2.5.1.1 Rouse Number Calculation

For this metric, a competence-based approach was applied whereby particle suspension is an assumed function of flow stratification that scales with the ratio between settling and shear velocity. For gradually varying flow in a wide channel, most of the sediment is concentrated near the bed with hydraulic turbulence effectively diffusing sediment from this deeper zone of high concentration toward a lower concentration zone near the water surface. The suspended sediment within the water column can generally be represented as a concentration profile (Figure 2-15) that varies with depth according to the general Rouse equation:

$$\frac{C}{C_a} = \left(\frac{D-y}{y}\,\frac{a}{D-a}\right)^{\mathcal{R}_*}$$

Which calculates the sediment concentration (C) at an elevation y above the bed relative to the near bed concentration C_a, for flow depth D, and scaling parameter $\mathcal{R}_*$.

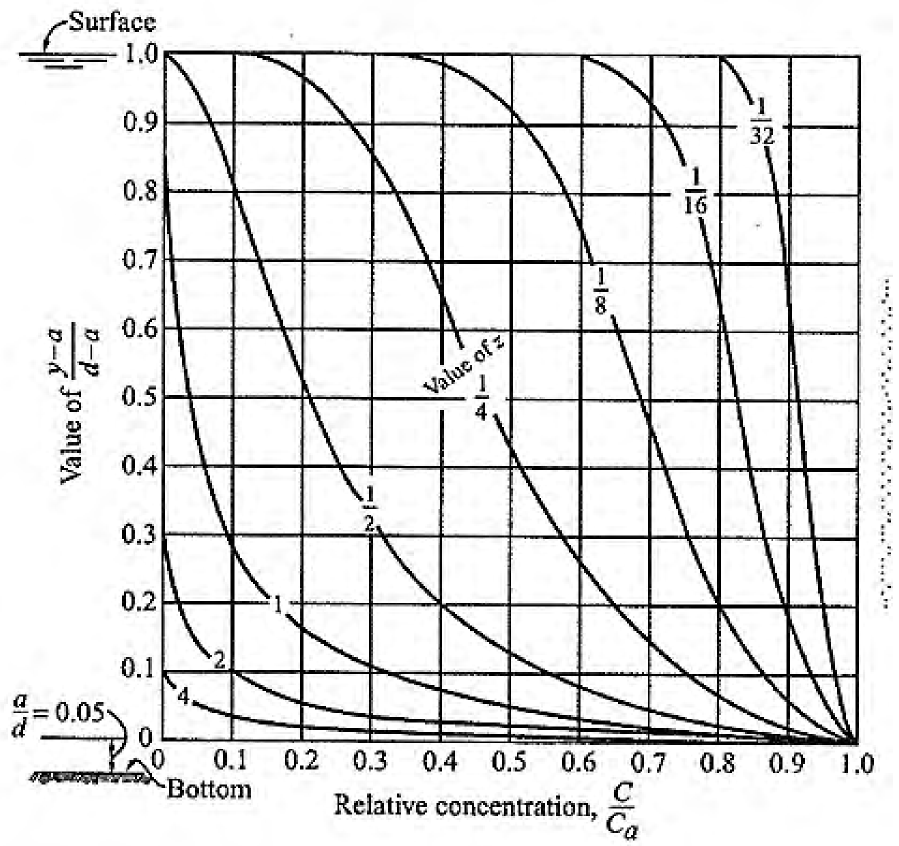


Figure 2-15. Standard Rouse Profile

Source: ASCE Manual of Practice 54, Figure 2.32

The entrainment and deposition of sediment in suspension depends upon the balance between downward gravitational forces and the turbulent uplift/mixing forces acting on discrete sediment particles. In the Rouse equation above, the parameter ($\mathcal{R}_*$) is used to scale a relative sediment concentration profile to a specific particle size and hydraulic condition, representing the threshold between suspension and deposition, assuming independence of sediment concentration and particle size distribution. More specifically, $\mathcal{R}_*$ defines this force balance as a ratio between a characteristic particle fall velocity (ω_s) and the boundary layer shear velocity ($u_*= \sqrt{\tau_b/\rho_w}$), a hydraulic surrogate that is proportional to the lift velocity acting on a particle at the channel bed, according to the relation:

$$\mathcal{R}_* = \frac{\omega_s}{\kappa u_*}$$

Where the parameter κ represents the Von-Karman constant ≈ 0.4. With the suspended sediment concentration being continuously distributed through the water column, the Rouse parameter ($\mathcal{R}_*$) has been shown to correlate with the mode of sediment transport according to Whipple (2004) as shown in Table 2-17.

Table 2-17. Suspended Sediment Transport Mode by Rouse Parameter

Transport Mode	Rouse Parameter
Initiation of Motion	$\mathcal{R}_* \leq 7.5$
Bedload / Saltation	$2.5 < \mathcal{R}_* \leq 7.5$
<50% Suspension	$1.8 < \mathcal{R}_* \leq 2.5$
50% Suspension	$1.2 < \mathcal{R}_* \leq 1.8$
100% Suspension	$0.8 < \mathcal{R}_* \leq 1.2$
Wash Load	$\mathcal{R}_* \leq 0.8$

For this study, a competence-based threshold approach was used to estimate the maximum particle size that would be expected for a selected mode of transport. This approach provided a direct calculation to quantify the relative departure in equilibrium suspended particle size capacity that could result from operational changes affecting shear velocity (u_*) within the system.

It is important to note that this threshold approach quantifies the steady-state equilibrium particle suspension hydraulic capacity and does not directly account for spatiotemporal changes in the longitudinal sediment supply as described earlier. In other words, the Rouse threshold suspension capacity does not inherently indicate that a size class will be present in suspension; instead it indicates the maximum particle size capacity for suspension based on hydraulic conditions, if it is present in the upstream sediment supply or the active layer of the local reach channel bed.

2.5.1.2 Potential for Sediment Passing Metric

The 100 percent suspended grain-size threshold duration curves used in this metric are developed from daily average data extracted from the 5,000-year stochastic reservoir operation model. Distributions and duration curves were computed for each subreach of the study area. The 50 percent exceedance values are investigated as an indicator of change.

2.5.1.3 Potential for Sediment Passing Impact Thresholds

Thresholds are based on a percent change in grain class on a logarithmic (ψ) scale (e.g., very fine sand to fine sand). A less than ±10 percent change in ψ grain-size class is likely unmeasurable and unable to be observed and is considered negligible. A ±10 percent to ±50 percent change is likely the threshold for being measurable but likely not observable and considered small. A ±50 percent to ±100 percent change would be the threshold to be observable and considered moderate. A greater than 100 percent ψ grain size class change would be observable in the field and is considered a large change (Table 2-18).

Table 2-18. Magnitude of Effects: Sediment Passing Reservoirs and Reaches

Percent Grain-Size Class Change	Impact Threshold
$|\Delta\psi| = 0\%$	No Effect
$0\% < |\Delta\psi| < 10\%$	Negligible Effect
$10\% < |\Delta\psi| < 50\%$	Minor Effect
$50\% < |\Delta\psi| < 100\%$	Moderate Effect
$|\Delta\psi| > 100\%$	Major Effect

2.5.2 Potential for Bed Material Change

This metric is designed to indicate the hydraulic potential for the bed of the river to become coarser (sand to gravel) or finer (gravel to sand) due to operations of CRSO projects. Changes in operations can alter hydraulic conditions in run-of-river reservoirs and free-flowing reaches such that the river can move more or less riverbed sediment of various size classes. A change in the hydraulic ability for a reach to move sediment does not necessarily indicate that bed material will change. Sediment of specific size classes must be available in the reach at a sufficient supply for a change to occur. A bedrock or heavily armored (i.e., coarse) bed may withstand increases in the hydraulic capacity to transport sediment without changing. Conversely, a decrease in hydraulic ability to move sediment may not result in finer material depositing if no finer material is being locally supplied or transported into the reach. This metric calculates the distribution of critical grain size at the subreach level for each alternative supplemented with qualitative interpretation of existing bed material and sediment load to estimate if there is potential for bed material to trend coarser or finer in run-of-river reservoirs and reaches.

2.5.2.1 Critical Grain-Size Calculation

For this metric, a standard competence-based approach was applied whereby particle mobility is computed as a force balance between applied and resisting forces. For gradually varying flow in a wide channel, the applied force results from the hydrodynamics of the flow while the resisting force is related to the submerged weight of a non-cohesive sediment particle. The seminal work of Shields (1936) used a similarity approach to derive a dimensionless shear stress for a sediment particle as:

$$\tau^* = \frac{\tau'}{(\gamma_s - \gamma_w)d_s}$$

Where, τ' represents the fraction of the boundary shear stress acting on the sediment, $(\gamma_s - \gamma_w)$ represents the submerged unit weight of the sediment, and d_s represents the sediment particle diameter. Shields described the fundamental process of sediment mobility by establishing that at the threshold of sediment movement, the critical Shields stress (τ_c^*) is a function of the critical particle Reynolds number with an empirically derived envelope between 0.03 and 0.06 for non-laminar conditions as illustrated in the traditional Shields curve as shown below (Figure 2-16).

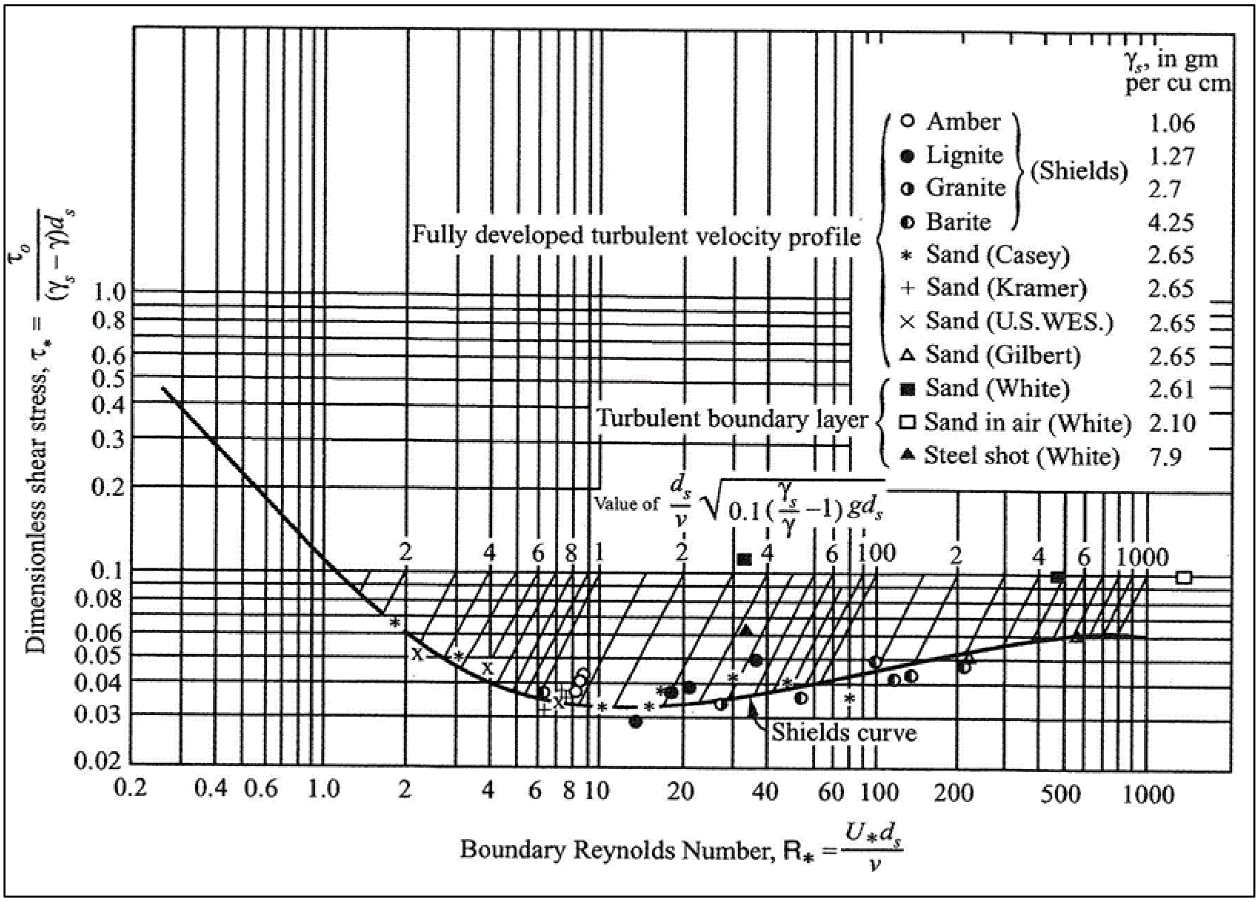


Figure 2-16. Shields Diagram for Particle Mobility

Source: ASCE Manual of Practice 54, Figure 2.43

For this metric, the Shields threshold approach was used to estimate the grain-size distribution of mobile particle sizes within each subreach and quantify the departure that could result from operational changes affecting system hydrodynamics. The applied forces acting on a sediment particle on the streambed include hydrodynamic drag acting in the direction of flow, and hydrodynamic lift acting normal to the flow. The methodology for this study partitioned a modeled depth-slope product estimate of boundary shear stress ($\tau = \rho g R S = \rho u_*^2$) into two components: the grain shear stress (τ') and the form drag shear stress (τ'') due to bedforms and other channel irregularities according to the equation (Einstein 1950):

$$\frac{\bar{u}}{u'_*} = 6.25 + 5.75 \log_{10}\left(\frac{R'}{k_s}\right)$$

Where $\bar{u}$ represents the section averaged velocity, u'_* represents the grain shear velocity ($\sqrt{gR'S}$), R' represents the grain hydraulic radius, and k_s represents the bed roughness height. Assuming a critical Shields stress ($\tau_c^* \approx 0.047$), the critical particle size was subsequently calculated from the ratio of grain shear stress to critical shields stress normalized by the submerged sediment unit weight according to:

$$d_c = \frac{\tau'}{\tau_c^* \, (\gamma_s - \gamma_w)}$$

Sediment mobility is inherently a statistical problem that depends upon the probability of near-bed hydrodynamics and parameters of bed material composition (size distribution, spatial sorting, vertical packing, etc.). Considering the large spatial scale of this study and the variable uncertainty levels of sediment and hydrodynamic data necessary to support more advanced functional relationships, the Shields critical size method was deemed appropriate to estimate the relative departure in mobile grain size for this study despite its simplifying assumptions.

2.5.2.2 Potential for Bed Material Change Metric

Critical grain-size threshold duration curves used in this metric are developed from daily average data extracted from the 5,000-year stochastic reservoir operation model. Ranked daily exceedance curves are developed for each discrete subreach within Regions A-D and provided in Chapter 4 of this appendix. The 90 percent exceedance values are investigated as an indicator of change.

2.5.2.3 Potential for Bed Material Change Impact Thresholds

Thresholds are based on a percent change in grain class on a logarithmic (ψ) scale (e.g., very fine sand to fine sand). A less than ±10 percent change in ψ grain-size class is likely unmeasurable and unable to be observed and is considered negligible. A ±10 percent to ±50 percent change is likely the threshold for being measurable but likely not observable and considered small. A ±50 percent to ±100 percent change would be the threshold to be observable and considered moderate. A greater than 100 percent ψ grain-size class change would be observable in the field and is considered a large change (Table 2-19).

Table 2-19. Magnitude of Effects: Potential for Bed Material Change

Percent Grain-Size Class Change	Impact Threshold
$|\Delta\psi| = 0\%$	No Effect
$0\% < |\Delta\psi| < 10\%$	Negligible Effect
$10\% < |\Delta\psi| < 50\%$	Minor Effect
$50\% < |\Delta\psi| < 100\%$	Moderate Effect
$|\Delta\psi| > 100\%$	Major Effect

2.5.3 Potential Changes in Width-to-Depth Ratio

This metric evaluates if proposed changes in reservoir operations will alter the range and frequency of width-to-depth (W/D) ratios relative to affected environment conditions. Storage reservoirs and run-of-river reservoirs alter the physical landscape of rivers. Reservoirs change the width and depth of river channels and connectivity to floodplain surfaces and wetlands. Changes in the river framework alter ecological functions, including habitat, water quality, and riparian corridors, to name a few. The affected environment has larger wetted widths and hydraulic depths relative to pre-dam conditions due to reservoir conditions. Changes in the W/D ratio can indicate a potential for departure in channel hydraulics, or wetland and floodplain availability. Alternatives that do not change the minimum or maximum operating levels within a reservoir affected reach would not be expected to have a change in W/D ranges. However, operation changes could alter the frequency of W/D ratios, affecting the frequency of connectivity to floodplain surfaces or wetlands depending on local topography. A dam removal would be expected result in the largest change to W/D ratios.

2.5.3.1 Width-to-Depth Ratio Change Metric

Duration curves of width to hydraulic depth ratio are developed from daily average data extracted from the 5,000-year stochastic reservoir operation model. Ranked daily exceedance curves are developed for each discrete subreach within Regions A-D and provided in Chapter 4 of this appendix. The 90 percent exceedance values are investigated as an indicator of change.

2.5.3.2 Width-to-Depth Ratio Change Impact Thresholds

Thresholds are based on a relative percent change in scalar W/D ratios, which is computed as the difference normalized by the mean. A less than ±5 percent change in W/D is likely unmeasurable and unable to be observed and is considered negligible. A ±5 percent to ±10 percent change is likely the threshold for being measurable but likely not observable and considered small. A ±10 percent to ±25 percent change would be the threshold to be observable and considered moderate. A greater than 25 percent relative change would be observable in the field and is considered a large change (Table 2-20).

Table 2-20. Magnitude of Effects: Change in Width-to-Depth Ratio

W/D Ratio Change	Impact Threshold
$\lvert\Delta x\rvert = 0\%$	No Effect
$0\% < \lvert\Delta x\rvert < 5\%$	Negligible Effect
$5\% < \lvert\Delta x\rvert < 10\%$	Minor Effect
$10\% < \lvert\Delta x\rvert < 25\%$	Moderate Effect
$\lvert\Delta x\rvert > 25\%$	Major Effect

2.5.4 Potential Changes to Navigation Channel Dredging Volumes

This metric evaluates if there is an expected change in the volume of sediment needing to be dredged from the federally authorized navigation system to provide safe and efficient deep- and shallow-draft navigation. As a part of its Congressional authorization, the U.S. Army Corps of Engineers (Corps) operates and maintains the navigation system from Lewiston, Idaho, to the Pacific Ocean along the Snake and Columbia Rivers. Changes in flow have the potential to change the volume of material depositing in the navigation channel. This metric estimates the average annual volume of sediment depositing in the deep- and shallow-draft sections based on relationships between flow in the river and sediment shoaling and historical dredging rates.

2.5.4.1 Snake River Navigation Channel Dredging

The purpose of this metric is to evaluate potential alternative impacts on dredging requirements. As detailed in the 2014 Lower Snake River Programmatic Sediment Management Plan (PSMP, Corps 2014), the lower Snake River navigation channel is dredged on an as-needed basis to maintain authorized channel depth. A need to dredge is determined by the depth of sediment accumulated within the navigation channel, which is correlated with the upstream sediment loading and local hydraulic effects. However, the timing of dredging actions and volume of material removed is further influenced by secondary socioeconomic and regulatory factors.

Sediment deposition in some locations (e.g., within deep pools or outside of the navigation channel) does not directly impact navigation or flood conveyance, and therefore has not been historically dredged. Deposition may also be more critical in certain locations than in others, resulting in either an accelerated or decelerated need for dredging. This variability complicates developing a generalized method for predicting dredging event frequency and corresponding dredged material volumes.

Ideally, a relationship would be derived that only considers deposition within areas of concern and neglects deposition elsewhere, while also accounting for secondary factors. Such a relationship would require significant data and result in a complex analysis. The analysis can be simplified greatly by focusing on two general principles: (1) an increase in sediment load results in an increase in dredged material volume, and (2) the sediment that deposits in navigable water is primarily bedload and suspended sand. The proposed dredging metric quantifies the relative increase in suspended sand load and bedload and assumes that the corresponding increase in dredged volume is roughly proportional. The dredging metric is computed as follows:

$$\frac{\sum t\left(Q_{bedload} + Q_{susp\ sand}\right)_{alternative}}{\sum t\left(Q_{bedload} + Q_{susp\ sand}\right)_{no\ action}}$$

where $Q_{bedload}$ is the bedload, and $Q_{susp\ sand}$ is the suspended sand load, both of which are upstream loading rates in tons per day; t is time in days and is included for completeness to show that the ratio of total sediment in the alternative to the total sediment in the No Action Alternative is being computed. However, t can be omitted from the equation because it must be the same in both the numerator and denominator for the metric to be valid. The metric is evaluated on a daily time scale ($t = 1$ day), summed across the entire hydrologic Monte Carlo simulation period detailed in Appendix A.

The streamwise distribution of sediment deposition affecting navigation in Lower Granite Reservoir, in the vicinity of the Snake River and Clearwater River confluence, is primarily controlled by (1) sediment size, and (2) Lower Granite's pool elevation. Fine-grained suspended sediments largely remain in suspension into the deeper portions of the reservoir pool and do not affect navigation. Coarser sediments are generally deposited between Silcott Island and the Snake-Clearwater confluence area as they encounter the lower stream velocity region of the upstream end of the Lower Granite pool. These overall patterns would not be expected to change appreciably for a given alternative (with the exception of dam removal), considering the relatively limited changes in discharge and corresponding sediment yields, coupled with the unchanged operating conditions in Lower Granite. Changes are therefore expected to primarily manifest themselves in the rate at which sediment accumulates.

The alternatives being evaluated alter only the flow upstream of Lower Granite Reservoir. Deposition downstream of Lower Granite Dam is not expected to change appreciably under any of the non-dam removal alternatives due to the influence of the lower Snake River dams; therefore, dredging in that region has not been accounted for in this analysis. The dredging metric therefore need only be applied to the flow entering Lower Granite Reservoir. That flow is computed as the sum of the Clearwater River discharge at Spalding and the Snake River discharge at Anatone. The equations in Table 2-21 can be used to compute the bedload and suspended sand load at those locations (Corps, 2019e). These relationships for load estimation are power regression equations that generally fit measured sediment concentration and load data. The power functions take the form:

$$Q_S = aQ_W{}^b$$

Where Q_S is the sediment discharge (U.S. tons per day), Q_W is the water discharge (cubic feet per second [cfs]), and the coefficients *a* and *b* are derived from prior regression analysis. Only the equations for bedload and suspended sand load are provided in Table 2-21 (see Corps, 2019e for other equations). The equations are evaluated at each daily timestep for the entire hydrologic Monte Carlo simulation period.

Table 2-21. Power Functions for Bedload and Suspended Sand Load

Location	Function
Snake River at Anatone	$Q_{Suspended\ Sand} = (3.56\mathrm{x}10^{-14}Q_{Snake}^{3.4861})1.6357$
	$Q_{Bedload} = (1.46\mathrm{x}10^{-11}Q_{Snake}^{2.7595})1.8140$
Clearwater River at Spalding	$Q_{Suspended\ Sand} = (1.82\mathrm{x}10^{-10}Q_{Clearwater}^{2.7983})1.2428$
	$Q_{Bedload} = (3.91\mathrm{x}10^{-5}Q_{Clearwater}^{1.4603})1.1377$

Source: PSMP (2014), Corps, 2019e

Figure 2-17a shows the flows computed from the No Action Alternative simulation at Anatone, ranked in descending order to form a flow duration curve. Each of the daily discharges that make up this curve were then used to compute $(Q_{bedload} + Q_{suspended\ sand})$, which resulted in the sediment load distribution plotted in Figure 2-17b. To get the total No Action Alternative sediment yield, all of the loads in Figure 2-17b are summed, resulting in a 4.02 billion-ton sediment yield at Anatone on the Snake River over a 5,000-year simulation. This process is repeated for Spalding, resulting in an additional 0.894 billion tons from the Clearwater River. The total estimated baseline sediment yield, $\sum(Q_{bedload} + Q_{suspended\ sand})_{no\ action}$, is therefore 4.91 billion tons, which results in an expected annual average estimated yield of 982 thousand tons per year.

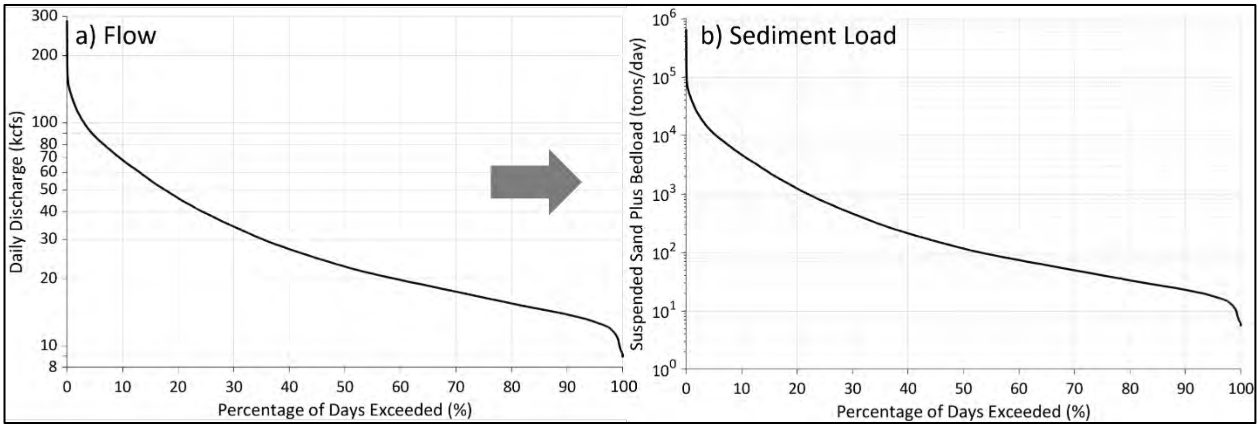


Figure 2-17. No Action Flow (a) and Sediment Load (b) Duration Curves for Snake River at Anatone

Using the same process, a total sediment yield can be computed for a comparison alternative. That total sediment yield could then be divided by the 4.91 billion–ton baseline to compute the proposed metric, which is a dimensionless ratio. However, based on observed patterns within the dredged areas, sediment from the Clearwater River tends to deposit at a disproportionately faster rate, relative to the upstream sediment supply, than the combined load does in the Snake River. Applying the sediment load equations in Table 2-21 to the No Action Alternative hydrology resulted in an estimated 18 percent of the total sediment load originating from the Clearwater River, while the dredging records show that 33 percent of the dredged material that deposited between 1992 and 2015 came from the Clearwater River arm at the confluence. This indicates a need to have a separate ratio for the Clearwater River and the Snake River. Dredging records from 1992 and earlier did not separate the Clearwater and Snake River arms of the confluence. However, the 33 percent ratio was judged to be representative of the full range of years. This was justified by computing the percentage of sediment that deposited in the Clearwater River arm for all three post–1992 dredging actions separately, which ranged from 28 percent to 37 percent. This relatively small departure from the 33 percent average encouraged the use of a 0.33 partitioning factor. For simplicity in reporting a single metric, the Clearwater and Snake River ratios are combined as follows:

$$\frac{(dredged\ volume\ upstream\ of\ Lower\ Granite)_{alternative}}{(dredged\ volume\ upstream\ of\ Lower\ Granite)_{no\ action}} \cong$$

$$0.33\left[\frac{\Sigma\left(Q_{bedload}+Q_{susp\ sand}\right)_{alternative}}{\Sigma\left(Q_{bedload}+Q_{susp\ sand}\right)_{no\ action}}\right]_{Clearwater} + 0.67\left[\frac{\Sigma\left(Q_{bedload}+Q_{susp\ sand}\right)_{alternative}}{\Sigma\left(Q_{bedload}+Q_{susp\ sand}\right)_{no\ action}}\right]_{Snake+Clearwater}$$

where the denominator of the first term on the right-hand side is 0.894 billion tons and the denominator of the second term is 4.91 billion tons. This ratio can be multiplied by the No Action Alternative (historical average in Table 2-22) dredged volume to approximate the alternative dredged volume. Similarly, the ratio could be multiplied by the baseline No Action Alternative cost to estimate the alternative cost.

Table 2-22. Lower Snake River Historical Average Dredged Volumes from 1975 to 2015

Location	Average Annual Dredged Volume (cubic yards per year)
Upstream of Lower Granite	122,000
Downstream of Lower Granite	1,760

The historical average dredged volumes in Table 2-22 have been grouped into dredged material upstream of Lower Granite and dredged material downstream of Lower Granite. The dredging metric ratio should only be multiplied by the dredged volume upstream of Lower Granite. In all alternatives (with the exception of the dam removal alternative), the dredged volume is assumed to be unchanged downstream of Lower Granite. The historical dredging activities, along with their associated purposes, for the lower Snake River are summarized in Corps, 2019e. All types of dredging activities were included when computing the values in Table 2-22. Dredging to maintain flow conveyance has not been conducted since 1992, but significant volumes were dredged in prior years. Under the PSMP, there is a provision for dredging outside of the navigation channel for the sole purpose of increasing flow conveyance to maintain flood risk reduction. The stringent criteria for flow conveyance dredging outlined in the PSMP will likely result in less flow conveyance dredging compared to historical dredging.

2.5.4.2 Lower Columbia Navigation Channel Dredging

The Corps Portland District is responsible for maintaining sufficient water depth in the Federal Navigation Channel (FNC) of the Columbia River to provide safe and efficient deep-draft and shallow-draft navigation. The Columbia River is a dynamic system that poses an annual challenge for maintenance of the lower Columbia River FNC (LCR FNC) to the authorized deep-draft depth of 43 feet from River Miles (RM) 3.0 to 106.5. Material dredged from the deep-draft channel in that reach is placed at multiple sites including: a mix in-water, shoreline, upland, or ocean sites.

The shallow-water portion of the Columbia River FNC (CR FNC) from Vancouver, Washington, to The Dalles, Oregon, (VTD FNC) includes the channel from RM 106.5 to 145 (Bonneville Dam). It is immediately upstream of the deep-draft FNC. Material dredged to maintain the VTD FNC is generally placed in-water upstream of Vancouver, Washington. The Lower Willamette River (LWR) FNC is located between RM 0 and 12 in Portland, Oregon, to its confluence with the Columbia River (at RM 102). The most recent material dredged to maintain the LWR FNC was placed upland at a site also used for the CR FNC.

Present sedimentation processes require that the Corps annually remove 6 to 10 million cubic yards (Mcy) of sand from the LCR FNC below Bonneville Dam at a cost of tens of millions of dollars annually.

A systematic approach was developed to evaluate potential impacts to Corps operations and maintenance (O&M) dredging and deep-draft restrictions within the LCR FNC, associated with different river discharges at Bonneville Dam. The Corps *Sedimentation Implications for Maintenance Dredging and Navigation within the Lower Columbia River Federal Navigation Channel from Bonneville Dam Hydro-Regulation Flows* (Corps 2019d) technical memorandum describes the work performed for the lower Columbia River in terms of the methodology, data, and tools employed to understand and characterize the potential navigation benefits and impacts to the LCR FNC due to changes in river flow (hydroregulation) passing Bonneville Dam.

In support of the approach, the U.S. Geological Survey (USGS) developed sediment transport rating curves for each hydrogeomorphic (HG) reach of the lower Columbia River from the Pacific Ocean to Bonneville Dam (Figure 2-18). The reach-based sediment transport rating curves were differentiated between HG reaches to allow the estimation of cumulative (bulk) FNC shoaling within each reach; for a given flow year (expressed as an annual daily average river discharge timeseries). The cumulative annualized shoaling for each HG reach, for a given hydroregulation flow, was differenced from the current condition hydroregulation to evaluate the effect that given flow may have on an FNC sedimentation on a reach-by-reach basis. Figure 2-19 illustrates how this process was performed. See Corps (2019d) for additional details on the methodology and calculations.

Figure 2-18. Lower Columbia River and Estuary Represented by Eight Hydro-Geomorphic Reaches

Note: Each HG reach characterizes similar attributes of river morphology, sediment transport, and hydraulic/tidal conditions. River kilometers denote boundaries between reaches, 1 kilometer (km) = 0.62 miles.

Source: Simenstad et al. 2011

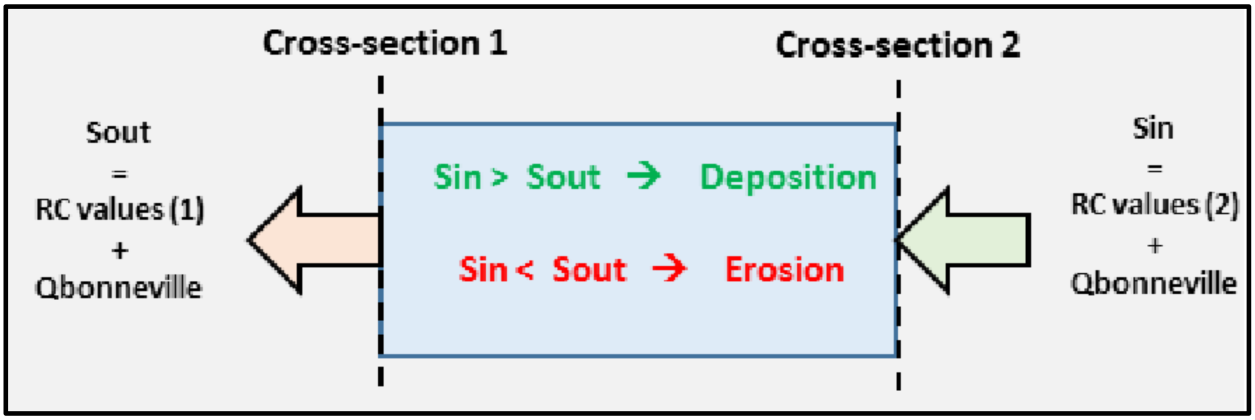


Figure 2-19. Conceptual "Box-Model" for Estimating the Sediment Budget Within a Given Hydro-Geomorphic Reach Based on the Difference Between the Computed Flux of Sediment (S) "In" and "Out" of the Reach

Note: A negative value for "Sin – Sout" indicates net erosion (or scour) from the reach; a positive value for "Sin – Sout" indicates net deposition (or shoaling) within a given HG reach.

CHAPTER 3 - ALTERNATIVE ANALYSES

The river mechanics alternatives analysis presented herein includes details of the estimated departure from the No Action Alternative for seven metrics representing sediment transport and geomorphic processes (see Chapter 2). Due to the generally localized and small response in river mechanics metrics across the basin, the analysis descriptions are grouped by alternative, and then by metric (storage and run-of-river projects), and lastly by location where a notable response was identified. Attribution of river mechanics effects under a select MO to specific operational measures was estimated; however it is often not possible to draw definitive boundaries around the influence of one measure over another, due to component measure interactions. In order to facilitate efficient location of estimated departure under select metrics and alternatives, the analysis is presented as a brief narrative organized within summary tables. Additional summary comparison tables and data plots are also provided to complement the analysis.

3.1 NO ACTION ALTERNATIVE (NAA)

This analysis of the No Action Alternative focused on the geomorphology and sediment transport conditions within the CRSO study area, without any changes in system configuration, maintenance or operation. In other words, the No Action Alternative shows what would happen if proposed new actions were not taken and project operations, maintenance and configuration remained the same as they were in September 2016 (the EIS Notice of Intent date). For this No Action Alternative assessment, future geomorphology and sediment transport conditions are evaluated for the next 50 years. Baseline impacts related to the No Action Alternative are enumerated in Table 3-1. These impacts establish the baseline for relative comparisons of the MOs as detailed herein.

Table 3-1 Summary of No Action Alternative (NAA) River Mechanics Impact Estimates.

Metric	No Action Alternative Impact
Storage Projects	
Head-of-Reservoir Sediment Mobilization	Negligible change in erosion or deposition processes, patterns and rates at the head of storage project reservoirs.
Sediment Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those historically experienced.
Shoreline Exposure	Negligible change in the amount of time that the storage project water surface elevations spend at any given elevation indicating that reservoir shoreline erosion processes are expected to continue at locations and rates similar to those historically experienced at each project.
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches indicating that reservoir sediment pass-through at CRS run-of-river projects will continue at magnitudes and rates similar to those historically experienced.

Metric	No Action Alternative Impact
Potential for Bed Material Change	Current processes that supply, transport, and deposit sediment in the system will continue at historical rates.
Potential Change to Width-to-Depth Ratio	Negligible change in the overall geomorphic character of the rivers due to continued operation of the Columbia River System.
Potential Changes to Navigation Channel Dredging Volumes	Negligible change in the average annual navigation channel dredging volumes due to continued operations of the Columbia River System. The navigation system will continue to be maintained through existing authorities and operational plans. **Snake River:** Estimated average annual volume of sediment depositing in the Snake River navigation channel due to No Action Alternative operations is 0.124 Mcy per year **Lower Columbia River:** Estimated average annual volume of sediment depositing in the LCR FNC due to No Action Alternative operations is 6.68 Mcy per year.

3.1.1 Storage Projects: No Action Alternative Baseline

The six storage projects include Libby, Hungry Horse, Albeni Falls, Grand Coulee, John Day, and Dworshak Dams. For the No Action Alternative, these projects were evaluated for impacts to the head-of-reservoir sediment mobilization, sediment trap efficiency, and shoreline exposure.

The head-of-reservoir sediment mobilization metric is designed to indicate the potential for changes in sediment scour and deposition patterns in the most upstream portion of storage reservoirs. Under the No Action Alternative, water storage patterns are expected to be generally within the same range as currently experienced. There is a wide range in the water elevation in the storage reservoirs depending on the season and precipitation, and this variation affects the location of the transition between riverine and reservoir conditions. Since the range of watershed, hydrologic, and climactic conditions was assumed to remain consistent with what has historically been experienced, the conditions in the head-of-reservoir and the transportation of sediment from the head of the reservoir downstream are generally expected to remain within the historically experienced range with negligible changes.

Sediment trap efficiency refers to the amount of sediment that can deposit within or pass through the storage reservoir.. The trap efficiency depends on the sediment inflow rate and type of sediment entering the reservoir (the loading) as well as reservoir conditions (storage volume and residence time). Under the No Action Alternative, land use patterns and the amount of sediment entering the reservoirs from upstream is expected to remain the same as historically experienced. The reservoir operation, including water levels, in-flows, and out-flows, is expected to remain similar to the historical range experienced. Changes to the amount of sediment trapped are expected to be negligible because the reservoir operation and sediment loading are not expected to change.

Shoreline erosion occurs to varying degrees in the storage reservoirs, depending on water level, wind (wave erosion), ice, currents, and other processes. Under the No Action Alternative, the duration and timing of key reservoir pool water levels is not expected to change compared to the historic range. Similarly, it is anticipated that winds, freeze/thaw patterns, and flow rates within the reservoir would be within the historically experienced range. Because the conditions in the reservoirs are expected to be similar to those historically experienced, it is anticipated that under the No Action Alternative, shoreline processes such as erosion would occur at locations and rates similar to those historically experienced, with negligible changes.

3.1.2 Run-of-River and Free-Flowing Reaches: No Action Alternative Baseline

The remaining CRS reservoirs within the study area (Chief Joseph, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, The Dalles and Bonneville Dams) are run-of-river dams that do not store water for later discharge. These CRS reservoirs and the free-flowing sections of river (for example the Flathead River below Hungry Horse Dam) were evaluated for the potential for sediment to pass downstream, the potential for bed material changes, the potential for changes in the width-to-depth ratio of the channel, and the potential for changes to the navigational channel maintenance dredging requirements.

Under the No Action Alternative, the sediment loading throughout the basin is not expected to change from the historic range experienced. Climactic conditions, land use and precipitation are major drivers for sediment erosion and yield into the river system. For this analysis climatic conditions were assumed to be consistent within historic ranges of variability. Land use is anticipated to follow similar patterns as currently experienced, with discrete population centers in some areas, but with a large portion of the watershed held as public lands. Sources of sediment such as agricultural fields are expected to continue cultivation in a manner similar to the current conditions. The physical properties (such as grain size) of sediment entering a reservoir are also expected to be similar to the historic conditions. The range of precipitation is expected to be within the historic range experienced, including some very wet and some very dry years. The flow rates and project operating stages within the system are similarly expected to remain within the historic range of variations. The incoming flow rate and downstream stage within a river segment or reservoir directly affect the hydraulic grade, which is the primary driver of sediment transport and suspension. Because the sediment sources to the system and the energy regime within the rivers and reservoirs are expected to be within the historic range, the amount of sediment that passes a given reservoir or river reach is also expected to be similar to the historic range.

The bed material represents the sediment composition of the channel wetted perimeter and subgrade. It may contain a wide distribution of grain sizes that are hydraulically sorted both streamwise and laterally and may be vertically stratified. Within backwatered reservoir reaches, the bed material is commonly characterized by an annual deposition pattern due to downstream backwater influences. Conversely in free-flowing reaches, it may be relatively fixed or cyclically dynamic depending on the local geology and the balance between sediment supply and hydraulic conditions that influence transport trends and grain-sorting patterns. The bed material characterization within the basin varies by location; for example, coarser-grained materials are found upstream of Silcott Island on the lower Snake River, while finer-grained materials are generally found farther downstream as the river approaches the Lower Granite Dam forebay. Changes to the established bed material erosion and deposition patterns are expected to be negligible because flow rates, operational stages, and sediment loading to the system are expected to be similar to historical ranges.

The width-to-depth ratio (W/D) is a relative metric that reflects the free-flowing river conditions compared to the reservoir conditions; reservoirs typically decrease the width-to-depth ratio of river channels and also affect floodplain surfaces and wetlands. In turn, these changes affect the ecological functions of the system. For the No Action Alternative, the width-to-depth ratio is not expected to be affected because the operating water levels and flow rates within the system are expected to be within the historic range experienced.

Potential impacts to channel maintenance dredging volumes were also evaluated. Sediment that accumulates within a Federal Navigation Channel (FNC) is periodically removed by dredging, to maintain safe navigation conditions for a variety of vessel types. The accumulation of sediment is dependent on factors discussed above, including climatic conditions, watershed yield and loading to the reservoir, the hydraulic capacity to transport sediment material through the reservoir, and changes to the bed materials. Under the No Action Alternative, these items are not expected to change from the current range of conditions. Similarly, the amount of sediment that accumulates within the FNC is not expected to change, and periodic dredging at the historically documented accumulation areas is expected to continue into the future. Currently, dredging within the system occurs on the lower Columbia River and on the lower Snake River in discrete locations. Areas that historically have required dredging (lock chamber approaches, the confluence of the Snake and Clearwater Rivers, harbor-and-port berthing areas and entrances) would still experience shoaling (buildup of sediment into shallow areas). Dredging within the FNC and private dock-face/berthing areas to maintain navigation would still occur. Sediment management activities in the Snake River (as described in the Programmatic Sediment Management Plan [Corps 2014]) would continue as currently planned. In short, sediment is expected to continue to accumulate within the FNC, and sediment management activities would be in accordance with applicable guidance and regulations at the time of any future dredging project (Figure 3-1 - Figure 3-12).

3.1.3 Region A: No Action Alternative Baseline Metrics for Kootenai, Flathead, and Pend Oreille Basins

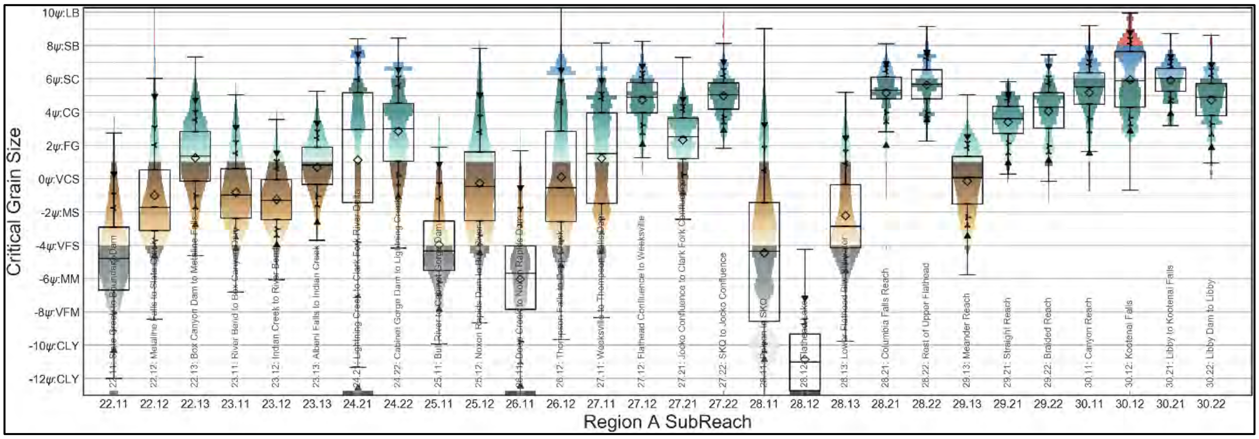


Figure 3-1. Region A Critical Grain-Size No Action Alternative Baseline for Bed Material Change Assessment

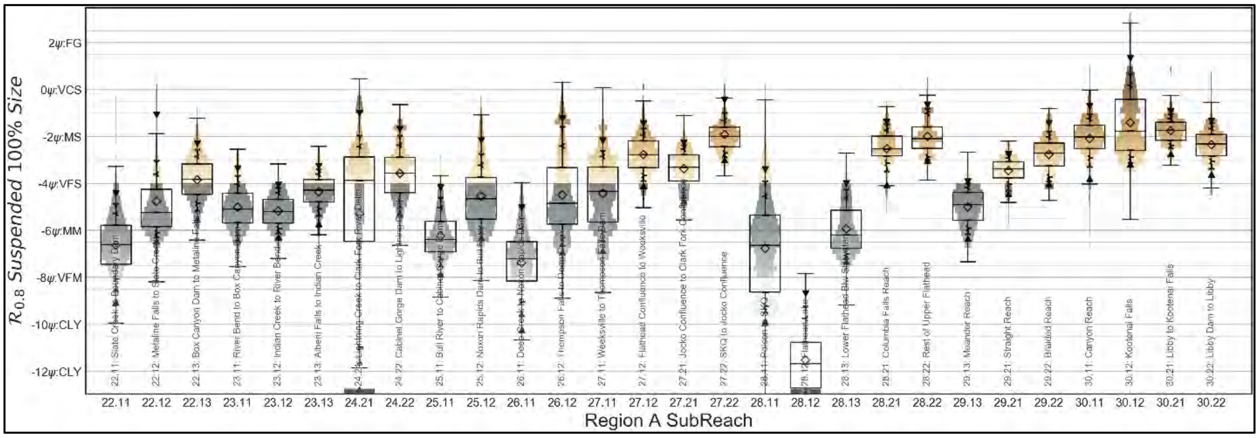


Figure 3-2. Region A Suspended Sediment Size No Action Alternative Baseline for Sediment Passing Assessment

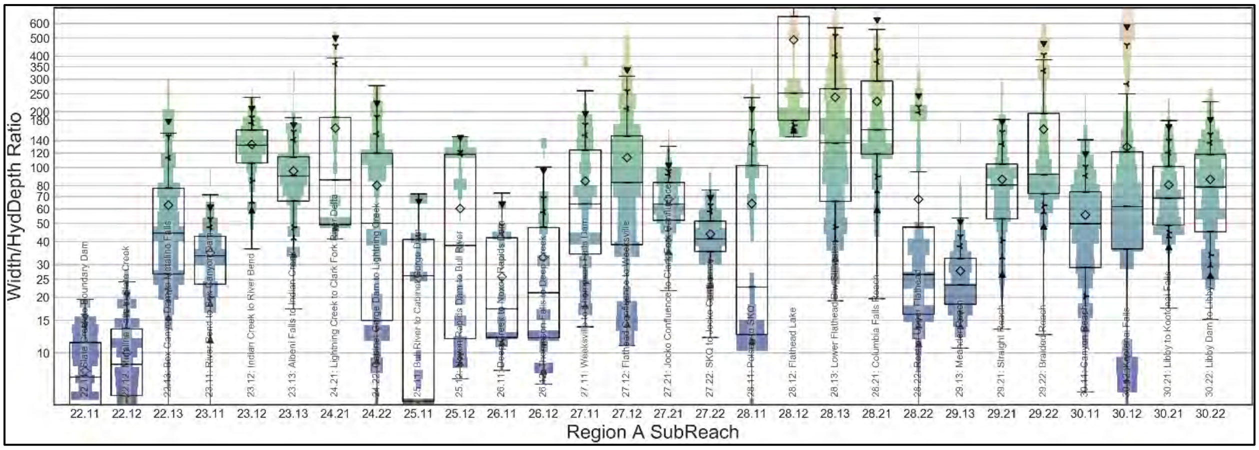


Figure 3-3. Region A Width-to-Depth Ratio No Action Alternative Baseline for Geomorphic Change Assessment

3.1.4 Region B: No Action Alternative Baseline Metrics for Middle Columbia River

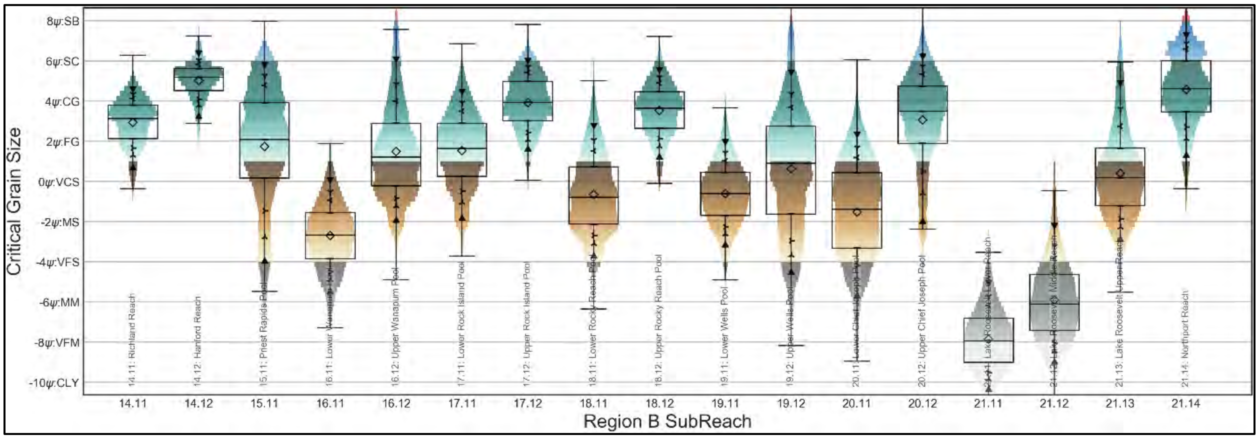


Figure 3-4. Region B Critical Grain-Size No Action Alternative Baseline for Bed Material Change Assessment

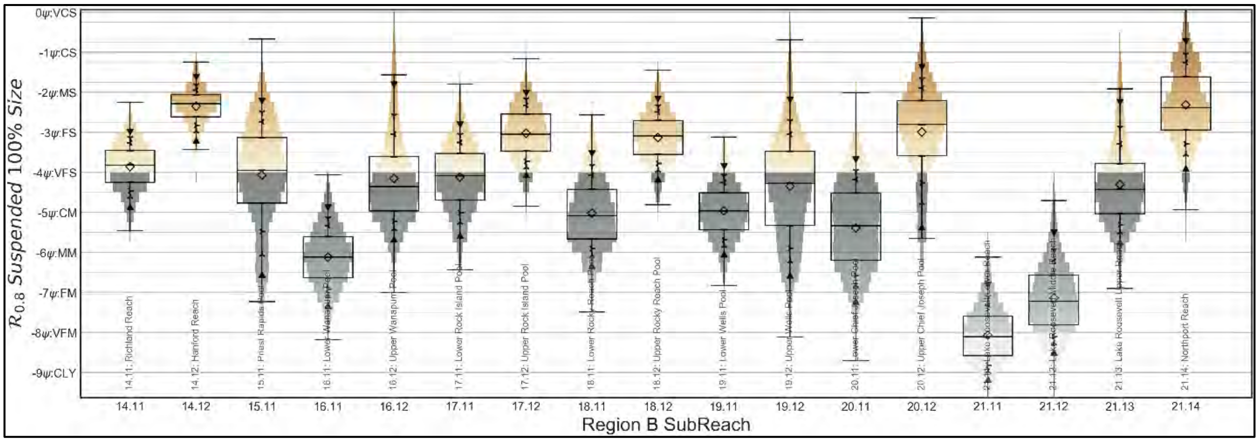


Figure 3-5. Region B Suspended Sediment Size No Action Alternative Baseline for Sediment Passing Assessment

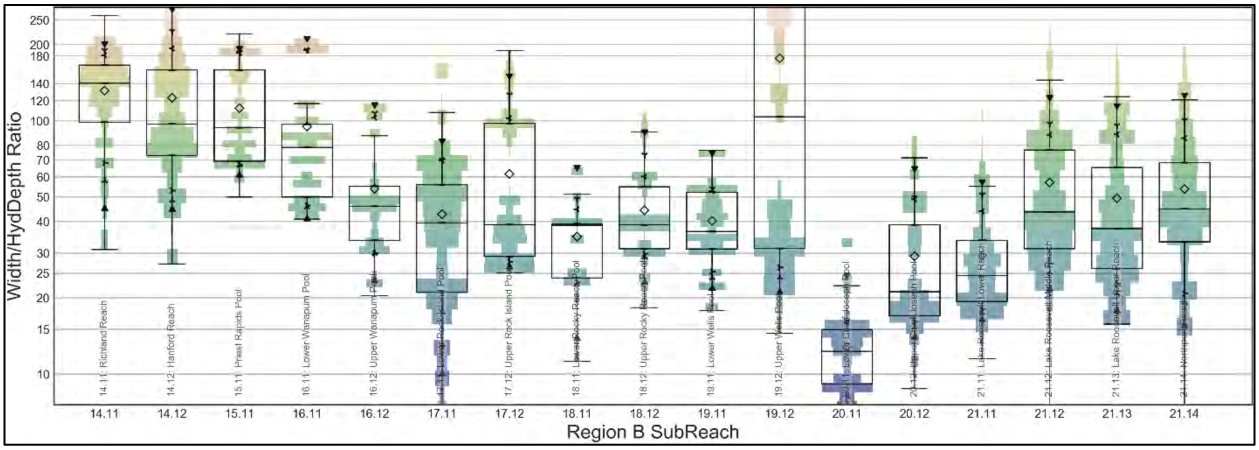


Figure 3-6. Region B Width-to-Depth Ratio No Action Alternative Baseline for Geomorphic Change Assessment

3.1.5 Region C: No Action Alternative Baseline Metrics for Clearwater and Lower Snake Rivers

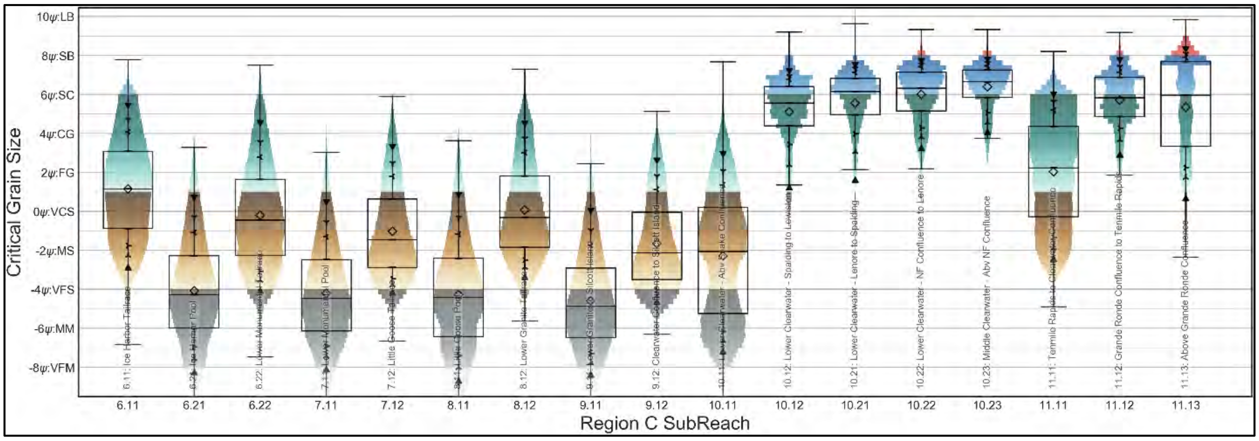


Figure 3-7. Region C Critical Grain-Size No Action Alternative Baseline for Bed Material Change Assessment

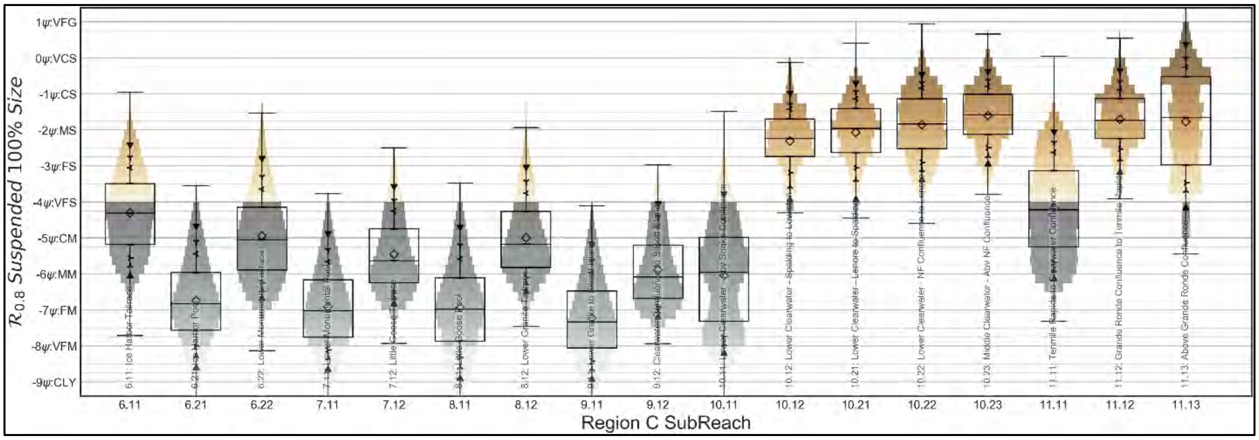


Figure 3-8. Region C Suspended Sediment Size No Action Alternative Baseline for Sediment Passing Assessment

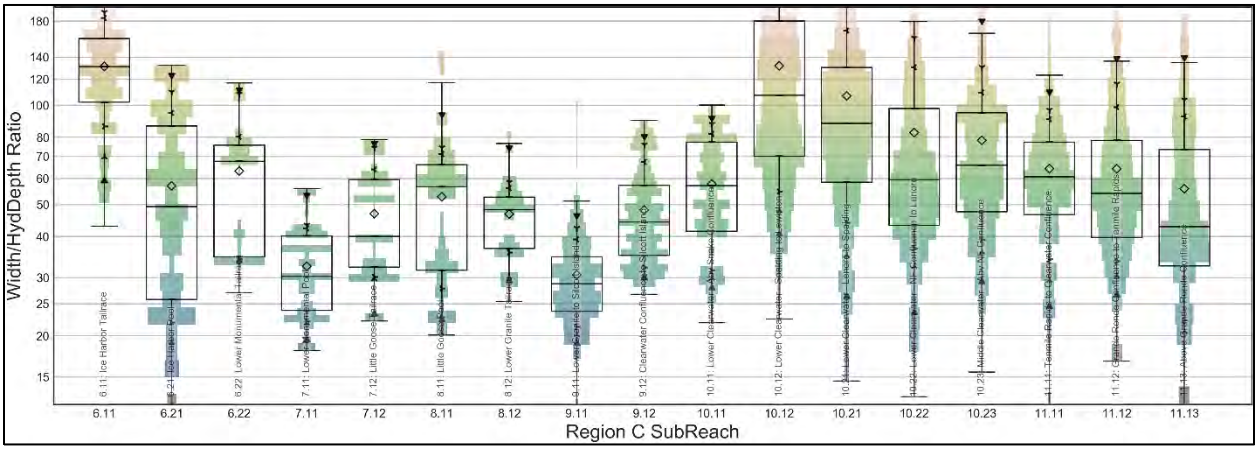


Figure 3-9. Region C Width-to-Depth Ratio No Action Alternative Baseline for Geomorphic Change Assessment

3.1.6 Region D: No Action Alternative Baseline Metrics for Lower Columbia River

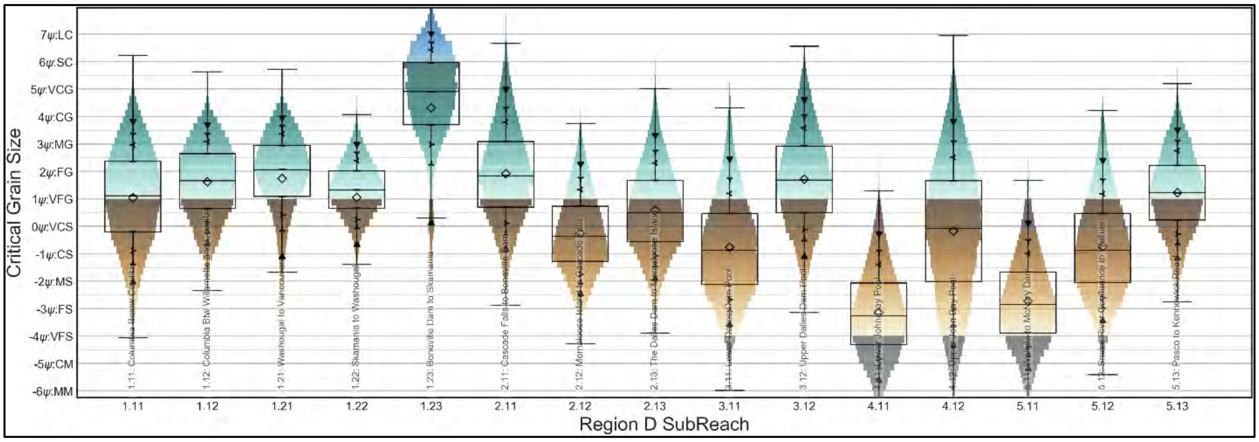


Figure 3-10. Region D Critical Grain-Size No Action Alternative Baseline for Bed Material Change Assessment

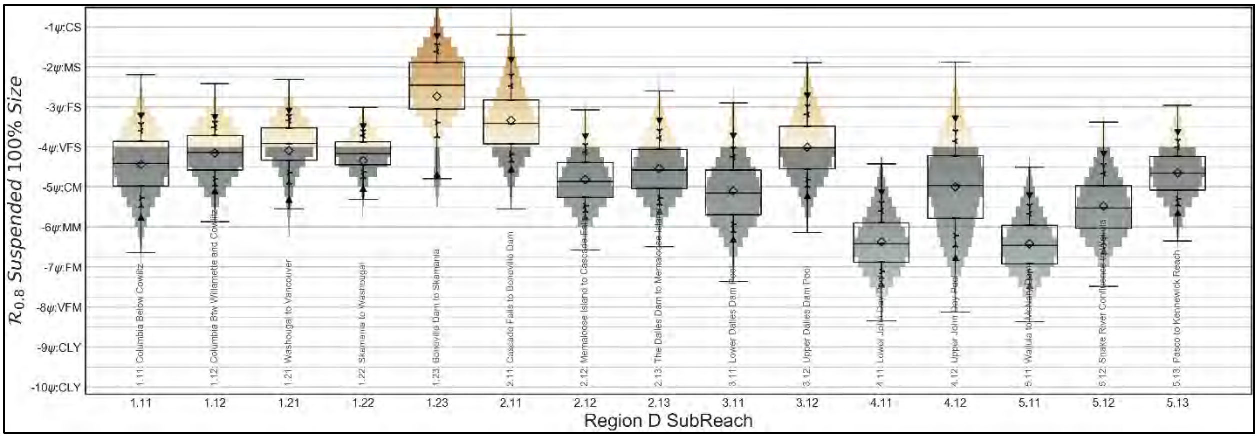


Figure 3-11. Region D Suspended Sediment Size No Action Alternative Baseline for Sediment Passing Assessment

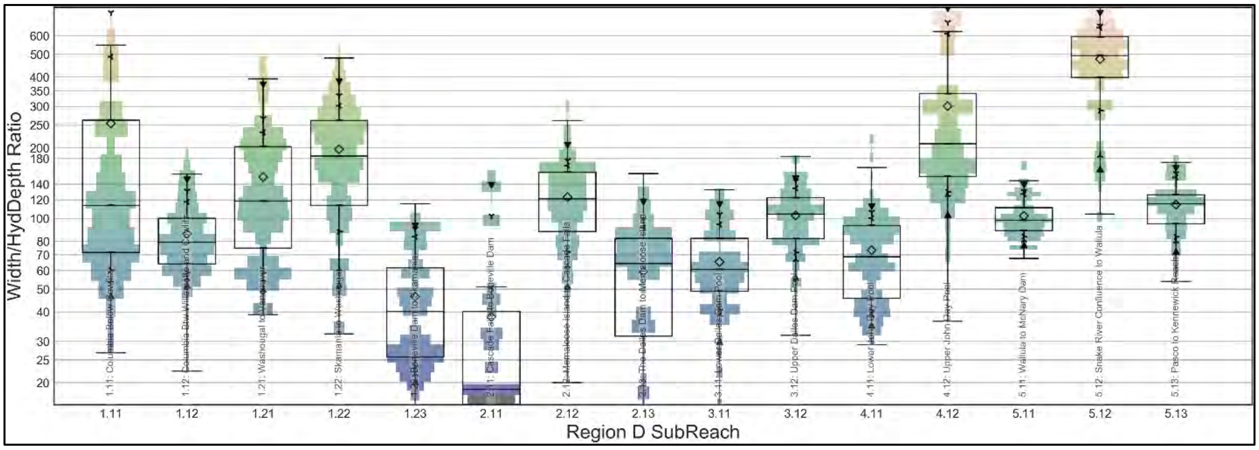


Figure 3-12. Region D Width-to-Depth Ratio No Action Alternative Baseline for Geomorphic Change Assessment

3.2 MULTIPLE OBJECTIVE ALTERNATIVE 1 (MO1)

Multiple Objective Alternative 1 (MO1) is aimed at completely or partially meeting multiple objectives related to fish populations and other authorized uses such as hydropower operation. To meet multiple objectives, an array of measures are included in this alternative. The large number of proposed measures would be implemented throughout the project study area. See Chapter 2 Section 2.3.3 for a complete description of MO1. Impacts related to MO1 relative to the No Action Alternative are enumerated in Table 3-2.

Table 3-2. Summary of Multiple Objective Alternative 1 River Mechanics Impact Estimates

Metric	MO1 Impact
Storage Projects	
Head-of-reservoir Sediment Mobilization	Negligible change in erosion or deposition processes and patterns at the head of storage project reservoirs with the exception of: **Columbia River enteringLake Roosevelt**. There is potential for a minor change in depositional patterns with temporary head-of-reservoir deposits shifting downstream, although available deposit volume is limited. Head-of-reservoir deposits may include contaminants (slag) that are also mobilized slightly farther downstream in the reservoir but are not expected to be transported past the dam. Ultimate long-term fate of head-of-reservoir sediments within the reservoir is expected to remain unchanged given there are no proposed changes in the Grand Coulee operational range. Draft duration related to *Winter System FRM Space* measure at Grand Coulee Dam contributes to the impact.
Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those under NAA.
Shoreline Exposure	Negligible change in the amount of time that the storage project water surface elevations spend at any given elevation indicating that reservoir shoreline erosion processes are expected to continue at locations and rates similar to those under NAA at each storage project.
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches with the exception of: **Lower Clearwater River above the Snake Confluence (Subreach 10.11)**. There is potential for a minor decrease in the amount of sediment passing the Clearwater River at the Snake-Clearwater confluence. The *Modified Dworshak Summer Draft* measure causes the impact.
Potential for Bed Material Change	Negligible change in the processes that supply, transport, and deposit sediment in the system with the exception of: **Lake Roosevelt Upper Reach on the Columbia River** (Subreach 21.13). There is potential for a minor amount of coarsening of bed sediment at the head of Lake Roosevelt. Draft duration related to *Winter System FRM Space* measure at Grand Coulee Dam contributes to the impact.
Potential Change in Width-to-Depth Ratio	Negligible change in the overall geomorphic character of the rivers.
Potential Changes to Navigation Channel Dredging Volumes	**Snake River:** Estimated average annual volume of sediment depositing in the Snake River

Metric	MO1 Impact
	navigation channel due to MO1 operations is less than 1% change from the No Action Alternative. **Lower Columbia River:** Estimated average annual volume of sediment depositing in the lower Columbia River FNC due to MO1 operations is less than 1% decrease from the No Action Alternative.

3.3 MULTIPLE OBJECTIVE ALTERNATIVE 2 (MO2)

The second Multiple Objective Alternative (MO2) includes measures intended to at least partly address fish-related and operational objectives. An array of measures are included, with some aimed at fish-related objectives and some aimed at hydropower operational efficiency. For more information, refer to the complete alternative description located in Chapter 2, Section 2.3.4. Impacts related to MO2 relative to the No Action Alternative are enumerated in Table 3-3.

Table 3-3. Summary of Multiple Objective Alternative 2 River Mechanics Impact Estimates

Metric	MO2 Impact
Storage Projects	
Head-of-reservoir Sediment Mobilization	Negligible change in erosion or deposition processes and patterns at the head of storage project reservoirs with the exception of: **Dworshak Reservoir.** There is potential for a minor change in depositional patterns with temporary head-of-reservoir deposits shifting downstream. Ultimate long-term fate of head-of-reservoir sediments within the reservoir is unchanged given no changes in Dworshak operational range. The *Slightly Deeper Draft for Hydropower* measure causes the impact.
Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those under NAA.
Shoreline Exposure	Negligible change in the amount of time that the storage project water surface elevations spend at any given elevation with the exception of: **Dworshak Reservoir.** There is potential for a minor change in shoreline exposure at Dworshak with the reservoir being held at lower elevations for a duration long enough to potentially cause a minor increase in the shoreline erosion pattern. The *Slightly Deeper Draft for Hydropower* measure causes the impact. At Lake Roosevelt, the increased shoreline exposure was estimated to be 1.8 feet which is within the negligible interval. In addition, the proposed measure for slower drawdown from the Planned Draft Rate at Grand Coulee could have the potential to provide minor reductions in local landslides related to reservoir levels.
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches.
Potential for Bed Material Change	Current processes that supply, transport and deposit sediment in the system will continue at historical rates (same as NAA) with the exception of: **Lower Flathead River between Stillwater and Flathead Lake (*Subreach 28.13*).** There is potential for a minor, unobservable amount of fining of bed sediment in

Metric	MO2 Impact
	the reach immediately upstream of Flathead Lake. The impact results from slight reductions in Hungry Horse outflow, which dampens the energy grade as the Flathead River enters Flathead Lake backwater; the flow reduction is tied to the reduced outflows during the flood risk management (FRM) period, which results from *Slightly Deeper Draft for Hydropower* measure during winter months. **Lake Roosevelt Upper Reach on the Columbia River (*Subreach 21.13*).** There is potential for a minor amount of coarsening of bed sediment at the head of Lake Roosevelt. Draft duration from the *Winter System FRM Space* and *Slightly Deeper Drafts for Hydropower* measures at Grand Coulee contribute to the impact.
Potential Change in Width-to-Depth Ratio	Negligible change in the overall geomorphic character of the rivers.
Potential Changes to Navigation Channel Dredging Volumes	**Snake River:** Estimated average annual volume of sediment depositing in the Snake River navigation channel due to MO2 operations is less than 1% change from the No Action Alternative. **Lower Columbia River:** Estimated average annual volume of sediment depositing in the lower Columbia River FNC due to MO2 operations is less than 1% increase from the No Action Alternative.

3.4 MULTIPLE OBJECTIVE ALTERNATIVE 3 (MO3)

Multiple Objective Alternative 3 (MO3) includes measures intended to at least partly address fish-related and operational issues. This alternative includes many operational measures similar to previous alternatives; however, it also includes breaching of embankments at the four lower Snake River dams. See Chapter 2 for a complete description of the dam embankment breach alternative. Structural measures at the four lower Snake River Dams (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) for this alternative include:

- Breach Snake Embankments: Remove earthen embankments, as required, at each dam to facilitate reservoir drawdown at the lower Snake River dams.
- Lower Snake Infrastructure Drawdown: Modify existing equipment and dam infrastructure at the lower Snake River dams to adjust to drawdown conditions (existing equipment would not be used for hydropower generation but would be used as low-level outlets for drawdown below spillway elevations).
- Additional Powerhouse Surface Passage: Construct additional powerhouse and surface passage routes at the McNary Project.

Under MO3, four reservoirs will be drawn down and converted to a riverine environment. The current reservoirs contain fine sediment deposits that will partially erode leaving margin sediment on high terraces behind. The new river bottom after breaching will initially become finer and gradually coarsen over the long-term. The change in the overall geomorphic character will occur on the Snake and Clearwater Rivers within the backwater extents of Lower Granite Reservoir downstream to the confluence with the Columbia River. River Mechanic metric impacts related to MO3 relative to the No Action Alternative are enumerated in Table 3-4.

1449 **Table 3-4. Summary of Multiple Objective Alternative 3 River Mechanics Impact Estimates**

Metric	MO3 Impact
Storage Projects	
Head-of-reservoir Sediment Mobilization	Negligible change in erosion or deposition processes and patterns at the head of storage project reservoirs.
Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those under NAA.
Shoreline Exposure	Negligible change in the amount of time that the storage project water surface elevations spend at any given elevation indicating that reservoir shoreline erosion processes are expected to continue at locations and rates similar to those under NAA at each storage project.
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches with the exception of: **The Snake River from the upstream extents to Lower Granite Reservoir downstream to the Columbia River (*Reaches 6–9 and 11.1*)** and the **Clearwater River backwatered by Lower Granite Reservoir (*Subreach 10.1*)**. There is potential for a major increase in the size and amount of sediment passing these reaches. The *Breach Snake Embankments* measure causes the impact by converting four run-of-river reservoirs to a riverine environment. **Columbia River from the Snake River confluence downstream to the Pacific Ocean (*Reaches 1–5*).** Due to the increase in amount of sediment passing from the Snake River into the Columbia River, there is potential for a major increase in the amount of sediment passing downstream of the Snake River confluence. The *Breach Snake Embankments* measure causes the impact.
Potential for Bed Material Change	Current processes that supply, transport and deposit sediment in the system will continue at historical rates (same as NAA) with the exception of: **The lower Snake River from the upstream extents of the CRS study area to Lower Granite Reservoir downstream to the Columbia River (*Reaches 6–9 and Subreach 11.1*)** and the **Clearwater River backwatered by Lower Granite Reservoir (*Subreach 10.1*)**. There is potential for a major amount of coarsening of bed sediment throughout these reaches. The *Breach Snake Embankments* measure causes the impact. **The Columbia River from the Snake River confluence to McNary Dam (*Subreach 5.1*).** Due to the increase in amount of sediment passing from the Snake River into the Columbia River, there is potential for a major increase in the amount of material depositing in McNary Reservoir. The bed material size may become finer in the short term and coarsen in the long term. The *Breach Snake Embankments* measure causes the impact.
Potential Change in Width-to-Depth Ratio	Negligible change in the overall geomorphic character of the rivers with the exception of: **The lower Snake River from the upstream extents of the CRS study area to Lower Granite Reservoir downstream to the Columbia River (*Reaches 6–9 and Subreach 11.1*)** and the **Clearwater River backwatered by Lower Granite Reservoir (*Subreach 10.1*).** There is a major change in geomorphic character in these reaches with the river becoming much shallower relative

Metric	MO3 Impact
	to its wetted width. The *Breach Snake Embankments* measure causes the impact. The four lower Snake River reservoirs contain fine sediment deposits that following dam embankment removal will partially erode leaving margin sediment on high terraces behind. The new lower Snake river bottom after breaching will initially become finer and gradually coarsen over the long-term. The change in the overall geomorphic character will occur on the Snake and Clearwater Rivers within the backwater extents of Lower Granite Reservoir downstream to the confluence with the Columbia River.
Potential Changes to Navigation Channel Dredging Volumes	**Snake River:** Navigation maintenance of the Snake River FNC is assumed to cease following breaching of the four Snake River projects. Estimated change in the average annual volume of watershed sediment yield to the lower Snake River is less than 1% compared to No Action. Following breaching of the dam embankments, this watershed sediment will now pass the breached dam embankments and be routed to the Columbia River confluence as discussed below. **Lower Columbia River:** Estimated average annual volume of sediment depositing in the lower Columbia River FNC due to MO3 operations less than 1% decrease from the No Action Alternative based on sediment load from the Lower Columbia River. In addition, near-term sedimentation effects following dam embankment breaching are expected to last 2 to 7 years as legacy sediment deposits within the dam pools are incrementally eroded and re-deposited throughout the lower Snake River Reach. Near-term sedimentation effects are expected to be particularly large in the upstream end of Lake Wallula above McNary Dam. The impacts of sediment deposition at left bank recreation and boat-launch sites below the Snake confluence would likely be permanent. Long-term sedimentation effects would include continued deposition in quiescent areas prone to shoaling as a result of annual sediment delivery that had previously been trapped by the lower Snake River dams.

Large impacts are identified in the Snake River and localized reaches of the Columbia River downstream of the Snake River confluence due to the breach Snake embankments measure in MO3. A more detailed analysis was untaken to provide information on sediment processes during and after drawdown and removal. A modeling and analysis methodology was developed to provide the following:

- Best available quantitative estimates of the volume of reservoir sediment mobilized during removal of the four dams.
- Timing of sediment in motion, including sediment concentrations, and return to quasi-equilibrium in the Snake River.
- Condition of the Snake River following dam removal.
- Sediment load to McNary Reservoir and McNary Reservoir Deposition.
- Sediment load and fate downstream of McNary Dam.

The analysis makes use of existing literature and data and several new hydraulic and sediment models. A new one-dimensional HEC-RAS quasi-unsteady mobile bed model of the lower Snake River was developed to provide information on sediment trends during removal and in the longer term (Corps 2019a). New two-dimensional adaptive hydraulics (AdH) models for McNary and John Day Reservoirs were developed. AdH output was used in new Particle Tracking Model applications to McNary and John Day Reservoirs (Corps 2019b & 2019c). Finally, one-dimensional unsteady state HEC-RAS mobile bed modeling of the Snake River and the Columbia River downstream of the Snake River confluence was used to calculate multiple sediment transport metrics including threshold grain size for 100 percent suspension using the Rouse method.

3.4.1 Volume of Reservoir Sediment Mobilized During Dam Removal

The total volume of sediment deposited in the lower Snake River reservoirs since construction was calculated using historical bathymetry and terrain data. A high-quality dataset developed from 1934 mapping provides the pre-dam condition baseline. Cross-section data collected by the Corps in 1997, 2003, and most recently in 2010, provides current conditions. The total volume of sediment stored in the four lower Snake River Dams between construction and 2010 is estimated to be approximately 180 Mcy. Lower Granite holds the most volume of sediment with 75Mcy, with the remainder distributed throughout the reach (Figure 3-13).

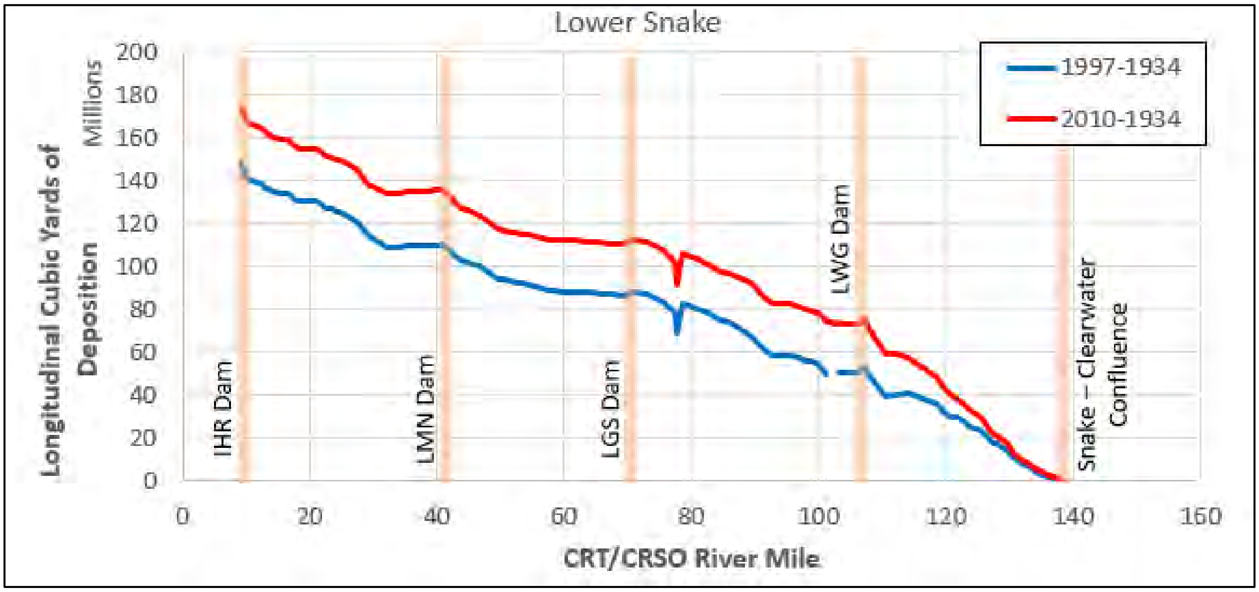


Figure 3-13. Total Sediment Deposition in the Lower Snake River

The average cross-sectional depth of deposition was extracted from the data and is shown in Figure 3-14. The greatest depths are located in Lower Granite Reservoir and can exceed 10 feet.

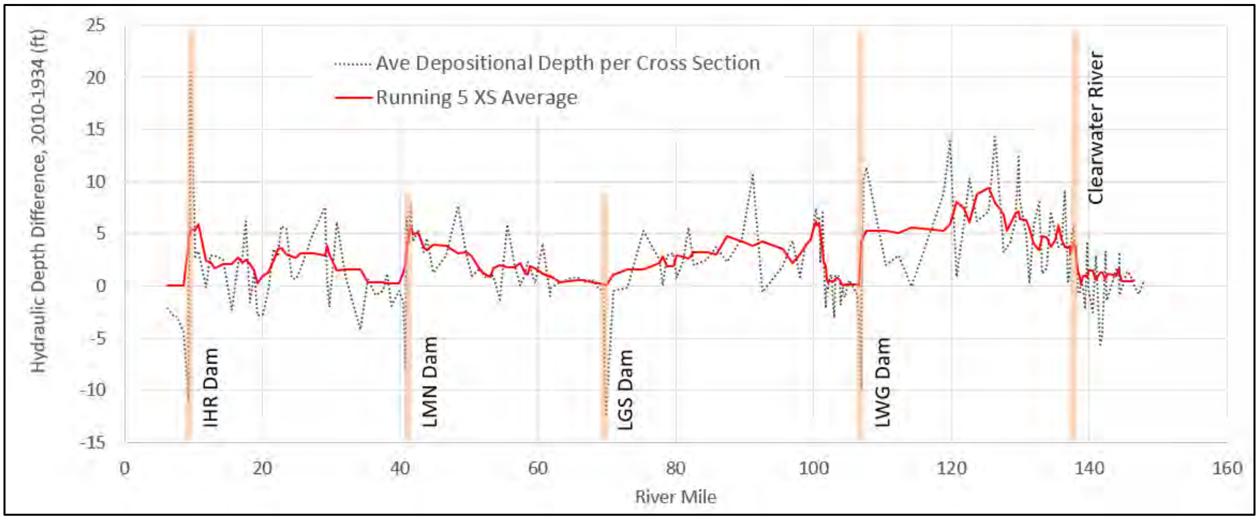


Figure 3-14. Average Depth of Deposition in the Lower Snake River

Stored sediments are predominately silt and clay-sized with some sand in the mix (generally localized to the upstream extent of each reservoir pool). Minimal amounts of gravel-size particles were sampled in the reservoirs. Figure 3-15 shows bed material gradations from 47 sample locations in the lower Snake River.

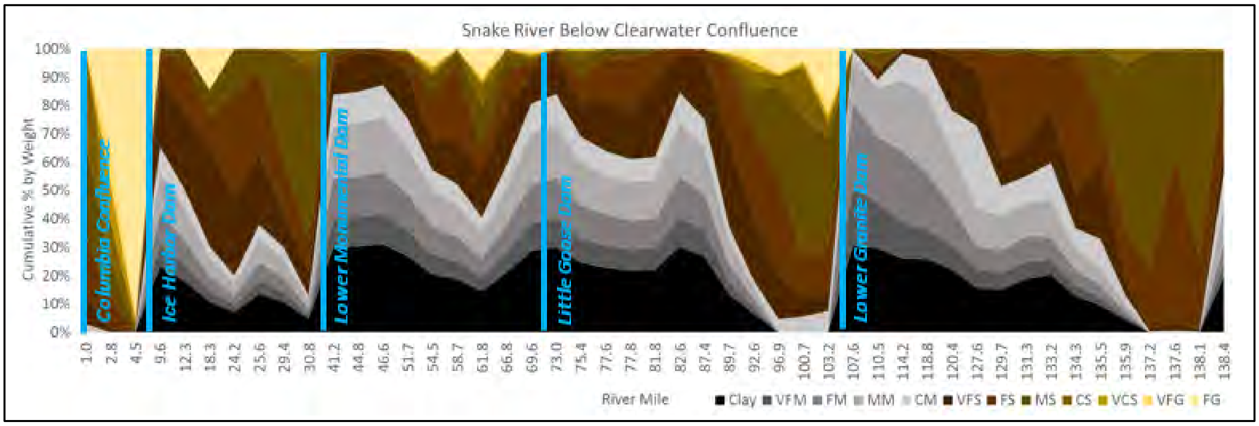


Figure 3-15. Bed Material in the Lower Snake River

The sediment currently being supplied to the system is largely fine-grained (83 percent clay and silt) and can be transported as suspended load that can deposit high on the banks of the reservoirs. Figure 3-16 shows an example cross section comparison between the pre-dam 1934 survey and the most recent 2010 survey. Deposition on the riverbed and high above the pre-dam water surface is readily seen.

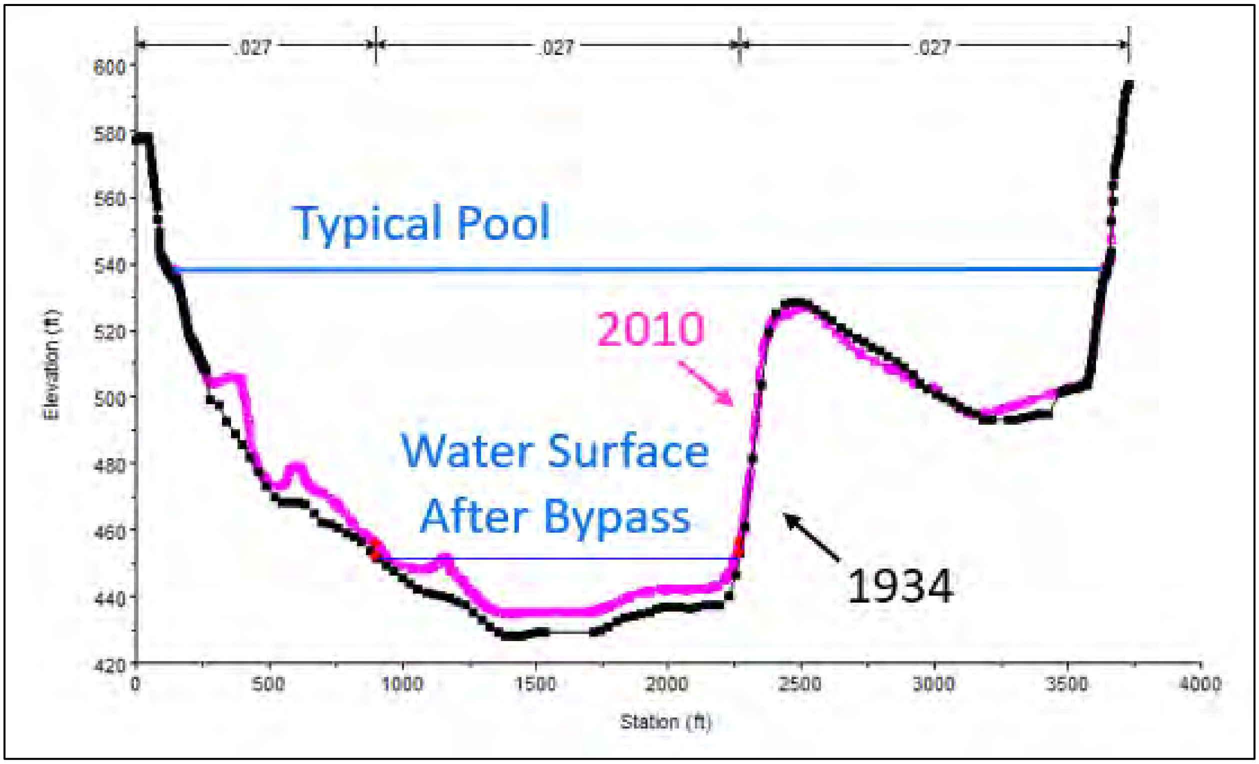


Figure 3-16. Example Cross Section Comparison Showing Bed and Bank Deposition

This deposition high above the historical river elevation will be abandoned in place when the reservoirs are drawn down and bypassed. The volume of material estimated to be abandoned above the free-flowing river following dam removal is approximately half of the total deposited sediment. The remaining half (84 Mcy) of the deposited sediment will be in the new free-flowing river, and the floodplain will be subject to river scour and sediment transport.

3.4.2 Timing of Sediment in Motion, Including Sediment Concentrations, and Return to Quasi-Equilibrium in the Snake River

The MO3 dam removal plan is taken from the 2002 *Lower Snake River Juvenile Salmon Migration Feasibility Study*. A prescribed drawdown rate of 2 feet per day, hold period, and breaching of the cofferdams is performed at each of the four dams. The drawdown starts in August with subsequent breaching occurring in October (Figure 3-17).

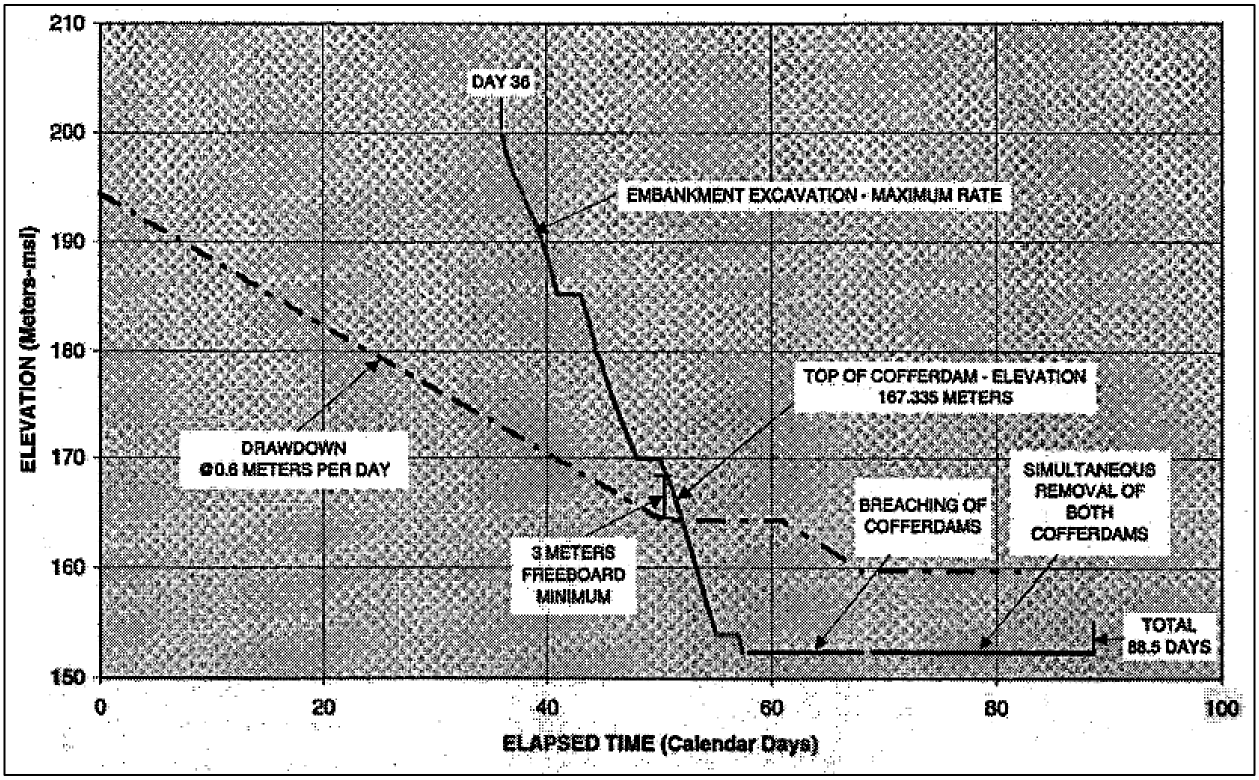


Figure 3-17. Typical Drawdown and Removal Timeline

The plan calls for removal of the earthen dam embankments to occur over the course of two subsequent years. The two upstream dams, Lower Granite and Little Goose, are to be removed in the first year, and the lower two dams, Lower Monumental and Ice Harbor, are to be removed in the second year (Figure 3-18). Drawdown and removal occurs during the low-flow period of the water year in August through October. The timing and sequence of the removal plan has a large influence on sediment processes in the Snake River during the removal. For the purposes of the CRSO study, it is assumed that the removals would occur in 2021 and 2022 following completion of the EIS.

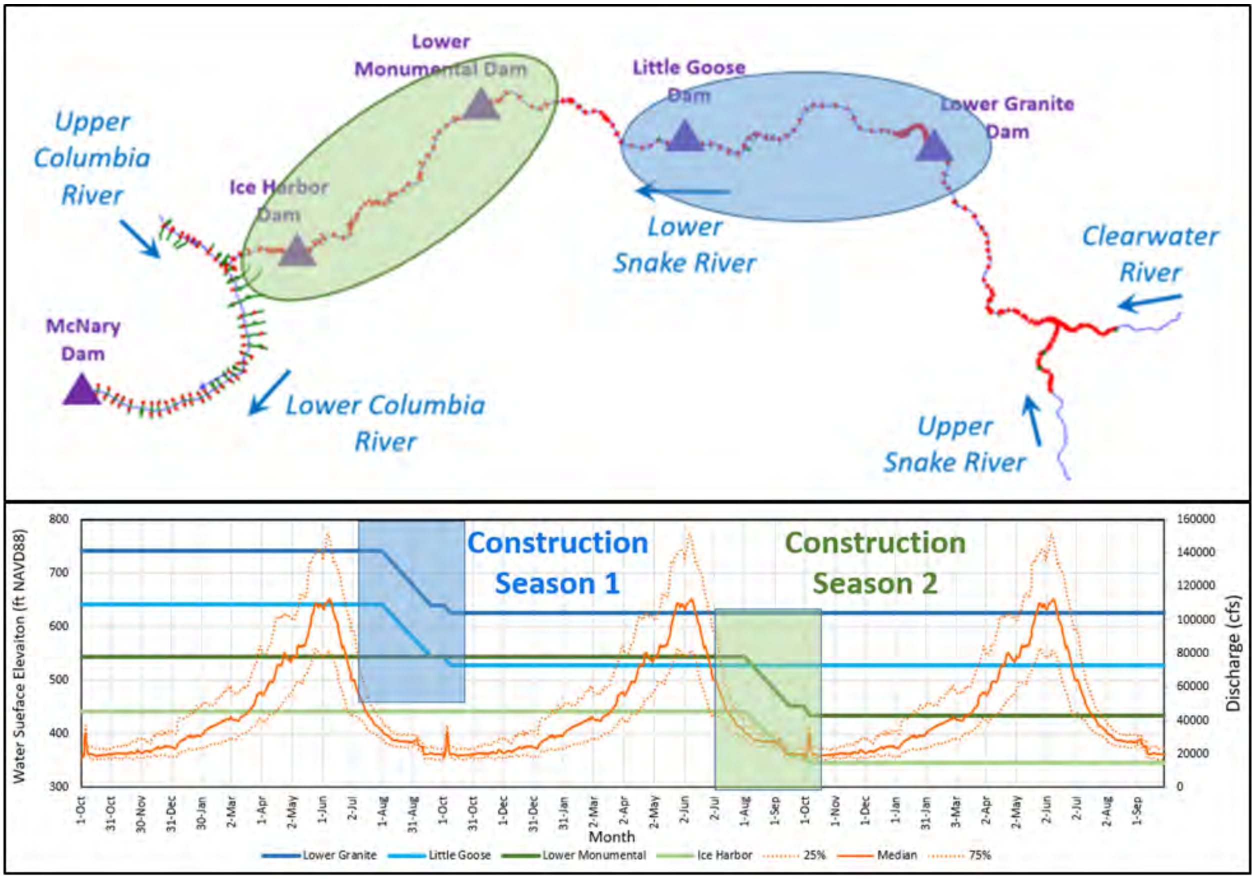


Figure 3-18. Dam Removal Timing and Sequence for Lower Snake River Projects

During construction season 1, the upstream two dams would be removed, and the lower two dams would remain in place (Figure 3-19). The sediment deposited in the historical channel, which is predominately fine material, rapidly scours down to the pre-dam bed elevation and moves into the Lower Granite pool as wash load. Two distinct sediment concentration peaks are predicted (Figure 3-20) during the initial drawdown and again during breaching of the cofferdam during the final bypass. Sediment concentrations are predicted to peak at over 20,000 milligrams per liter (mg/L).

This mobilized sediment is largely recaptured in Lower Monumental Reservoir (Figure 3-21) with only a small percentage passing into McNary Reservoir. Mobilized sediment that is recaptured in Lower Monumental Reservoir is expected to deposit in the historical channel and on the overbanks.

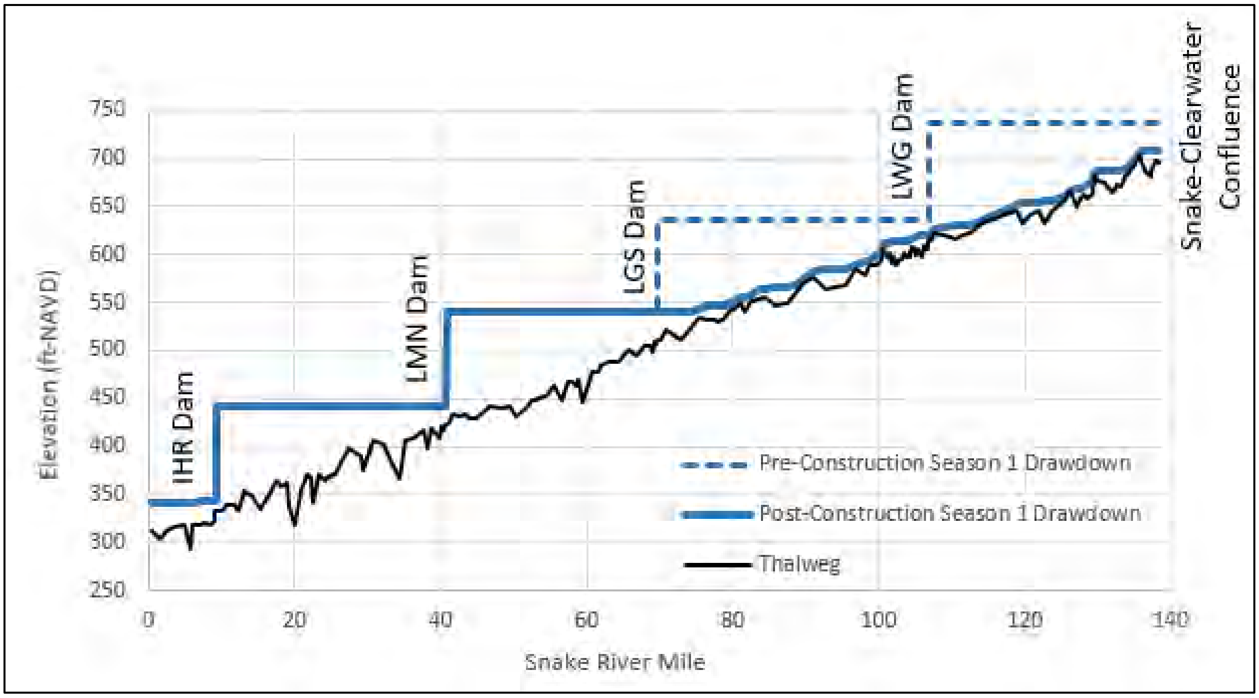


Figure 3-19. Dam Removal Construction Season 1 Water Surface Profiles

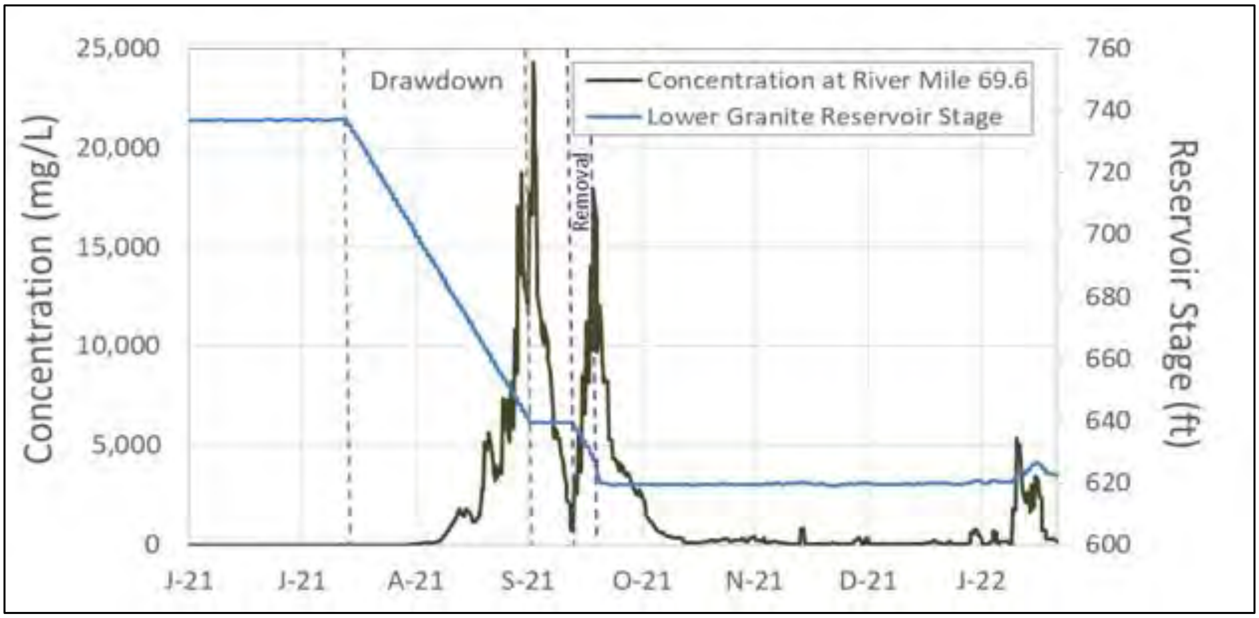


Figure 3-20. Dam Removal Construction Season 1 Sediment Concentration Timeseries Near the Location of Little Goose Dam

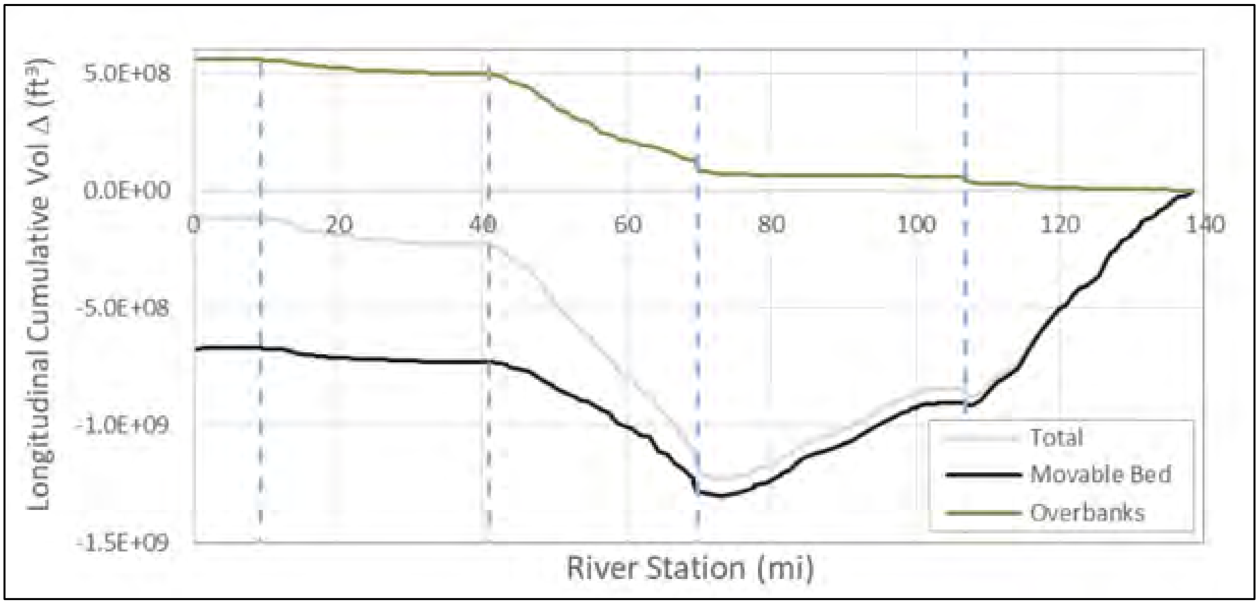


Figure 3-21. Dam Removal Construction Season 1 Longitudinal Cumulative Volume Plot Showing Scour in Lower Granite and Little Goose Reservoirs and Deposition in Lower Monumental Reservoir

During construction season 2, the downstream two dams would be removed (Figure 3-22), returning all of the lower Snake River to a free-flowing river. Similar to the construction season 1, deposited sediments above the free-flowing river water surface elevation are abandoned on the reservoir side slopes. The predominately fine-grained sediments deposited in the historical channel are rapidly scoured down to pre-dam elevations in the majority of the reach. Two distinct sediment concentration peaks are again predicted (Figure 3-23) during the initial drawdown and again during breaching of the cofferdam during the final bypass. Sediment concentrations are predicted to peak at over 15,000 mg/L during the second drawdown.

The fine-grained sediment mobilized during construction season 2 becomes wash load in the Snake River and is rapidly transported downstream to McNary Reservoir. The coarser sand and limited gravel component of the stored sediments are expected to move more slowly while interacting with the Snake River bed (Figure 3-24).

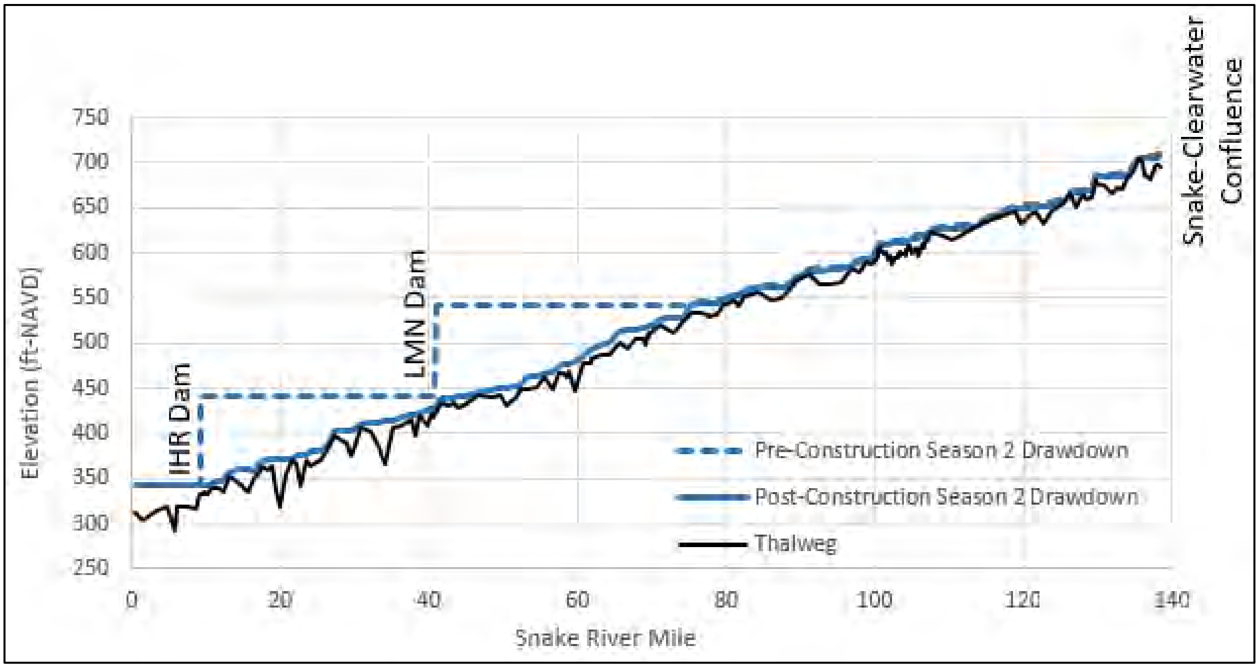


Figure 3-22. Dam Removal Construction Season 2 Water Surface Profiles

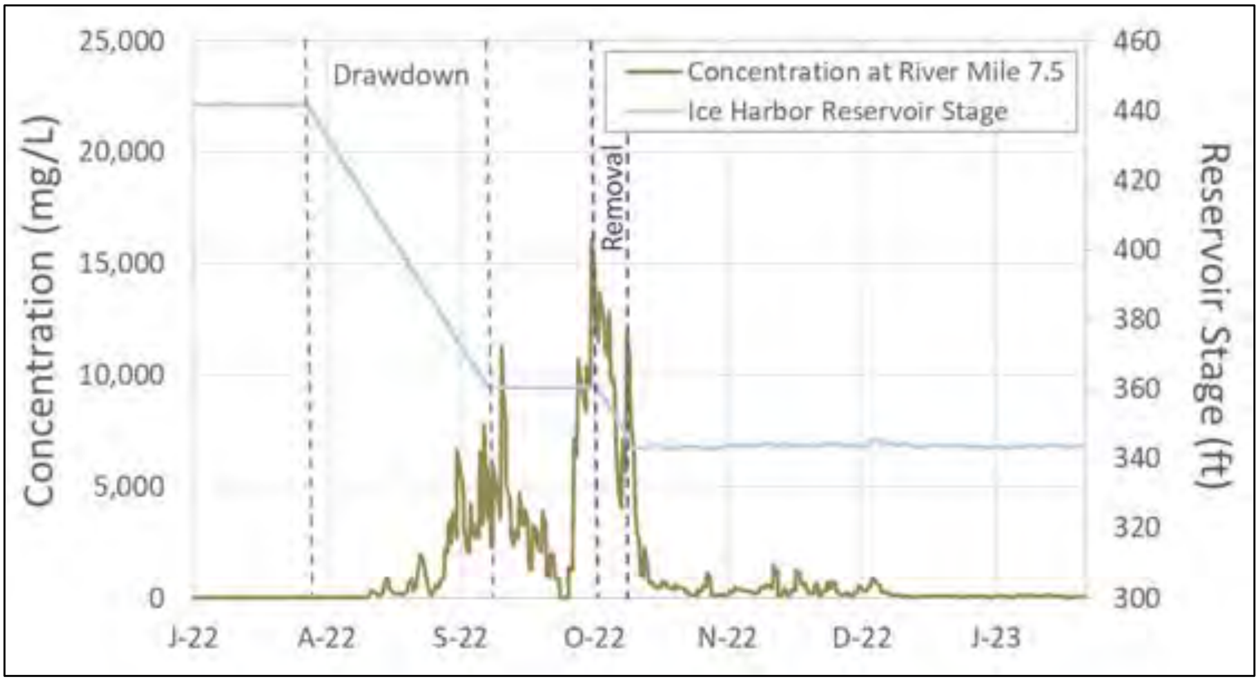


Figure 3-23. Dam Removal Construction Season 2 Sediment Concentration Timeseries Near the Location of Ice Harbor Dam

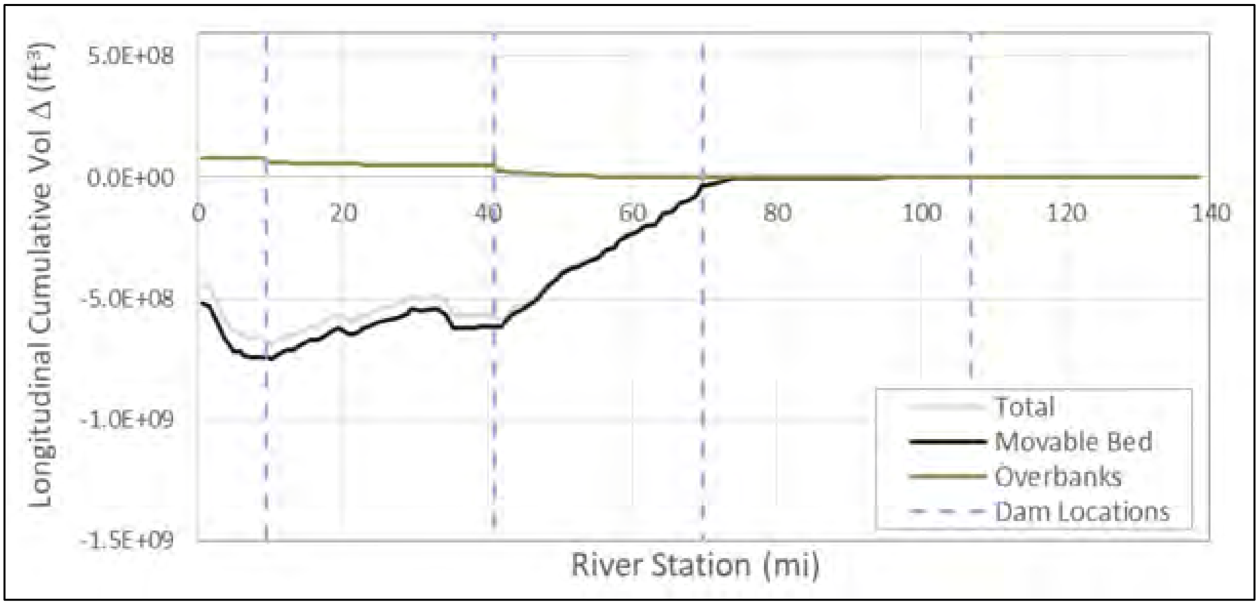


Figure 3-24. Dam Removal Construction Season 2 Longitudinal Cumulative Volume Plot Showing Scour in Lower Monumental and Ice Harbor Reservoirs and Deposition in the Snake River Downstream of Ice Harbor

Sediment concentration data for the two construction seasons are shown in Table 3-5. The analysis predicts a higher peak concentration and a longer duration of high sediment concentration during the first removal season relative to the second. The MO3 measures and removal plan, with two construction seasons, limit the extents of the very high sediment concentration peaks to only portions of the lower Snake River for each removal year. Figure 3-25 shows the maximum concentration profile over the two removal years along with the first and second season profile for the peak day. Lower Monumental effectively retains sediment mobilized in the first removal and limits the very high peaks from extending downstream of Lower Monumental Dam. Very high concentrations during the second removal are limited to the downstream two reservoirs and sediment entering McNary Reservoir.

Table 3-5. Sediment Concentration During Construction Seasons

Concentration	First Dam Removal	Second Dam Removal
Peak Concentration	24,300 mg/L	16,100 mg/L
Location of Peak Concentration	RM 69.6	RM 7.59
Duration >5,000 mg/L	26 days	18 days
Duration >1,000 mg/L	76 days	49 days

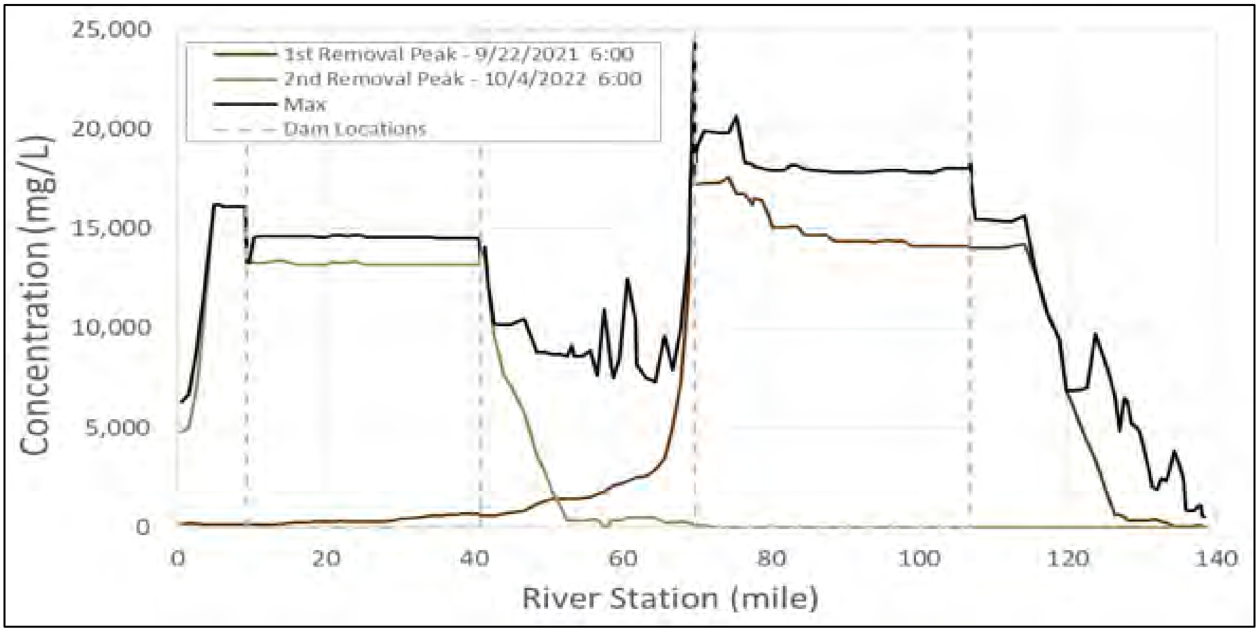


Figure 3-25. Sediment Concentration Profiles for the Two Dam Removal Construction Seasons

The removal plan calls for drawdown and removal to occur during a low-flow season (August through October). The rapid scour and resulting high concentrations during the removal years are driven by a large change in hydraulic condition in the river instead of high river flows. Sensitivity testing with respect to flow shows that drawdown and removal peaks and durations are insensitive to the typical range of hydrology during the summer season. This finding runs counter to the typical correlation between flow and sediment concentration, with high flows yielding high sediment loads. Once the drawdowns and removals have occurred and the readily available wash load has moved through the Snake River, sediment movement again becomes linked to hydrology and river flows.

It is estimated that it will take 2 to 7 years following removal of the dam for the coarser sands and gravels stored in the reservoirs to scour down to pre-dam bed elevation throughout the reach and establish a new dynamic equilibrium condition in the Snake River. Sediments stored on the historical floodplain may be accessed by subsequent flood events well beyond the near term and be transported downstream. During the near-term period following dam removal, sediment load and transport through the system will be highly correlated to flow; over time, this rating is expected to shift to be more supply limited as the transportable sediments are scoured from the system. The duration for this rating shift to occur will depend on the cumulative range of flows in the years following dam removal; higher flows are expected to mobilize more sediment, which would accelerate the rating shift; conversely, lower flows that mobilize less sediment would delay the effect.

Modeling results show that there are two condition types that will hold sands temporarily awaiting high-enough energy to scour down to pre-dam bed elevations: deep holes in the riverbed and the backwatered portion of the Snake River downstream of Ice Harbor Dam. The McNary Reservoir backwater extends up the Snake River to approximately the location of Ice

Harbor Dam at Snake RM 9.3. Modeling predicts that significant depths of deposition can occur in this reach, but that the Snake River is capable of scouring itself to historical bed elevations (Figure 3-26).

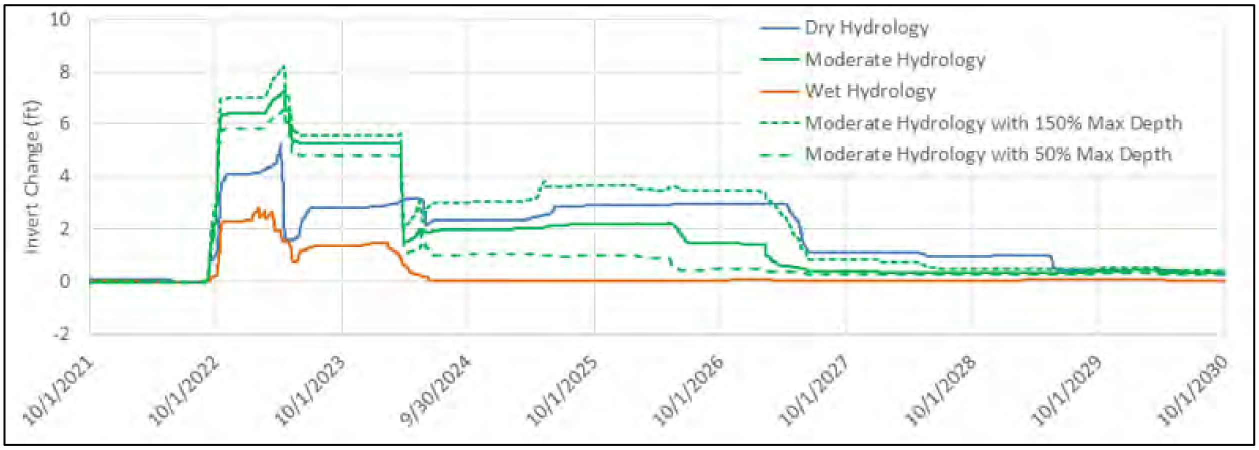


Figure 3-26. Estimated Deposition and Scour at Snake River Mile 3.5 in the McNary Reservoir Backwatered Portion of the Snake River following dam removal

The post-removal average annual sediment budget in the Snake River once the river reaches a quasi-equilibrium condition is depicted in Figure 3-27. The predominately fine sediment load entering the reach will be transported downstream to the McNary Reservoir with no expected net deposition.

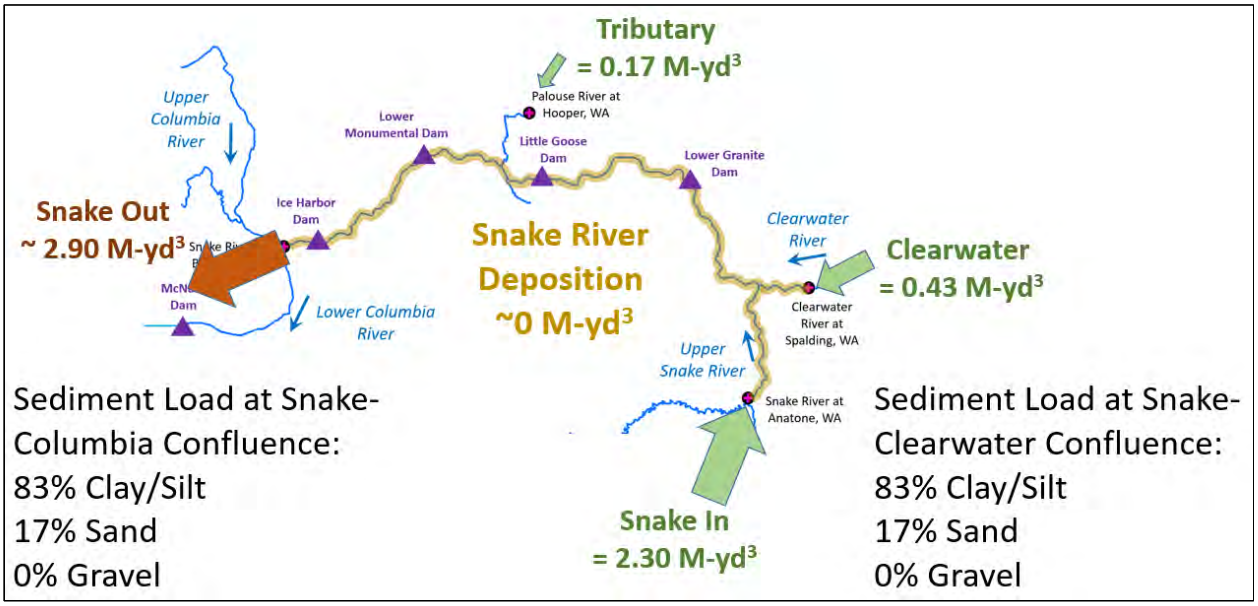


Figure 3-27. Average Annual Sediment Budget in the Snake River Following Removal Once Quasi-Equilibrium Conditions are Achieved in the Snake River

3.4.3 Condition of the Snake River Following Dam Removal

During drawdown and in the near term following dam removal, the lower Snake River and valley will be in a rapid state of change. All lands that are currently submerged by the reservoirs will be denuded and covered with varying depths of sand, silt, and clay as depicted in Figure 3-28. During drawdown, saturated and unstable slopes may slump and slide. Because drawdown and removal would occur during the low-flow season, the river will incise and recede into its historical channel abandoning the overbank and any historical floodplain as shown in Figure 3-29. With high content of clay and silt, the abandoned sediment covering the landscape is expected to desiccate in the semi-arid environment and crack similar to a dried lake bed.

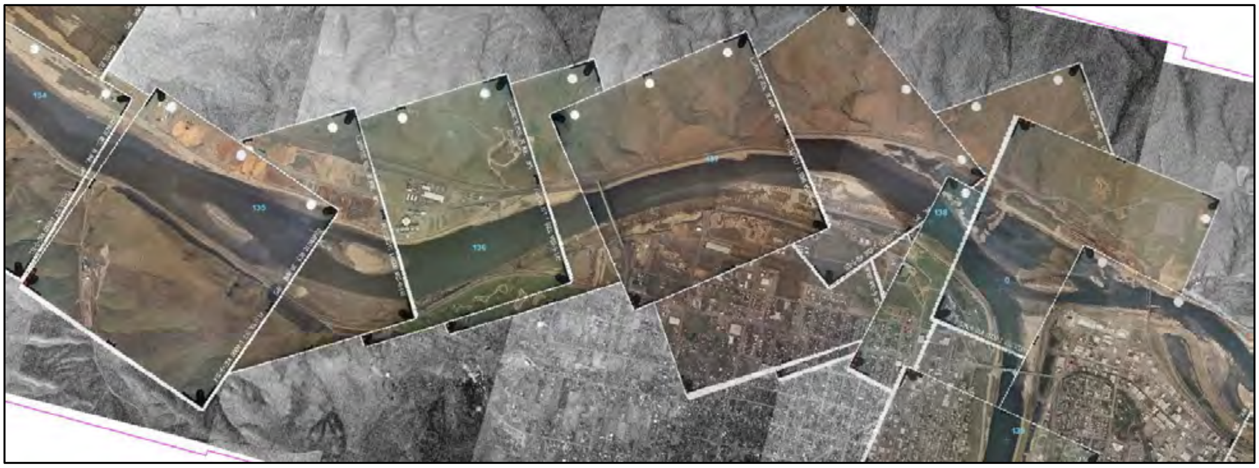


Figure 3-28. Example of Sediment Deposition in the Upstream Extents of Lower Granite Pool Observed During the 1992 Drawdown

In the wet seasons following removal, high flows and subsequent high-water surface elevations will inundate the historical alluvial features and potentially even floodplains, if the water year is large enough, and begin to scour the stored sediments. In-channel features, such as frequently inundated islands and bars, are expected to scour to pre-dam elevations rapidly once inundated. In areas where substantial deposition has occurred, toe erosion and bank failure will cut stored material back to stable conditions. Higher lands that inundate less frequently, such as floodplain terraces and paleo-geologic features, may only be inundated during rare high-flow events. Scour of sediments stored on these higher lands may occur if localized energies are high enough. Features that are inundated rarely are expected to develop a patchwork of deposited fines and pre-dam alluvium, colluvium, and bedrock. Pre-dam photography shows that the lower Snake River had a limited riparian border. In time, when banks stabilize, a similar zone of vegetation will develop.

Tributaries to the lower Snake River have been impacted by the presence of the dams. The reservoirs inundate the historical confluences with the Snake River and send backwaters up the tributary valleys varying distances. Tributary sediments and suspended Snake River sediments deposit in the backwatered tributary valleys and confluences. Once the Snake River becomes free flowing, it is expected that the tributaries will begin incising through these deposits. Because the erosive energy is limited by the flow of the tributary, it is expected that some tributaries will become perched above the free-flowing Snake River for a period of time and develop waterfall-like features that head-cuts its way up the tributary. It is expected that, in time, the tributaries will erode to near historical bed elevations and slopes and develop floodplain terraces within the deposited sediments.

Figure 3-29. Tributary Incising Through Deposited Sediments during the 1992 Drawdown of Lower Granite Dam

The resulting habitat condition in the lower Snake River, once the river reaches a quasi-equilibrium condition following dam removal, was studied and reported in the Appendix H of *the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environment Impact Statement* (Corps 2002). The analysis uses the 1934 survey data, which contains a large amount of information on bed material, bank material, rapid heads and toes, rapid velocities, and other observations to classify the geomorphology of the pre-dam condition. Figure 3-30 shows an example of the quality of the pre-dam survey effort and notation (Figure 3-31).

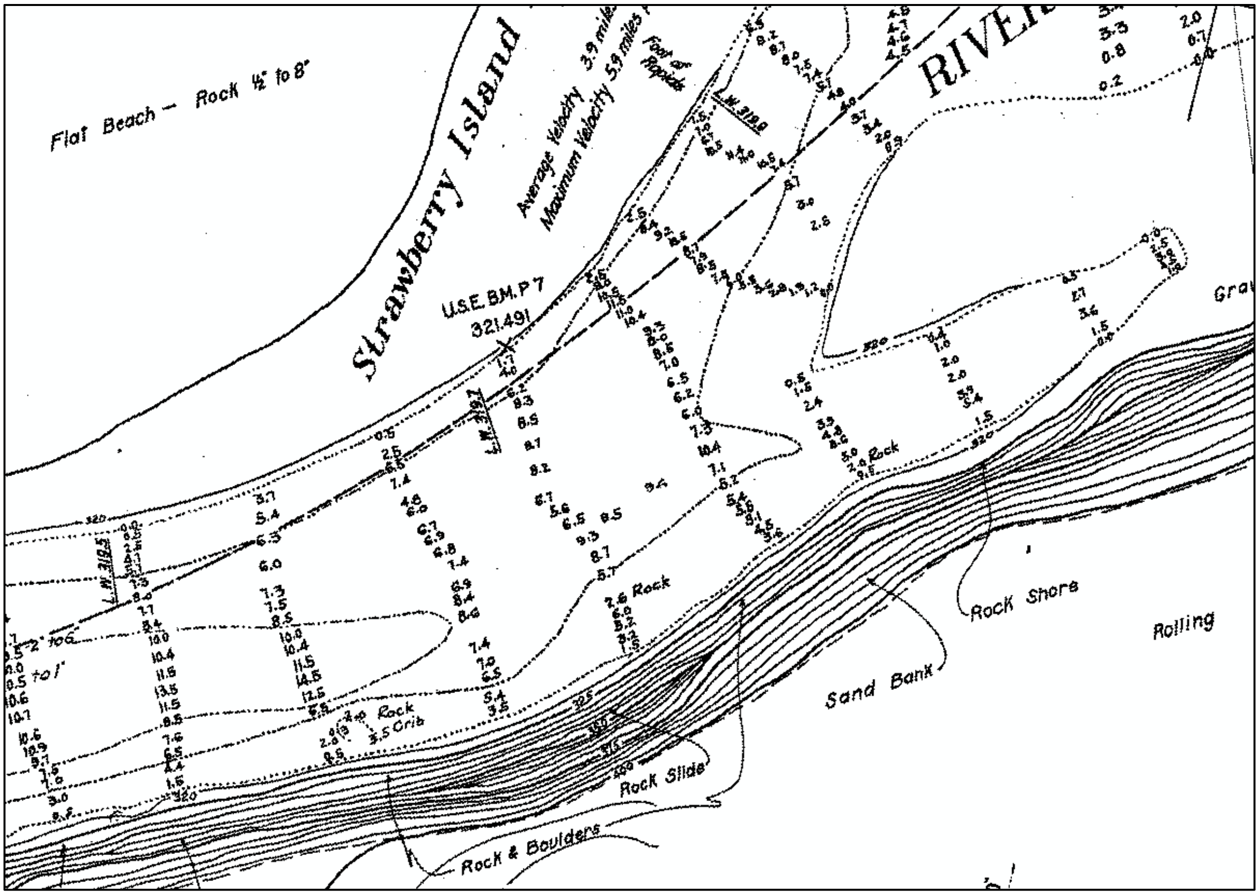


Figure 3-30. Example of the 1934 Snake River Survey Quality

Figure 3-31. Upstream Extents of Lower Snake River Prior to Construction of Lower Granite Dam (1956)

The Corps 2002 PSMP Appendix H concludes that the undammed lower Snake River is geomorphically straight or slightly sinuous. The river has characteristics of passive meandering, where the plan form pattern is imposed by the paleo-flood–shaped local landform. This characteristic is distinct from completely self-formed alluvial channels that are actively and freely forming the valley bottom (active meandering). In aggregate, 26 percent of the lower Snake River was determined to be highly confined by valley walls with no bars and/or islands present. The remaining 74 percent was determined to be moderately confined by valley walls with bars and island present.

The Corps 2002 Appendix H used a two-dimensional hydrodynamic model (MASS2) to investigate reach scale geomorphic properties within the lower Snake River. Based on established velocity and depth criteria, the pre-dam channel morphology at the 50 percent annual exceedance flow (estimated at 31,710 cfs for that study) was estimated to be 66 percent pool, 5 percent riffle/rapid, and 29 percent run. Total areas by reach are shown in Table 3-6 and expanded upon in the Corps 2002 Appendix H.

Table 3-6. Pool, Riffle/Rapid, Run Habitats of the Lower Snake River Segments

	Habitat by Segments – Hectares (%)			
Segment	**Pool**	**Riffle/Rapid**	**Run**	**Total**
Mouth to Ice Harbor	791.9 (97.7)	0.0 (0.0)	18.7 (2.3)	810.6 (100)
Ice Harbor to Lower Monumental	839.0 (57.5)	97.6 (6.7)	521.7 (35.8)	1458.3 (100)
Lower Monumental to Little Goose	694.8 (55.0)	72.1 (5.7)	495.8 (39.3)	1262.8 (100)
Little Goose to Lower Granite	970.2 (64.0)	72.9 (4.8)	471.9 (31.1)	1515.0 (100)
Upriver of Lower Granite	764.1 (70.5)	36.6 (3.4)	283.4 (26.1)	1084.1 (100)
Total	4060.0 (66.2)	279.2 (4.6)	1791.5 (29.2)	6130.7 (100)

Source: Corps 2002: Appendix H

Also extracted from the hydraulic modeling was information related to width/depth ratio. The report concludes the following: The relatively high width/depth values in the pre-dam lower Snake River are often indicators of channel instability. This indication is based on the fact that channels with high width/depth values distribute energy and stress on the near-bank region. Whether a reach with high width/depth values is indeed unstable depends on the erosion resistance characteristics of the bank material. Bank materials in the lower Snake River are predominantly highly erosion resistant. See Corps 2002 Appendix H for additional detail and geospatial distribution of geomorphic and habitat types.

New data collection and analysis including the HEC-RAS mobile bed model supports and adds additional information to the 2002 geomorphology analysis. The 2002 study concluded that historic and contemporary discharge records indicate that regulated flow regimes after dam breaching would be competent enough to maintain channel characteristics and riverine processes (e.g., channel bed mobilization) following removal. After the bulk of the fine-graded reservoir sediments are removed, the competency of the regulated flow regime (particularly the annual maximum discharge) will be sufficient to mobilize the channel bed surface. The time required for the initiation of such processes depends on the annual flow regimes during the period following dam breaching, particularly the frequency and duration of annual maximum discharge equaling or exceeding the pre-major storage period 1-year flood (95,600 cfs estimated for that study). Bed material and sediment loading data collected since the 2002 report and the new HEC-RAS mobile bed modeling indicate that the transition time to long-term habitat types may be faster than estimated in 2002 and may be achieved between 2 and 7 years following removal depending primarily on the magnitude and duration of river flows.

Part 2 of the Corps 2002 Appendix H estimates the resulting, post scour, fall chinook spawning and rearing habitat for the impounded and impounded condition (Table 3-7). The spawning habitat criteria require that depths are between 1.3 and 21 feet, with velocities between 1.3 and 6.4 feet per second. The rearing habitat criteria requires that depths are between 0.3 and 5.3 feet, velocities are less than 4 feet per second, and they must be located within 81.7 feet from shore.

Table 3-7. Acres of Potential SuiTable Fall Chinook Spawning and Rearing Habitat for the 50 Percent Exceedance Flow for Impounded and Unimpounded River

Habitats	Impounded (acres)	Unimpounded (acres)
Potential Suitable Spawning Habitat	226	3,521
Potential Possible Spawning Habitat *(depth and velocity criteria met, but substrate unknown)*	176	1,396
Unsuitable Spawning Habitat	32,177	10,392
Potential Suitable Rearing Habitat	652	889

Source: Corps 2002: Appendix H

The Corps 2002 report does provide the following caution regarding the habitat data above. The rearing habitat criteria are much more restrictive than spawning habitat criteria in that the habitat must be located within 81.7 feet from shore. The narrow range of depths is adequately resolved within the 1934 channel, but not for the narrow margins near shorelines for the impounded river. In addition, grid spacing within the numerical model has a near-shore spacing of nodes of about 40 feet, with nodes spaced about 80 to 90 feet in the cross-stream, and about 200 feet in the downstream direction. Consequently, the resulting difference in area of potential suitable rearing habitat of 652 and 89 acres should be viewed with caution. This difference in suitable rearing habitat is supported qualitatively by the difference in shoreline length of 285 and 306 miles (for the impounded and unimpounded rivers, respectively). This increase is the result of increased shoreline complexity with lower water levels and the emergence of midstream islands and bars. Refer to the 2002 Corps Appendix H for additional information on analysis process and geospatial data.

The Corps 2002 analysis, and the current analysis, acknowledge that the river channel will likely not be restored to its pristine pre-development condition by breaching the four lower Snake River dams. Exactly how the resultant channel bed would differ from the original channel bed is unknown. As with all systems where alluvial material is stored in the system, very rare flow events can cause substantial reworking of the river. Hydroregulation has reduced peak flows and sediment supply from pre-regulated conditions but reworking of stored pre-dam alluvial sediments is expected to occur given a long enough time frame.

3.4.4 Sediment Load to McNary Reservoir and McNary Reservoir Deposition

Sediment volumes and concentrations passing out of the Snake River will be elevated during draw-down and subsequent few years following removal (near-term). The Snake River is expected to eventually reach a new quasi-equilibrium condition and largely pass incoming sediment load (long-term).

Figure 3-32 shows the cumulative sediment load passing out of the Snake River into McNary Reservoir for a moderate future hydrology. During the second year of dam drawdowns and bypass, the Snake River becomes completely run-of-river and delivers a large amount of clay and silt previously stored in the Snake River reservoirs. A large silt-and-sand load is delivered in water year 2024 (year 2) due to bedload lag and scouring of temporary sediment sinks in the Snake River. Table 3-8 shows the average annual volume of Snake River sand, silt, and clay passing into McNary Reservoir for the near term and long term, assuming a moderate hydrologic future.

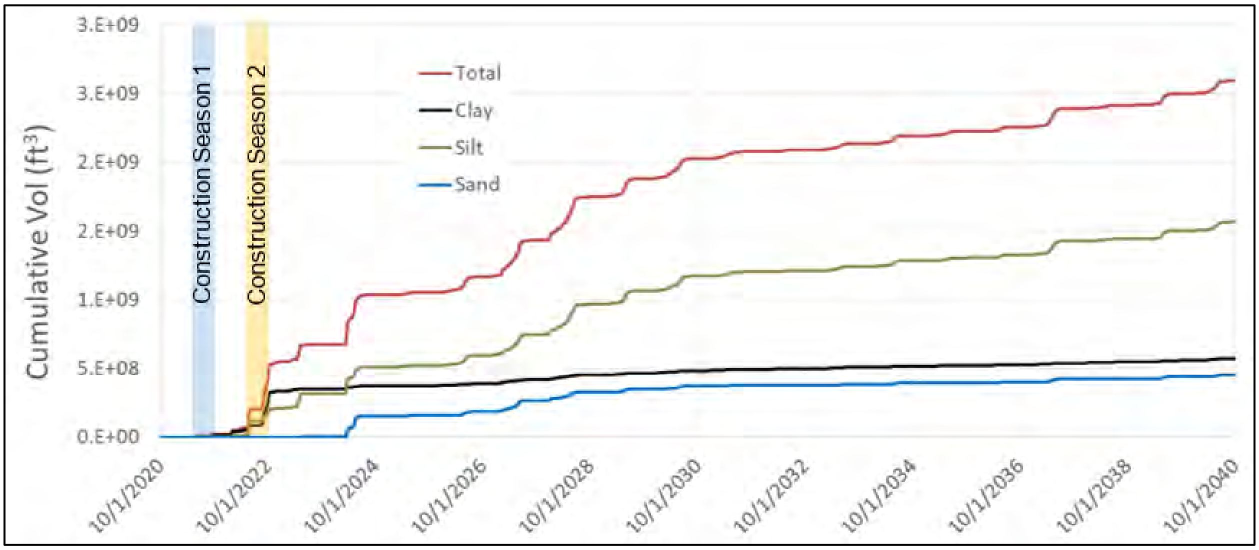


Figure 3-32. Predicted Cumulative Sediment Load from the Snake River into McNary Reservoir for a Moderate Future Hydrology following Dam Removal

Table 3-8. Average Annual Composition and Volume of Snake River Sediment Entering McNary Reservoir for a Moderate Future Hydrology

	Affected Environment		Near Term (July 1, 2021, to Oct. 1, 2024)		Long Term (Oct. 1, 2024, to Oct. 1, 2040)	
Sediment	**% of Total**	**Average Annual Volume (Mcy)**	**% of Total**	**Average Annual Volume (Mcy)**	**% of Total**	**Average Annual Volume (Mcy)**
Clay	50%	0.4	36%	4.5	13%	0.5
Silt	50%	0.4	49%	6.2	68%	2.4
Sand	0%	0.0	15%	1.9	19%	0.7
Total	100%	0.8	100%	12.6	100%	3.6

To put the Snake River sediment loading into perspective, literature was reviewed to estimate additional sediment sources to McNary Reservoir. Data was found for three sediment sources other than the Snake River: the Walla Walla, the upper Columbia, and the Yakima Rivers. The largest sediment source of the three is the Walla Walla River. Sediment sampling performed from 1951 to 1953 (Ord and Cannon 1963) and again in 1962 to 1965 (Mapes 1969) estimated a sediment yield of 2.5 to 3.9 million tons per year (Mton/year) (3.8 to 5.8 MCY assuming 70 percent silt and 30 percent clay), with a peak measured year of 6.2 Mton (9.3 Mcy) in 1964. The upper Columbia River is the next largest source of sediment. Beasley et al. (1986) report a measured sediment load of 2.2 Mton/year (3.3 Mcy) at Pasco, Washington, in 1966. The Yakima River is the smallest contributor of sediment with a measured yield of 0.1 to 0.2 Mton/year (0.2 to 0.3 Mcy) from 1999 to 2000.

McNary Reservoir is capable of effectively trapping nearly all sand and a portion of silt and clay-sized particles. HEC-RAS mobile bed model output was evaluated to determine trapping rates for the near term and long term (Table 3-9). It is notable that silt and clay are trapped at higher percentages in the near term than long term. This is because the large sediment load to McNary Reservoir associated with construction season 2 occurs during a low-flow period when McNary is a more effective trap. Average annual deposition rates for the near term and long term are shown in Table 3-10.

Table 3-9. McNary Reservoir Trapping Efficiency for Snake Sediments

Sediment	Near Term (July 1, 2021, to Oct. 1, 2024)	Long Term (Oct. 1, 2024, to Oct. 1, 2040)
Clay	40%	4%
Silt	82%	66%
Sand	100%	100%
Total Load	70%	64%

Table 3-10. Average Annual Composition and Volume of Snake River Sediment Depositing in McNary Reservoir for a Moderate Future Hydrology

Sediment	Affected Environment		Near Term (July 1, 2021, to Oct. 1, 2024)		Long Term (Oct. 1, 2024, to Oct. 1, 2040)	
	% of Total	Average Annual Volume (Mcy)	% of Total	Average Annual Volume (Mcy)	% of Total	Average Annual Volume (Mcy)
Clay	28%	0.1	22%	1.8	1%	0.0
Silt	72%	0.3	60%	5.1	67%	1.6
Sand	0%	0.0	19%	1.6	32%	0.8
Total	100%	0.4	100%	8.5	100%	2.4

Fate of sediment deposited in McNary Reservoir was investigated using two-dimensional AdH system and the Particle Tracking Model (PTM), a Lagrangian particle tracking code. Figure 3-33 depicts expected deposition locations of Snake River sediments in McNary Reservoir. Modeling predicts that the deposition will be concentrated along the Oregon shore with sands being retained higher in the pool than silts. This Oregon-shore–biased deposition is consistent with previous bed core sample findings made by Beasley et al. (1986).

The report stated, "Regions of most rapid accumulation appear to be near, but are not confined to, the Oregon shore of the river. Transects generally show higher accumulation rates there than on the Washington shore. Exceptions were noted at stations M-20 and M-22 (13.5 km upriver from the dam site) where rates were high on both sides of the river. Incoming Snake River water, with its relatively high suspended particle load (Whetten et al. 1969), is held toward the Oregon shore following its confluence with the lower Columbia River as is water from the much smaller Walla Walla River. Horizontal (lateral) mixing is therefore constrained and sedimentation on the Oregon shore is enhanced."

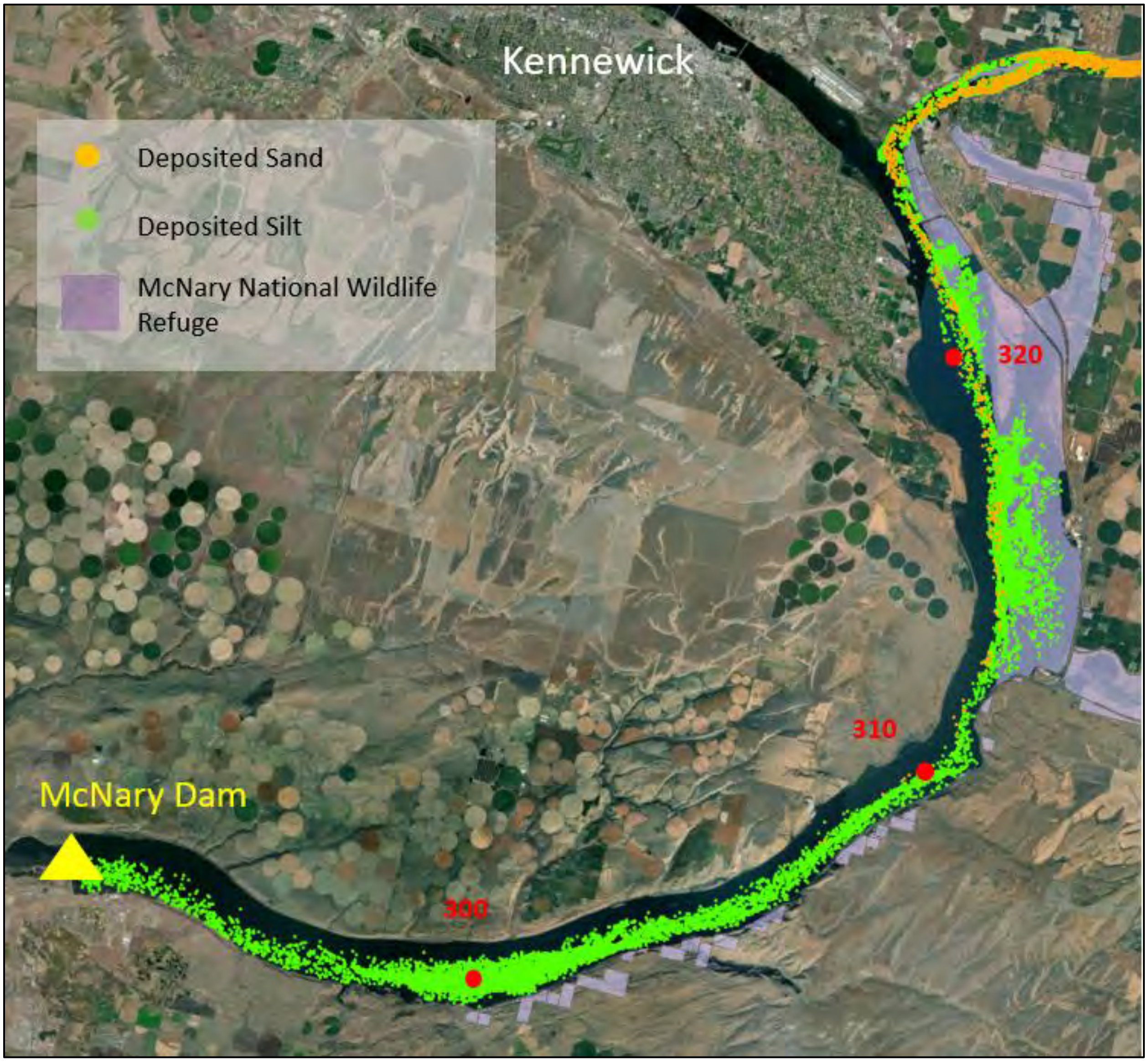


Figure 3-33. Predicted Deposition Locations in McNary Reservoir for Sand and Silt-Sized Particles from Particle Tracking Model Output

Cross-sectional average depth of deposition was extracted from the HEC-RAS mobile bed model for the near-term and long-term moderate future hydrology (Figure 3-34). Because deposition is biased toward the Oregon shore, this cross-sectional average underestimates the maximum depths of deposition occurring in locations predicted in Figure 3-34. Cross-sectional averages were increased assuming that deposition is largely confined to two-thirds of the reservoir width based on PTM output. Long-term Snake River sediment depths of deposition are on average expected to be near 2 feet with some areas approaching 5 feet.

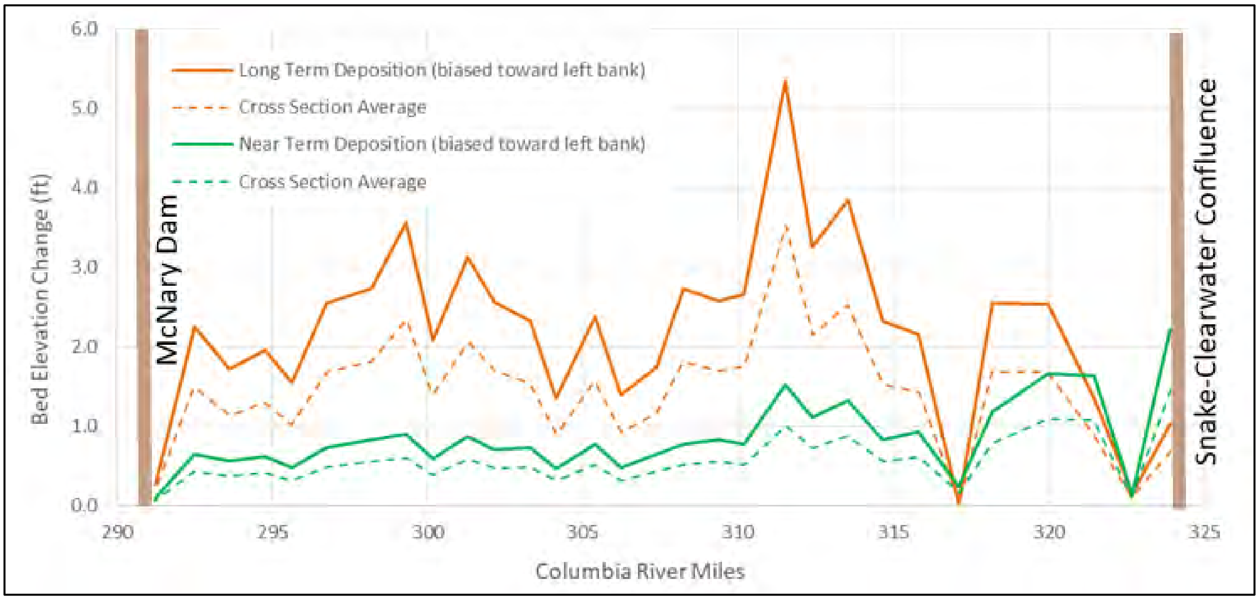


Figure 3-34. Predicted Bed Elevation Change in McNary Reservoir Due to Loading from Snake River Sediments

Impacts to McNary Reservoir volume due to the increase in Snake River sediment load were investigated. The volume of water in the reservoir downstream of the Snake River confluence for a normal pool elevation was calculated and compared to expected depositional volumes. The amount of Snake River sediments depositing in the McNary Reservoir during removal and the following 18 years is less that 5 percent of reservoir volume.

3.4.5 Sediment Load and Fate Downstream of McNary Dam

HEC-RAS mobile bed model results estimate that approximately 30 to 35 percent of the sediment entering McNary reservoir from the Snake River following dam removal passes McNary Dam into John Day Reservoir. Cumulative load for Snake River sediment for the moderate hydrology is shown in Figure 3-35. The large portion of the clay load associated with the construction season 2 dam removal and return to run-of-river conditions passes McNary Dam in the fall of 2022. Table 3-11 shows a breakdown of the composition of the passing sediment along with average annual volumes for the drawdown and removal period, as well as the long term. The 1D model results estimate that an additional 0.8 Mcy of sediment per year will pass McNary Dam in the long term following removal.

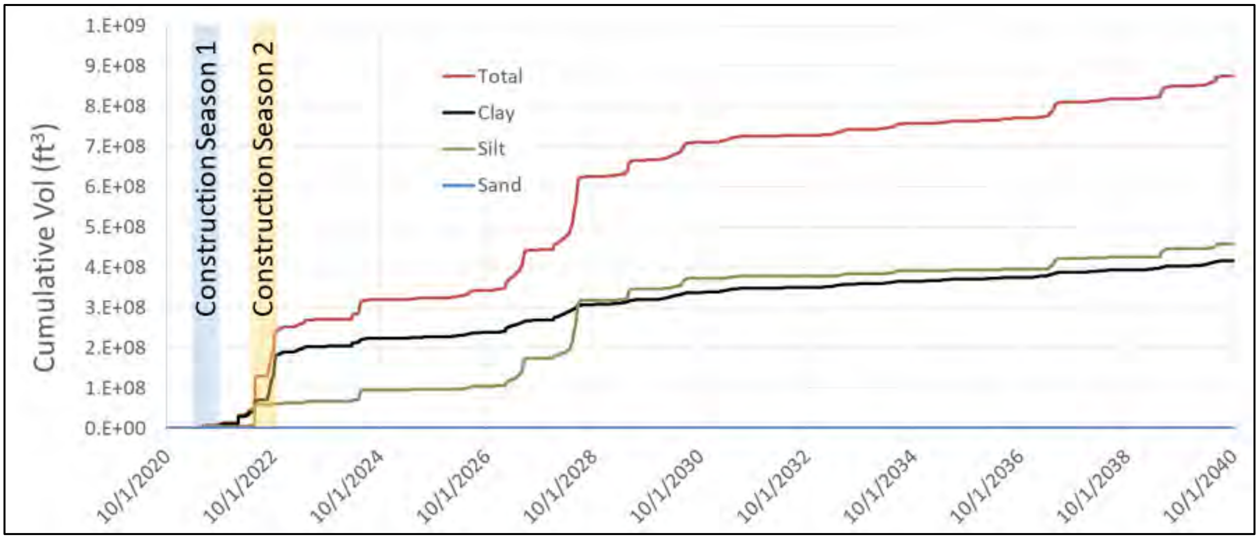


Figure 3-35. Predicted Cumulative Sediment Load Passing McNary Dam for a Moderate Future Hydrology

Table 3-11. Average Annual Composition and Volume of Snake River Sediment Passing McNary Dam for a Moderate Future Hydrology

	Affected Environment		Near Term (July 1, 2021, to Oct. 1, 2024)		Long Term (Oct. 1, 2024, to Oct. 1, 2041)	
Sediment	**% of Total**	**Average Annual Volume (Mcy)**	**% of Total**	**Average Annual Volume (Mcy)**	**% of Total**	**Average Annual Volume (Mcy)**
Clay	71%	0.3	70%	2.7	35%	0.4
Silt	29%	0.1	30%	1.1	65%	0.8
Sand	0%	0.0	0%	0.0	0%	0.0
Total	100%	0.4	100%	3.8	100%	1.2

Again, to put the Snake River sediment load passing McNary Dam into system perspective, literature was reviewed to estimate additional sediment sources passing McNary Dam. A single source of data was found in Haushild et al. (1966) and summarized in Beasley et al. (1986). The report estimated a total sediment load of 2.0 Mton (3.6 Mcy assuming 50 percent clay and 50 percent silt) passing McNary Dam in 1966. Downstream of McNary Dam, much of the sand brought to the Columbia River upstream of Cascade Locks is from tributaries whose headwaters are in the Cascades or Blue Mountains, notably the John Day and Deschutes Rivers (Haushild et al. 1966; Whetten, Kelley, and Hanson 1969). Past Vancouver, Washington, and then downstream, additional sand carried to the lower reach comes from two tributaries: the Willamette and the Cowlitz Rivers (RM 70). The Willamette River carries a substantial quantity of silt and clay to the Columbia River, as well. The total fluvial input of sediment to the estuary (RM 33) is estimated to be 12 to 14 Mtons/year (12 to 14 Mcy/year assuming 50 percent silt and 50 percent sand) (Beasley, et al. 1986).

It is not expected that bed sediments in the Columbia River downstream of McNary Dam will change in the long term following removal of the Snake River dams. McNary effectively traps sand and coarser material, leaving wash load to move through the system. An analysis of MO3 hydraulic conditions and threshold grain size for having a particle being held 100 percent in suspended in the water column shows that reaches downstream of McNary Dam can pass material that makes it through McNary Dam (Figure 3-36). The downstream subreach of John Day Dam is one notable exception where the grain-size threshold for suspension is similar to McNary. The Rouse analysis presented in Figure 3-36 is based on one-dimensional hydraulic modeling, which is limited to cross-section average trends. Localized deposition in currently observed patterns will continue. Areas that are silt bed are expected to continue to be silt bed, and areas that are sand or coarser are expected to continue to be sand or coarser.

The Beasley et al. (1986) report, *Sediment Accumulated Rates in the Lower Columbia River*, was designed to provide information on this particular question. The report, which is specific to sediment deposition in the lower Columbia River, states the following, “Our results do not support the view that sediment transport by the river is unaffected by dam construction. For example, the annual sediment storage we estimate for McNary Reservoir alone (2.9×10^9 kg) represents, on average, 20 percent of the annual suspended sediment thought to be discharged by the Columbia to the northeast Pacific Ocean (1.4×10^{10} kg) (Karlin 1980). From the data in Table 3-11 it is clear that sediment storage occurs behind both The Dalles and Bonneville Dams, conceivably in combined amounts comparable to that estimated for McNary Reservoir. By contrast, our data suggest that storage of sediment in the estuary is probably less important than has previously been assumed. Gross (1972) suggested that as much as 30 percent of the suspended load entering the estuary remained there; our data would place that figure nearer 7 percent based on an accumulation of some 0.1×10 m kg y^{-1} and Karlin's export estimate of 1.4×10^{10} kg y^{-1}.

Beasley et al. (1986) used methods based on depositional rates observed in field-collected reservoir bed cores. While new numerical data implies an efficient pass through of material, it should be assumed that the reservoirs downstream of McNary Dam may trap a portion of the sediment delivered by the Columbia River, continually fining the load passing downstream. It is reasonable to believe that this fine wash load passing Bonneville Dam can be transported in large part through the Columbia Estuary and into the Pacific Ocean as found by Beasley et al. (1986).

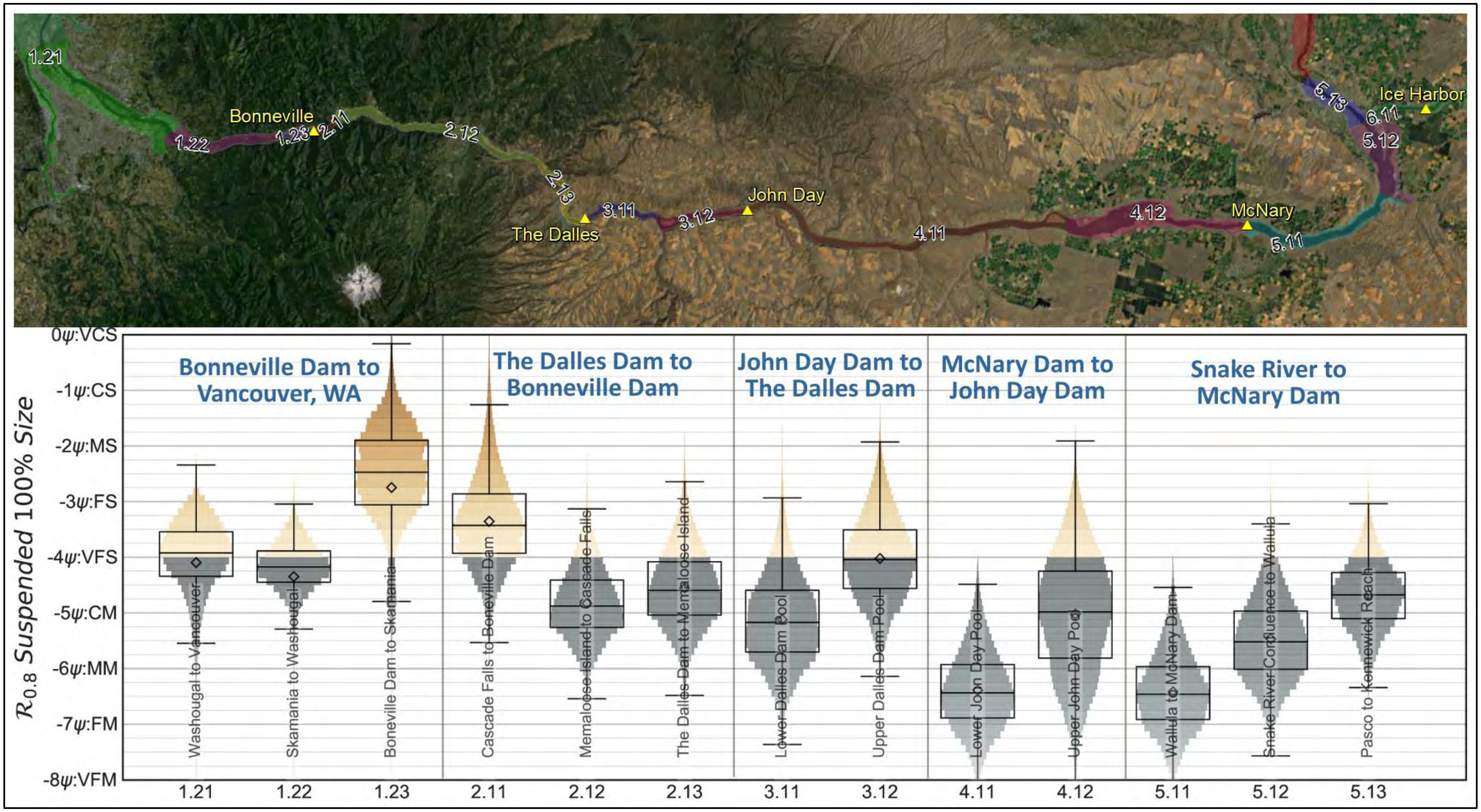


Figure 3-36. Multiple Objective Alternative 3 Rouse 100 Percent Suspended Grain-Size Threshold for All Daily Flows by Subreach

3.5 MULTIPLE OBJECTIVE ALTERNATIVE 4 (MO4)

Multiple Objective Alternative 4 (MO4) is intended to meet a broad range of objectives including supporting anadromous juvenile fish, supporting anadromous adult fish, minimizing greenhouse gas emissions, maximizing operational flexibility, and meeting existing and authorized water supply obligations. A complete description of the MO4 alternative can be found in Chapter 2 Section 2.3.6. The alternative includes structural and operational measures. The structural measures are related to powerhouse, turbine, spillway, and fish passage features and do not include the breaching of any dams. The operational measures include a long list of changes to current flow and power operations, including increasing the irrigation to authorized amounts, which are detailed in Chapter 2. Impacts related to MO4 relative to the No Action Alternative are enumerated in Table 3-12.

Table 3-12. Summary of Multiple Objective Alternative 4 River Mechanics Impact Estimates

Metric	MO4 Impact
Storage Projects	
Head-of-reservoir Sediment Mobilization	Negligible change in erosion or deposition processes and patterns at the head of storage project reservoirs with the exception of: **Columbia River and Spokane River entering Lake Roosevelt.** There is potential for a minor change in depositional patterns with temporary head-of-reservoir deposits shifting downstream, although available deposit volume is limited. Head-of-reservoir deposits may include contaminants (slag) that are also mobilized slightly farther downstream in the reservoir but are not expected to be transported past the dam. Ultimate long-term fate of head-of-reservoir sediments within the reservoir is expected to remain unchanged given there are no changes in the Grand Coulee operational range. The *Winter System FRM Space*, *Planned Draft Rate*, and *McNary Flow Target* measures at Grand Coulee contribute to the impact. **Columbia River Entering John Day Reservoir.** There is potential for a minor change in head-of-reservoir sediment mobilization with deposits becoming coarser. The *Drawdown to MOP* measure at the John Day Project is causing in the impact.
Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those under NAA.
Shoreline Exposure	Negligible change in the amount of time that the storage project water surface elevations spend at any given elevation with the exception of **Hungry Horse Reservoir**. There is potential for a minor increase in shoreline exposure duration at Hungry Horse with the reservoir being held at lower elevations for a long enough period to potentially increase the erosion pattern. A combination of the *Hungry Horse Additional Water Supply* and *McNary Flow Target* measures cause the impact. At Lake Roosevelt, the increased shoreline exposure was estimated to be 4.7 feet which is within the negligible interval. In addition, the proposed measure for slower drawdown from the Planned Draft Rate at Grand Coulee could have the potential to provide minor reductions in local landslides related to reservoir levels.

Metric	**MO4 Impact**
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches with the exception of **Columbia River upstream of Kettle Falls, WA to the U.S.-Canada (*Subreaches 21.13 and 21.14*).** There is potential for a minor increase in the amount of sediment passing through the upper reach of Lake Roosevelt and into the middle reach of Lake Roosevelt Downstream of Kettle Falls, WA. The *Winter System FRM Space*, *Planned Draft Rate*, and *McNary Flow Target* measures at Grand Coulee are contributors the impact.
Potential for Bed Material Change	Negligible change in the processes that supply, transport and deposit sediment in the system with the exception of: **The Columbia River between Grand Coulee Dam and the international border with Canada (*Reach 21*).** There is potential for a minor amount of bed sediment coarsening in Lake Roosevelt and reaches upstream to the international border with Canada. The *Winter System FRM Space*, *Planned Draft Rate* and *McNary Flow Target* measures at Grand Coulee contribute to the impact. **Snake River downstream of Ice Harbor (*Subreach 6.1*).** There is potential for a minor amount of bed sediment coarsening. The *Drawdown to MOP* measure at the McNary Project is causing in the impact. **Columbia River from the Snake River Confluence to Wallula, Washington (*Subreach 5.12*).** There is potential for a minor amount of bed sediment coarsening. The *Drawdown to MOP* measure at the McNary Project is causing in the impact. **Columbia River at the upstream end of John Day Pool (*Subreach 4.12*).** There is potential for a minor amount of bed sediment coarsening. The *Drawdown to MOP* measure at the John Day Project is causing in the impact. **Columbia River between John Day Dam and Skamania, Washington (*Reaches 2, 3, and subreach 1.23*).** There is potential for a minor amount of bed sediment coarsening. The *Drawdown to MOP* measure at The Dalles and Bonneville Projects causes this impact.
Potential Change in Width to Depth Ratio	Negligible change in the overall geomorphic character of the rivers.
Potential Changes to Navigation Channel Dredging Volumes	**Snake River:** Estimated average annual volume of sediment depositing in the Snake River navigation channel due to MO4 operations is less than 1% change from the No Action Alternative. **Lower Columbia River:** Estimated average annual volume of sediment depositing in the lower Columbia River FNC due to MO4 operations is less than 1% decrease from the No Action Alternative.

3.6 PREFERRED ALTERNATIVE (PA)

The preferred alternative as described in Chapter 7, includes measures that would be implemented to operate the CRS to better meet the Purpose and Need and objectives of the study. Impacts related to the Preferred Alternative relative to the No Action Alternative are enumerated in Table 3-13 below.

1880 **Table 3-13. Summary of Preferred Alternative River Mechanics Impact Estimates**

Metric	PA Impact
Storage Projects	
Head-of-reservoir Sediment Mobilization	Negligible change in erosion or deposition processes and patterns at the head of storage project reservoirs with the exception of: **Kootenai River entering Lake Kookanusa upstream of Libby Dam.** There is potential for a minor change in depositional patterns with temporary head-of-reservoir deposits shifting downstream. Ultimate long-term fate of head-of-reservoir sediments within the reservoir is unchanged given no changes in Libby Dam operational range. The *Sliding Scale Summer Draft* and *Modified Draft at Libby* measures contribute to the impact. **Columbia River Entering John Day Reservoir.** There is potential for a minor decrease in head-of-reservoir sediment mobilization with deposits becoming finer. The *John Day Full Pool* and *Increased Forebay Range Flexibility* measures at the John Day Project contribute to the impact.
Trap Efficiency	Negligible change in potential for storage projects to trap sediment indicating that reservoir sediment pass-through at CRS storage projects will continue at magnitudes and rates similar to those under NAA.
Shoreline Exposure	Negligible change in the amount of time that the storage projects water surface elevations spend at any given elevation indicating that reservoir shoreline erosion processes are expected to continue at locations and rates similar to those under NAA at each storage project.
Run-of-River Reservoirs and Free-Flowing Reaches	
Potential for Sediment Passing Reservoirs and Reaches	Negligible change in the potential for sediment to pass run-of-river reservoirs and free-flowing reaches.
Potential for Bed Material Change	Negligible change in the processes that supply, transport and deposit sediment in the system with the exception of: **Columbia River upstream of John Day Dam (subreach 4.12).** There is potential for a minor amount of bed sediment fining in the John Day pool. The John Day Full Pool and Increased Forebay Range Flexibility measures at the John Day Project contribute to the impact.
Potential Change in Width to Depth Ratio	Negligible change in the overall geomorphic character of the rivers.
Potential Changes to Navigation Channel Dredging Volumes	**Snake River:** Estimated average annual volume of sediment depositing in the Snake River navigation channel due to PA operations is less than 1% change from the No Action Alternative. **Lower Columbia River:** Estimated average annual volume of sediment depositing in the lower Columbia River FNC due to PA operations is less than 1% increase from the No Action Alternative.

1881

CHAPTER 4 - ALTERNATIVE COMPARISON SUMMARY

This section provides tables and figures to enumerate/illustrate the MO alternative comparisons with the NAA baseline for seven select metrics representing both storage and run-of-river projects. As described in Chapter 2.3 above, seven quantitative metrics were developed to represent various physical characteristics and processes that could affect storage reservoirs, run-of-river reservoirs, and free-flowing reaches:

- Storage project metrics
    - Head-of-Reservoir Sediment Mobilization
    - Sediment Trap Efficiency
    - Shoreline Exposure
- Run-of-river reservoirs and free-flowing reach metrics
    - Potential for Sediment Passing Reservoirs and Reaches
    - Potential for Bed Material Change
    - Potential Change to Width to Depth Ratio
    - Potential Changes to Navigation Channel Dredging Volumes

As described in Sections 2.4 and 2.5, the degree of change for impact thresholds are specific to each metric, and are normalized to the following five standardized levels:

- No Effect: No change.
- Negligible: Change so small as to be unmeasurable and unable to be observed in the field.
- Minor: Change passes the likely threshold for being measureable but is likely not observable in the field.
- Moderate: Change is measurable and also passes the likely threshold for being observable in the field.
- Major: Change would be readily apparent to an observer in the field.

An example of a minor impact in the “Potential for Bed Material Change” metric would be hydraulic conditions modified from No Action Alternative such that the median grain size in the bed (by mass) could change by up to 10 percent of a grain size class. This means that a fine sand bed reach would still have fine sand bed. A moderate impact would mean the bed material could change by up to 50 percent of a grain size class. A major impact would mean the bed material could change by one whole grain class or more. An example of a major impact would be a reach where the bed material could change from a fine sand to a medium sand or coarser (larger grain sizes) or from a fine sand to a very fine sand or finer (smaller grain sizes).

4.1 STORAGE PROJECT COMPARISON SUMMARIES

This section includes tables and figures that enumerate the storage project comparison summaries for three metrics (Table 4-1 – Table 4-18; Figure 4-1 – Figure 4-27):

- Trap Efficiency
- Shoreline Exposure
- Head-of-Reservoir Sediment Mobilization

Table 4-1. Storage Metrics – Trap Efficiency and Shoreline Exposure Quantitative Analysis

	M01 vs. NAA		M02 vs. NAA		M03 vs. NAA		M04 vs. NAA		PA vs. NAA	
Project	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**
Libby	0.0%	0.0 ft	0.0%	-3.7 ft	0.0%	-3.7 ft	0.0%	-0.3 ft	-0.1%	-0.6 ft
Hungry Horse	0.0%	-4.4 ft	0.0%	-2.4 ft	0.0%	-4.8 ft	0.0%	**-5.4 ft**	0.0%	0.5 ft
Albeni Falls	0.2%	0.0 ft	-0.1%	0.0 ft	0.2%	0.0 ft	0.0%	-0.3 ft	0.0%	0.0 ft
Grand Coulee	0.0%	-1.6 ft	-0.2%	-1.8 ft	0.2%	0.0 ft	-0.4%	-4.7 ft	0.0%	-0.1 ft
Dworshak	0.0%	0.0 ft	-0.1%	**-6.7 ft**	0.0%	0.2 ft	0.0%	0.2 ft	0.0%	-0.7 ft
John Day	0.6%	0.2 ft	0.0%	0.0 ft	0.6%	0.1 ft	0.0%	-0.6 ft	0.8%	1.0 ft

Table 4-2. Storage Metrics – Trap Efficiency and Shoreline Exposure Qualitative Analysis

	M01 vs. NAA		M02 vs. NAA		M03 vs. NAA		M04 vs. NAA		PA vs. NAA	
Project	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**	**Trap Efficiency**	**Shoreline Exposure**
Libby	No Effect	No Effect	No Effect	Negligible	No Effect	Negligible	No Effect	Negligible	Negligible	Negligible
Hungry Horse	No Effect	Negligible	No Effect	Negligible	No Effect	Negligible	No Effect	**Minor**	No Effect	Negligible
Albeni Falls	Negligible	No Effect	Negligible	No Effect	Negligible	No Effect	No Effect	Negligible	No Effect	No Effect
Grand Coulee	No Effect	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible
Dworshak	No Effect	No Effect	Negligible	**Minor**	No Effect	Negligible	No Effect	Negligible	No Effect	Negligible
John Day	Negligible	Negligible	No Effect	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible

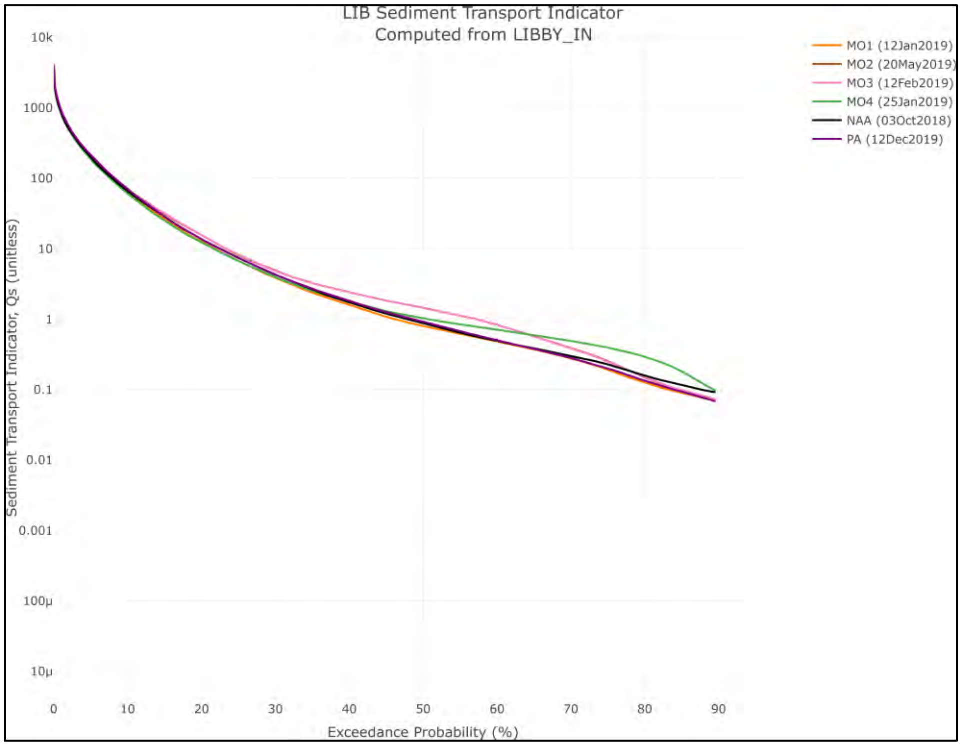
Table 4-3. Storage Metrics – Head-of-Reservoir Sediment Mobilization Analysis

Reservoir	M01 vs. NAA	M02 vs. NAA	M03 vs. NAA	M04 vs. NAA	PA vs. NAA
Libby – Kootenai River	-0.1%	2.1%	2.0%	-1.7%	**8.8%**
Hungry Horse – Flathead River	5.9%	9.8%	4.7%	6.9%	-0.4%
Albeni Falls – Clark Fork River	-0.2%	1.5%	-0.2%	-0.1%	0.1%
Albeni Falls – Lightning Creek	0.1%	0.2%	0.2%	1.0%	0.0%
Albeni Falls – Priest River	0.1%	0.2%	0.2%	1.0%	0.0%
Grand Coulee – Columbia River	**10.6%**	8.9%	1.5%	**28.5%**	1.2%
Grand Coulee – Spokane River	7.9%	7.4%	1.7%	**11.6%**	2.2%
Dworshak – North Fork Clearwater	0.4%	**16.9%**	0.1%	0.0%	2.8%
John Day – Columbia River	-7.1%	-0.8%	-6.0%	**14.6%**	**18.7%**

Table 4-4. Storage Metrics – Head-of-Reservoir Sediment Mobilization Analysis

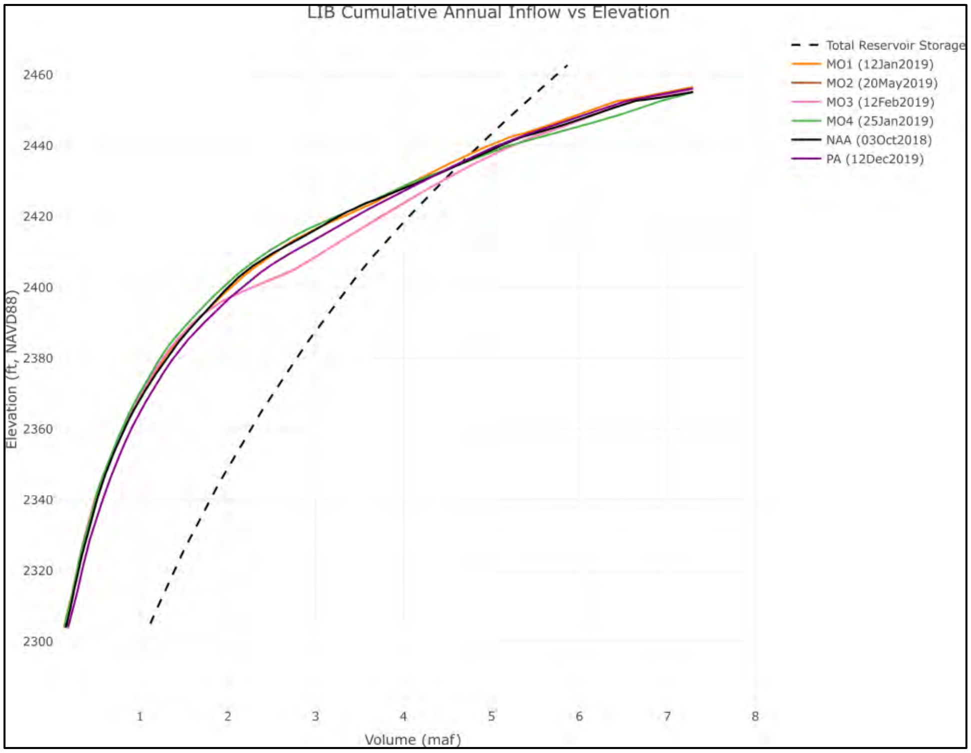
Project – Tributary	M01 vs. NAA	M02 vs. NAA	M03 vs. NAA	M04 vs. NAA	PA vs. NAA
Libby – Kootenai River	Negligible	Negligible	Negligible	Negligible	**Minor**
Hungry Horse – Flathead River	Negligible	Negligible	Negligible	Negligible	Negligible
Albeni Falls – Clark Fork River	Negligible	Negligible	Negligible	Negligible	Negligible
Albeni Falls – Lightning Creek	Negligible	Negligible	Negligible	Negligible	No Effect
Albeni Falls – Priest River	Negligible	Negligible	Negligible	Negligible	No Effect
Grand Coulee – Columbia River	**Minor**	Negligible	Negligible	**Minor**	Negligible
Grand Coulee – Spokane River	Negligible	Negligible	Negligible	**Minor**	Negligible
Dworshak – North Fork Clearwater	Negligible	**Minor**	Negligible	No Effect	Negligible
John Day – Columbia River	Negligible	Negligible	Negligible	**Minor**	**Minor**

1926 4.1.1 Region A: Libby Dam Storage Project (LIB)



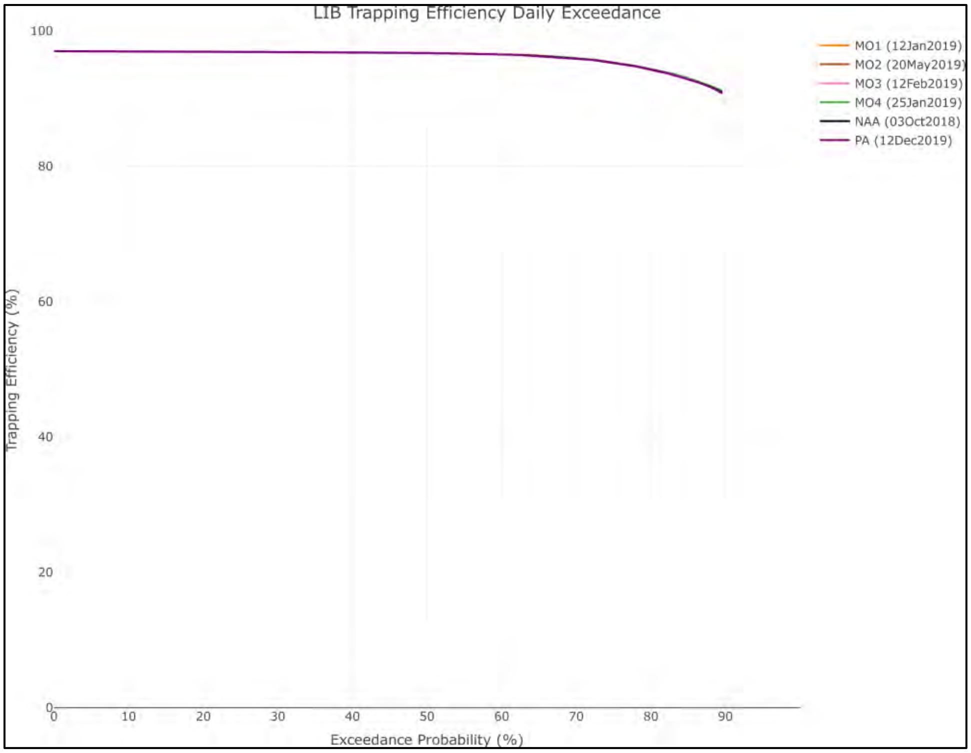
1927

1928 **Figure 4-1. LIB Sediment Transport Indicator**



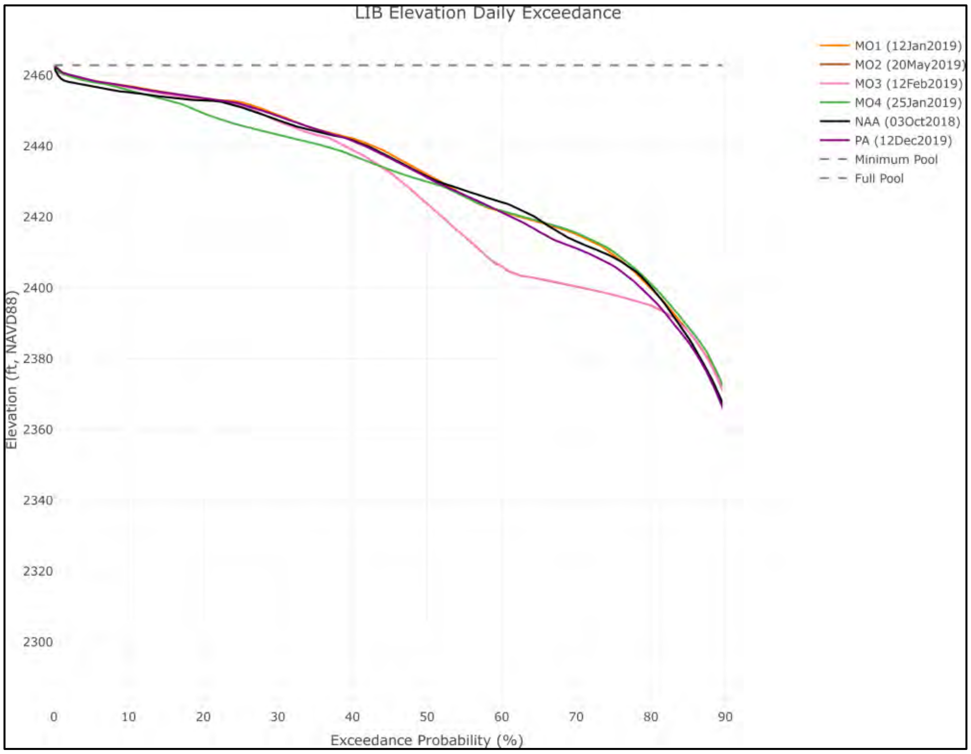
1929

1930 **Figure 4-2. LIB Cumulative Annual Inflow vs. Elevation**



1931

1932 **Figure 4-3. LIB Trapping Efficiency Daily Exceedance**



1933

1934 **Figure 4-4. LIB Elevation Daily Exceedance**

4.1.2 Region A: Hungry Horse Dam Storage Project (HGH)

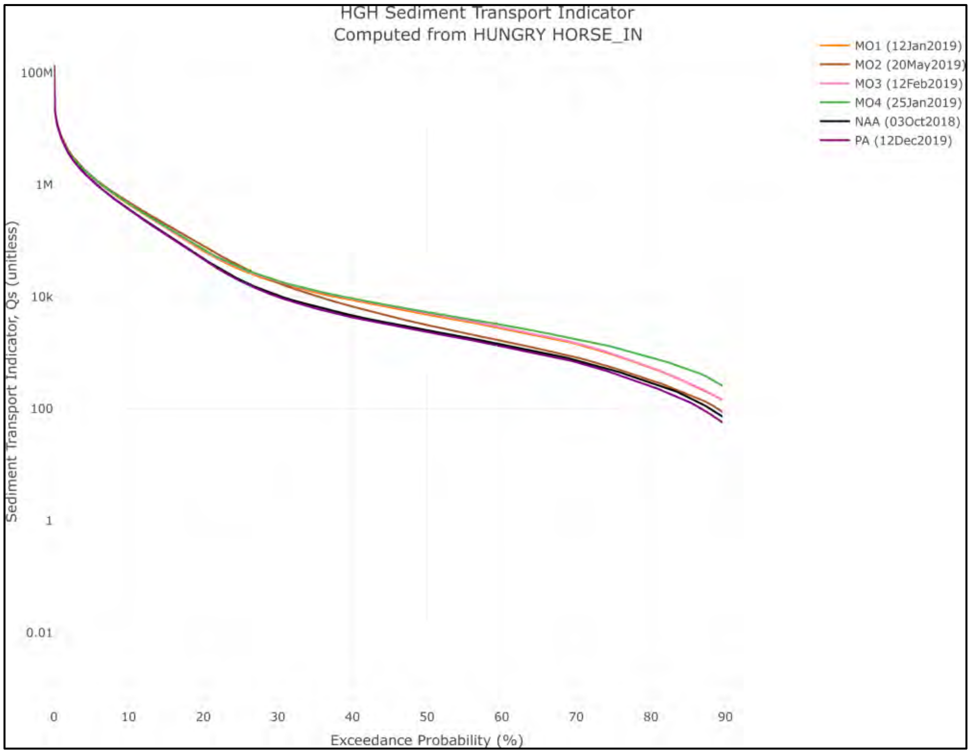


Figure 4-5. HGH Sediment Transport Indicator

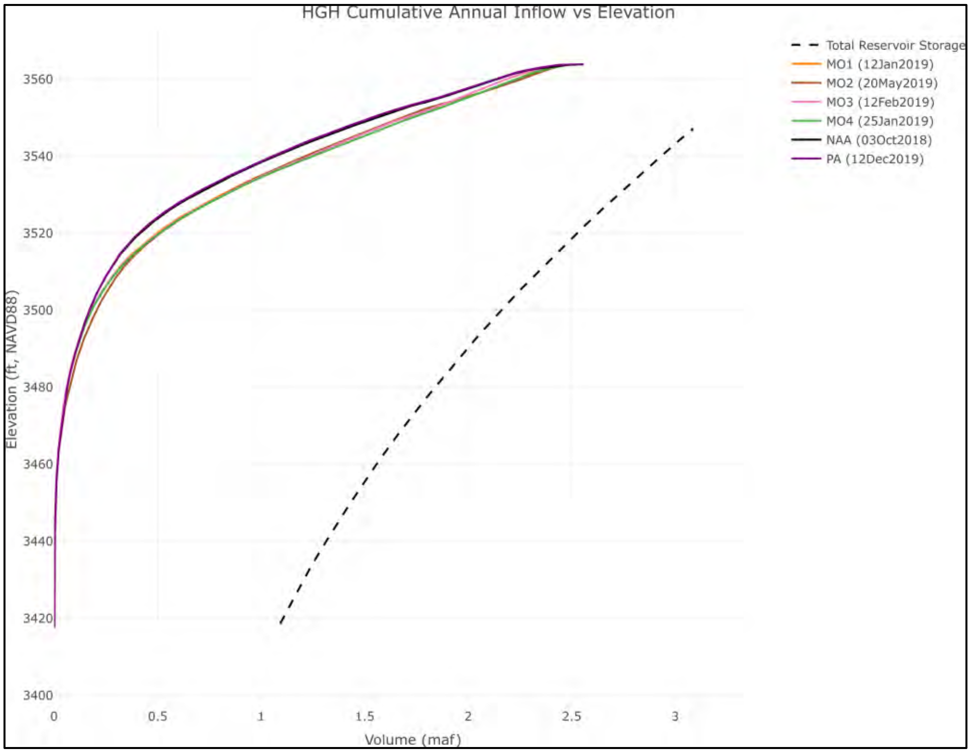


Figure 4-6. HGH Cumulative Annual Inflow vs. Elevation

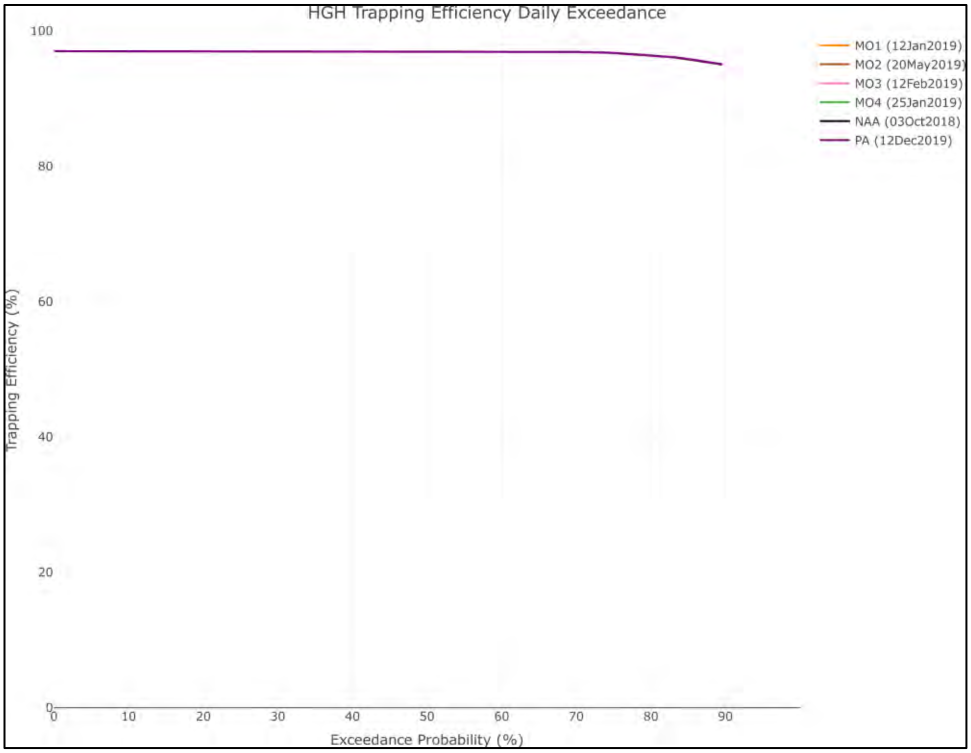


Figure 4-7. HGH Trapping Efficiency Daily Exceedance

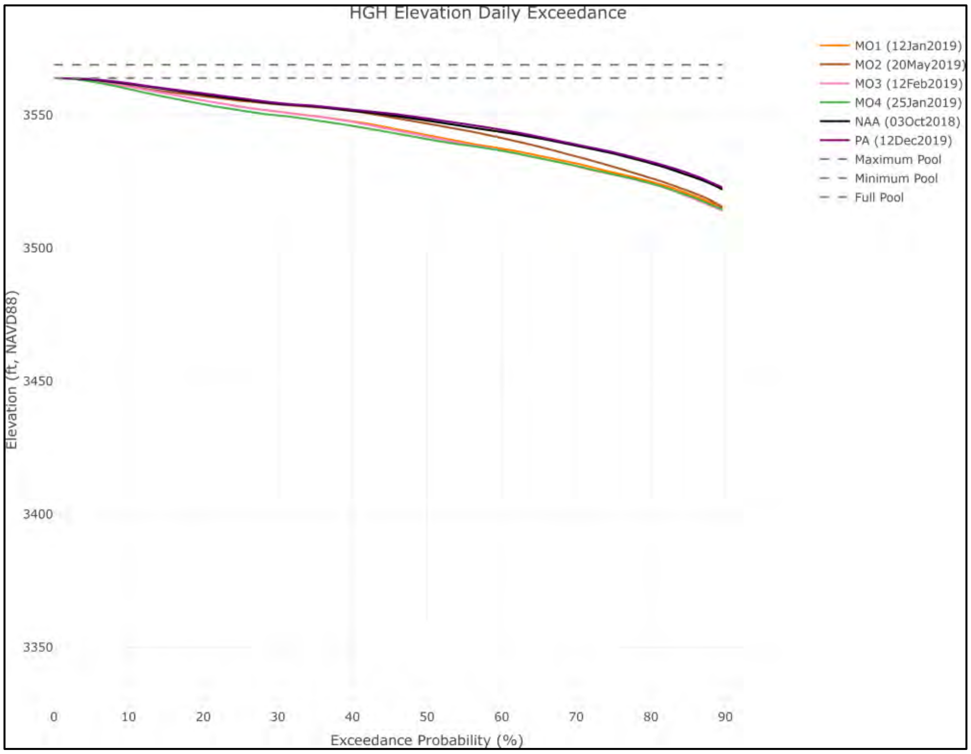


Figure 4-8. HGH Elevation Daily Exceedance

4.1.3 Region A: Albeni Falls Dam Storage Project (ALF)

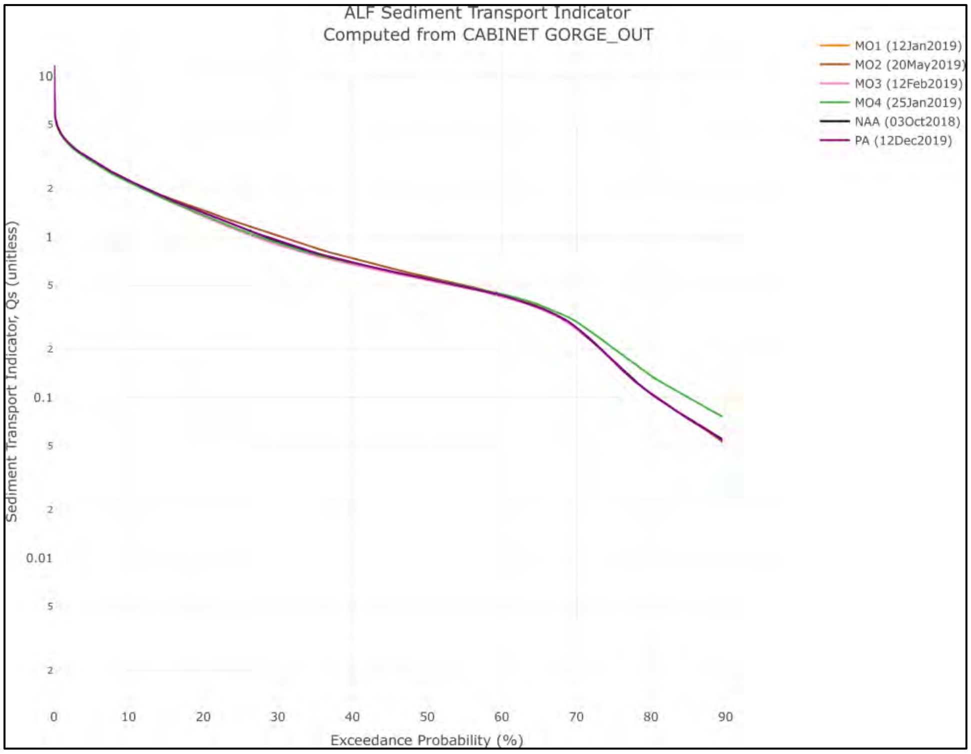


Figure 4-9. ALF Sediment Transport Indicator

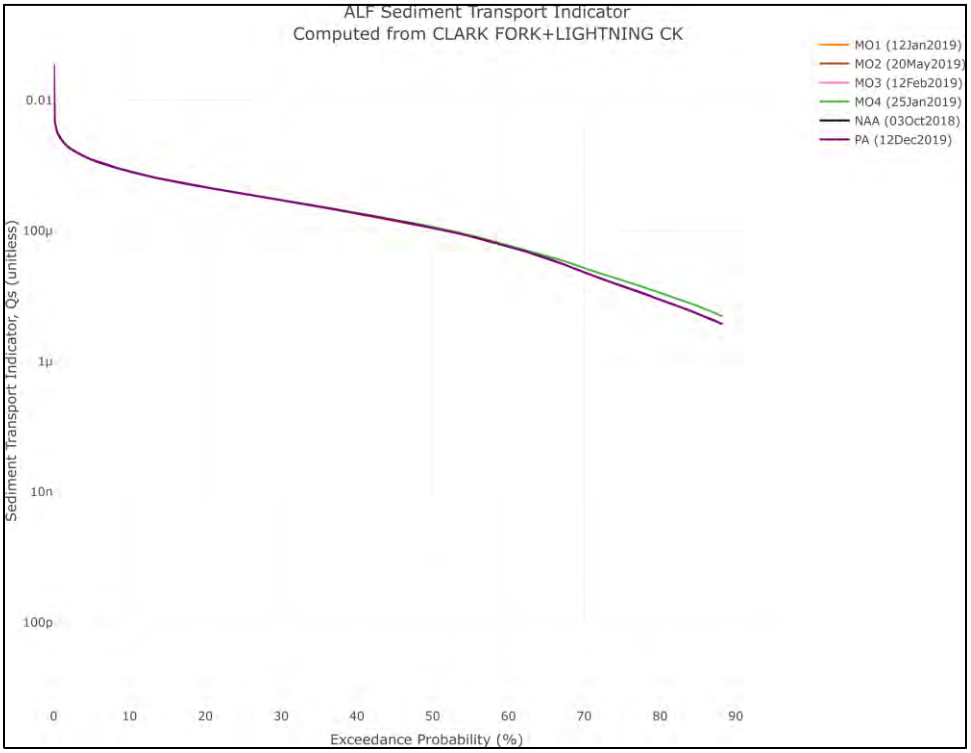


Figure 4-10. ALF Sediment Transport Indicator

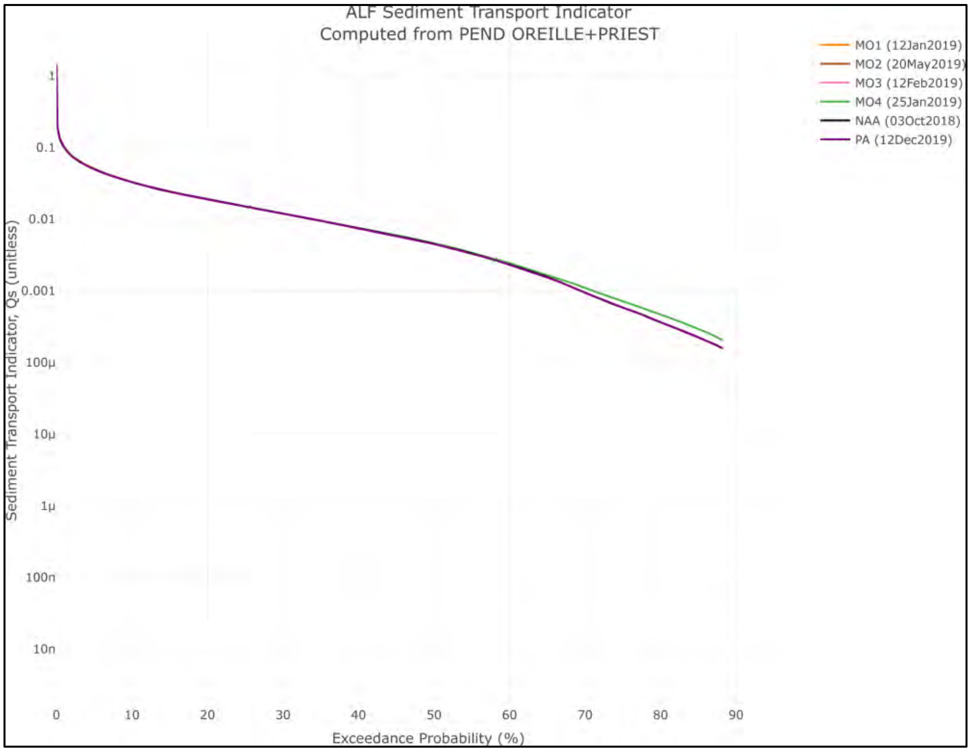


Figure 4-11. ALF Sediment Transport Indicator

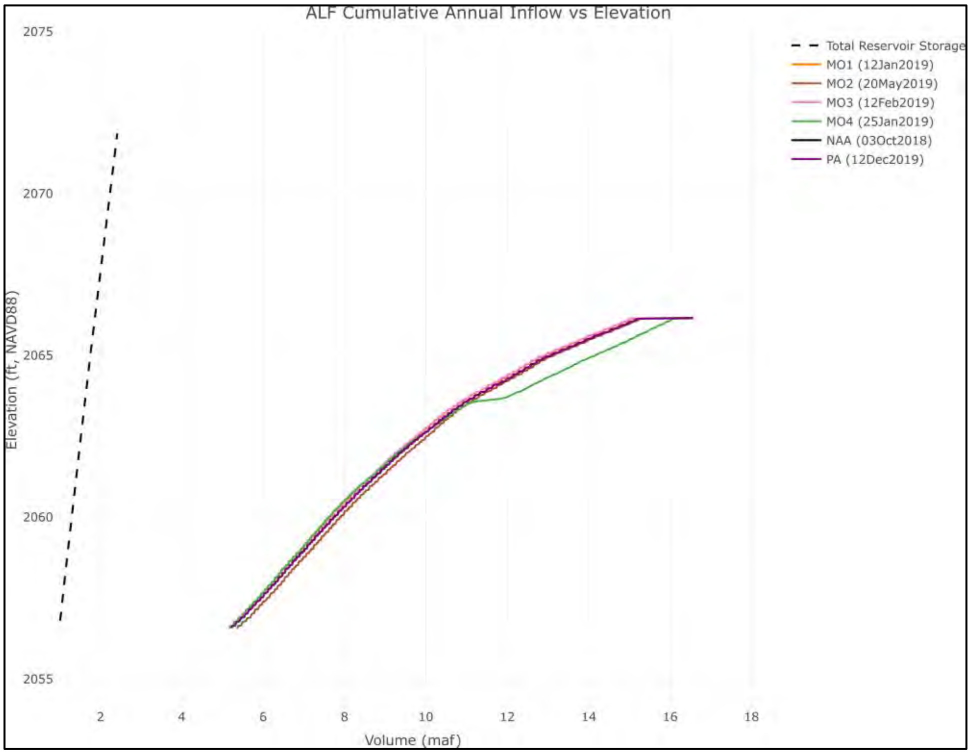


Figure 4-12. ALF Sediment Cumulative Annual Inflow vs. Elevation

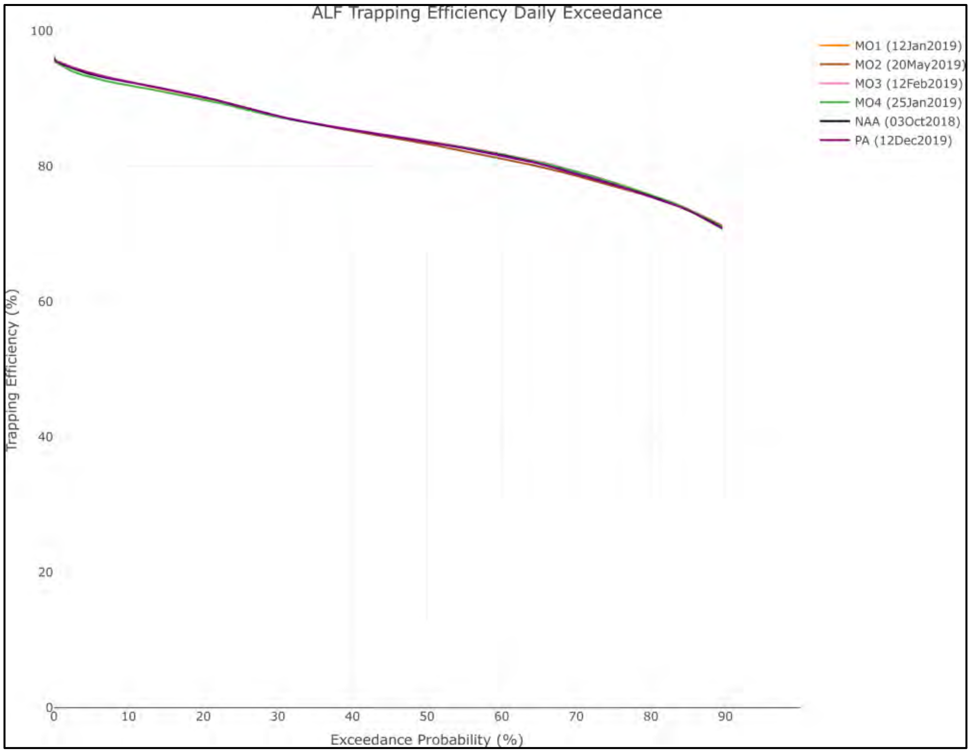


Figure 4-13. ALF Trapping Efficiency Daily Exceedance

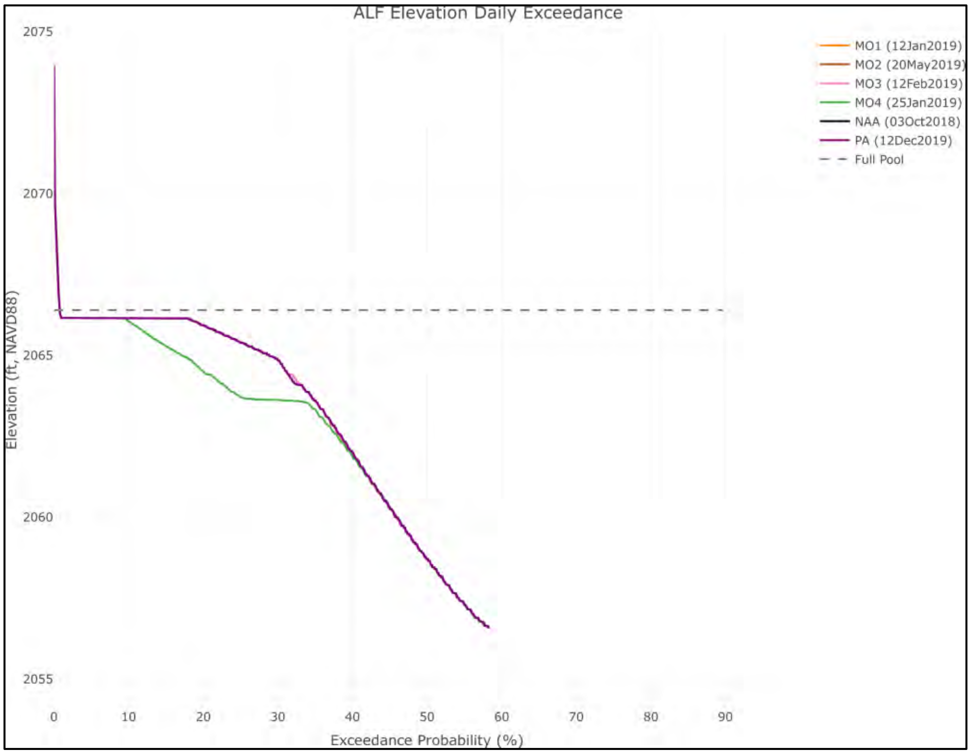


Figure 4-14. ALF Elevation Daily Exceedance

4.1.4 Region B: Grand Coulee Dam Storage Project (GCL)

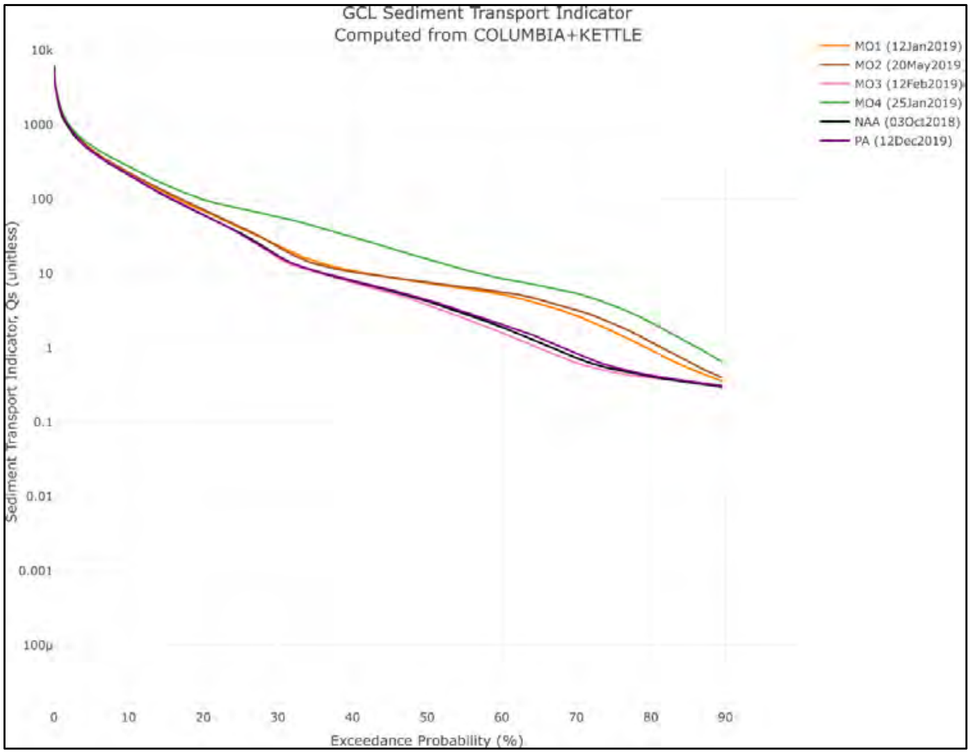


Figure 4-15. GCL Sediment Transport Indicator

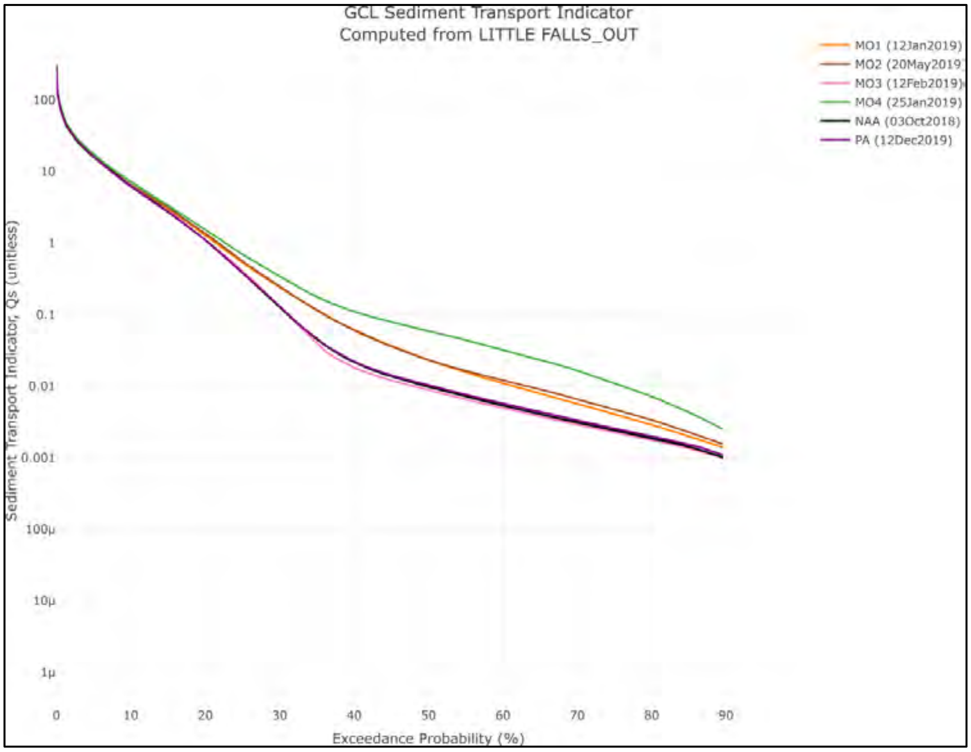


Figure 4-16. GCL Sediment Transport Indicator

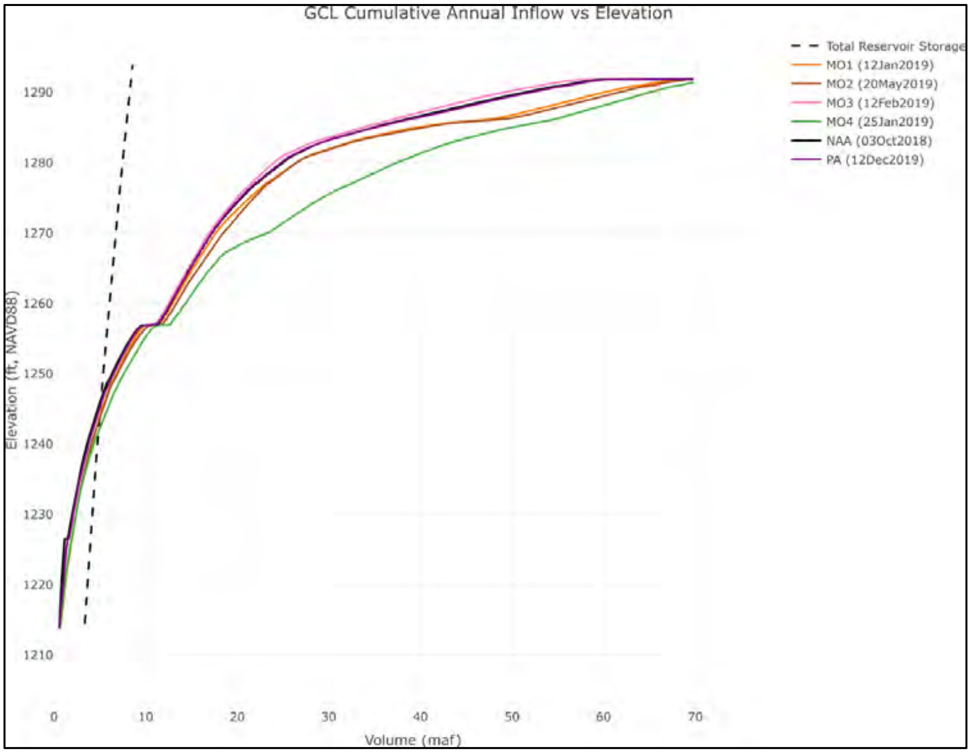


Figure 4-17. GCL Cumulative Annual Inflow vs. Elevation

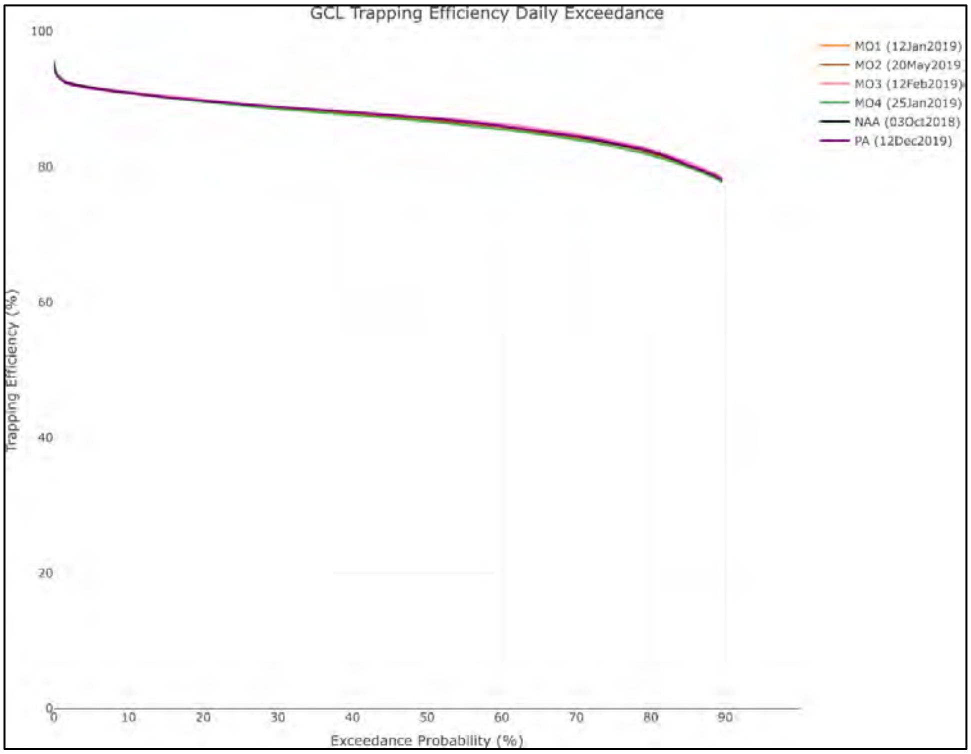


Figure 4-18. GCL Trapping Efficiency Daily Exceedance

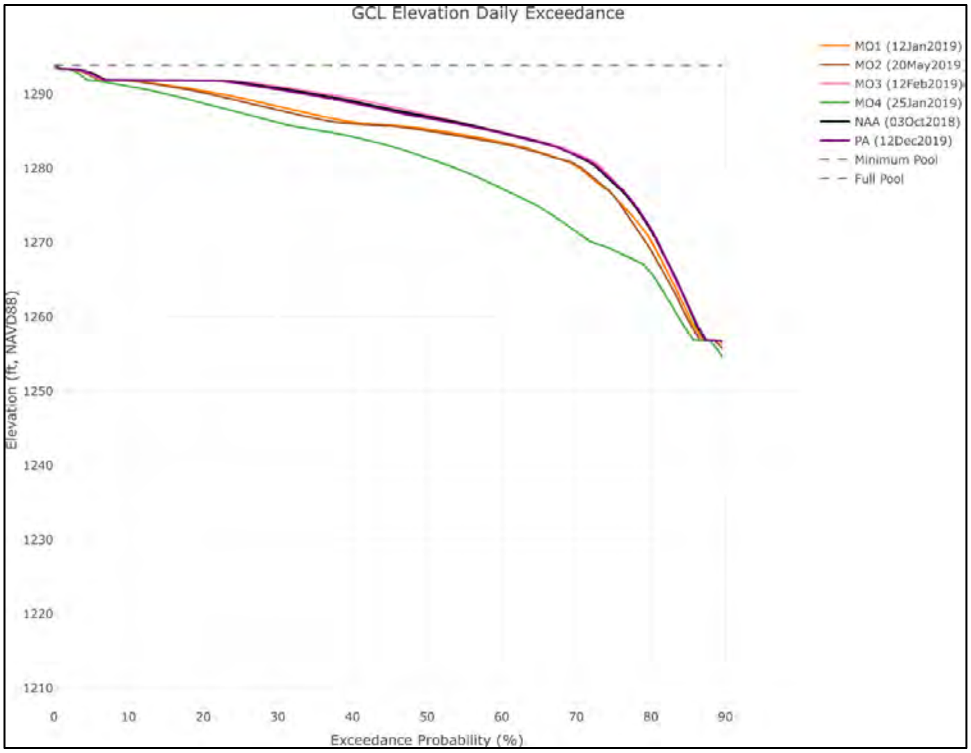


Figure 4-19. GCL Elevation Daily Exceedance

4.1.5 Region C: Dworshak Dam Storage Project (DWR)

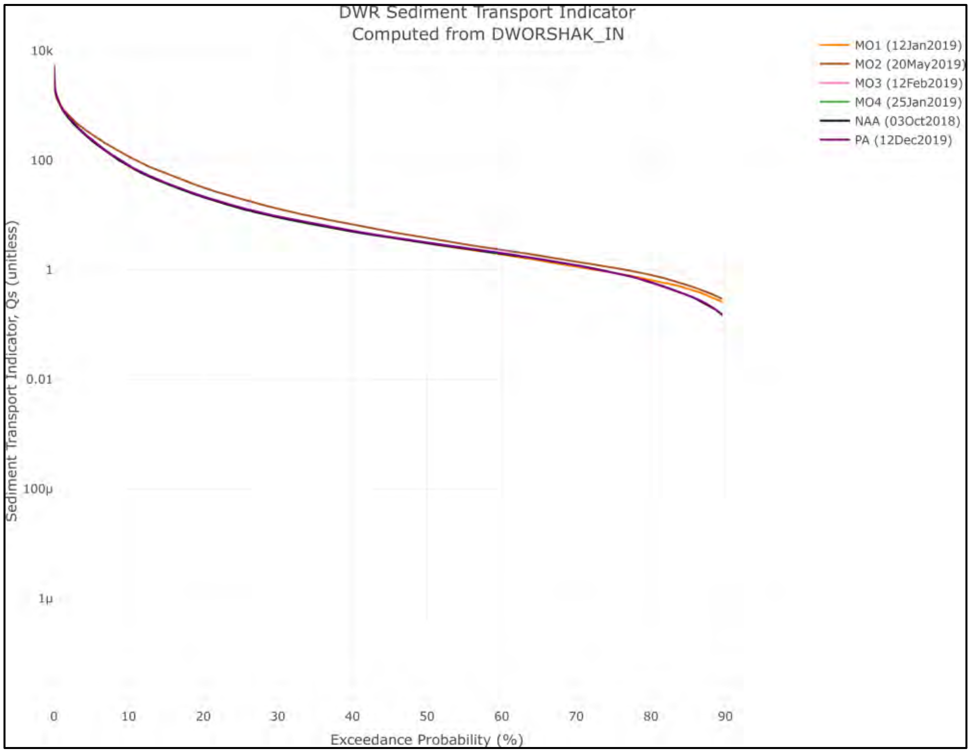


Figure 4-20. DWR Sediment Transport Indicator

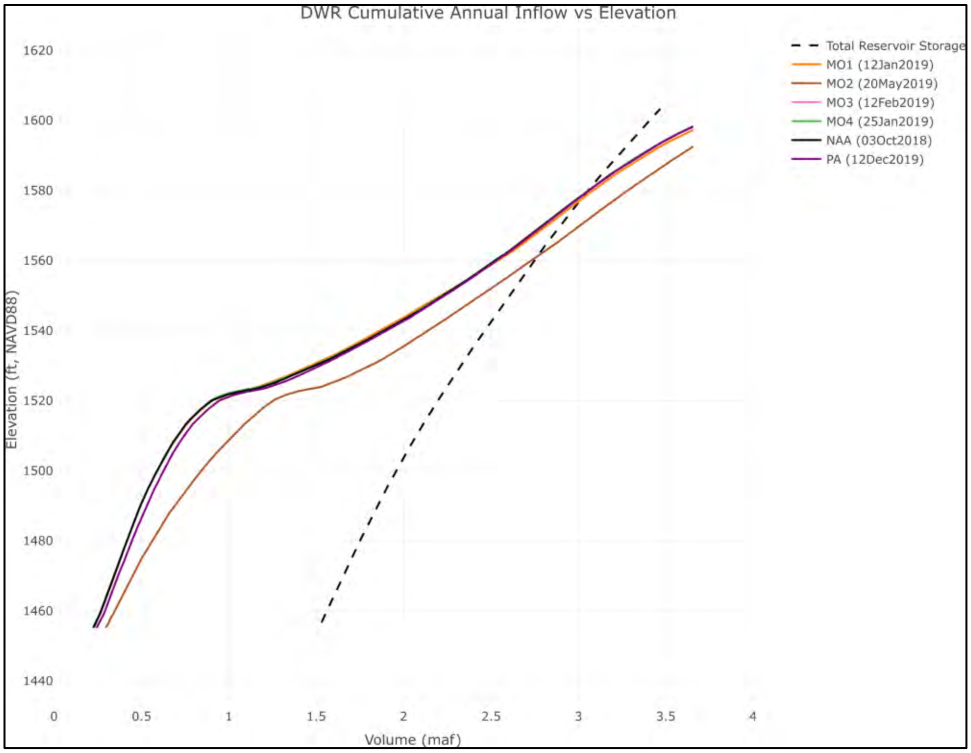


Figure 4-21. DWR Cumulative Annual Inflow vs. Elevation

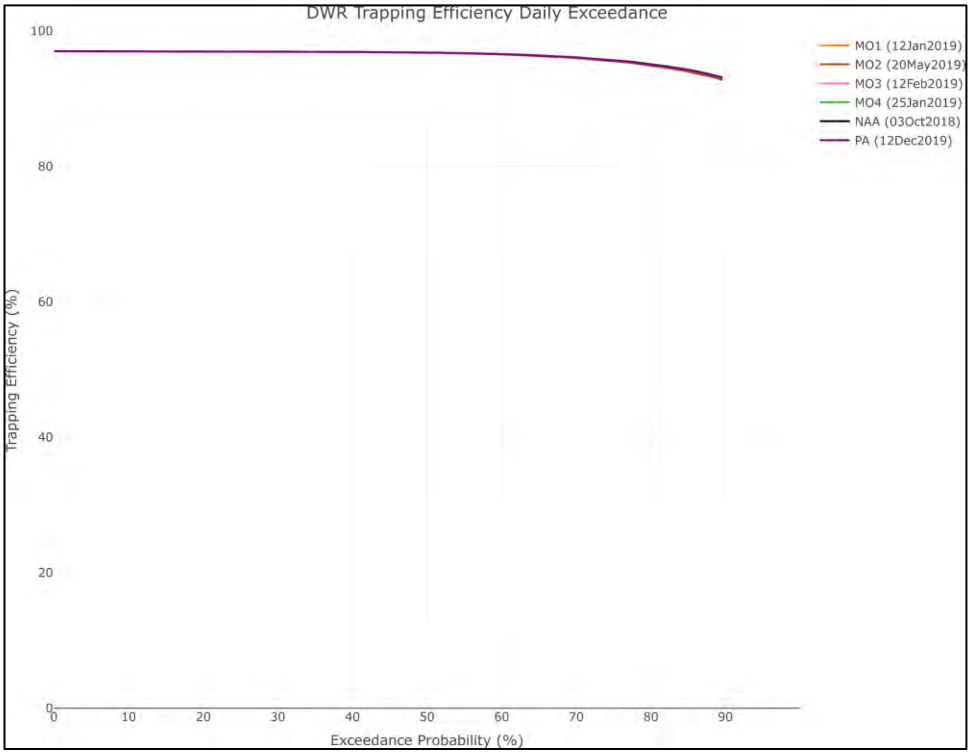


Figure 4-22. DWR Trapping Efficiency Daily Exceedance

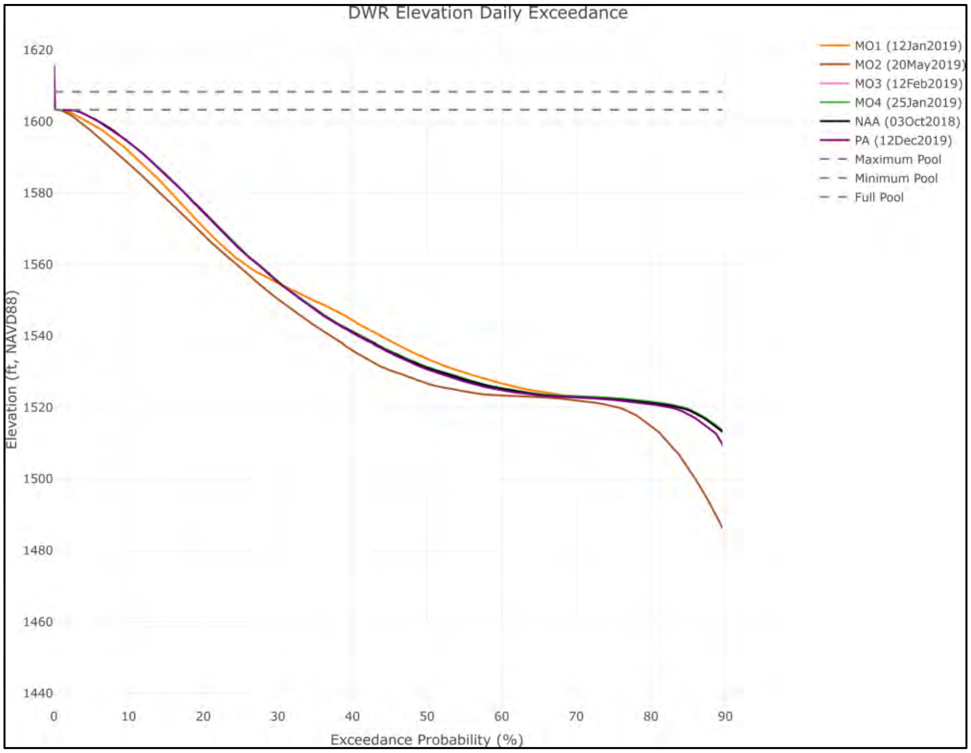


Figure 4-23. DWR Elevation Daily Exceedance

4.1.6 Region D: John Day Dam Storage Project (JDA)

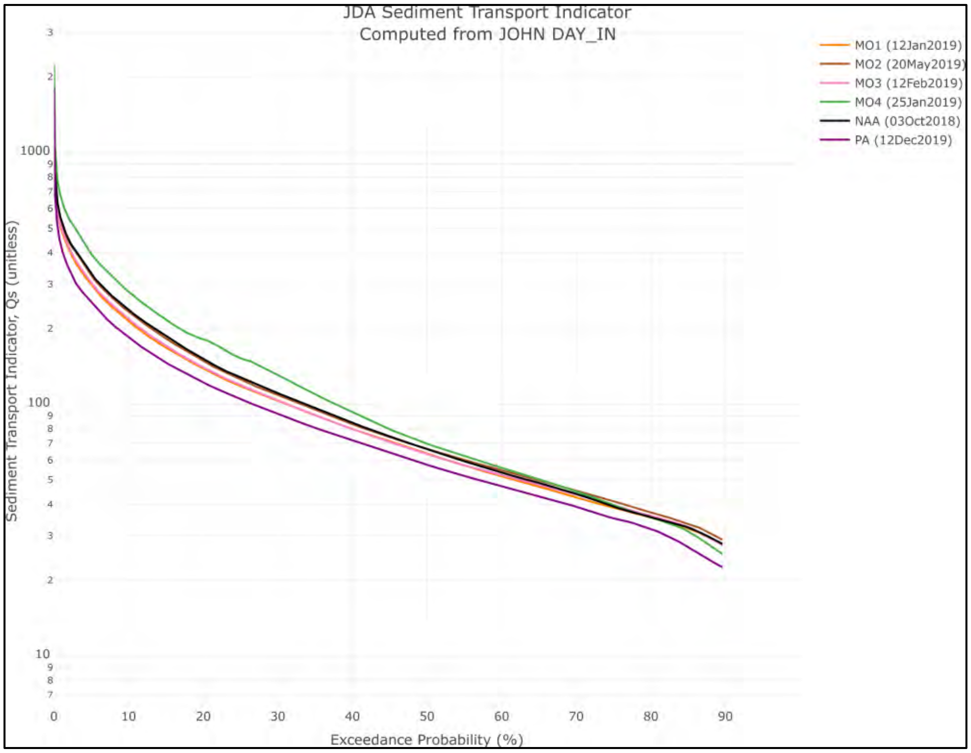


Figure 4-24. JDA Sediment Transport Indicator

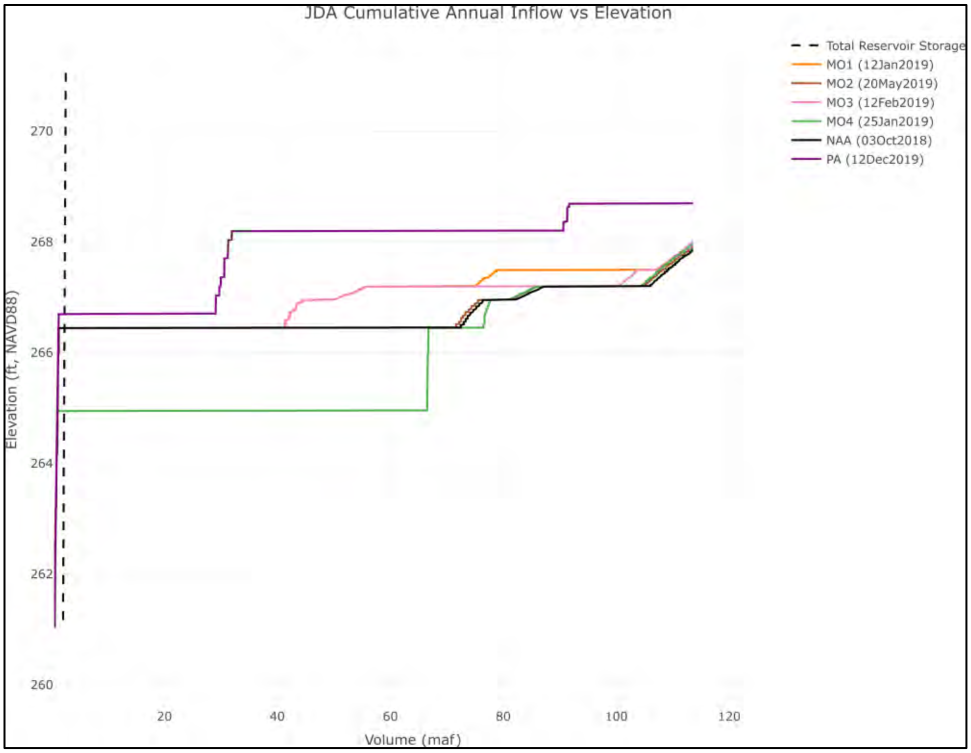


Figure 4-25. JDA Cumulative Annual Inflow vs. Elevation

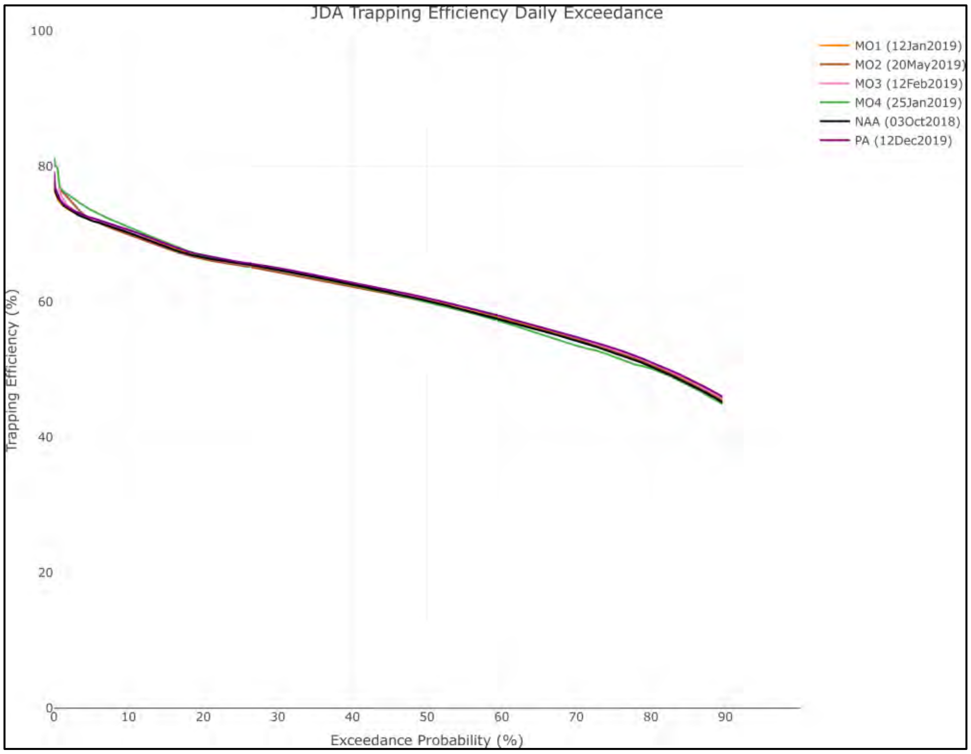


Figure 4-26. JDA Trapping Efficiency Daily Exceedance

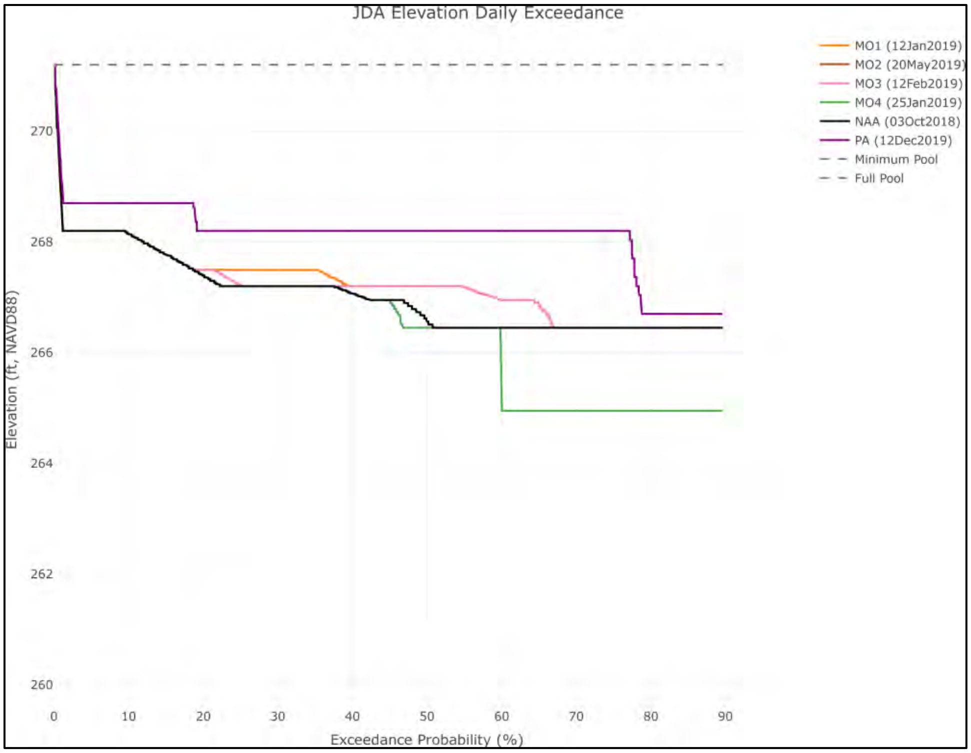


Figure 4-27. JDA Elevation Daily Exceedance

4.2 RUN-OF-RIVER RESERVOIR AND FREE-FLOWING REACH COMPARISON SUMMARIES

This section includes tables and figures that enumerate the run-of-river reservoir and free-flowing reach comparison summaries for three metrics (Figure 4-28 –Figure 4-183):

- Potential for Sediment Passing Reservoirs and Reaches
- Potential for Bed Material Change
- Potential Change to Width-to-Depth Ratio

4.2.1 Region A1: Kootenai Reach – Libby Dam to U.S.-Canada Border

4.2.1.1 Region A1: Kootenai Reach Comparison Tables

Table 4-5. Region A1: Kootenai Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	ID #	Name	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd
Kootenai	30.22	Libby Dam to Libby	0.0%	-0.8%	0.0%	-1.9%	-0.2%	0.3%	-1.9%	-0.2%	0.3%	-0.4%	-0.1%	0.0%	-0.4%	-1.8%	0.0%
	30.21	Libby to Kootenai Falls	-0.6%	-1.2%	-0.2%	-1.9%	2.2%	4.8%	-1.9%	2.2%	4.6%	-0.6%	-0.5%	-0.1%	-0.9%	0.1%	0.0%
	30.12	Kootenai Falls	-4.0%	-6.0%	-1.2%	1.5%	1.1%	1.7%	1.5%	1.0%	1.6%	-2.7%	-3.2%	-0.8%	-1.8%	-2.0%	1.2%
	30.11	Canyon Reach	0.4%	-0.9%	-1.2%	-0.6%	-0.7%	1.1%	-0.6%	-0.7%	1.0%	0.0%	-0.7%	-0.5%	0.1%	-0.5%	-0.5%
	29.22	Braided Reach	1.6%	-1.9%	0.5%	-1.5%	0.3%	-0.2%	-1.5%	0.2%	-0.2%	0.6%	-1.4%	0.4%	0.2%	-0.9%	-0.1%
	29.21	Straight Reach	-1.3%	-0.7%	-2.6%	1.3%	-1.5%	1.1%	1.3%	-1.5%	1.0%	-0.6%	1.7%	-2.0%	0.4%	-0.3%	-0.8%
	29.13	Meander Reach	0.0%	-4.4%	0.2%	0.4%	-1.2%	-0.3%	0.5%	-1.2%	-0.3%	0.5%	-3.0%	0.3%	-0.2%	-2.3%	0.1%

Table 4-6. Region A1: Kootenai Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	ID #	Name	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change
Kootenai	30.22	Libby Dam to Libby	No Effect	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	30.21	Libby to Kootenai Falls	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	30.12	Kootenai Falls	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	30.11	Canyon Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible
	29.22	Braided Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	29.21	Straight Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	29.13	Meander Reach	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

4.2.1.2 Region A1: Kootenai Reach Comparison Figures

REGION A1 MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

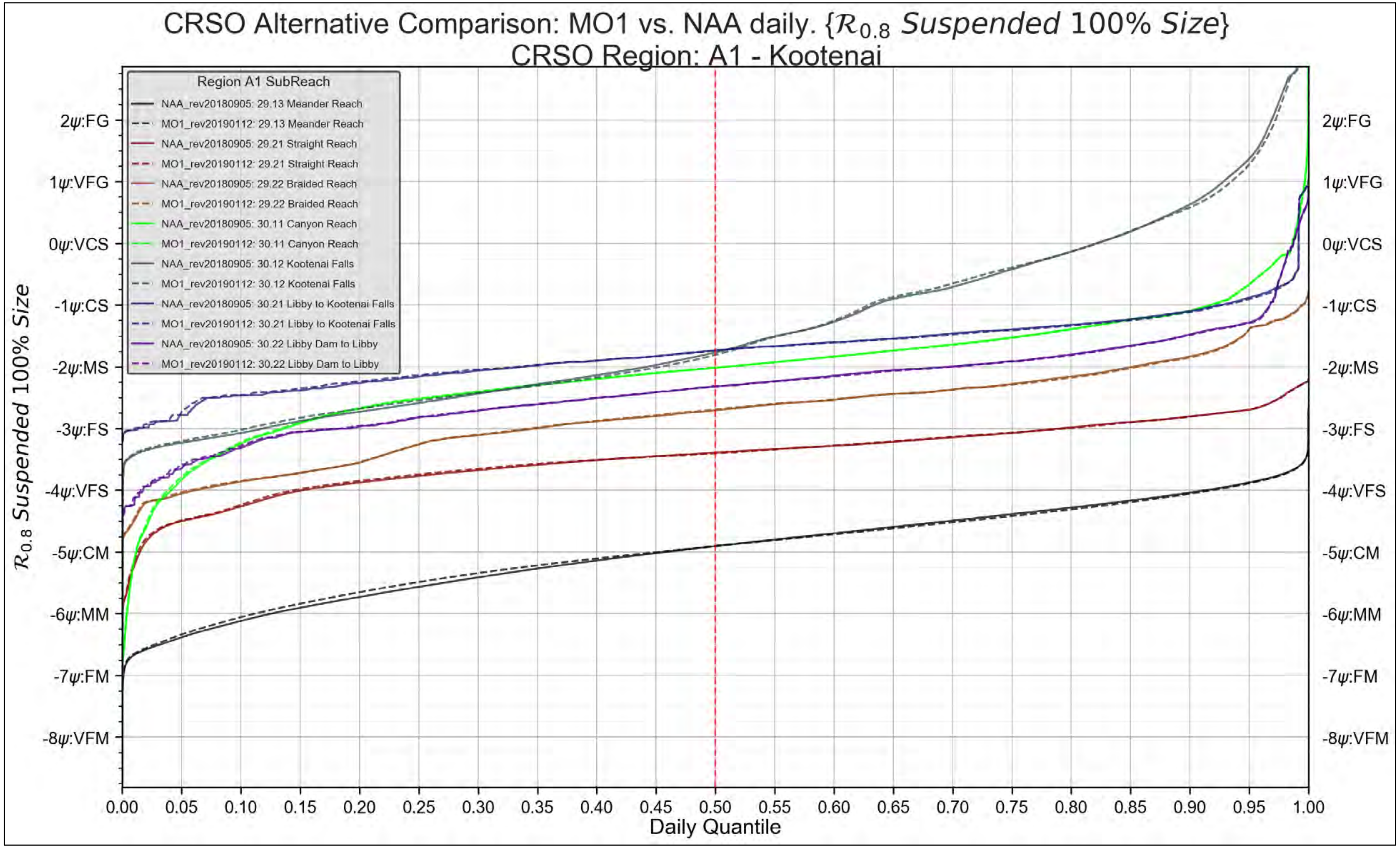


Figure 4-28. Region A1 - Kootenai. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

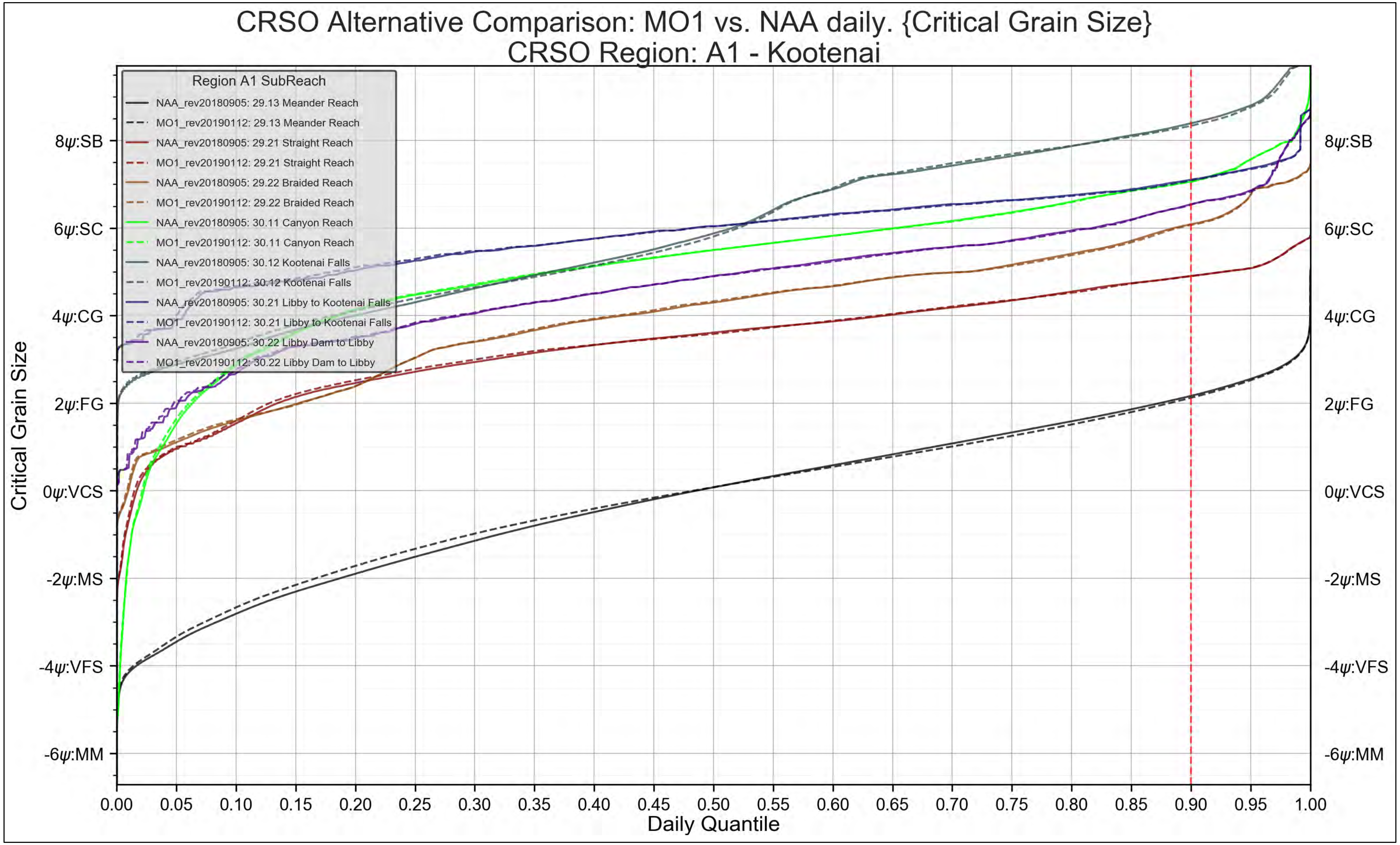


Figure 4-29. Region A1 - Kootenai. MO1 vs. NAA. Critical Grain-Size Threshold

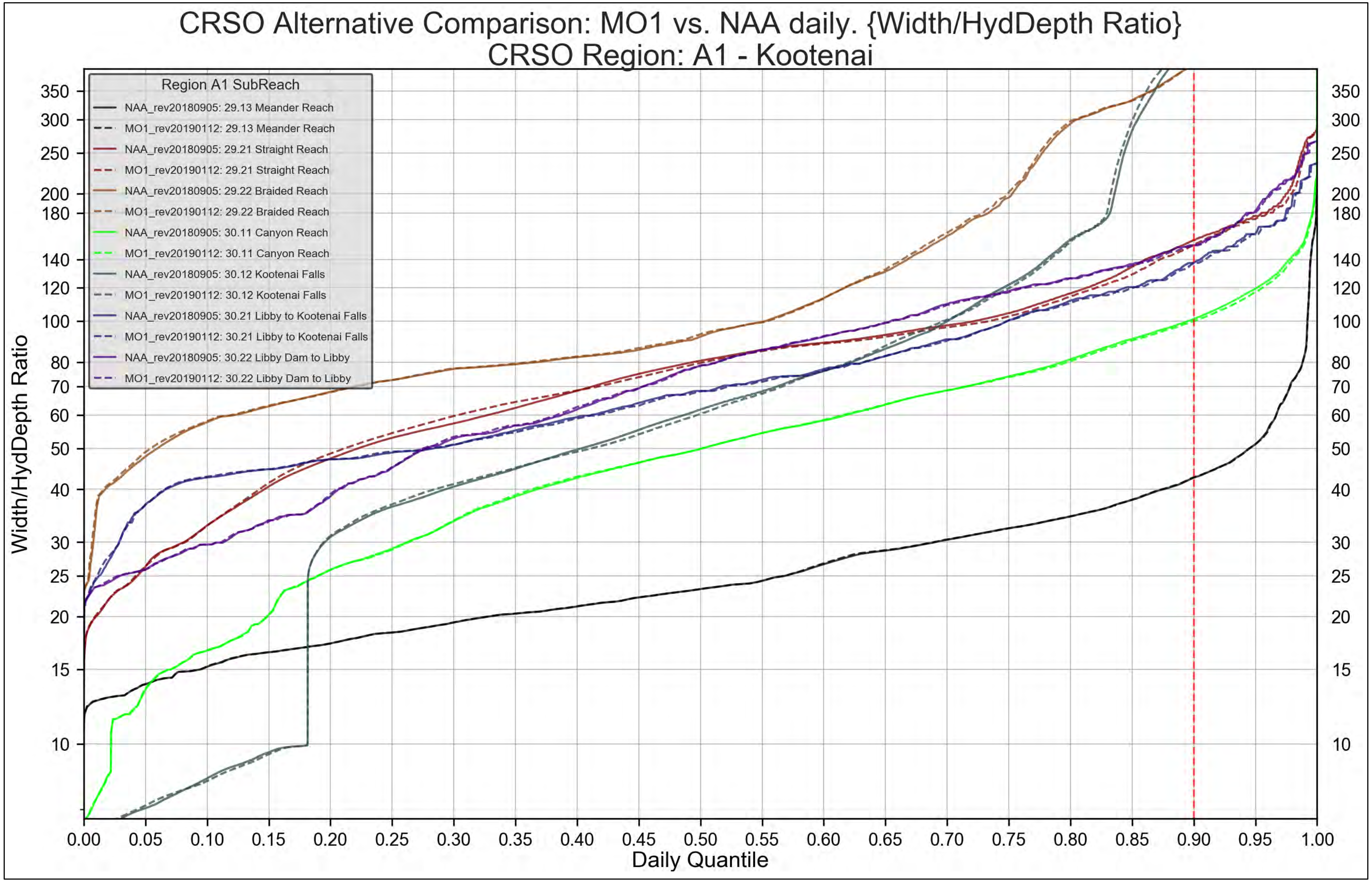


Figure 4-30. Region A1 - Kootenai. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION A1 MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

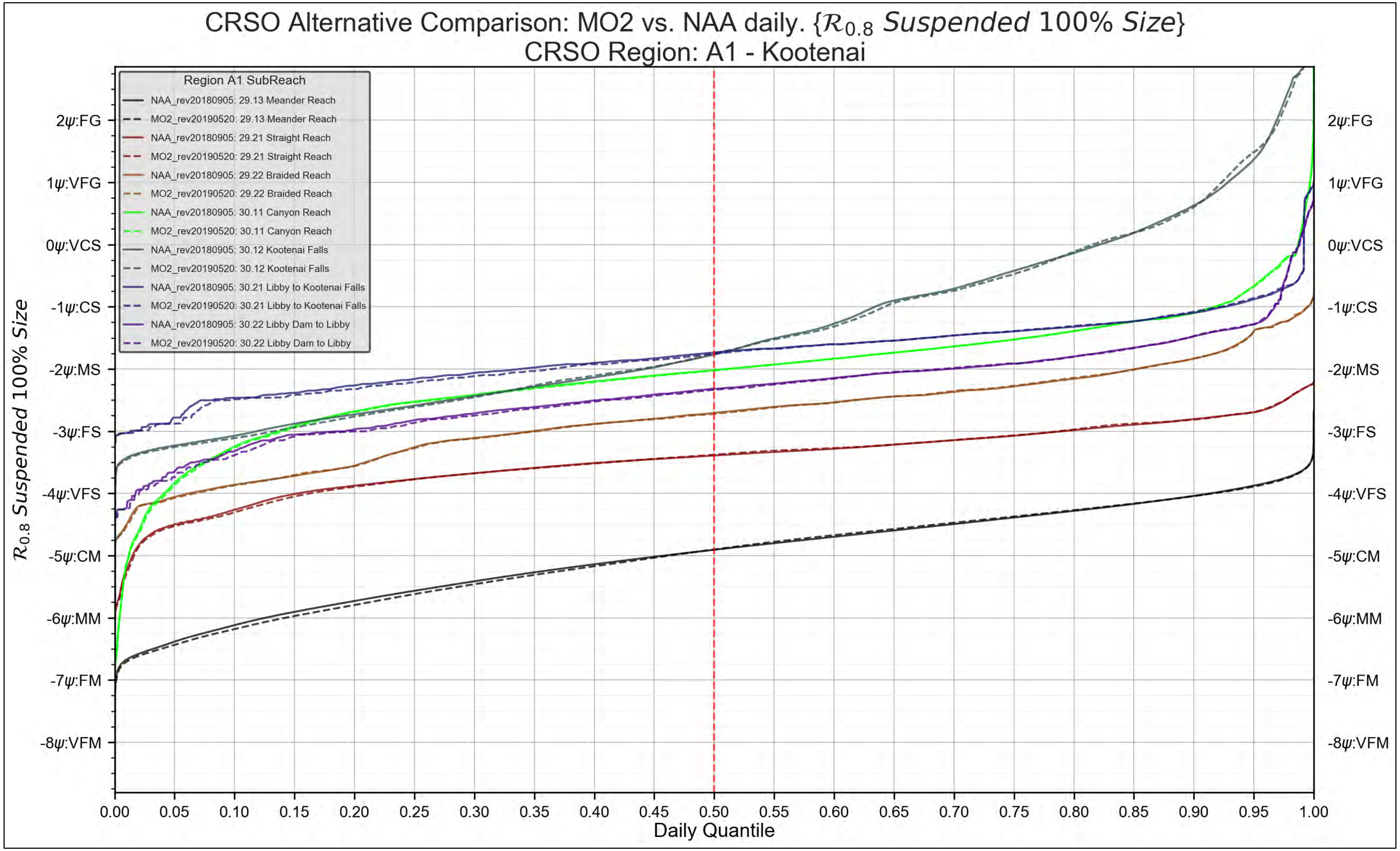
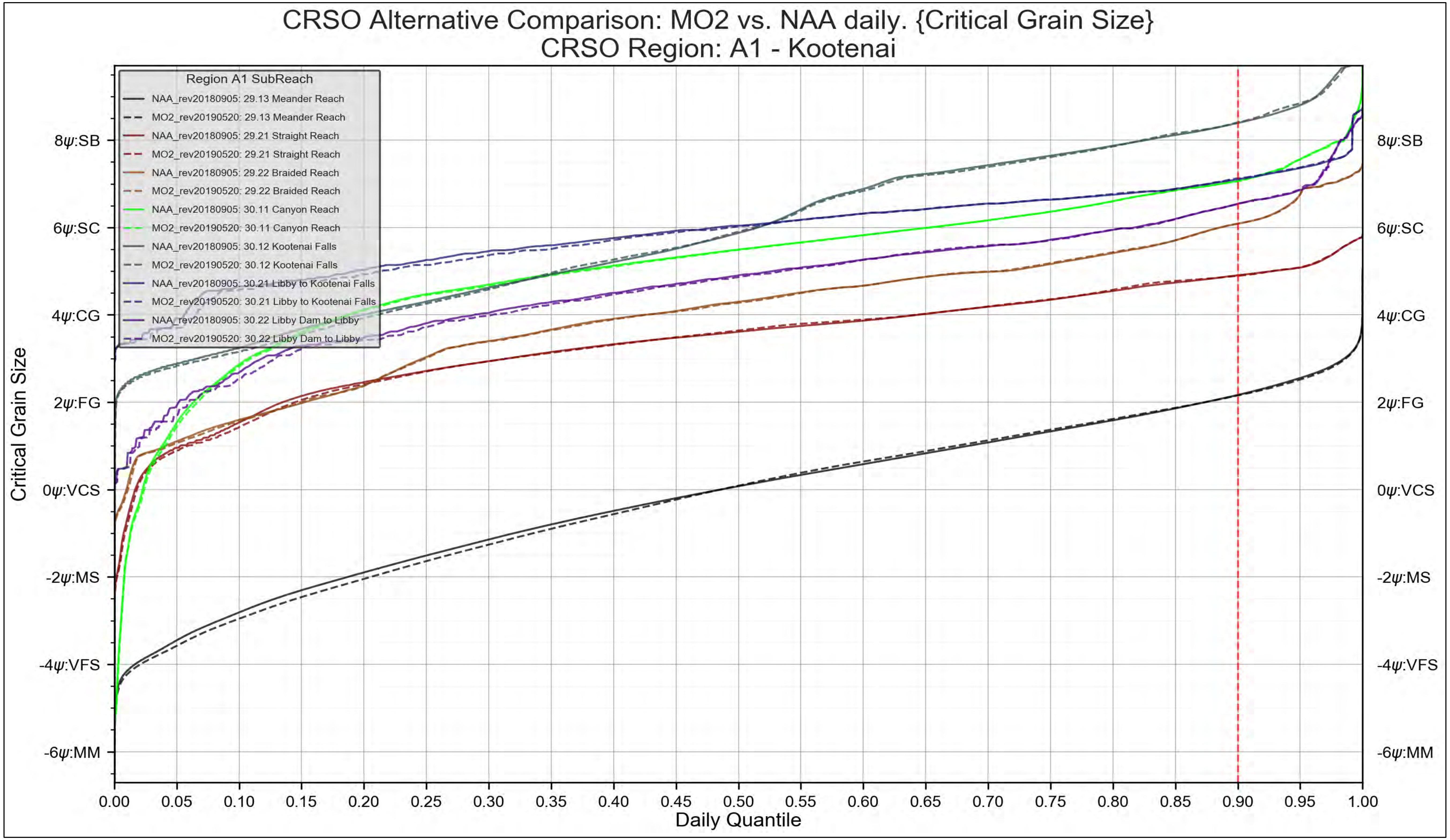


Figure 4-31. Region A1 - Kootenai. MO2 vs. NAA. 100% Suspended Grain-Size Threshold



2008

2009 **Figure 4-32. Region A1 - Kootenai. MO2 vs. NAA. Critical Grain-Size Threshold**

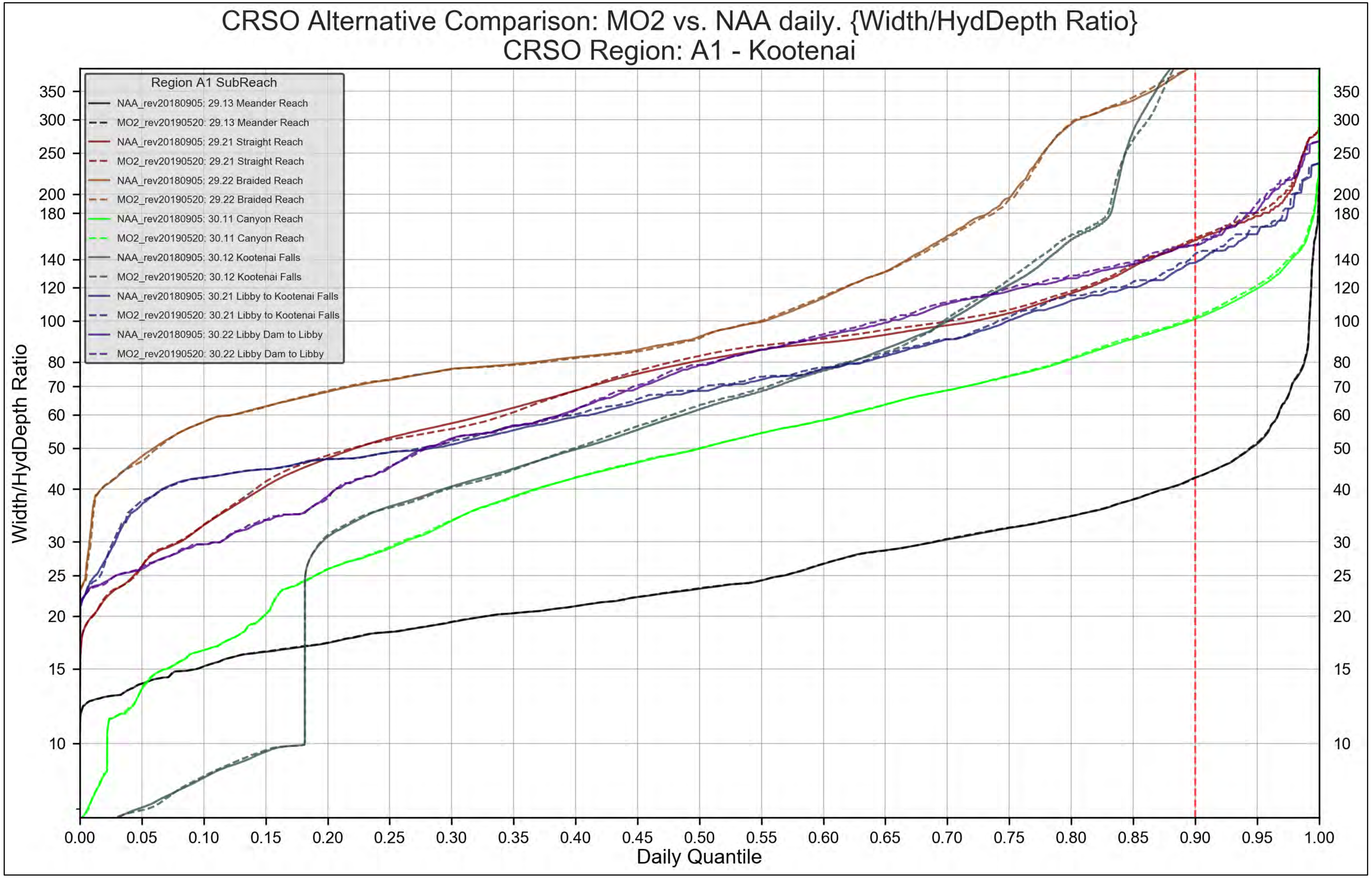


Figure 4-33. Region A1 - Kootenai. MO2 vs. NAA. Width/Hydraulic Depth Ratio

REGION A1. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

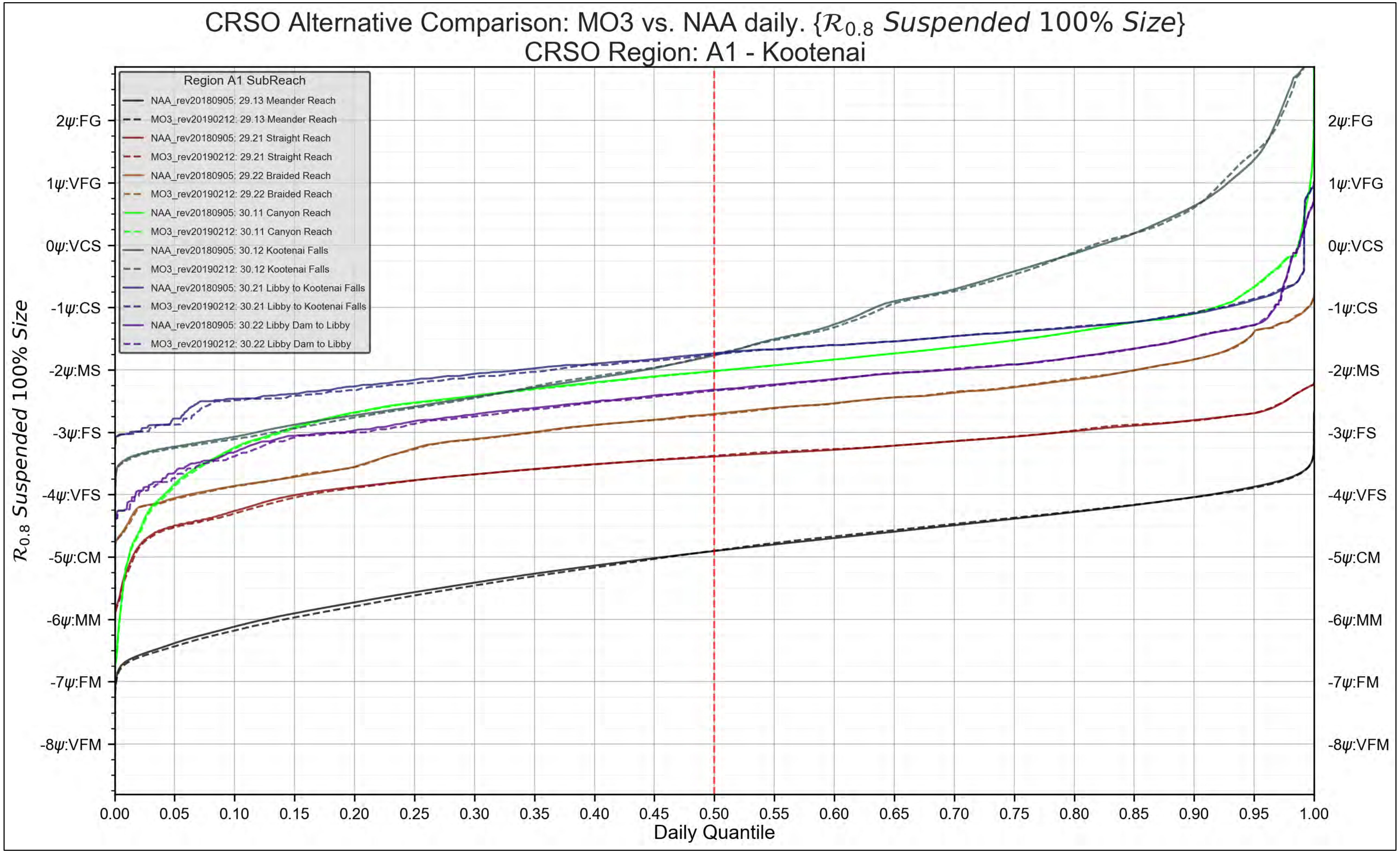
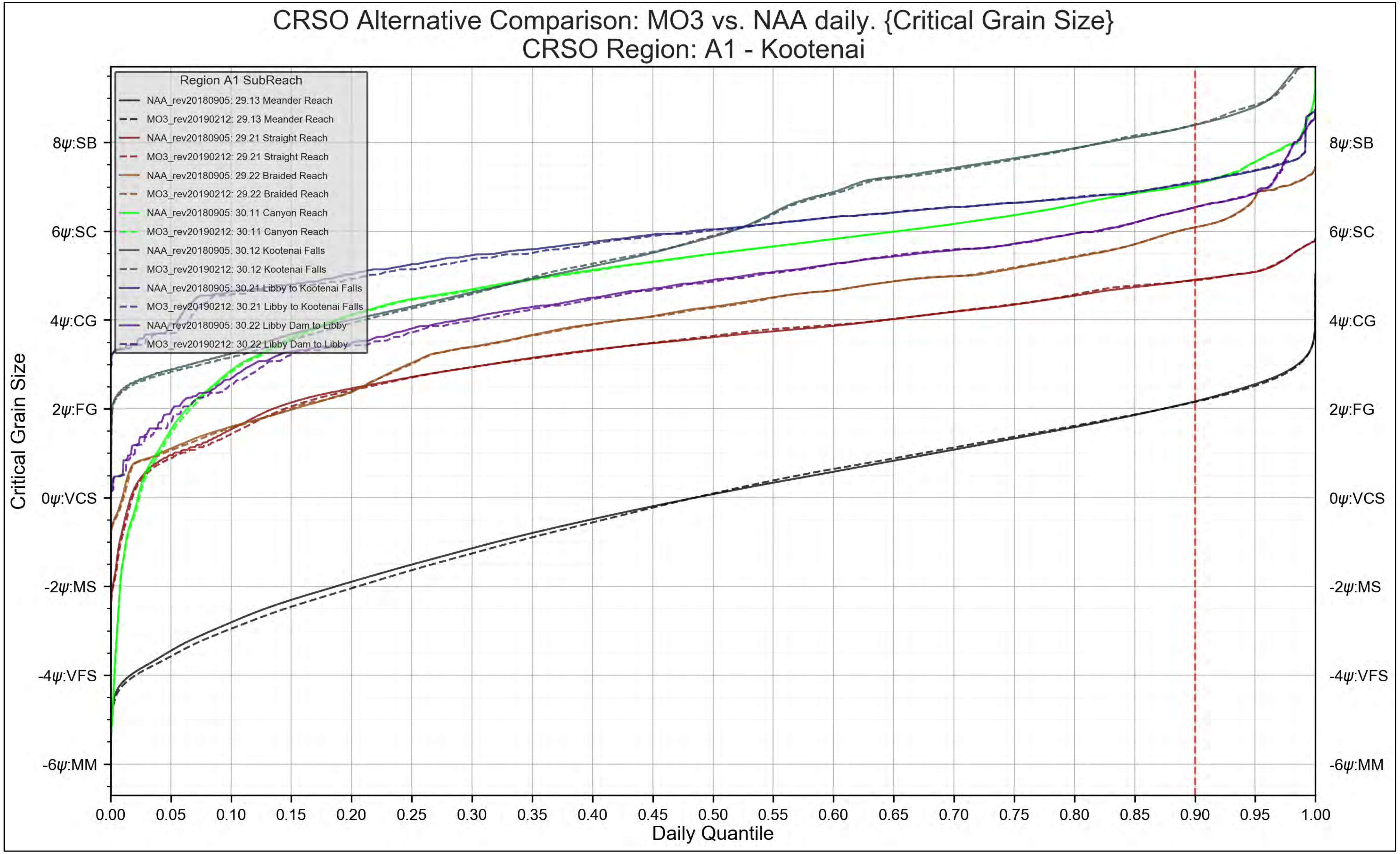
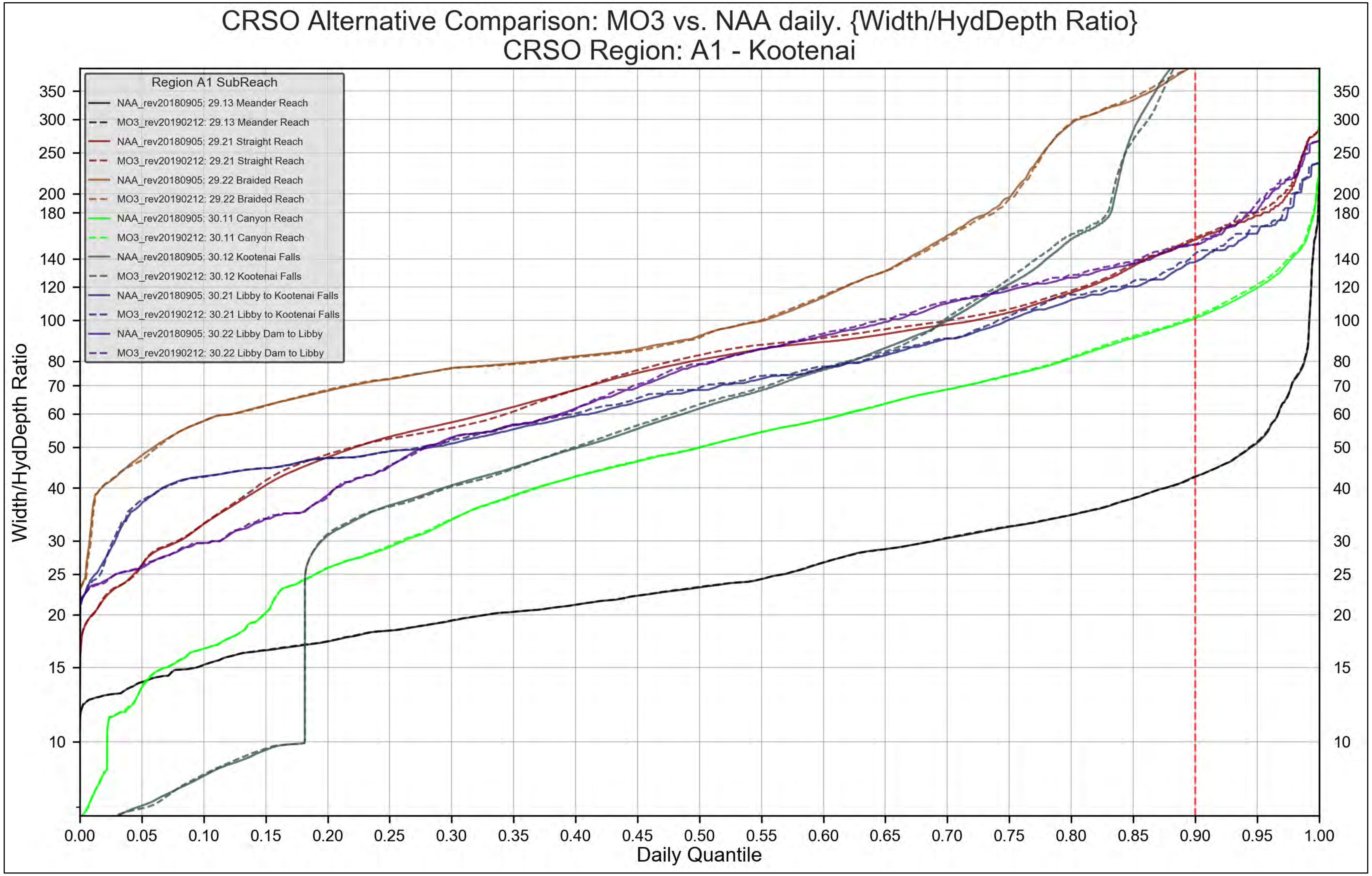


Figure 4-34. Region A1 - Kootenai. MO3 vs. NAA. 100% Suspended Grain-Size Threshold



2015
2016 **Figure 4-35. Region A1 - Kootenai. MO3 vs. NAA. Critical Grain-Size Threshold**



2017
2018 **Figure 4-36. Region A1 - Kootenai. MO3 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A1. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE

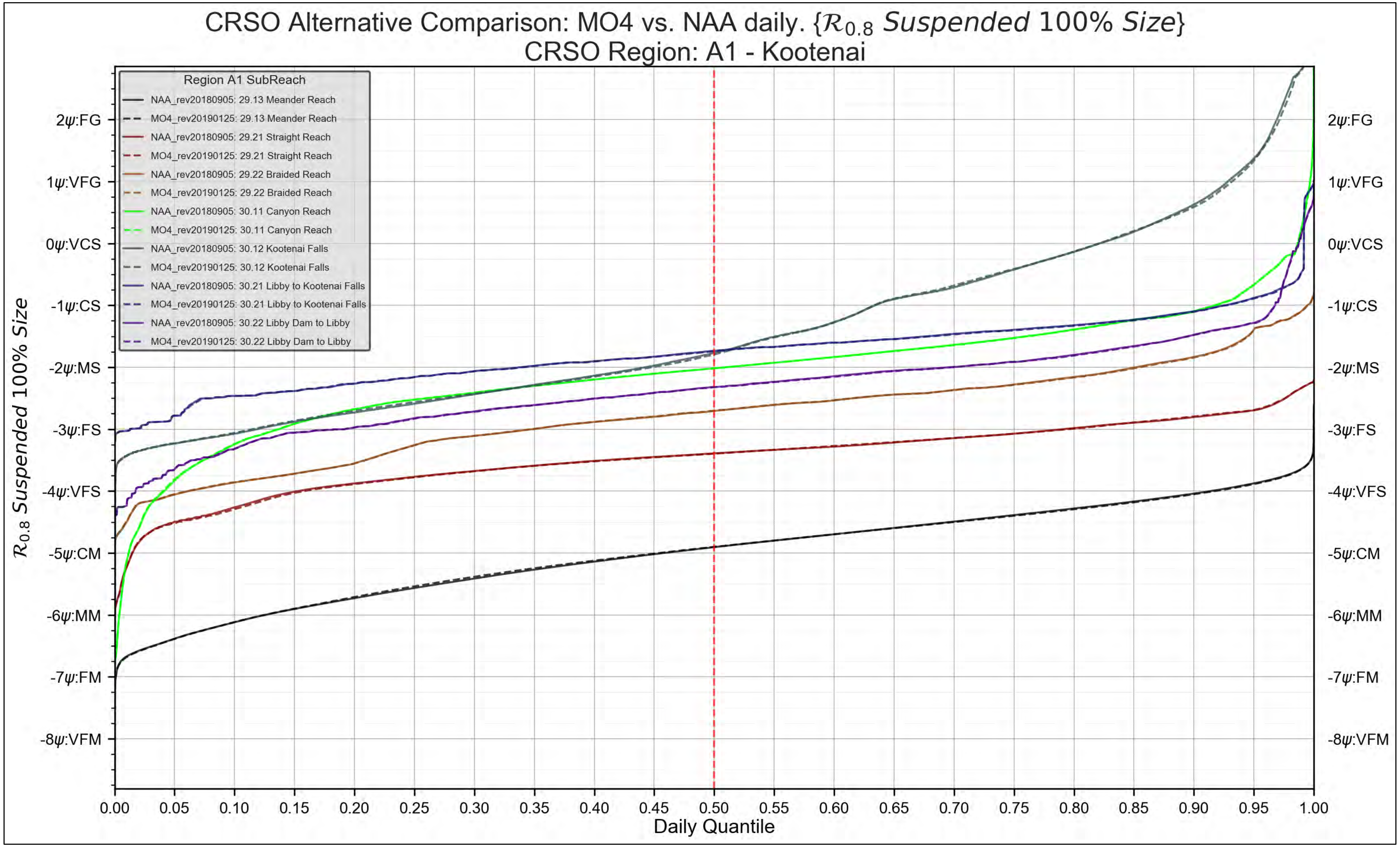
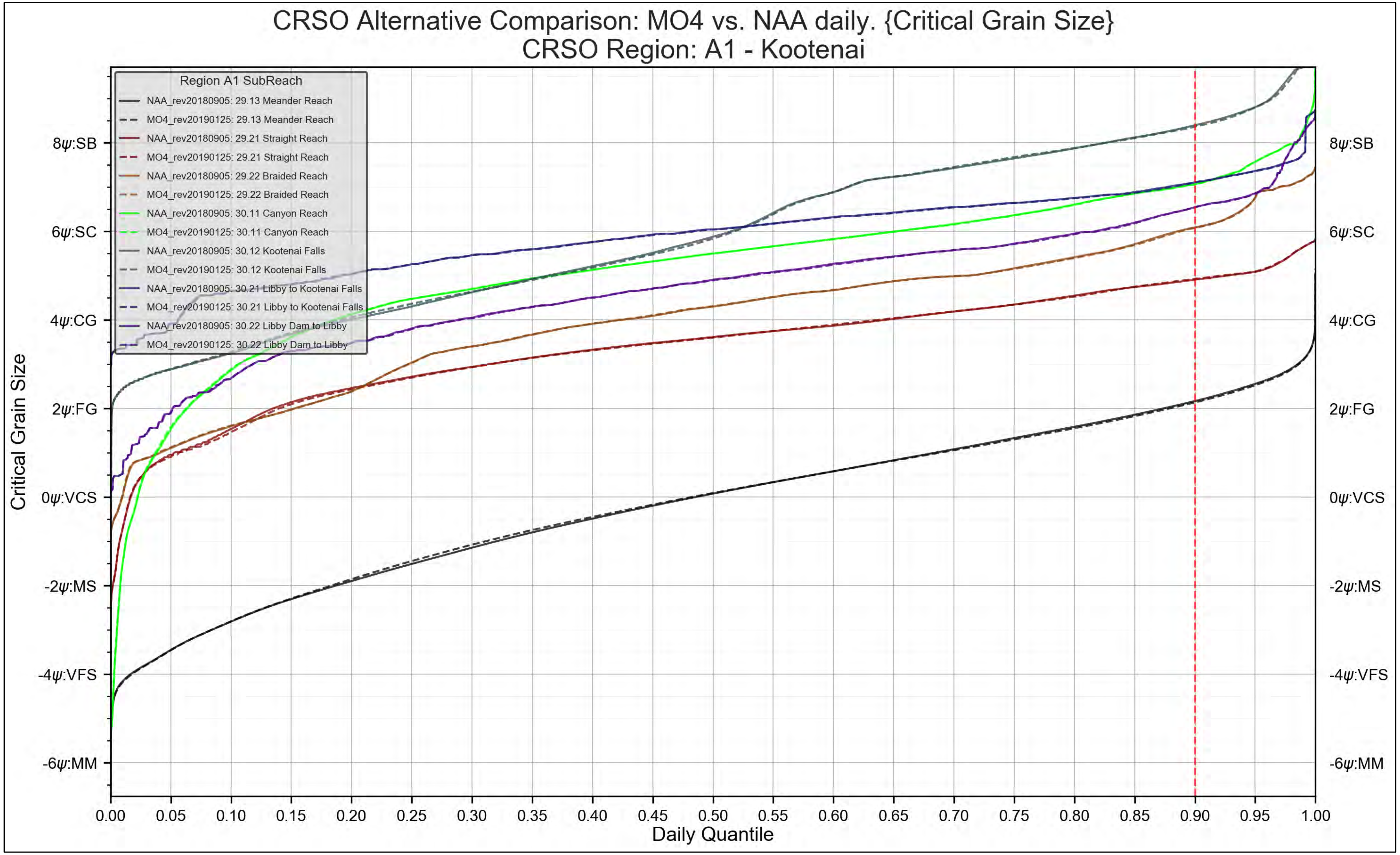


Figure 4-37. Region A1 - Kootenai. MO4 vs. NAA. 100% Suspended Grain-Size Threshold



2022
2023 **Figure 4-38. Region A1 - Kootenai. MO4 vs. NAA. Critical Grain-Size Threshold**

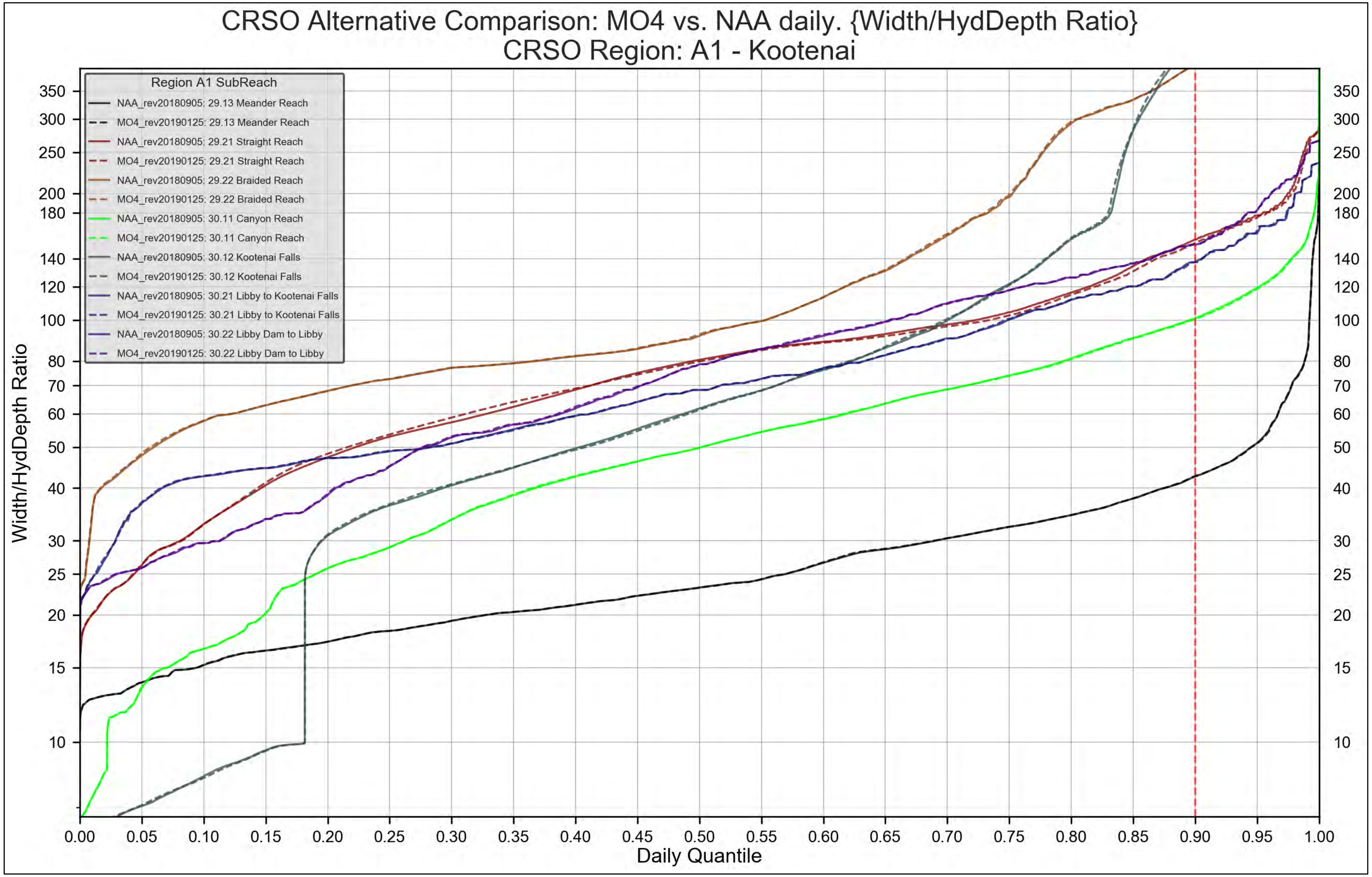


Figure 4-39. Region A1 - Kootenai. MO4 vs. NAA. Width/Hydraulic Depth Ratio

REGION A1. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE

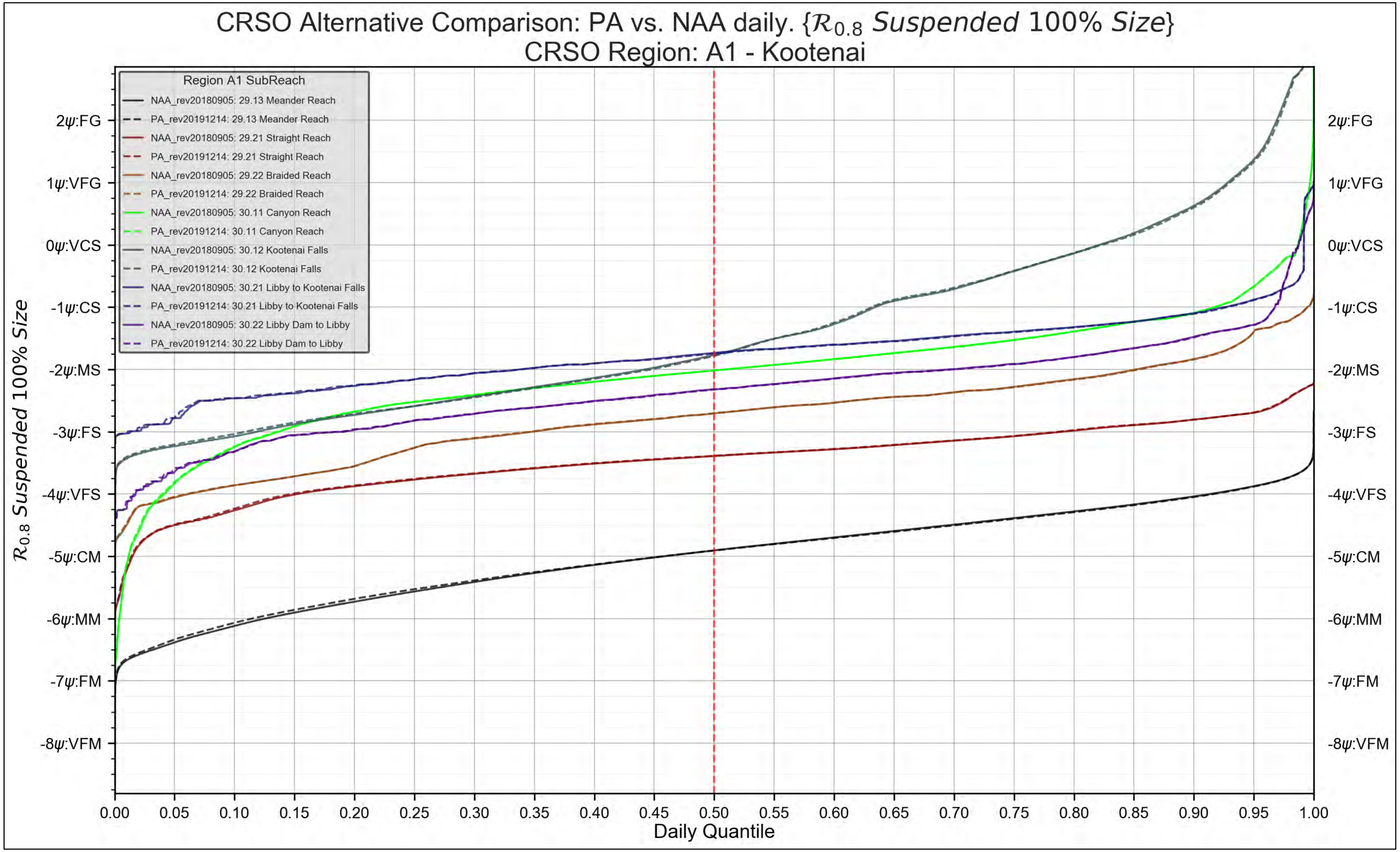
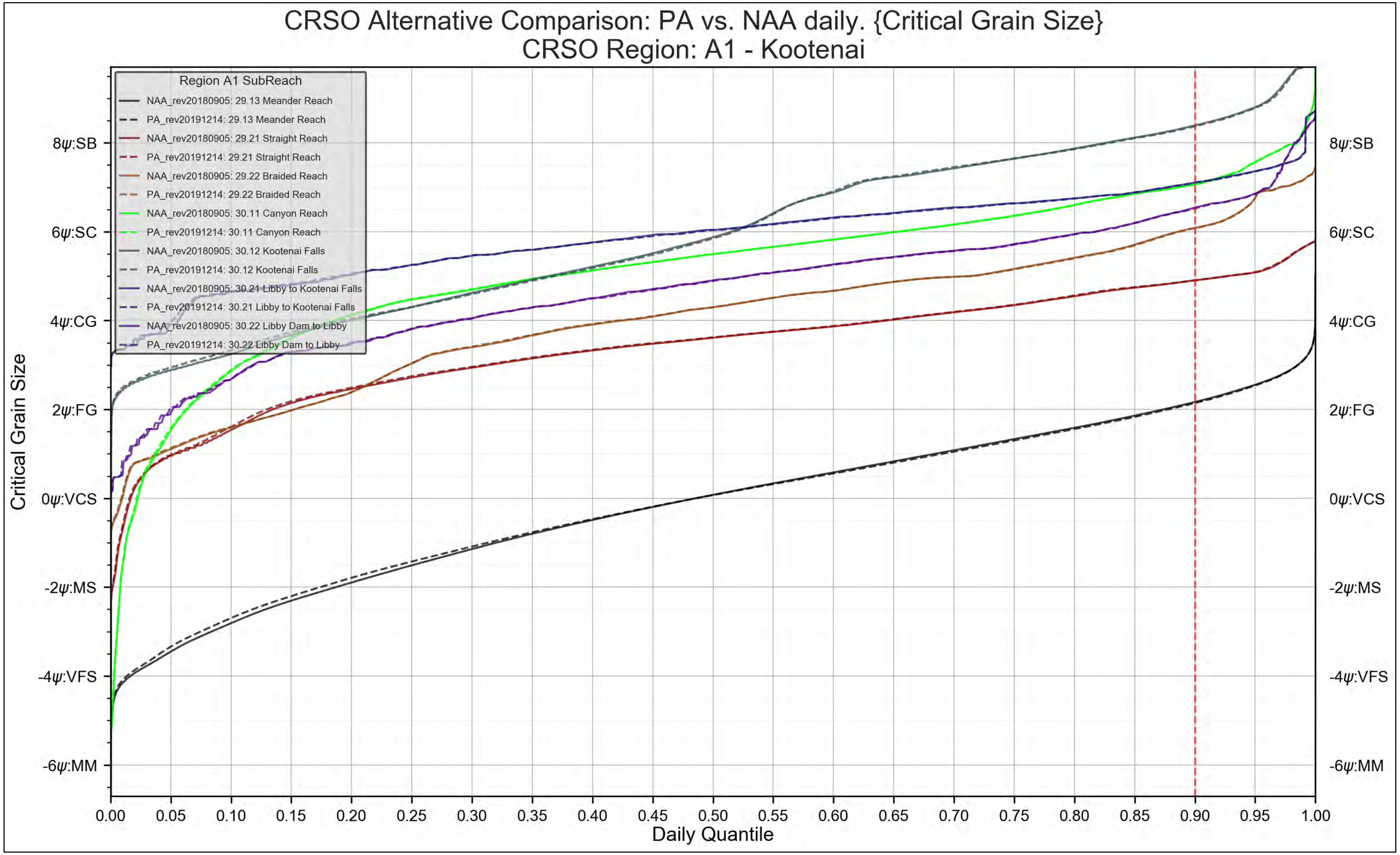


Figure 4-40 Region A1 - Kootenai. PA vs. NAA. 100% Suspended Grain-Size Threshold



2029
2030 **Figure 4-41 Region A1 - Kootenai. PA vs. NAA. Critical Grain-Size Threshold**

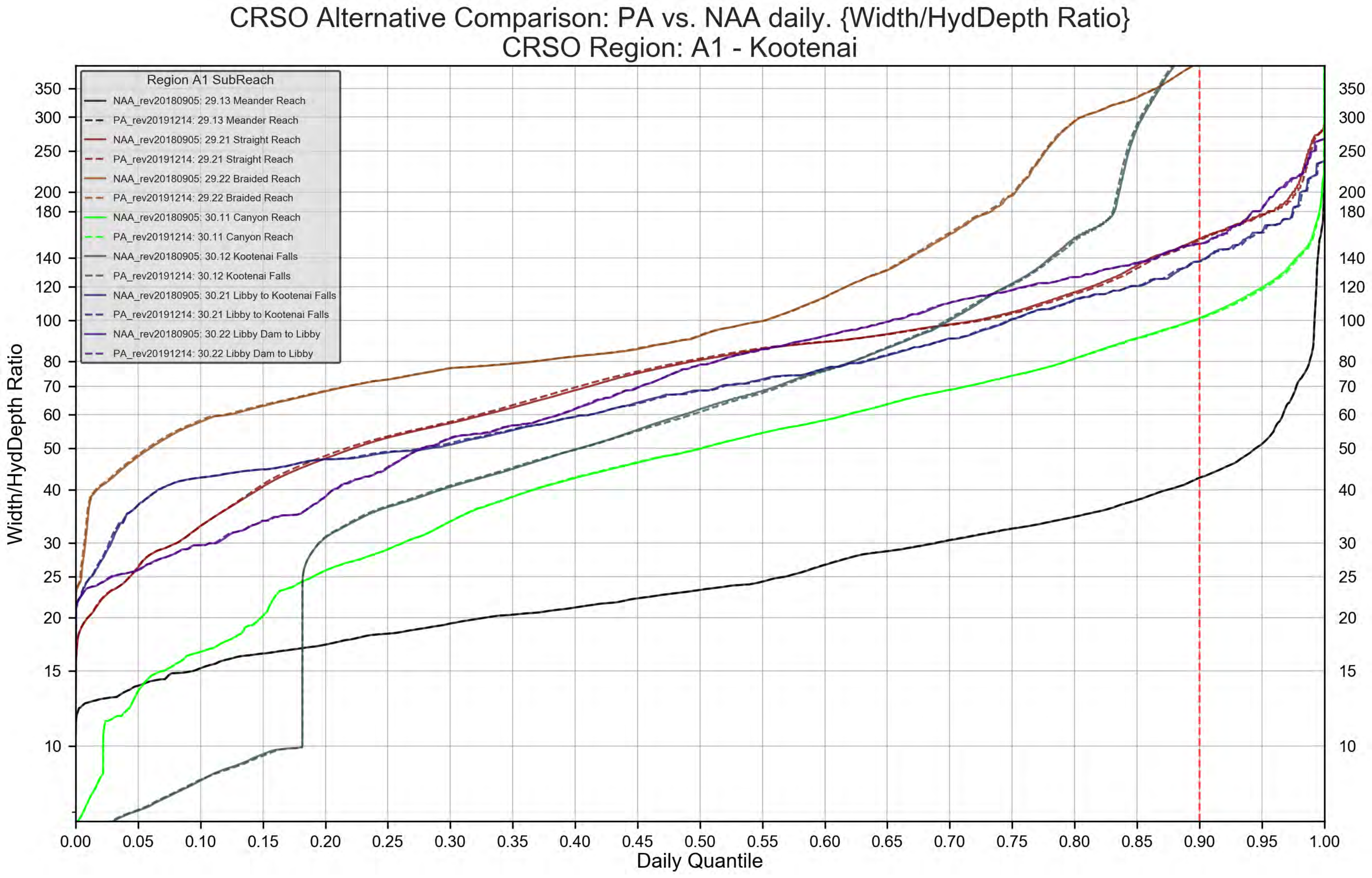


Figure 4-42 Region A1 - Kootenai. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.2 Region A2: Flathead Reach – Hungry Horse Dam to Clark Fork River Confluence

4.2.2.1 Region A2: Flathead Reach Comparison Tables

Table 4-7. Region A2: Flathead Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**
Flathead – Hungry Horse to SKQ	28.22	Flathead above Columbia Falls	-1.1%	-0.4%	-0.1%	-2.7%	0.0%	0.2%	-1.3%	-0.4%	0.0%	1.1%	1.9%	-0.3%	-1.2%	-0.4%	0.0%
	28.21	Columbia Falls Reach	-0.6%	-0.8%	-0.2%	1.4%	0.0%	-0.3%	-1.0%	-1.0%	-0.2%	0.9%	-0.6%	0.1%	-0.2%	0.0%	0.0%
	28.13	Lower Flathead below Stillwater	-1.0%	-5.4%	-0.7%	5.3%	**-18.5%**	-0.3%	-1.6%	-6.2%	-0.5%	2.3%	-5.2%	0.0%	-0.2%	0.1%	0.0%
	28.12	Flathead Lake	-0.2%	-2.6%	0.0%	3.9%	6.9%	0.0%	-0.2%	-2.9%	0.1%	0.9%	1.2%	0.0%	0.4%	0.5%	0.0%
	28.11	Polson to SKQ	1.4%	-9.6%	0.9%	-0.9%	-7.0%	0.6%	0.9%	**-11.1%**	1.0%	4.1%	-9.7%	0.7%	-0.9%	0.2%	0.0%
SKQ to Clark Fork Confluence	27.22	SKQ to Jocko Confluence	-0.9%	-1.5%	0.6%	0.3%	0.2%	-0.2%	-1.1%	-1.5%	0.8%	-0.4%	-1.1%	0.1%	-0.1%	0.4%	0.1%
	27.21	Jocko Confluence to Clark Fork Confluence	-1.6%	-1.6%	0.2%	1.2%	1.7%	-0.1%	-1.8%	-2.1%	0.2%	-1.3%	-1.2%	-0.2%	0.0%	0.0%	0.1%

Table 4-8. Region A2: Flathead Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**
Flathead - Hungry Horse to SKQ	28.22	Flathead Above Columbia Falls	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	28.21	Columbia Falls Reach	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect
	28.13	Lower Flathead Below Stillwater	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	28.12	Flathead Lake	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	28.11	Polson to SKQ	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
SKQ to Clark Fork Confluence	27.22	SKQ to Jocko Confluence	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	27.21	Jocko Confluence to Clark Fork Confluence	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	Negligible

4.2.2.2 Region A2: Flathead Reach Comparison Figures

REGION A2: MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

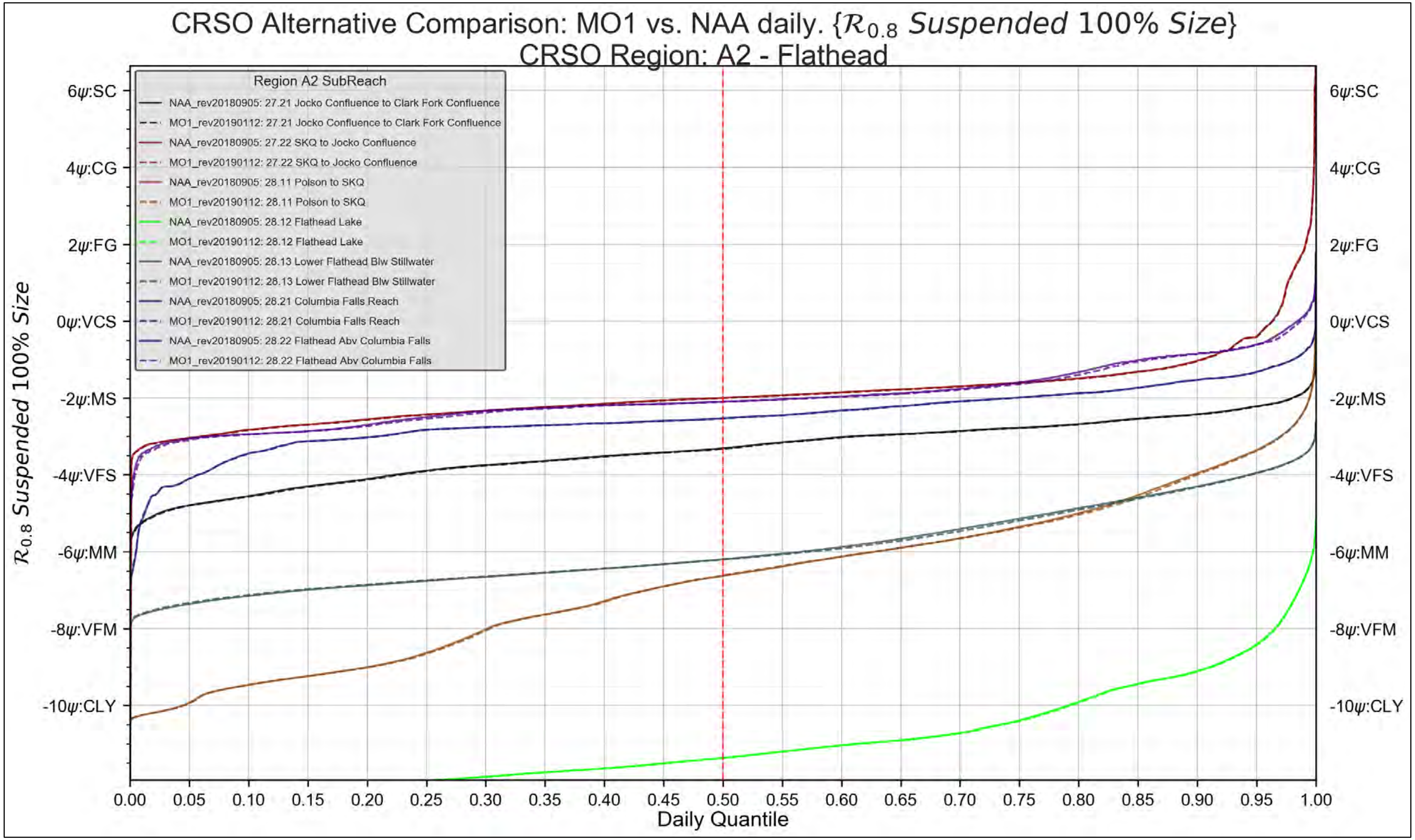
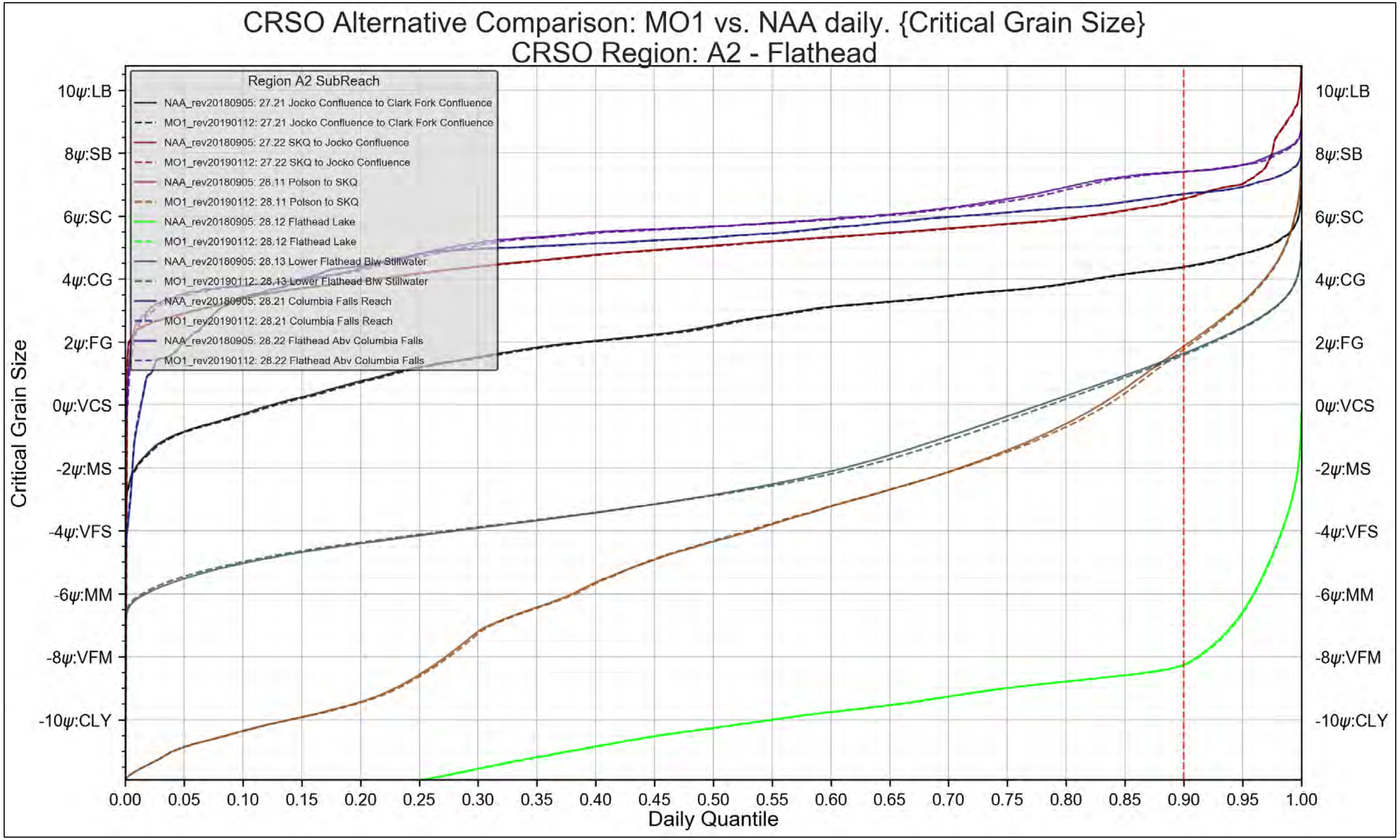
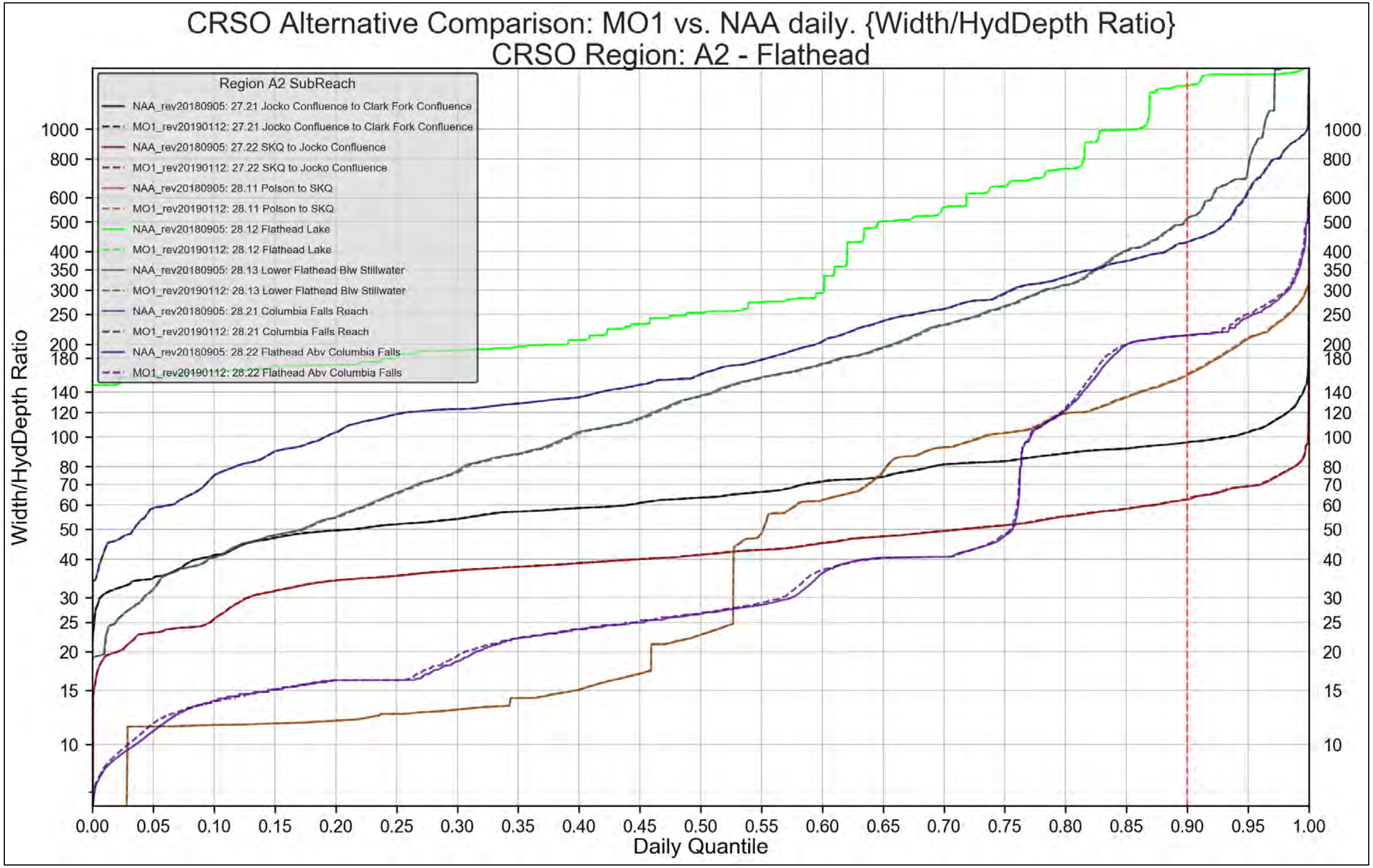


Figure 4-43. Region A2 - Flathead. MO1 vs. NAA. 100% Suspended Grain-Size Threshold



2041

2042 **Figure 4-44. Region A2 - Flathead. MO1 vs. NAA. Critical Grain-Size Threshold**



2043

2044 **Figure 4-45. Region A2 - Flathead. MO1 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A2. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

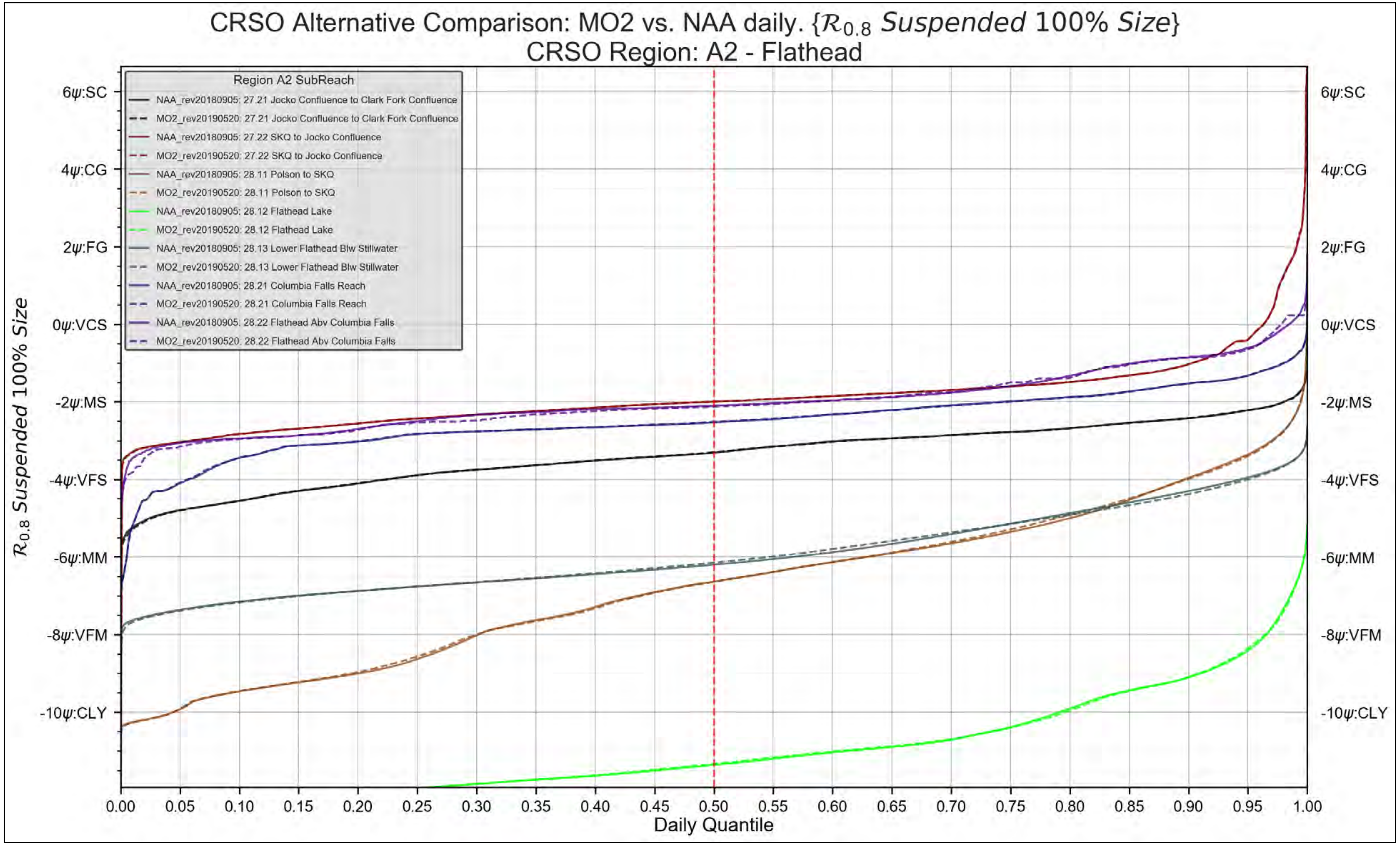


Figure 4-46. Region A2 - Flathead. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

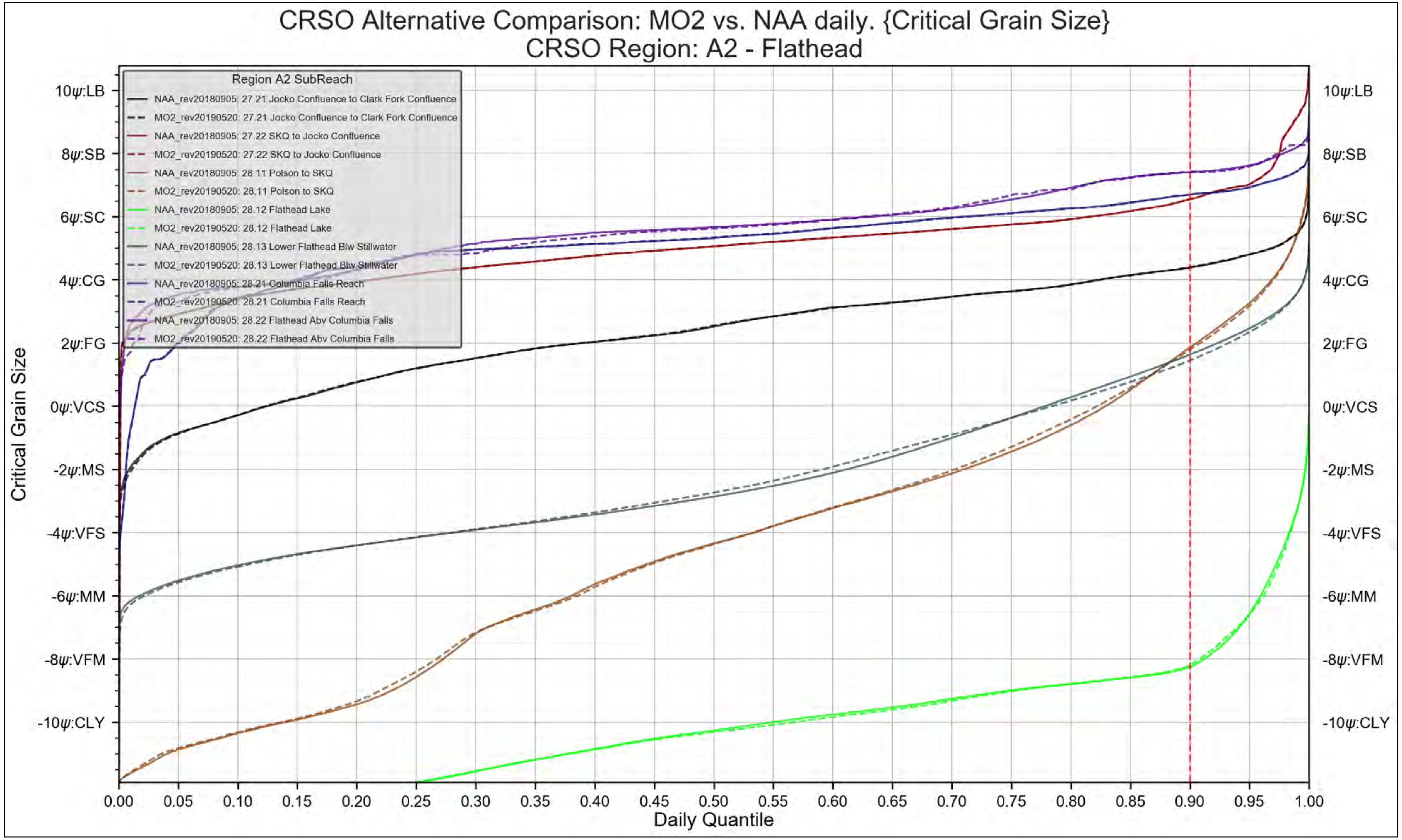


Figure 4-47. Region A2 - Flathead. MO2 vs. NAA. Critical Grain-Size Threshold

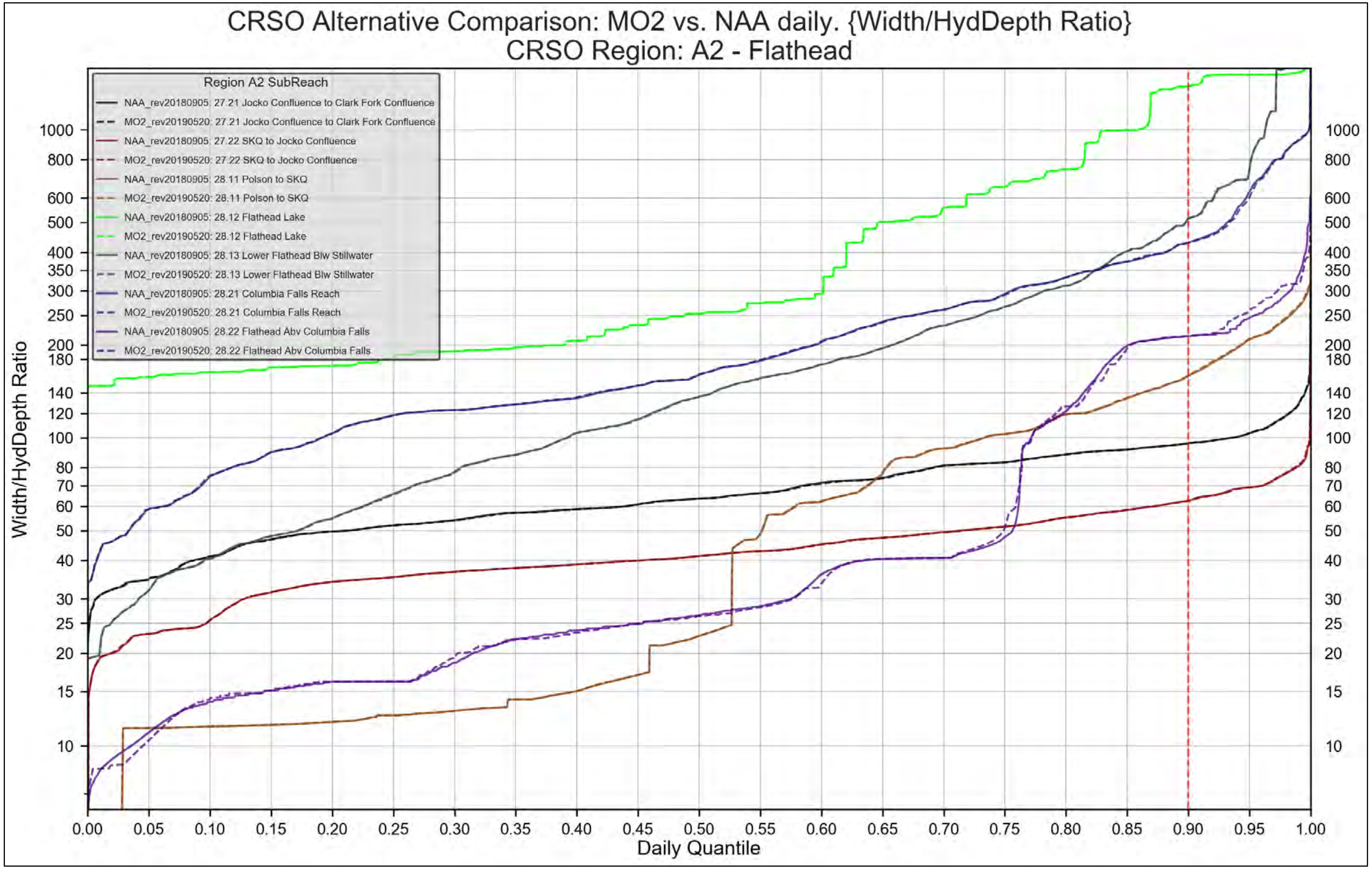


Figure 4-48. Region A2 - Flathead. MO2 vs. NAA. Width/Hydraulic Depth Ratio

REGION A2. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

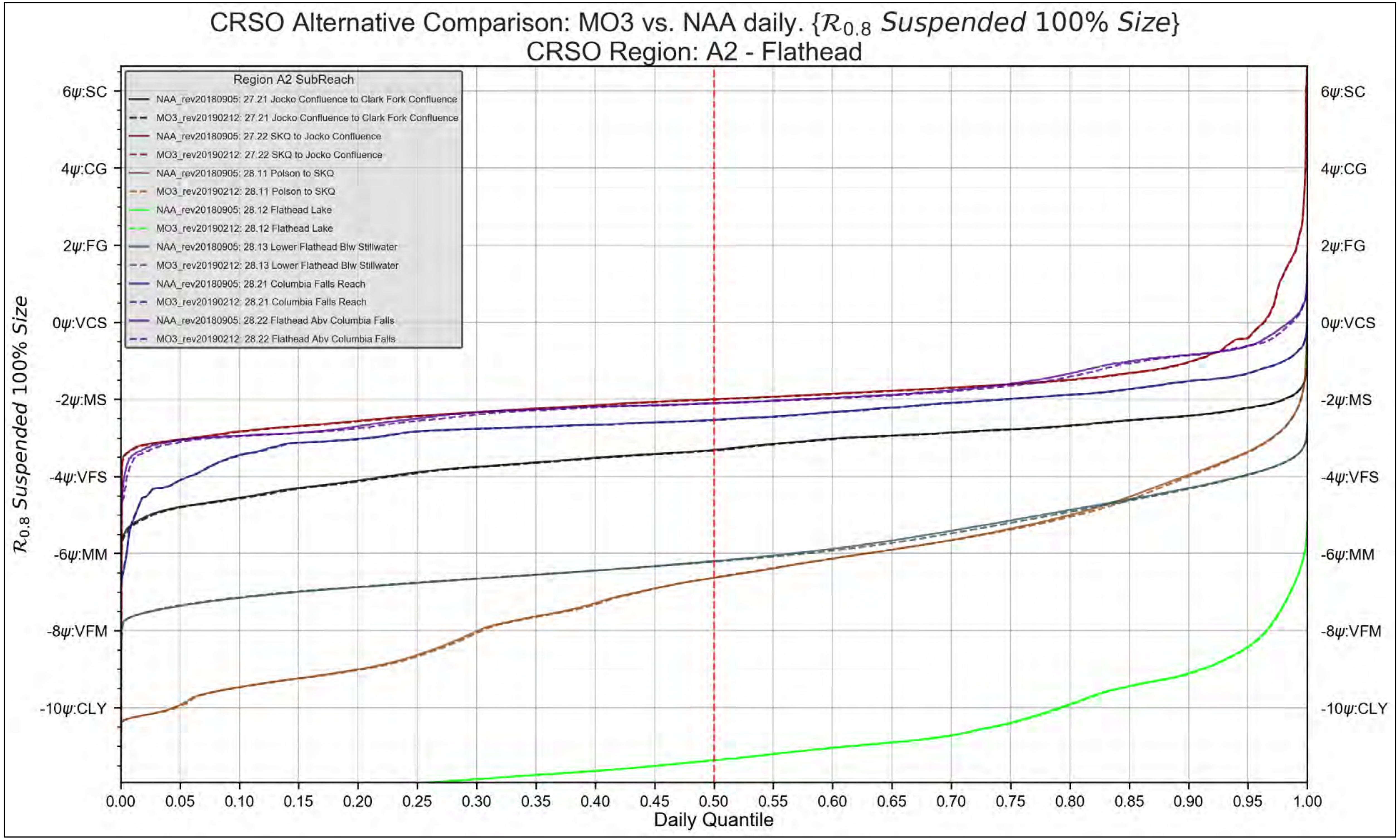


Figure 4-49. Region A2 - Flathead. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

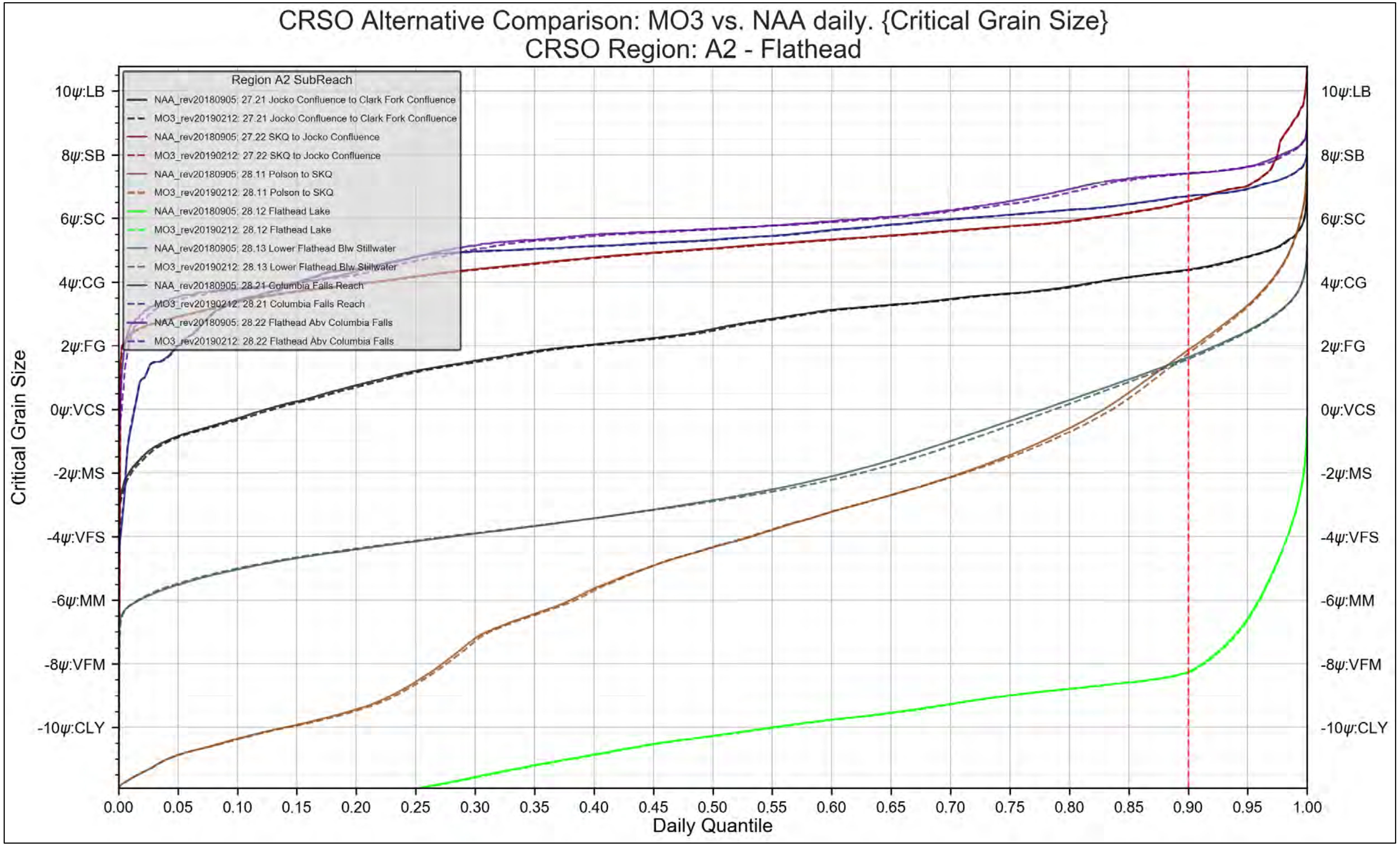
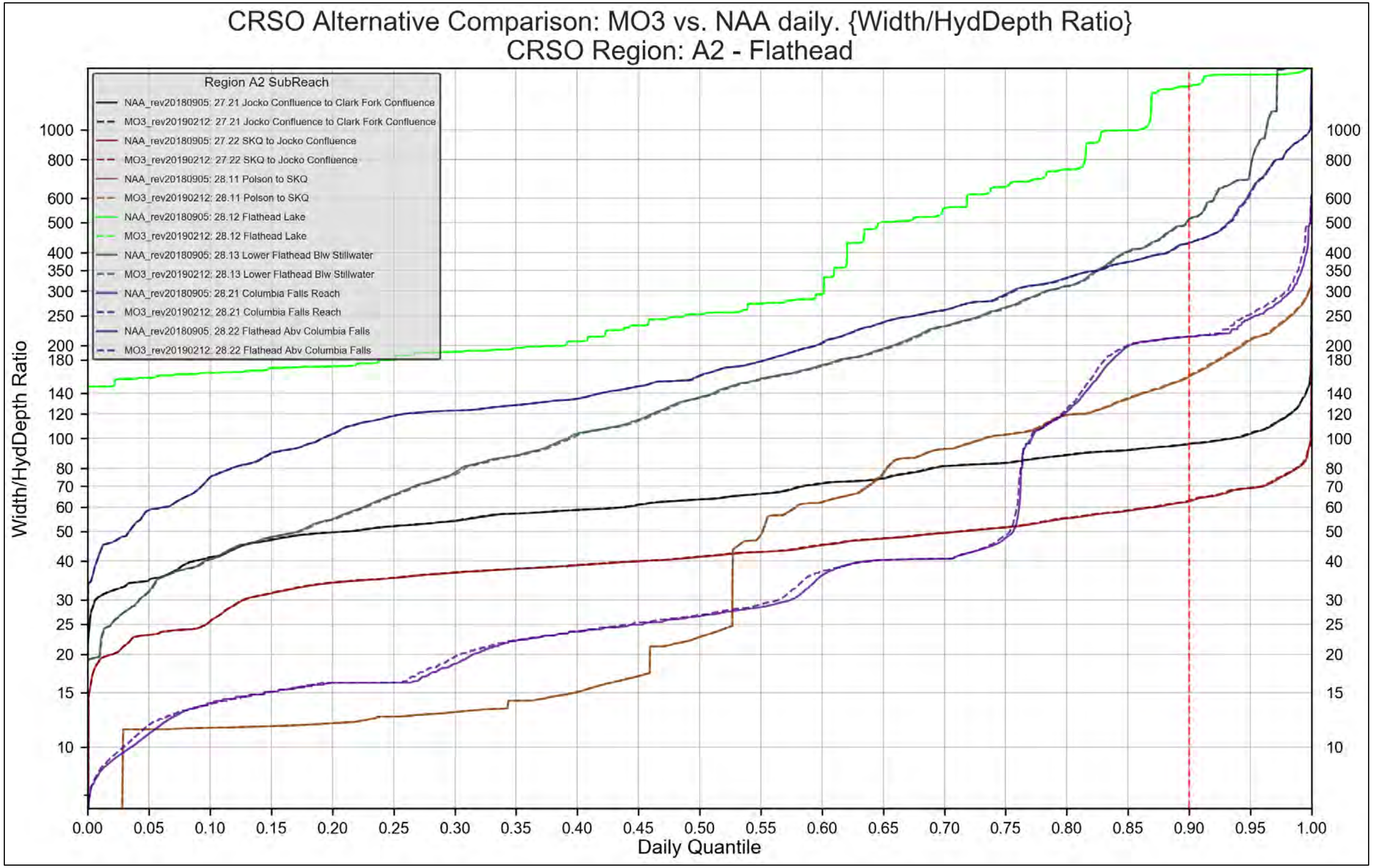


Figure 4-50. Region A2 - Flathead. MO3 vs. NAA. Critical Grain-Size Threshold



2057

2058 **Figure 4-51. Region A2 - Flathead. MO3 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A2. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE

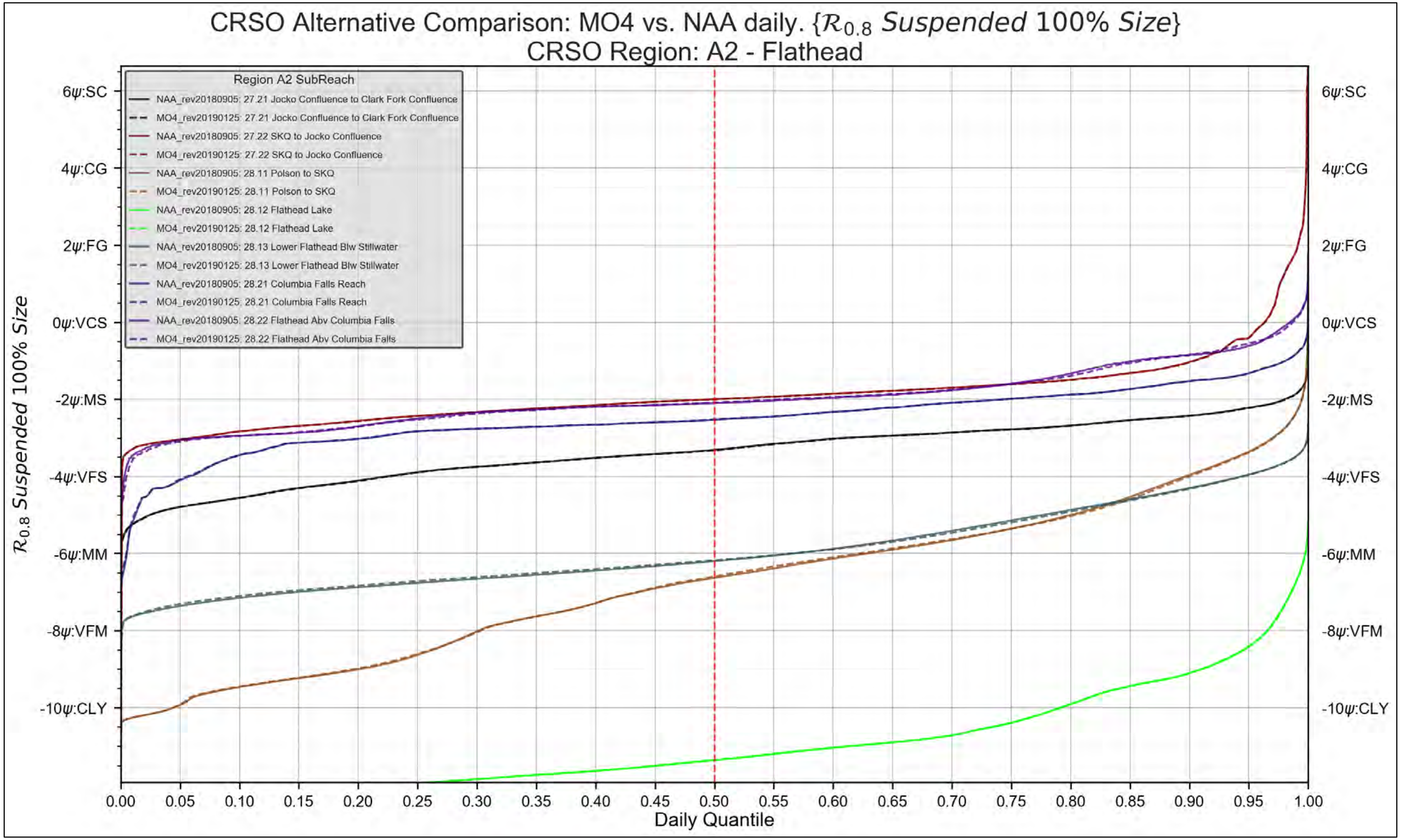


Figure 4-52. Region A2 - Flathead. MO4 vs. NAA. 100% Suspended Grain-Size Threshold

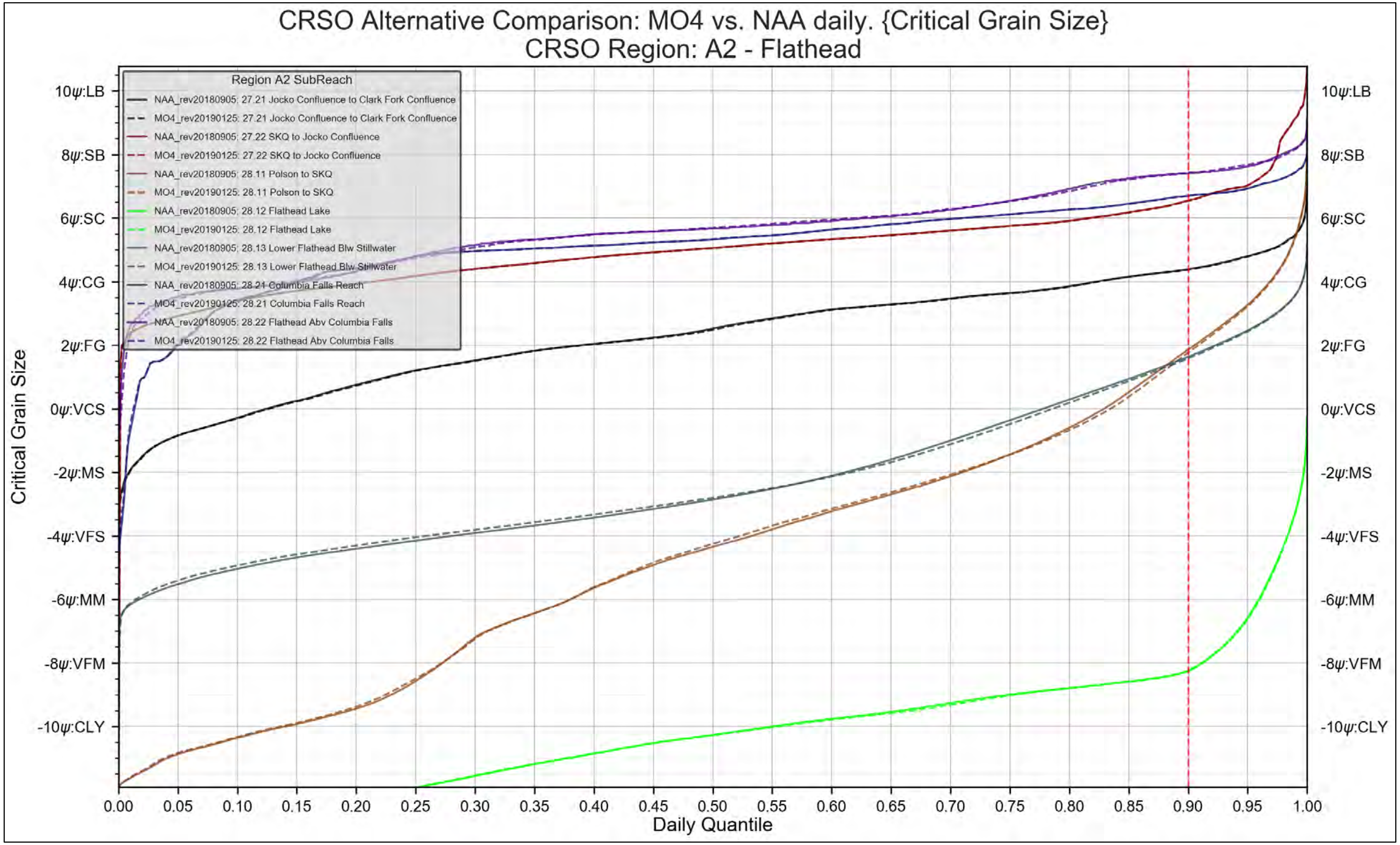
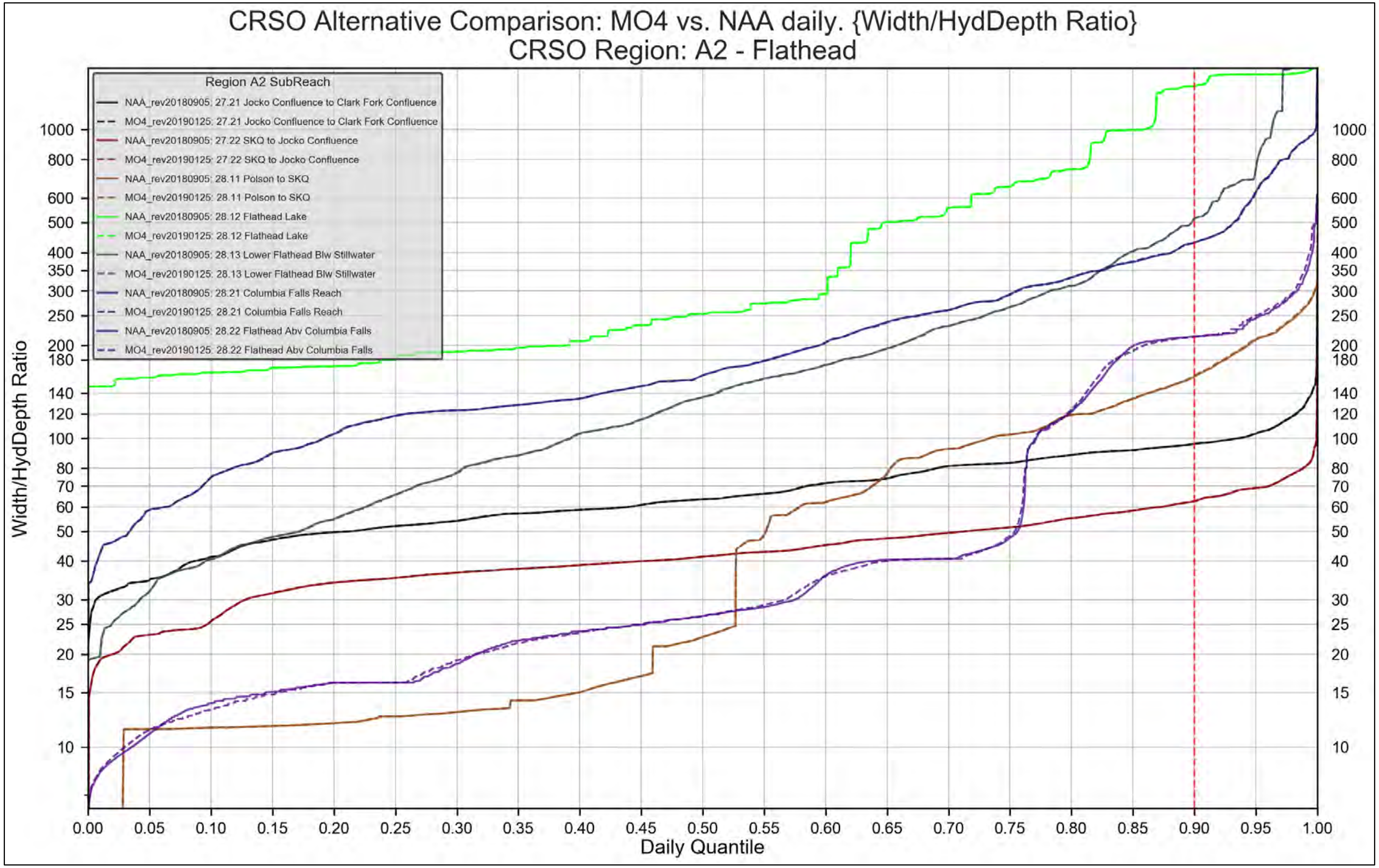


Figure 4-53. Region A2 - Flathead. MO4 vs. NAA. Critical Grain-Size Threshold



2064
2065 **Figure 4-54. Region A2 - Flathead. MO4 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A2. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE

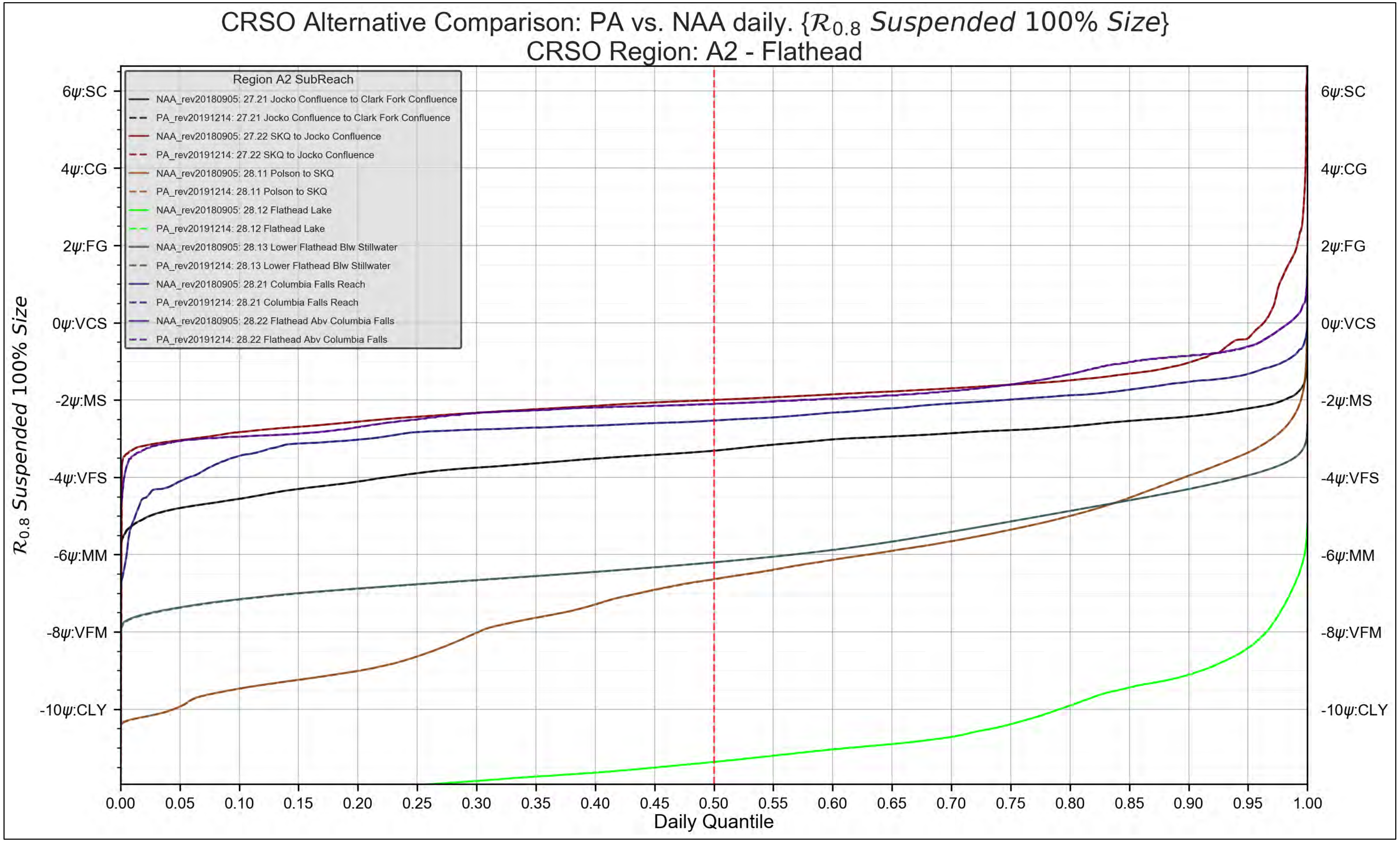


Figure 4-55 Region A2 - Flathead. PA vs. NAA. 100% Suspended Grain-Size Threshold

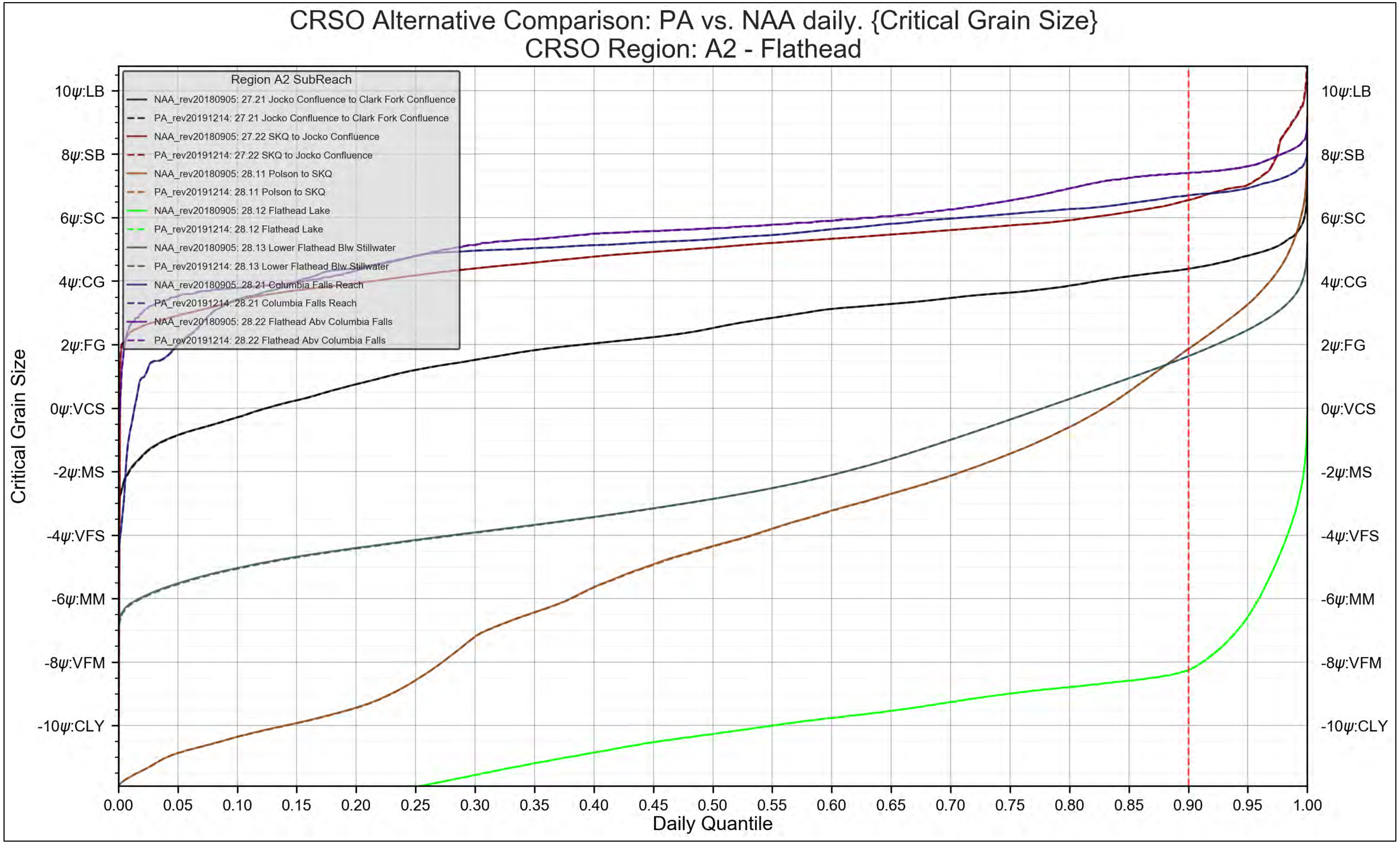


Figure 4-56 Region A2 - Flathead. PA vs. NAA. Critical Grain-Size Threshold

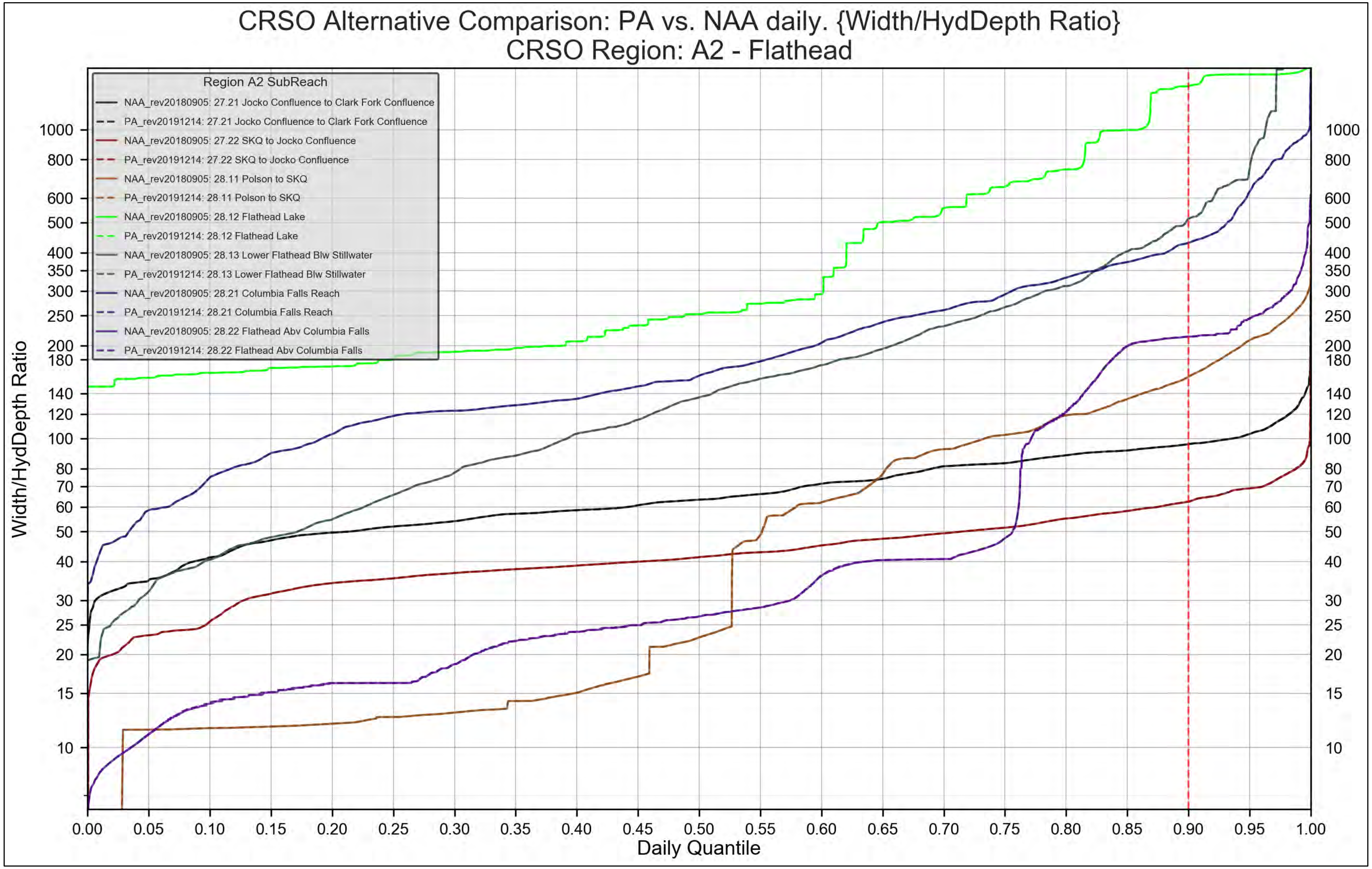


Figure 4-57 Region A2 - Flathead. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.3 Region A3/A4: Clark Fork and Pend Oreille Reaches – Flathead Confluence to U.S.-Canada Border

4.2.3.1 Region A3/A4: Clark Fork and Pend Oreille Reach Comparison Tables

Table 4-9. Region A3/A4: Clark Fork and Pend Oreille Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	Name	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd
Clark Fork and Pend Oreille – Flathead Confluence to the U.S.-Canada border	27.12	Flathead Confluence to Weeksville	-0.8%	-1.2%	0.0%	0.1%	-1.0%	-0.1%	-1.1%	-1.5%	0.0%	-0.5%	-1.0%	0.2%	0.0%	-0.1%	0.0%
	27.11	Weeksville to Thompson Falls Dam	-1.8%	-1.6%	0.0%	0.7%	-1.8%	-0.1%	-2.2%	-1.6%	0.0%	-1.0%	-1.5%	0.0%	-0.1%	0.0%	0.0%
	26.12	Thompson Falls to Deep Creek	-2.0%	-2.7%	0.1%	2.8%	1.0%	0.2%	-2.3%	-2.9%	0.1%	-1.1%	-2.3%	0.1%	0.0%	0.1%	0.0%
	26.11	Deep Creek to Noxon Rapids Dam	-2.2%	-4.3%	0.0%	1.2%	-6.7%	0.0%	-2.3%	-4.5%	0.0%	-0.3%	-4.2%	0.0%	-0.5%	0.0%	0.0%
	25.12	Noxon Rapids Dam to Bull River	-2.1%	-4.3%	0.0%	1.6%	-3.0%	0.0%	-2.1%	-4.9%	0.0%	-0.7%	-4.2%	0.0%	-0.1%	0.3%	0.0%
	25.11	Bull River to Cabinet Gorge Dam	-1.7%	-4.6%	0.0%	3.3%	-8.7%	0.0%	-1.9%	-4.9%	0.0%	-0.6%	-4.6%	0.0%	0.0%	-0.2%	0.0%
	24.22	Cabinet Gorge Dam to Lightning Creek	-1.4%	-0.9%	0.2%	0.8%	-1.9%	-0.6%	-1.6%	-1.1%	0.2%	2.6%	3.7%	0.0%	0.0%	-0.1%	0.0%
	23.13	Albeni Falls to Indian Creek	-0.9%	-1.4%	0.0%	1.4%	-0.6%	0.0%	-1.1%	-1.8%	0.0%	-0.5%	-0.1%	0.0%	0.0%	0.1%	0.0%
	23.12	Indian Creek to River Bend	-1.4%	-1.8%	-0.1%	1.6%	-1.4%	0.0%	-1.6%	-1.9%	-0.1%	-0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
	23.11	River Bend to Box Canyon Dam	-1.5%	-2.8%	0.0%	1.8%	-3.2%	0.0%	-1.7%	-3.1%	0.0%	-0.7%	0.3%	0.0%	0.0%	0.1%	0.0%
	22.13	Box Canyon Dam to Metaline Falls	-1.3%	-2.3%	0.4%	1.5%	0.0%	0.7%	-1.6%	-2.4%	0.5%	-0.7%	-0.2%	0.1%	-0.1%	0.2%	0.0%
	22.12	Metaline Falls to Slate Creek	-1.8%	-3.0%	0.0%	2.1%	-2.3%	0.0%	-1.9%	-3.6%	0.0%	-0.6%	-1.0%	0.0%	0.1%	-0.1%	0.0%
	22.11	Slate Creek to Boundary Dam	-1.5%	-3.4%	0.0%	1.5%	-3.0%	0.0%	-2.0%	-3.8%	0.0%	-0.9%	-0.8%	0.0%	-0.1%	0.1%	0.0%

Table 4-10. Region A3/A4: Clark Fork and Pend Oreille Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**
Clark Fork and Pend Oreille – Flathead Confluence to the U.S.-Canada border	27.12	Flathead Confluence to Weeksville	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	No Effect	Negligible	No Effect
	27.11	Weeksville to Thompson Falls Dam	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	No Effect	No Effect
	26.12	Thompson Falls to Deep Creek	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	No Effect
	26.11	Deep Creek to Noxon Rapids Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	No Effect	No Effect
	25.12	Noxon Rapids Dam to Bull River	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	25.11	Bull River to Cabinet Gorge Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	24.22	Cabinet Gorge Dam to Lightning Creek	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	23.13	Albeni Falls to Indian Creek	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	23.12	Indian Creek to River Bend	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	No Effect	No Effect	No Effect
	23.11	River Bend to Box Canyon Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	22.13	Box Canyon Dam to Metaline Falls	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	22.12	Metaline Falls to Slate Creek	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	22.11	Slate Creek to Boundary Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect

4.2.3.2 Region A3: Clark Fork Reach Comparison Figures

REGION A3. MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

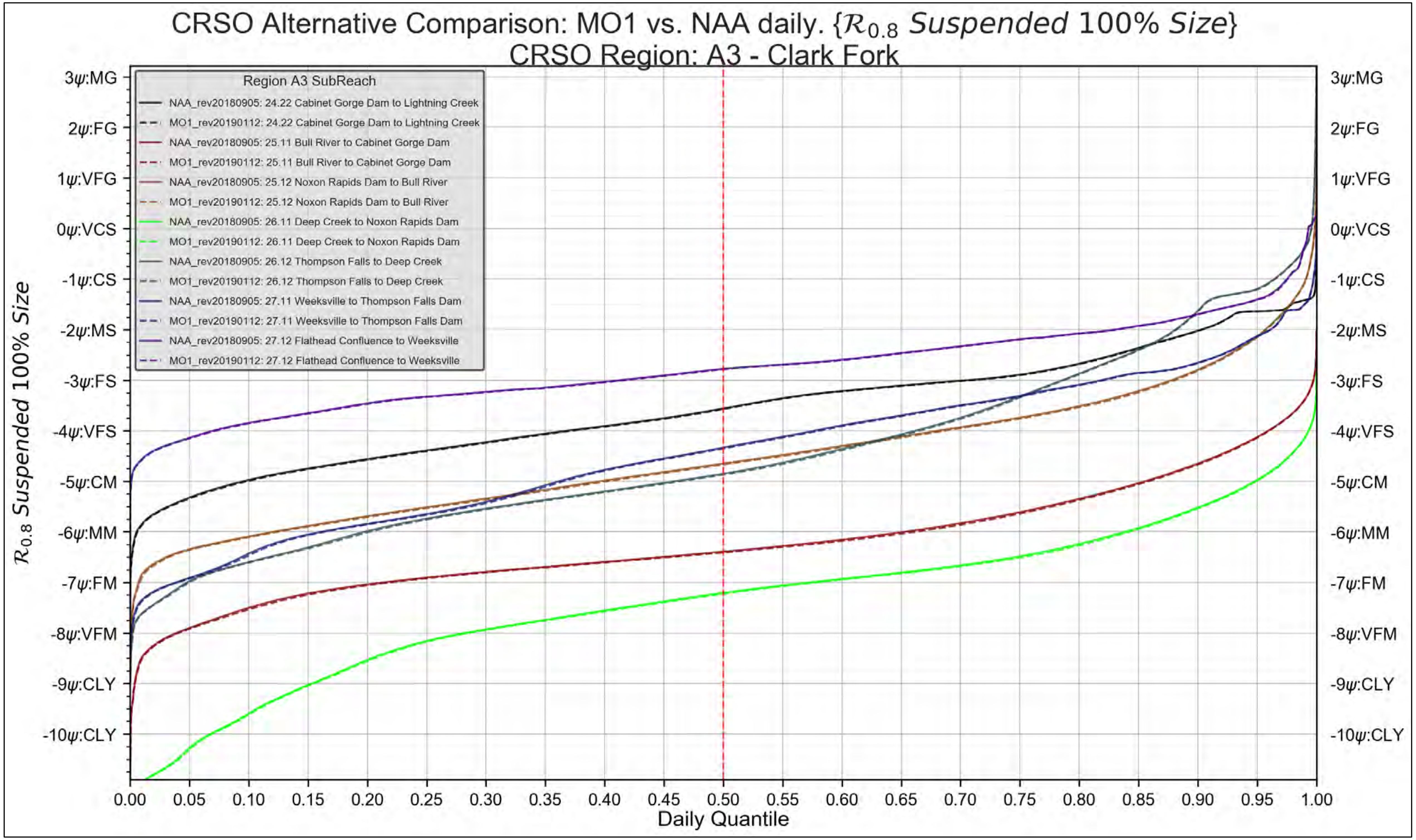
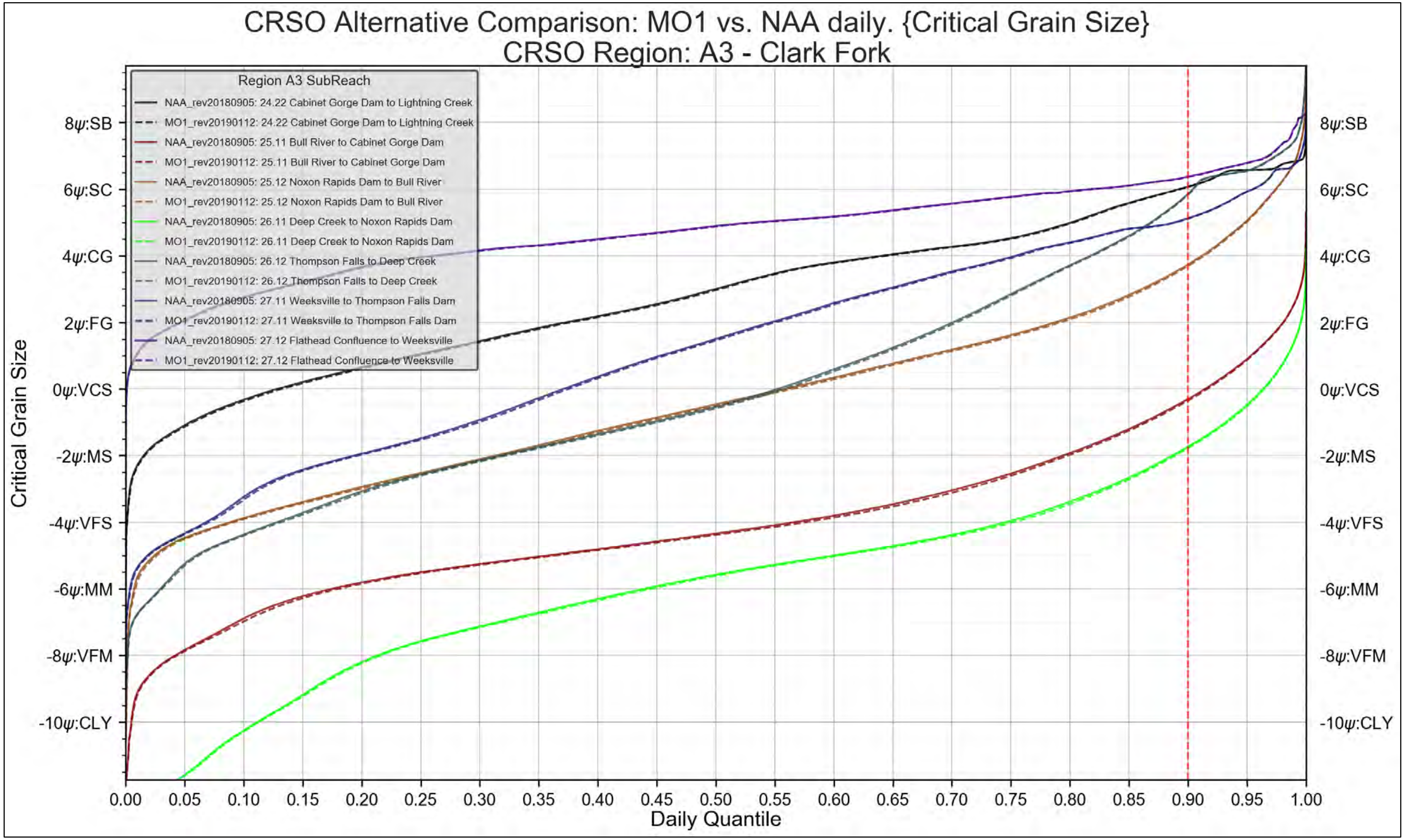


Figure 4-58. Region A3 – Clark Fork. MO1 vs. NAA. 100% Suspended Grain-Size Threshold



2081

2082 **Figure 4-59. Region A3 – Clark Fork. MO1 vs. NAA. Critical Grain-Size Threshold**

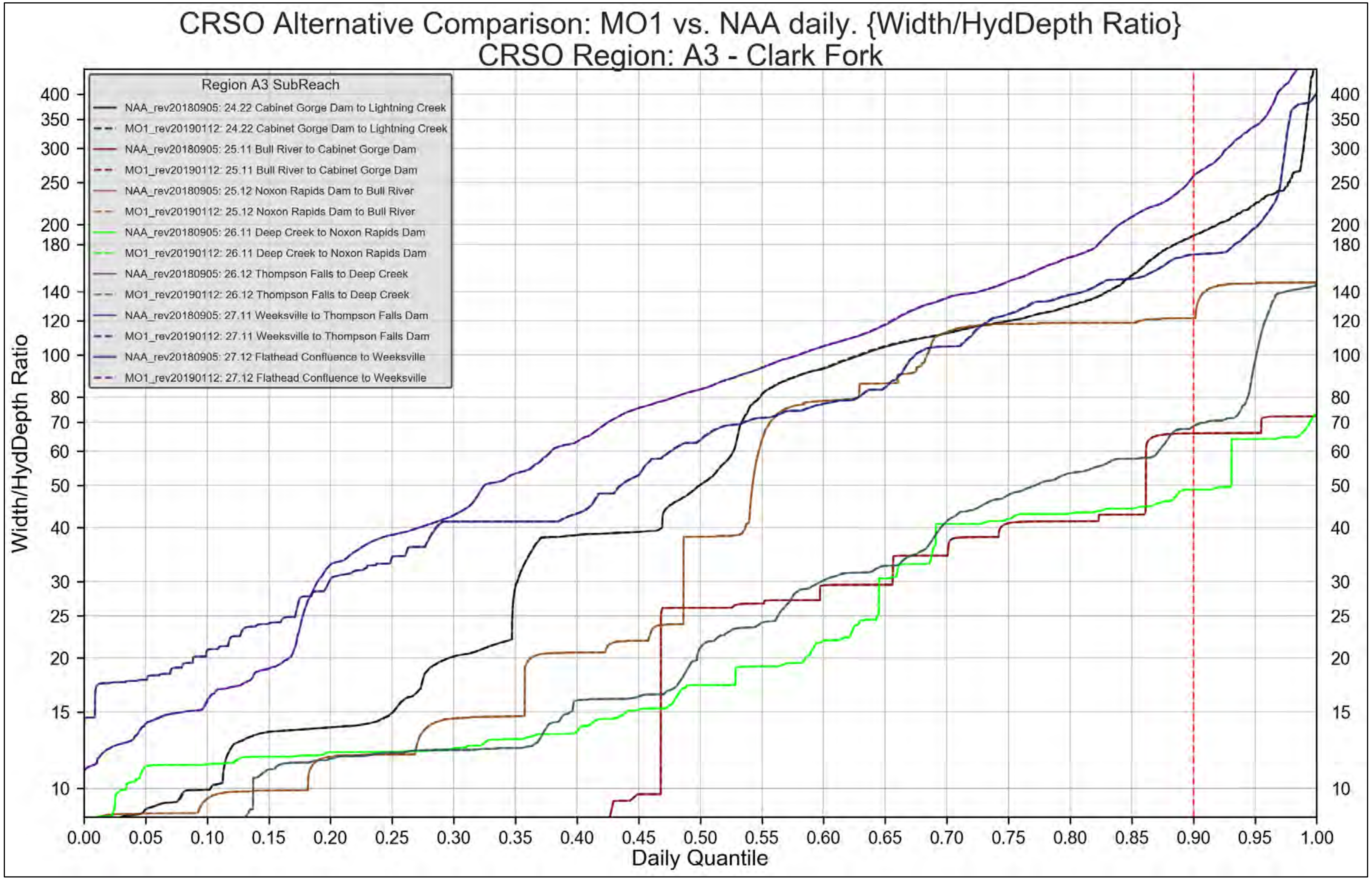


Figure 4-60. Region A3 – Clark Fork. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION A3. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

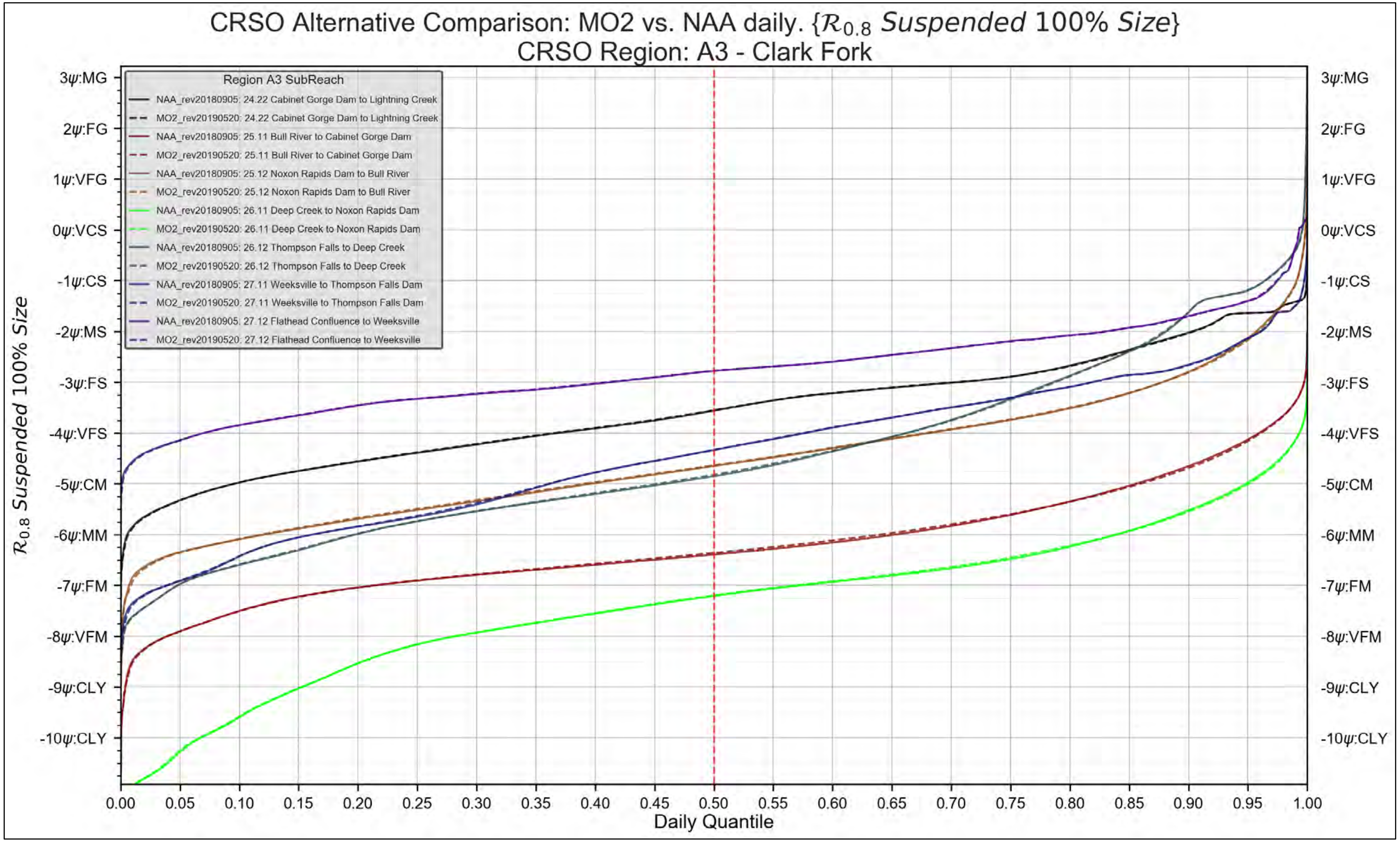


Figure 4-61. Region A3 – Clark Fork. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

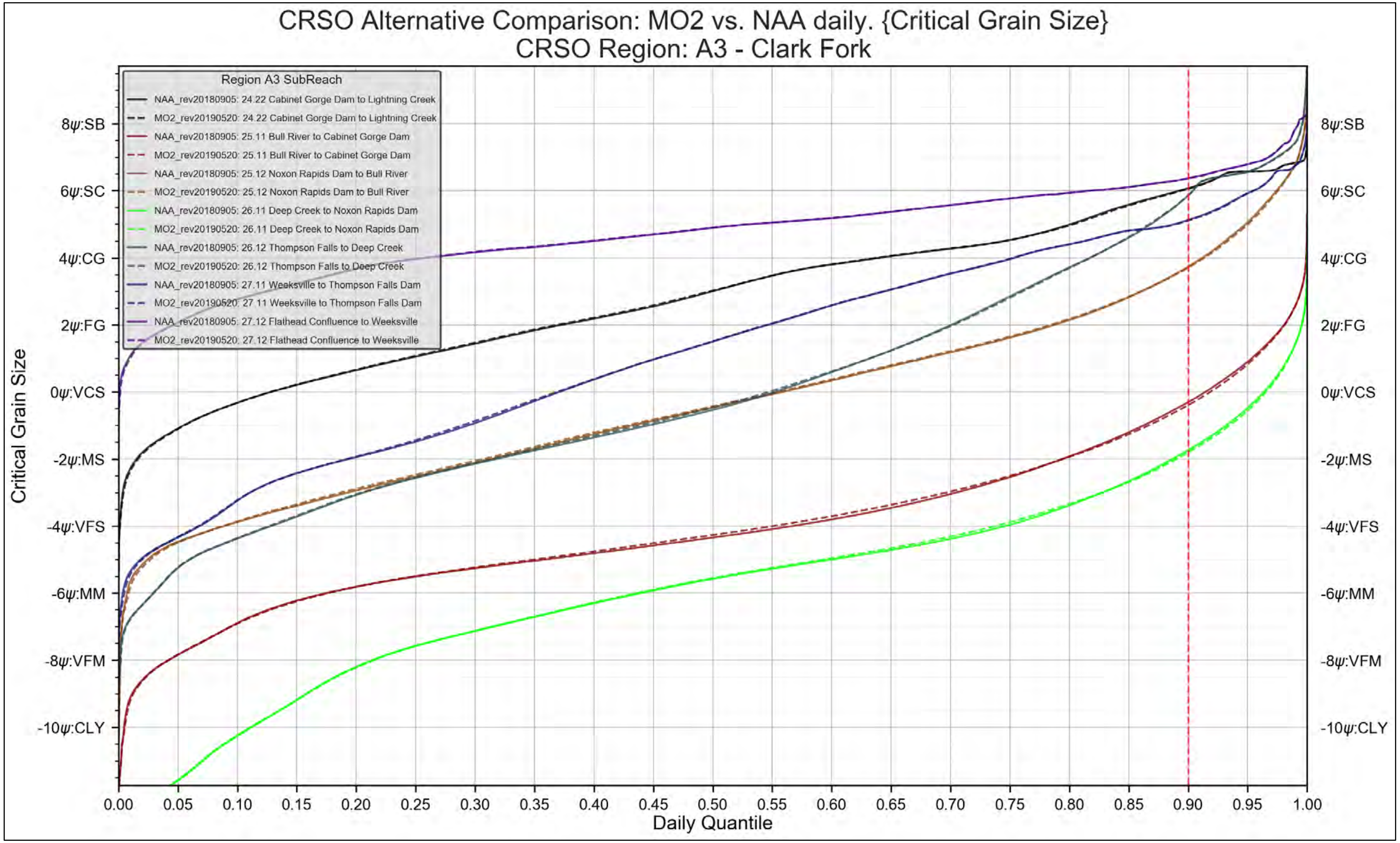


Figure 4-62. Region A3 – Clark Fork. MO2 vs. NAA. Critical Grain-Size Threshold

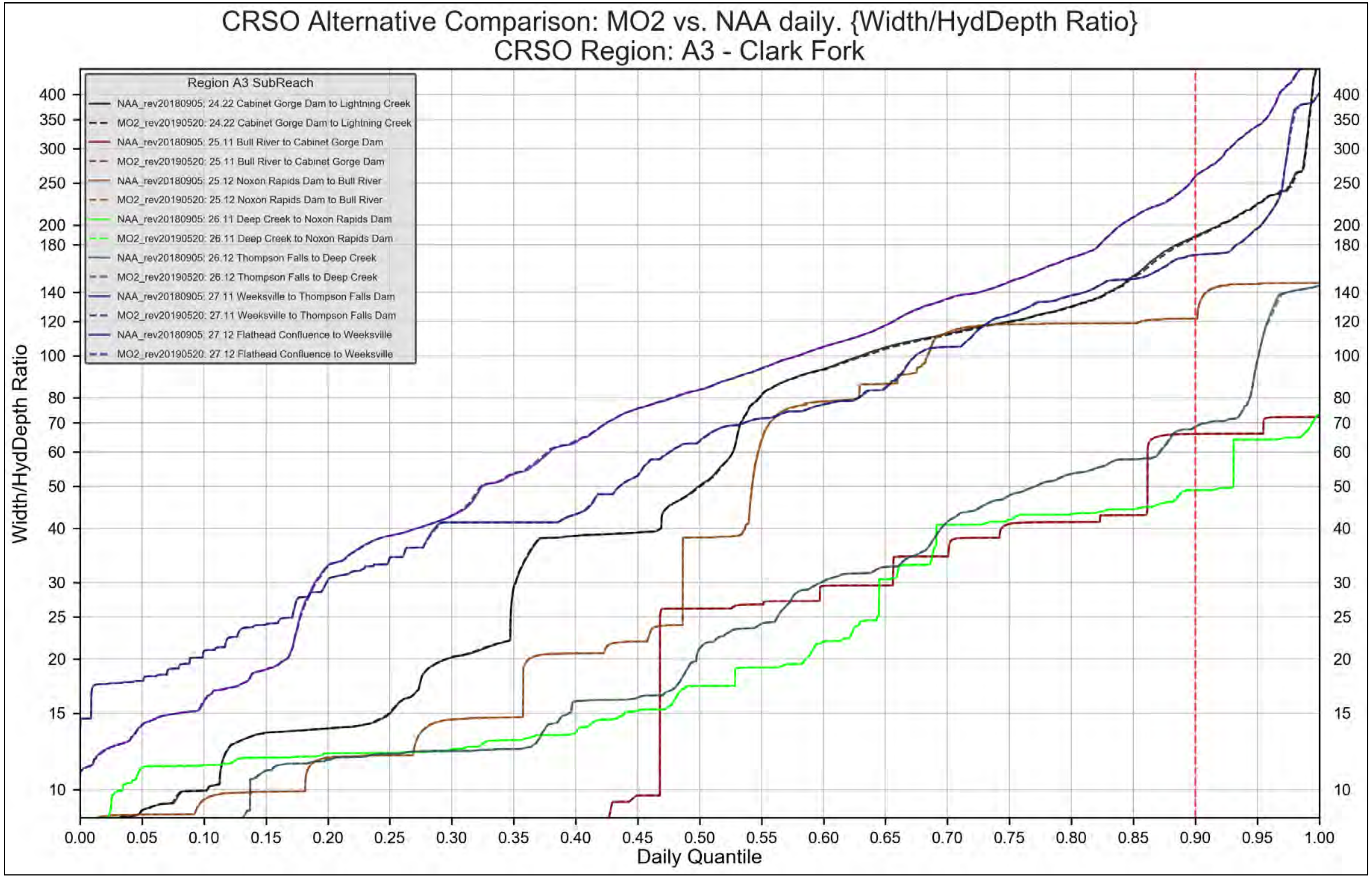


Figure 4-63. Region A3 – Clark Fork. MO2 vs. NAA. Width/Hydraulic Depth Ratio

REGION A3. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

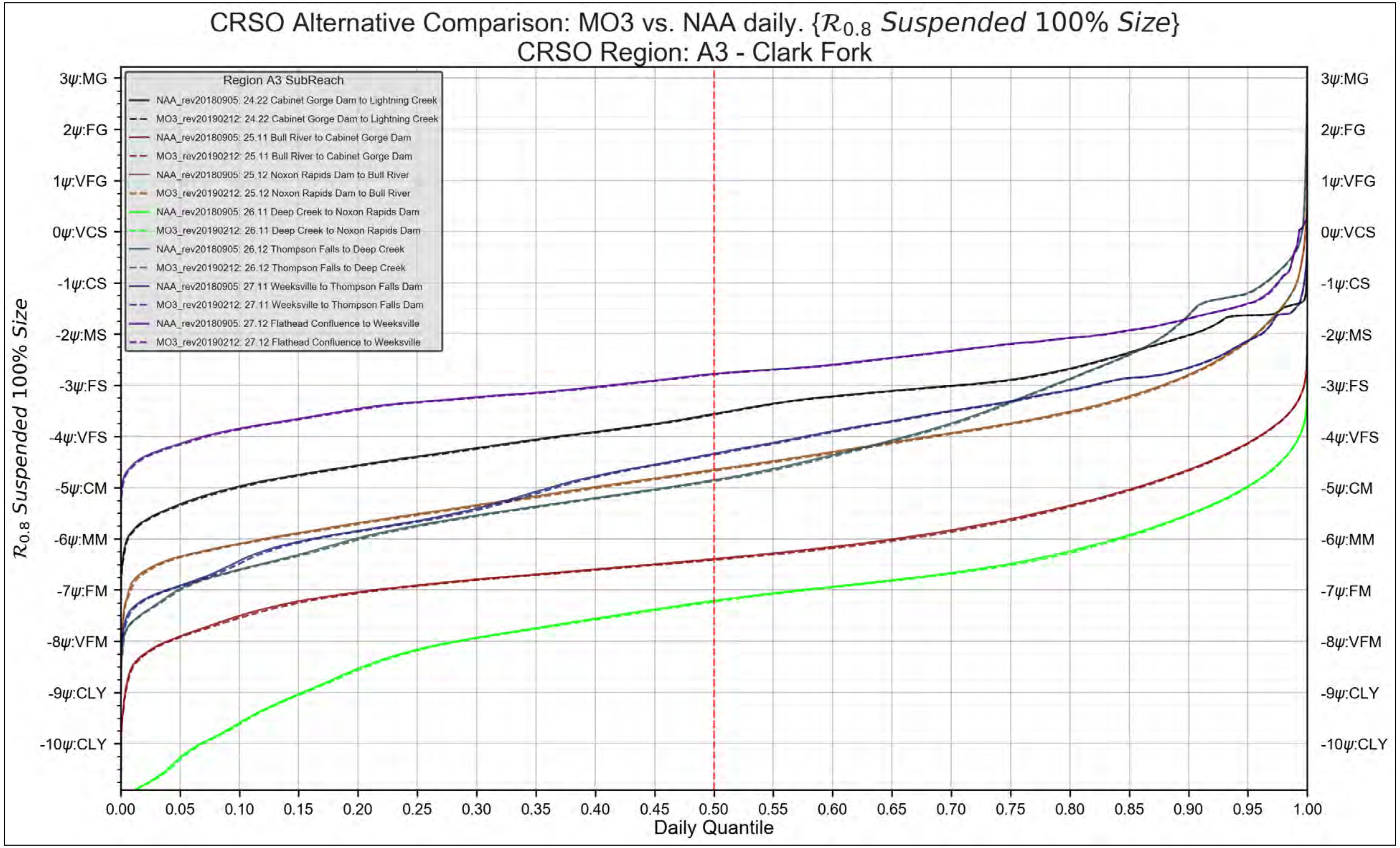


Figure 4-64. Region A3 – Clark Fork. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

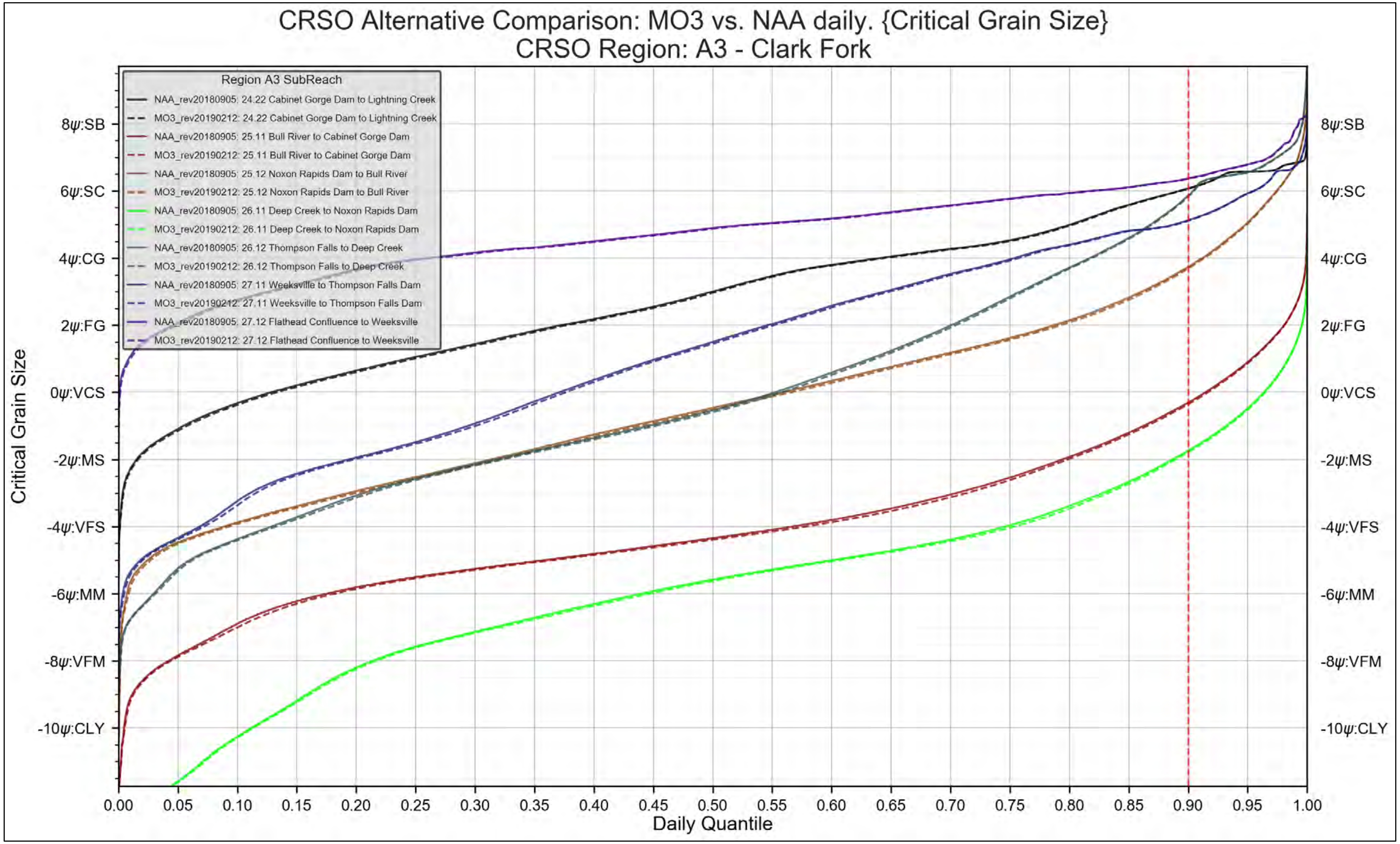
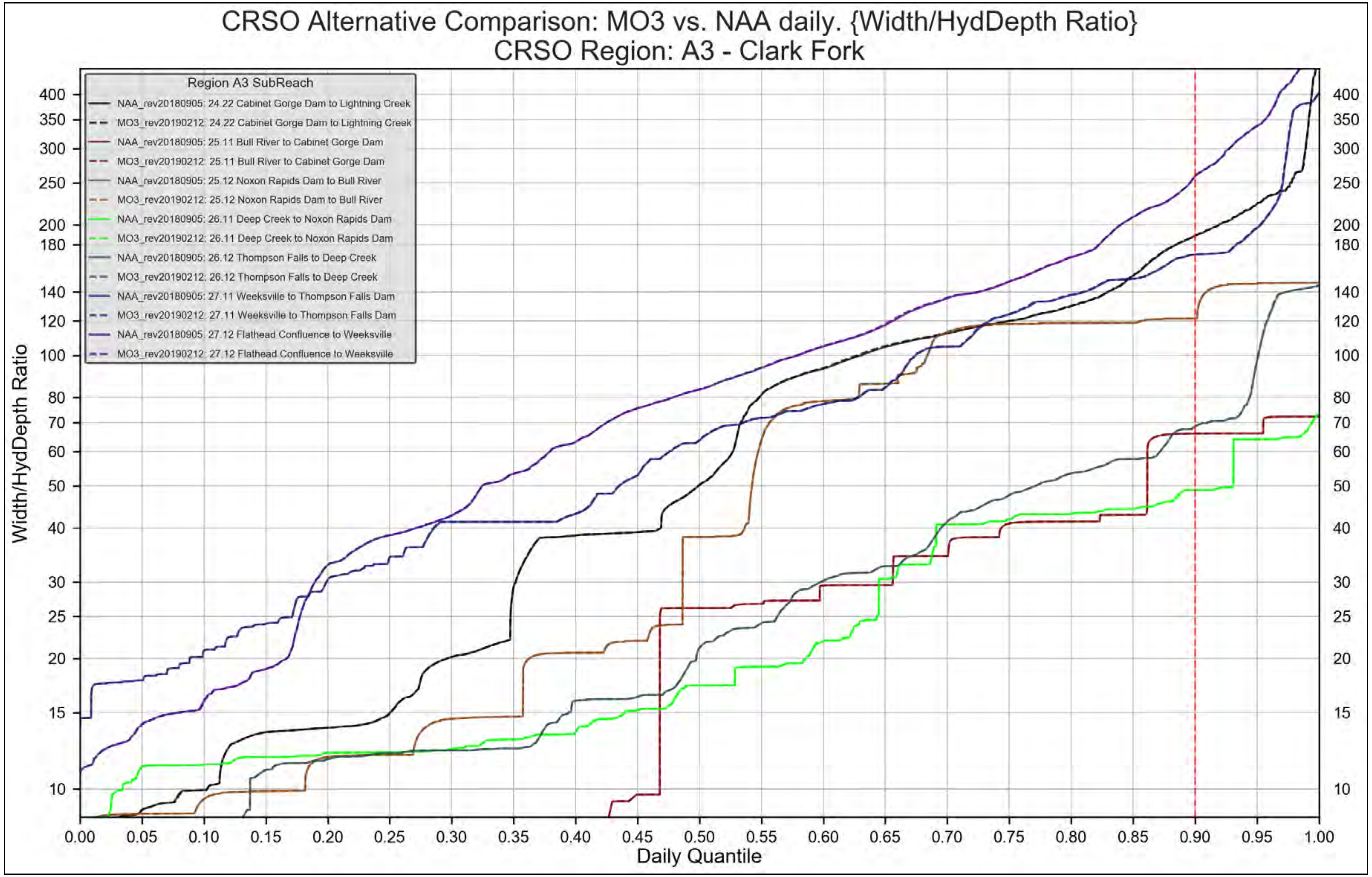


Figure 4-65. Region A3 – Clark Fork. MO3 vs. NAA. Critical Grain-Size Threshold

2097


2098 **Figure 4-66. Region A3 – Clark Fork. MO3 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A3. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE

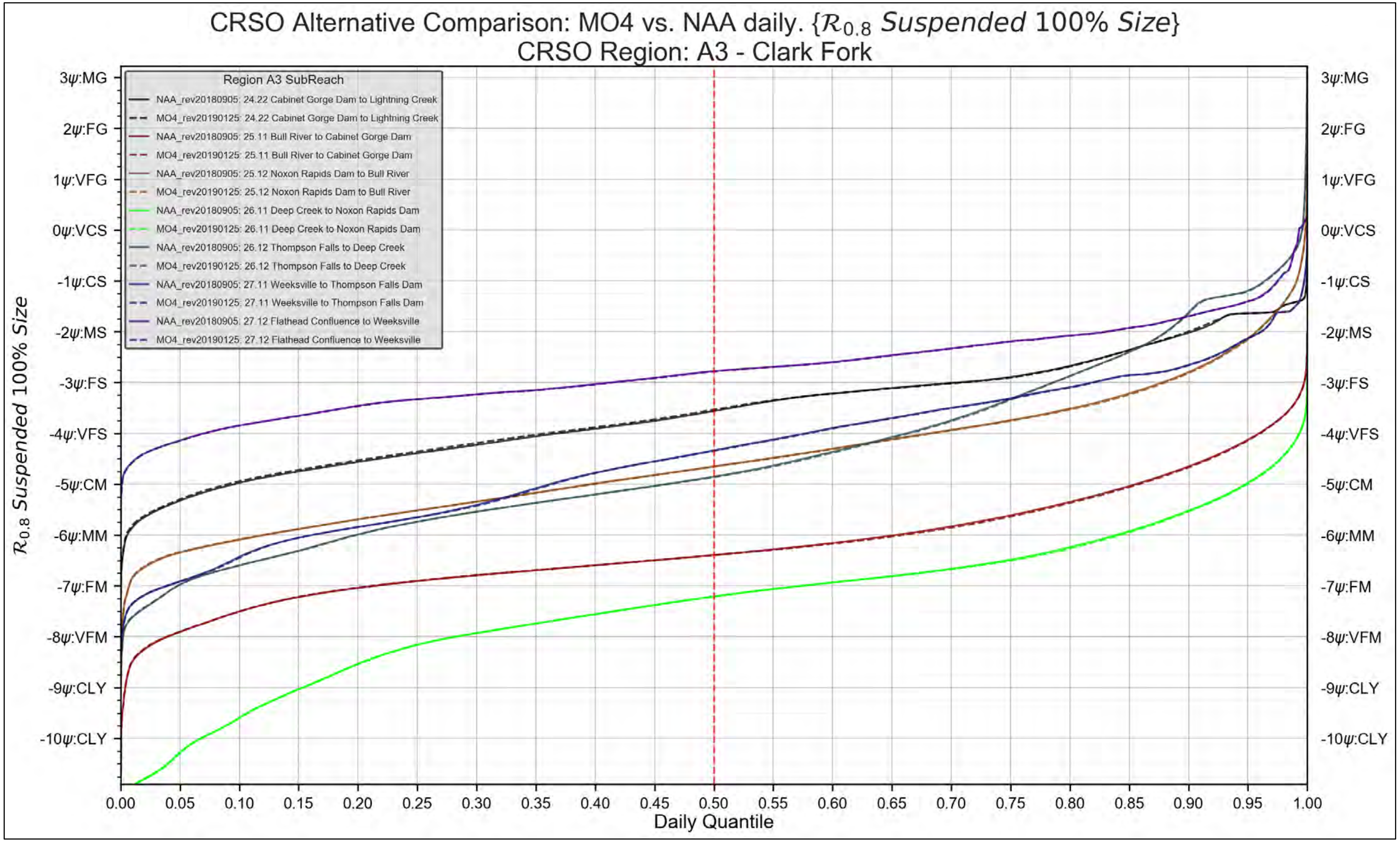
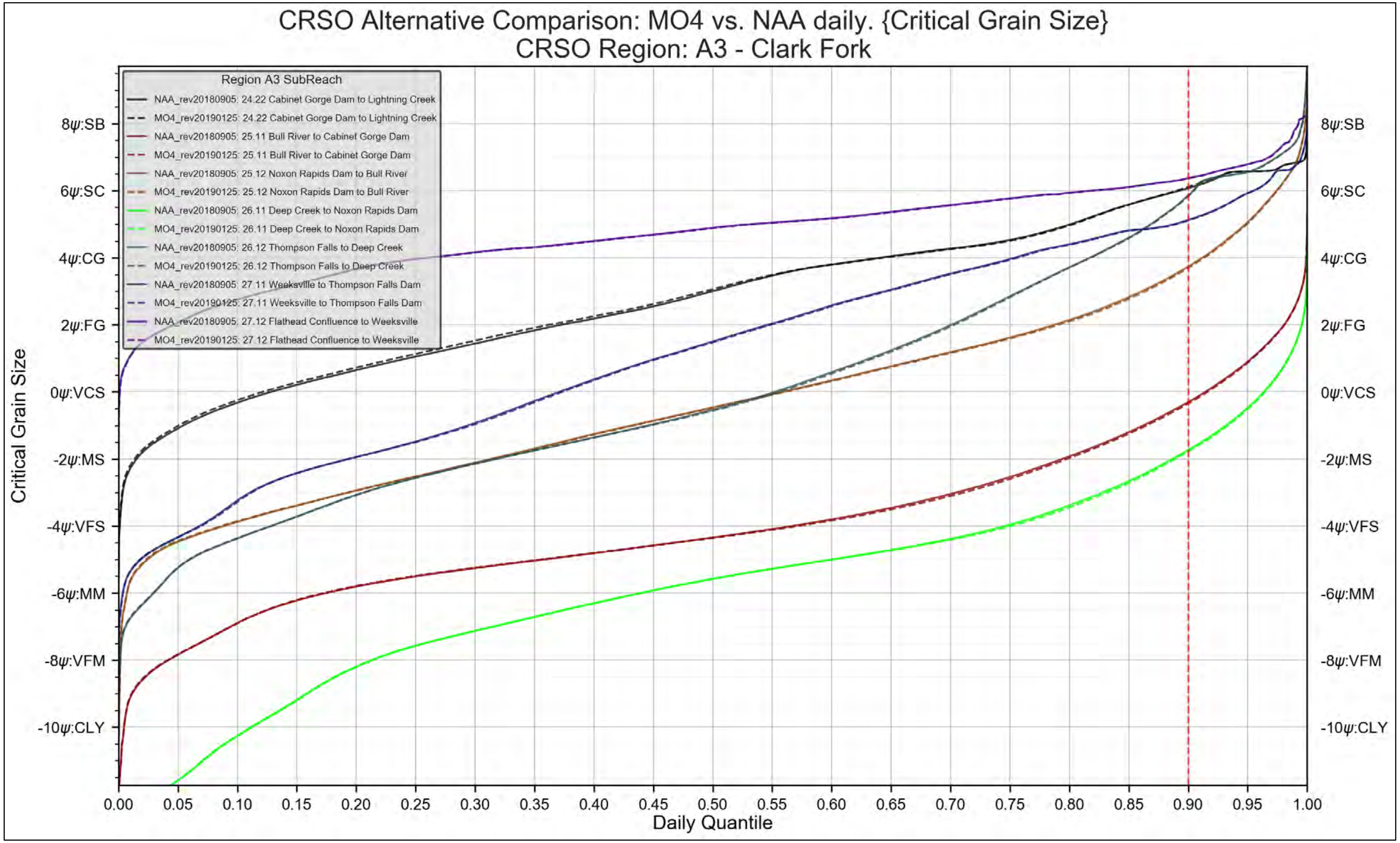


Figure 4-67. Region A3 – Clark Fork. MO4 vs. NAA. 100% Suspended Grain-Size Threshold



2102

2103 **Figure 4-68. Region A3 – Clark Fork. MO4 vs. NAA. Critical Grain-Size Threshold**

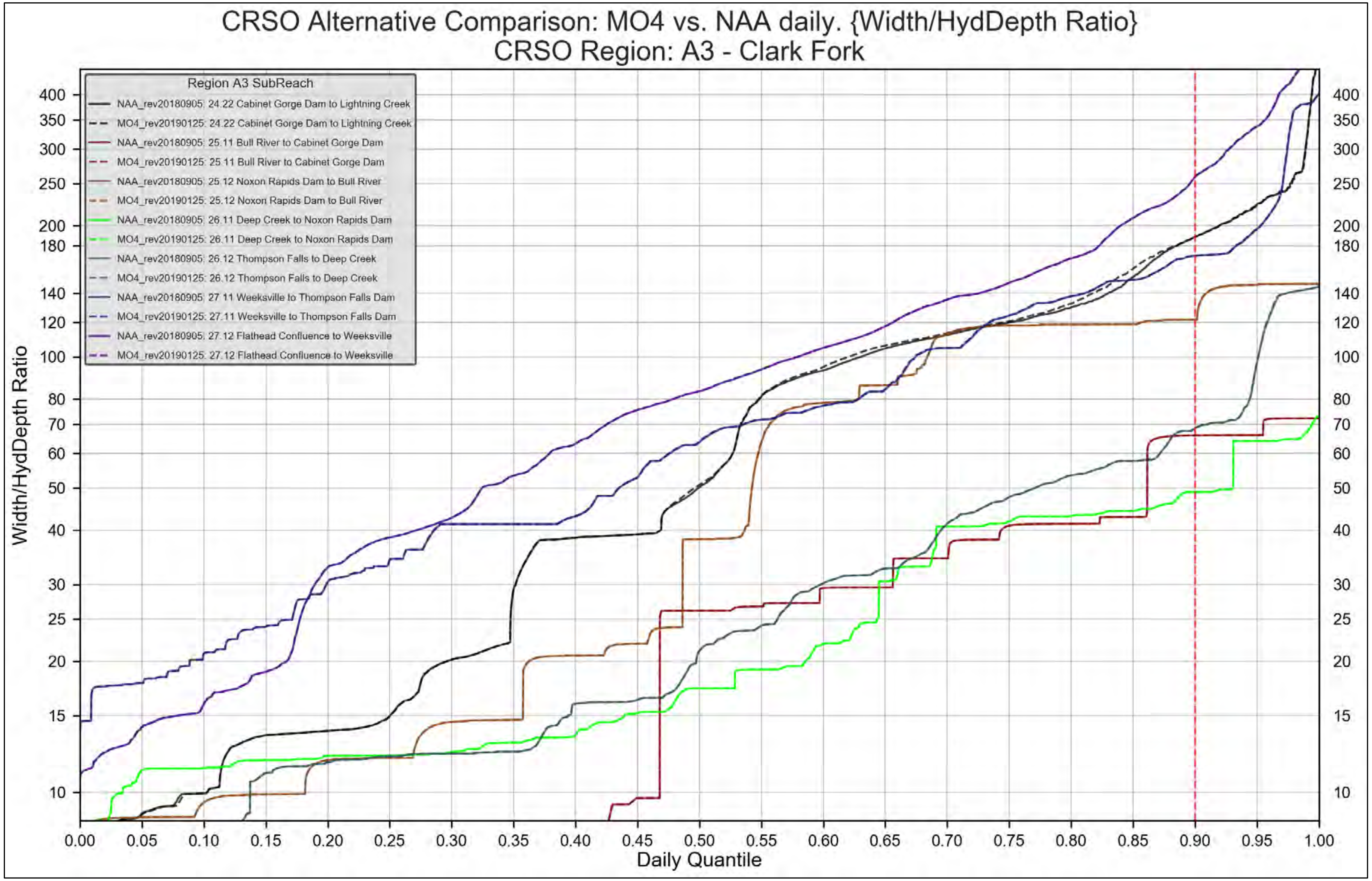


Figure 4-69. Region A3 – Clark Fork. MO4 vs. NAA. Width/Hydraulic Depth Ratio

REGION A3. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE

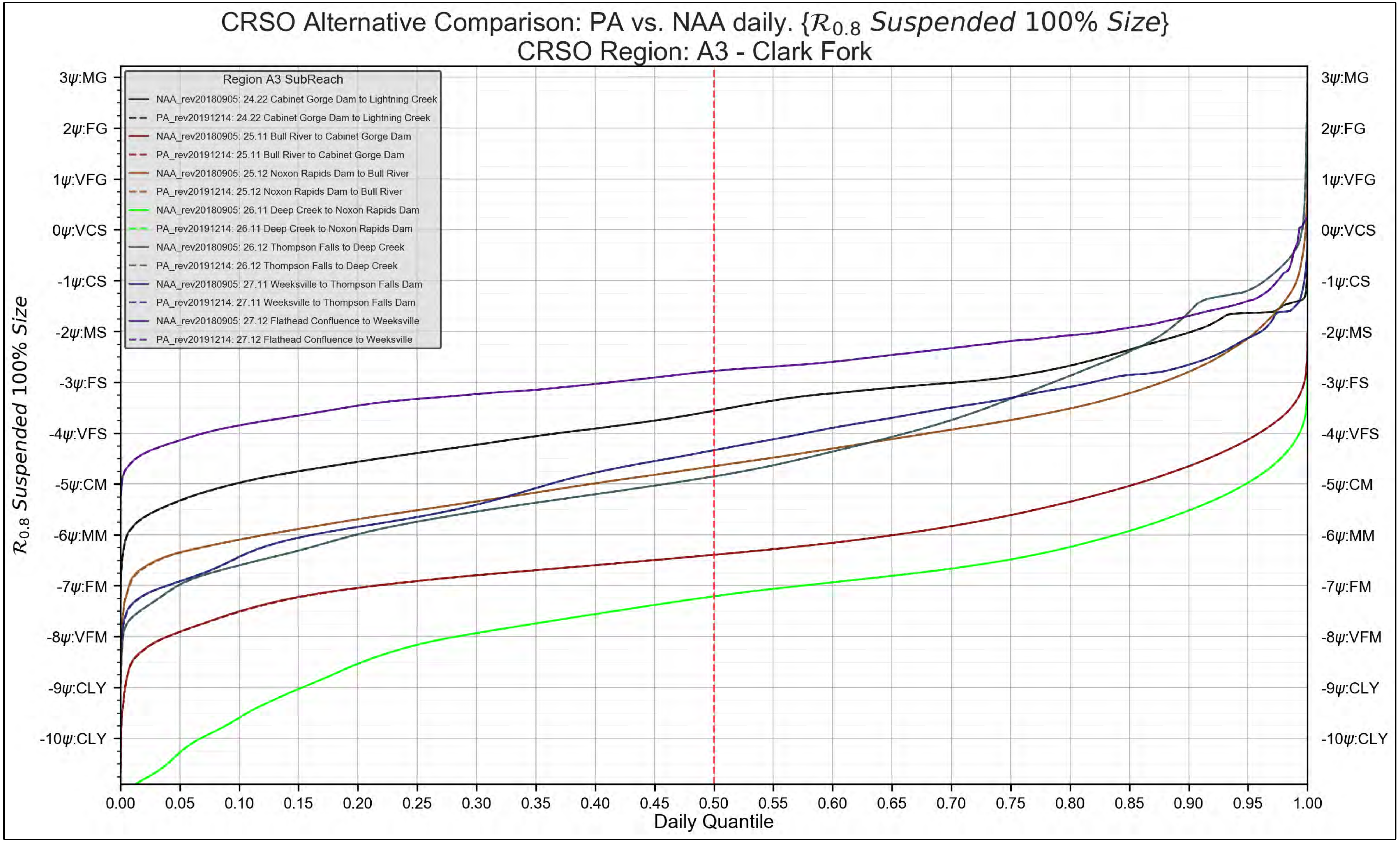
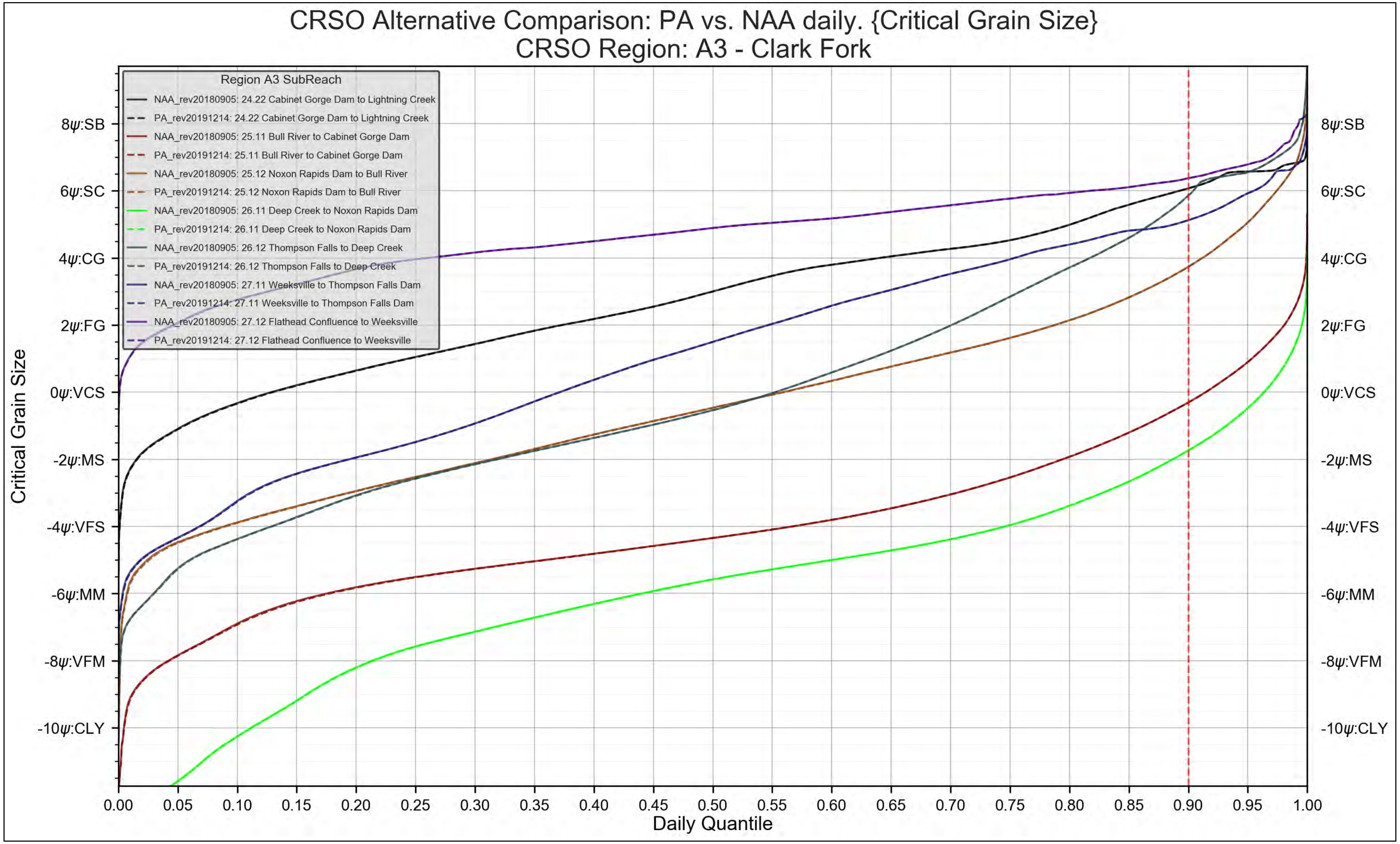


Figure 4-70 Region A3 – Clark Fork. PA vs. NAA. 100% Suspended Grain-Size Threshold

2109 

2110 **Figure 4-71 Region A3 – Clark Fork. PA vs. NAA. Critical Grain-Size Threshold**

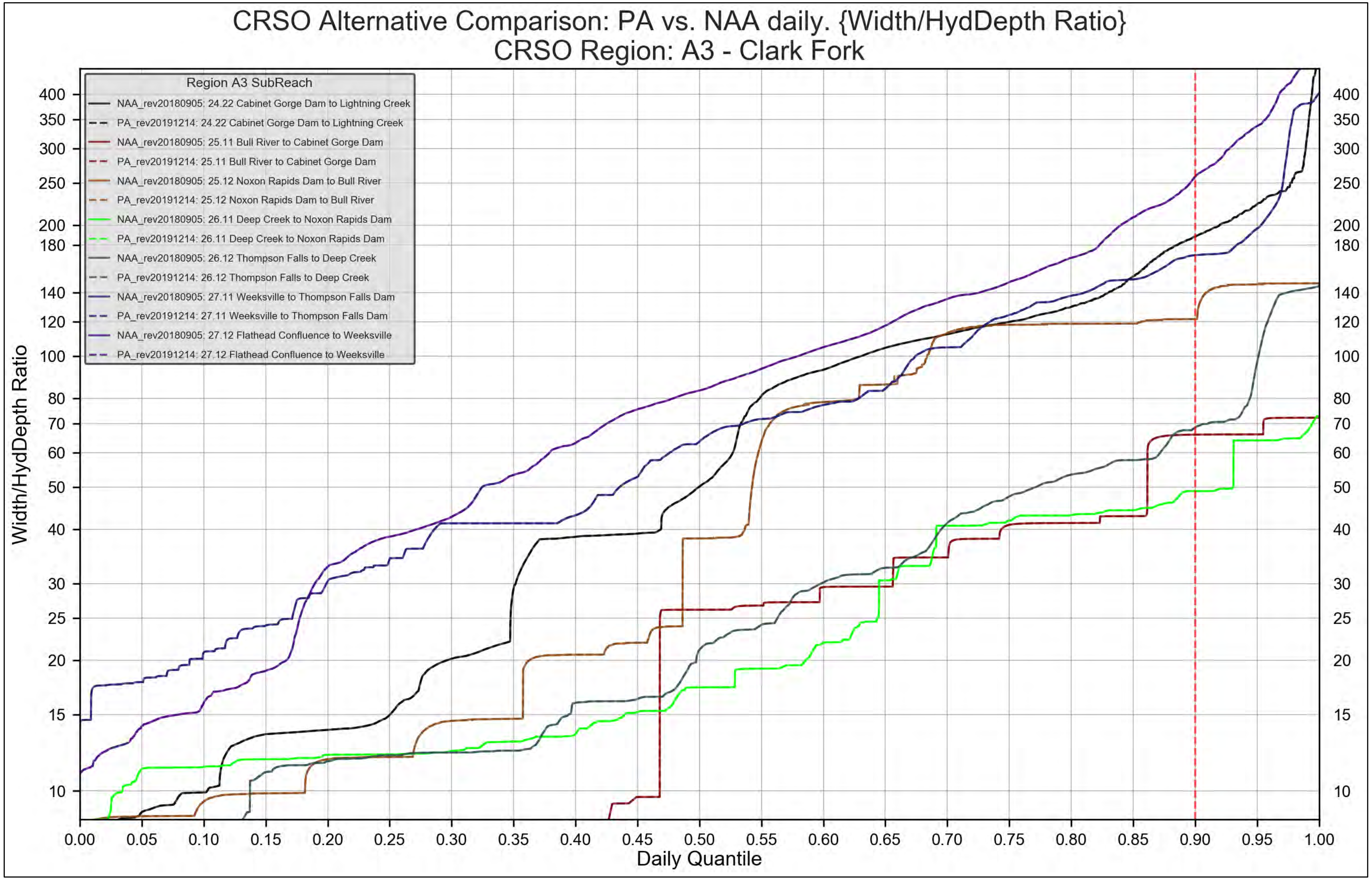


Figure 4-72 Region A3 – Clark Fork. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.3.3 Region A4. Pend Oreille Reach. Comparison Figures

REGION A4. MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

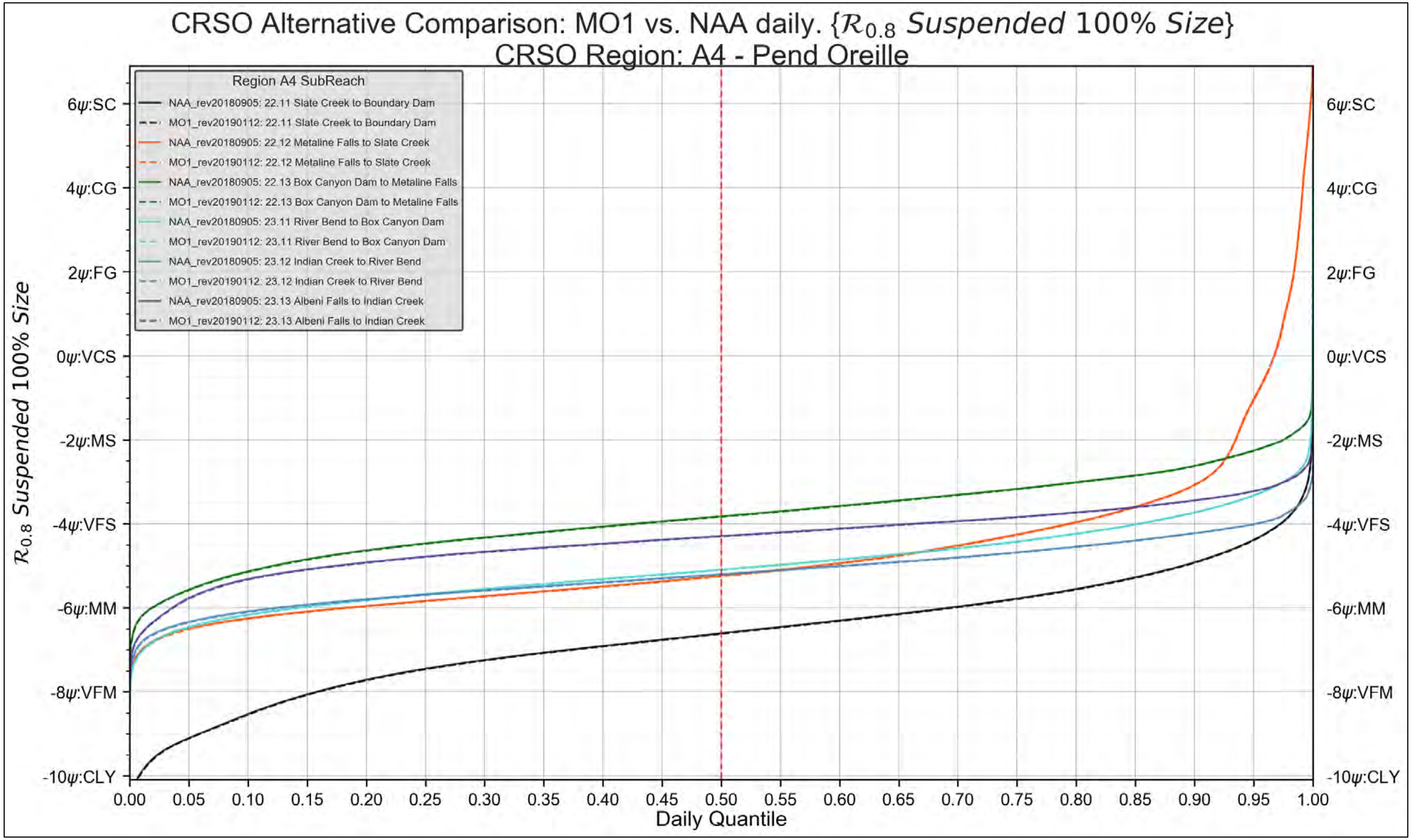


Figure 4-73. Region A4 – Pend Oreille. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

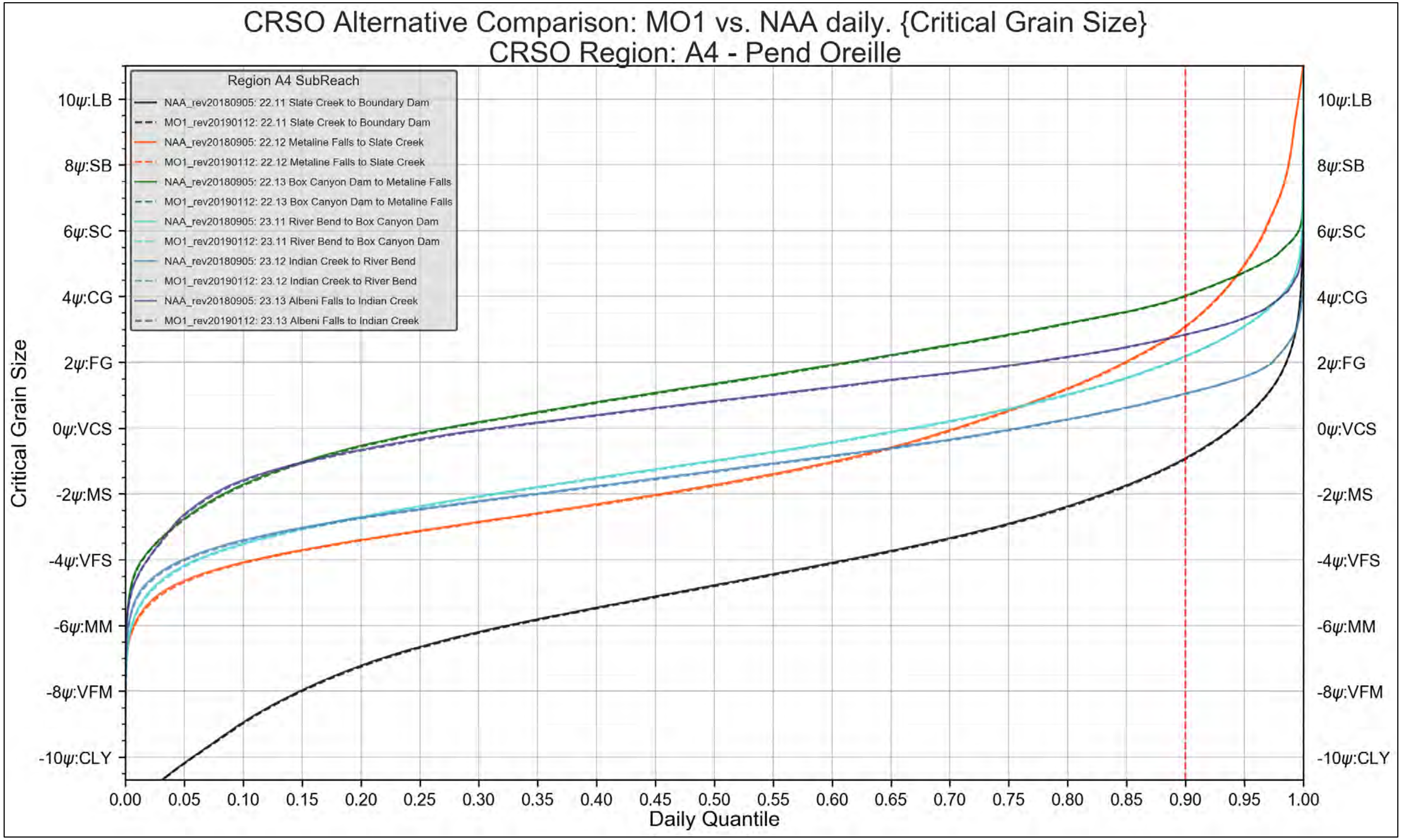
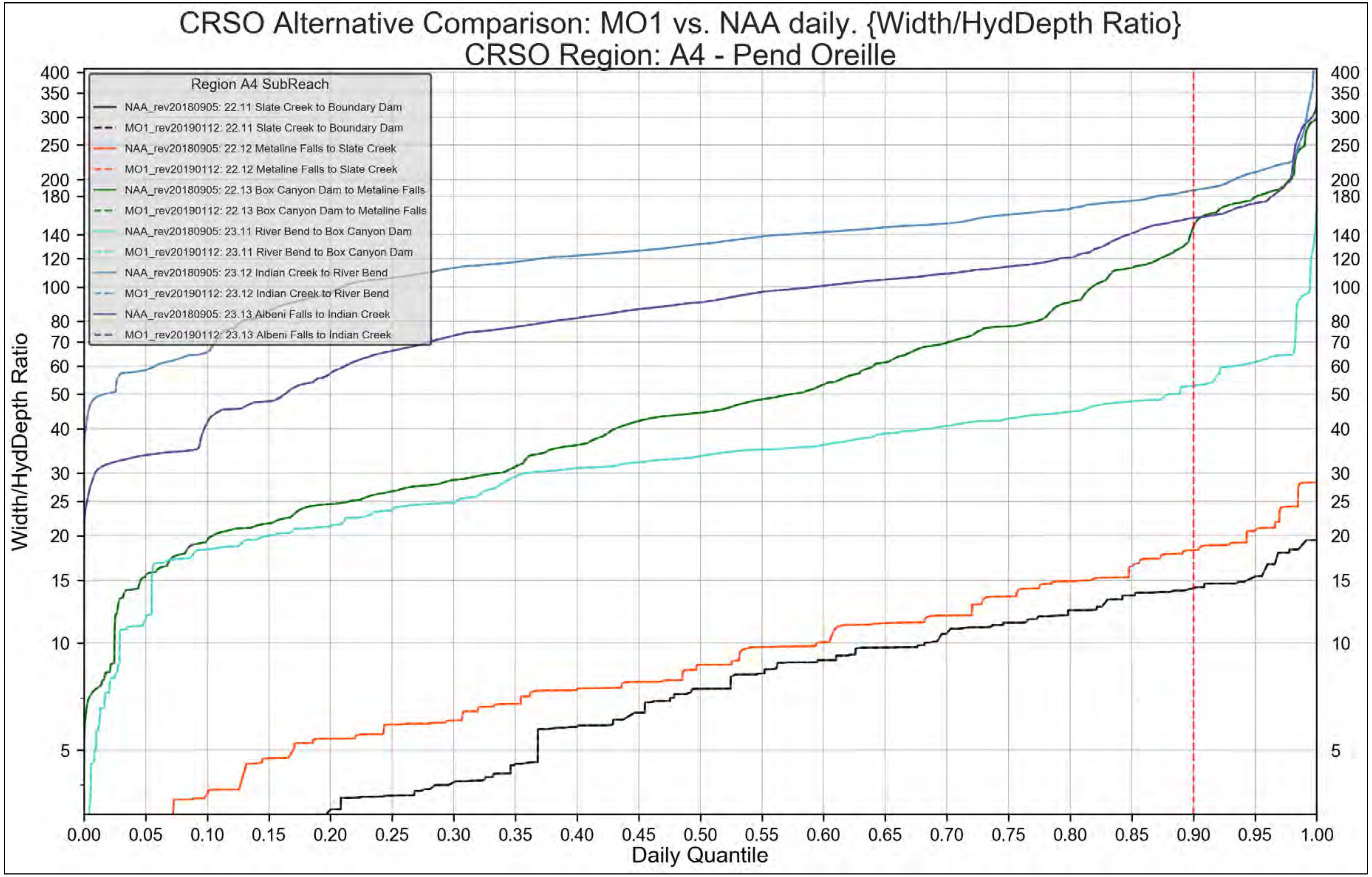


Figure 4-74. Region A4 – Pend Oreille. MO1 vs. NAA. Critical Grain-Size Threshold



2119

2120 **Figure 4-75. Region A4 – Pend Oreille. MO1 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A4. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

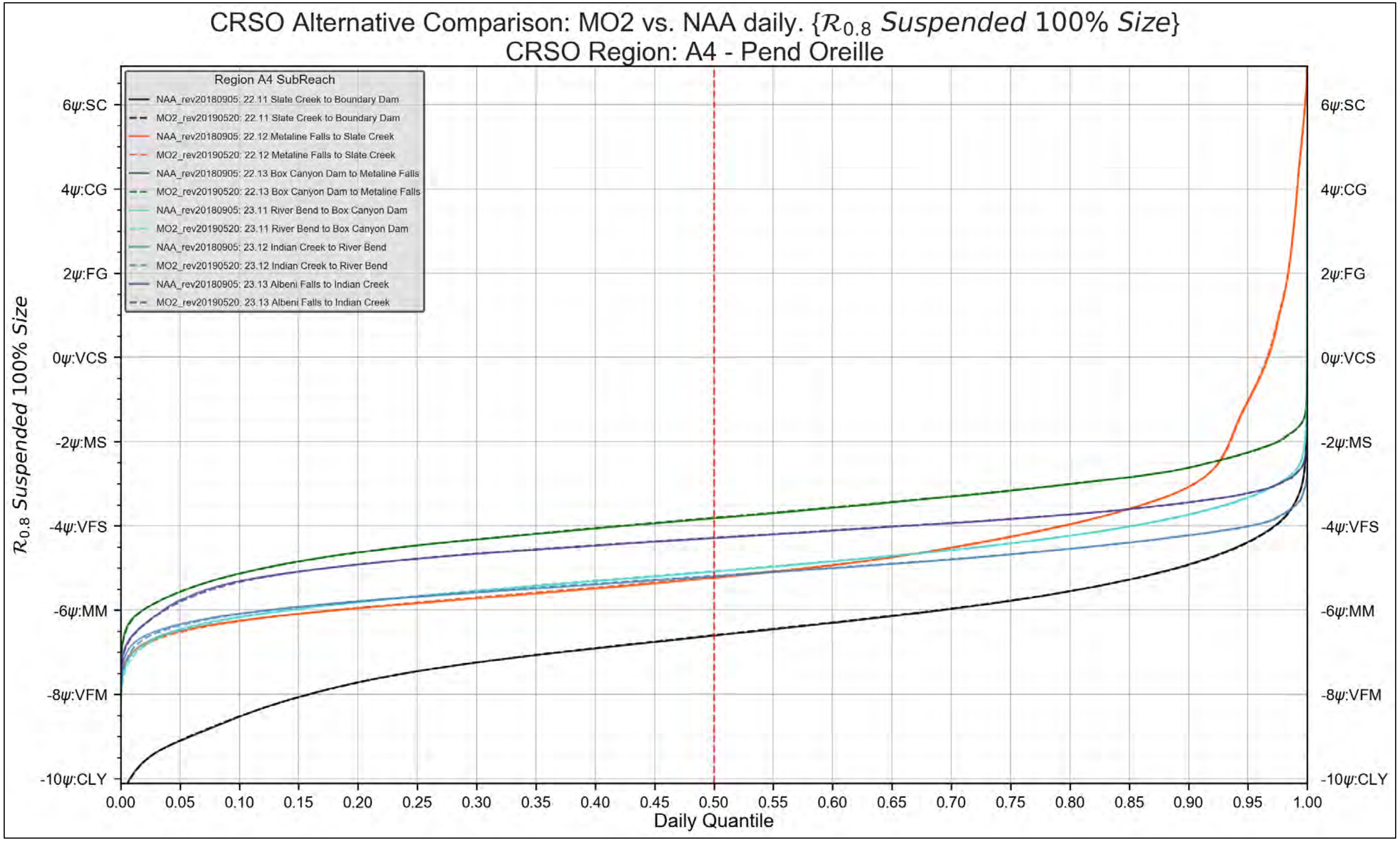


Figure 4-76. Region A4 – Pend Oreille. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

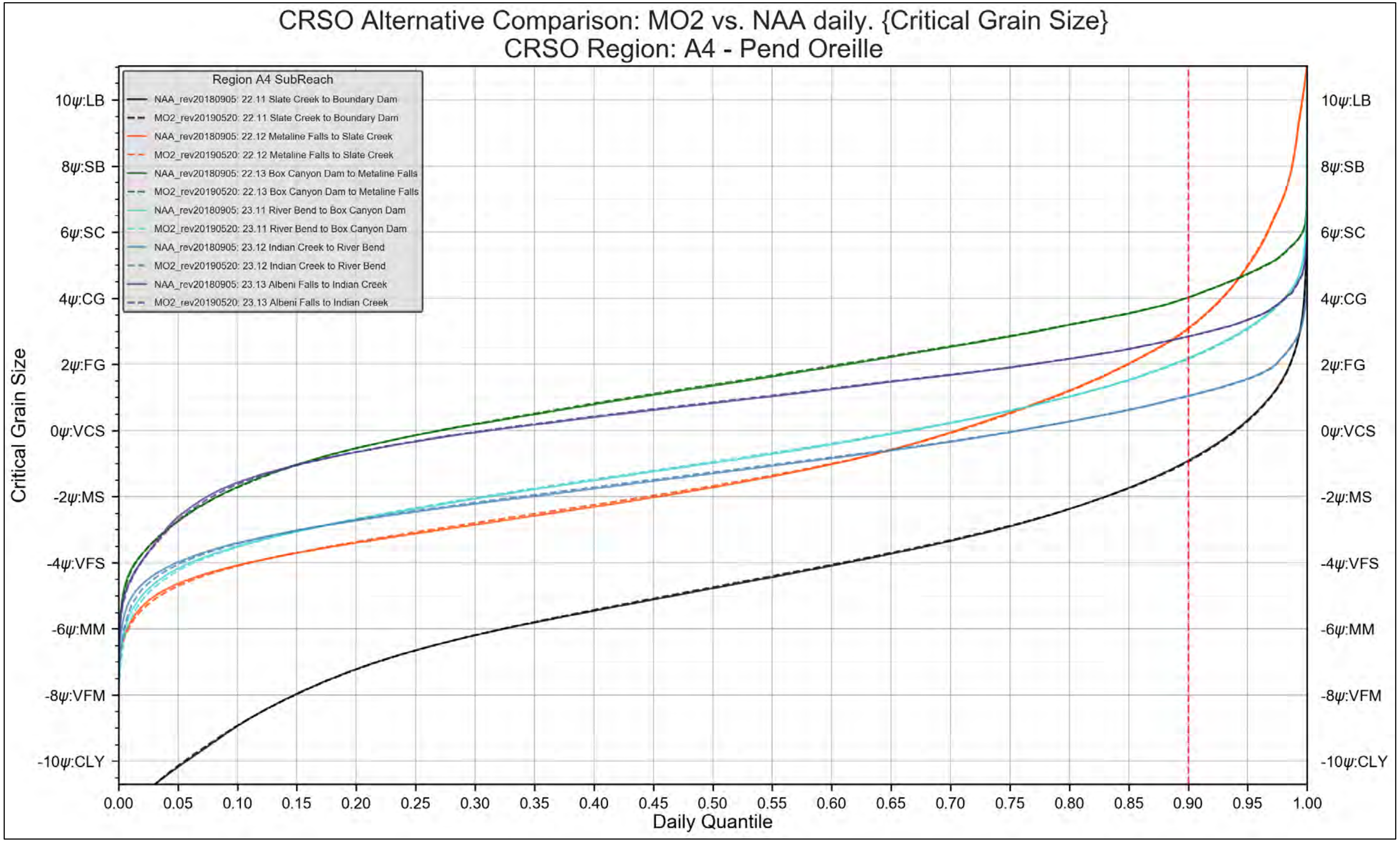
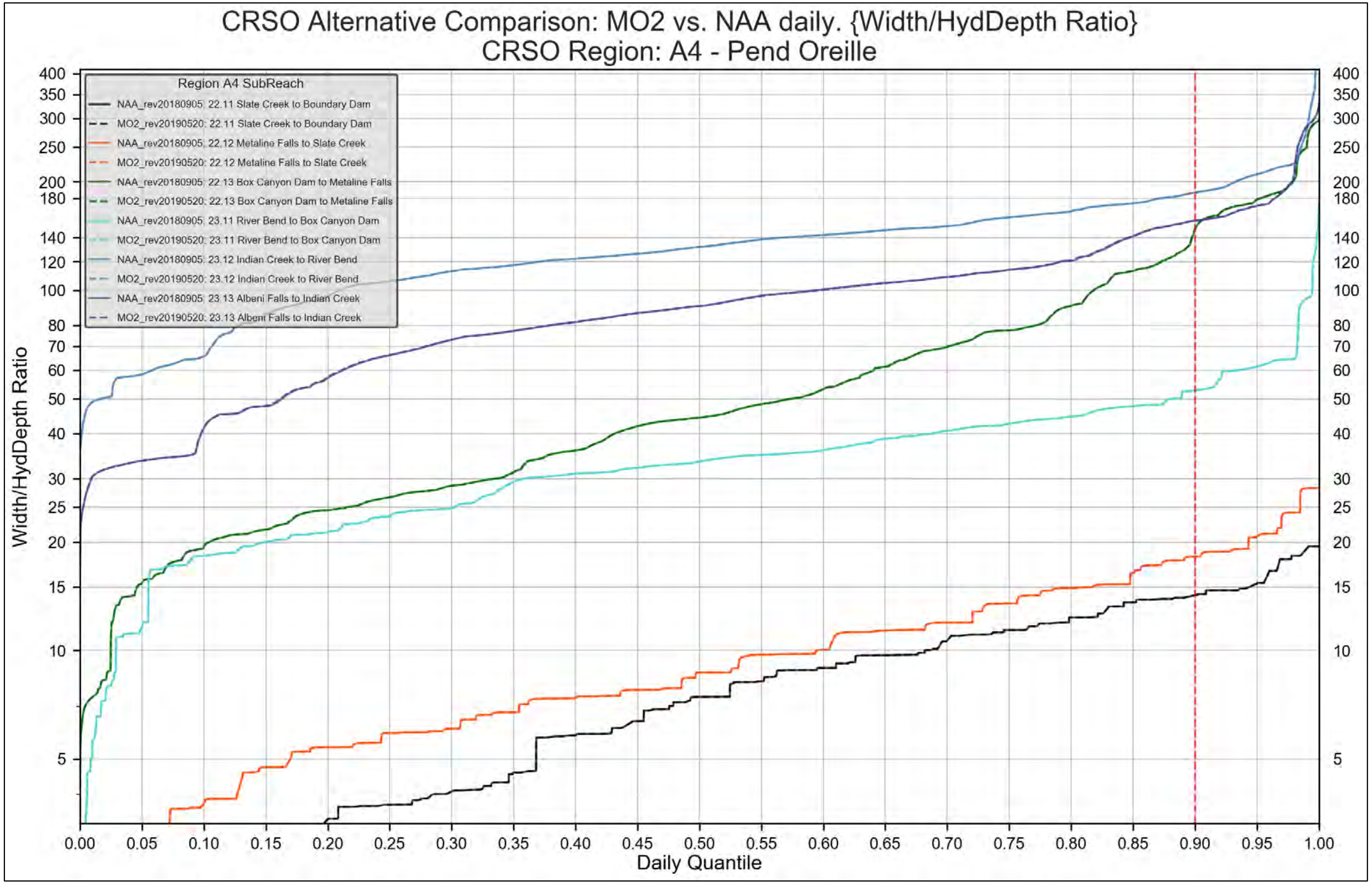


Figure 4-77. Region A4 – Pend Oreille. MO2 vs. NAA. Critical Grain-Size Threshold



2126
2127 **Figure 4-78. Region A4 – Pend Oreille. MO2 vs. NAA. Width/Hydraulic Depth Ratio**

REGION A4. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

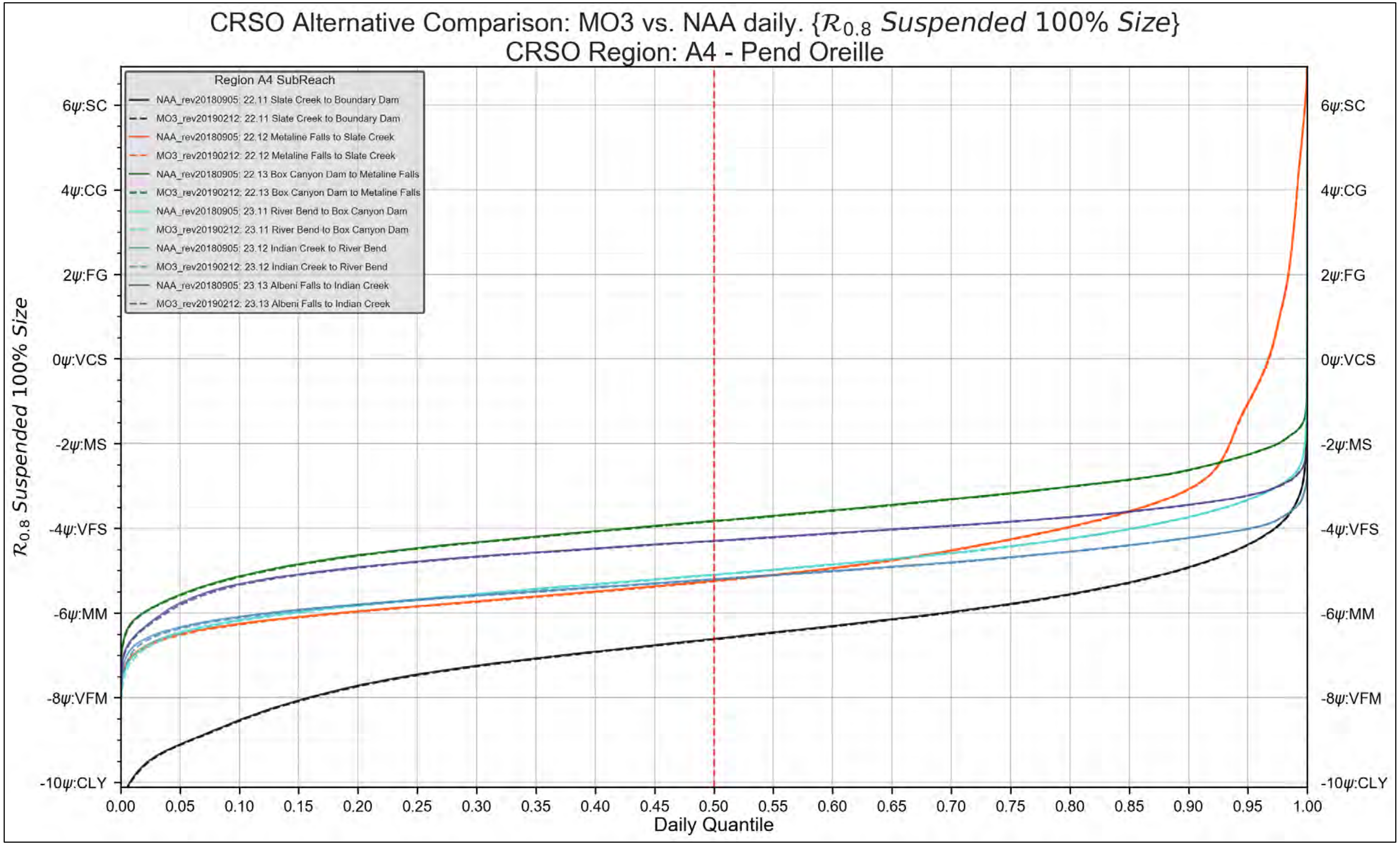


Figure 4-79. Region A4 – Pend Oreille. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

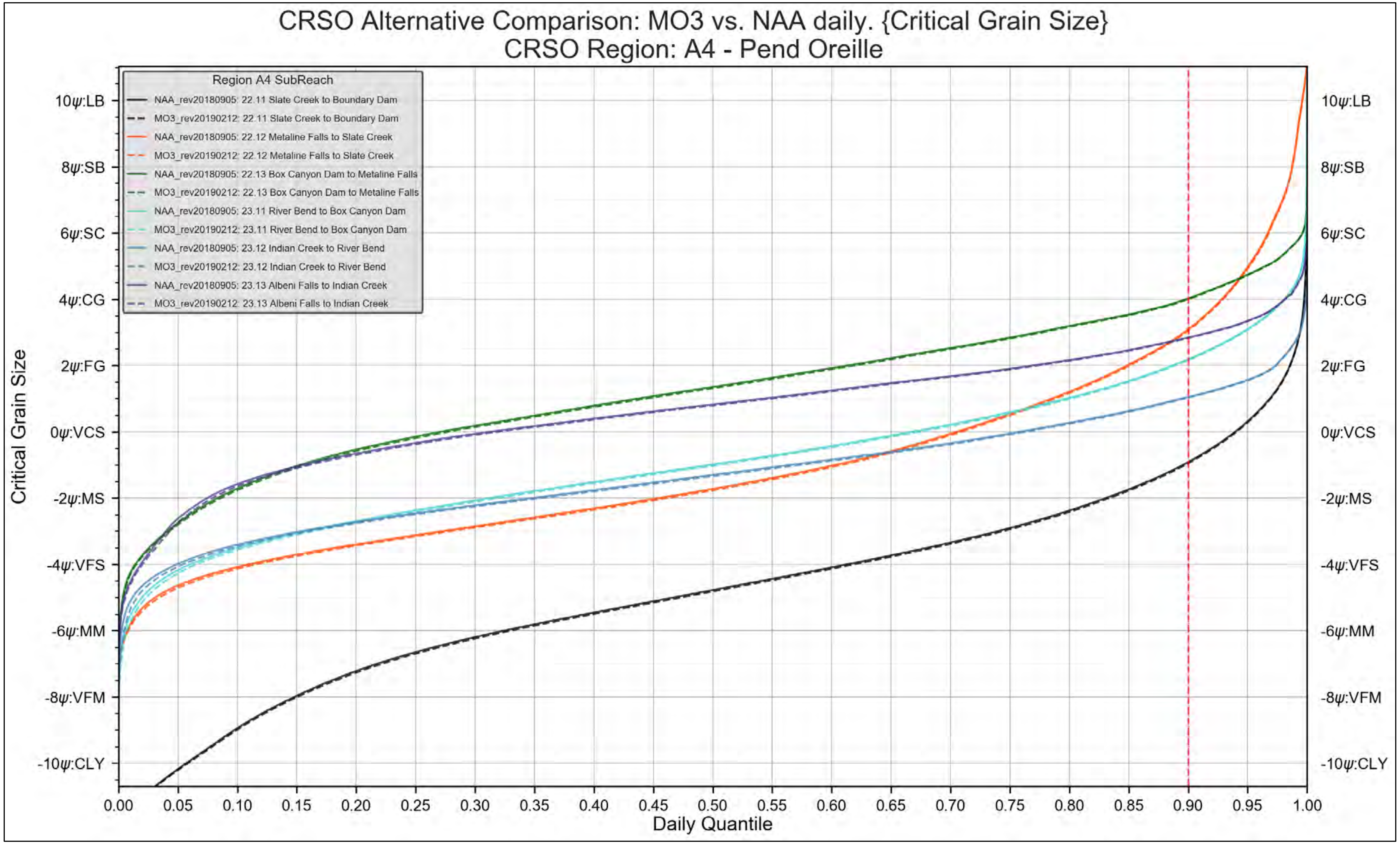
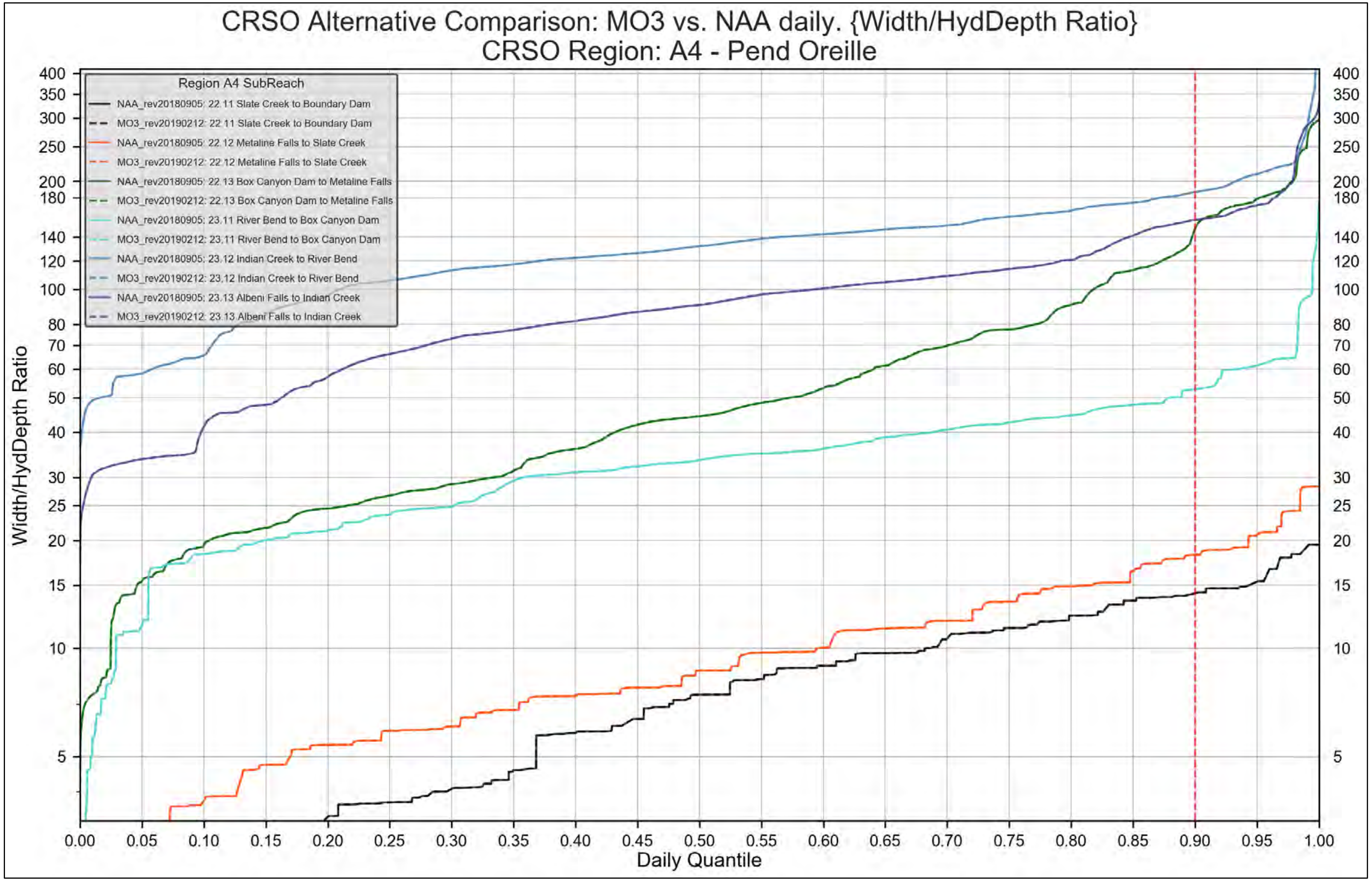


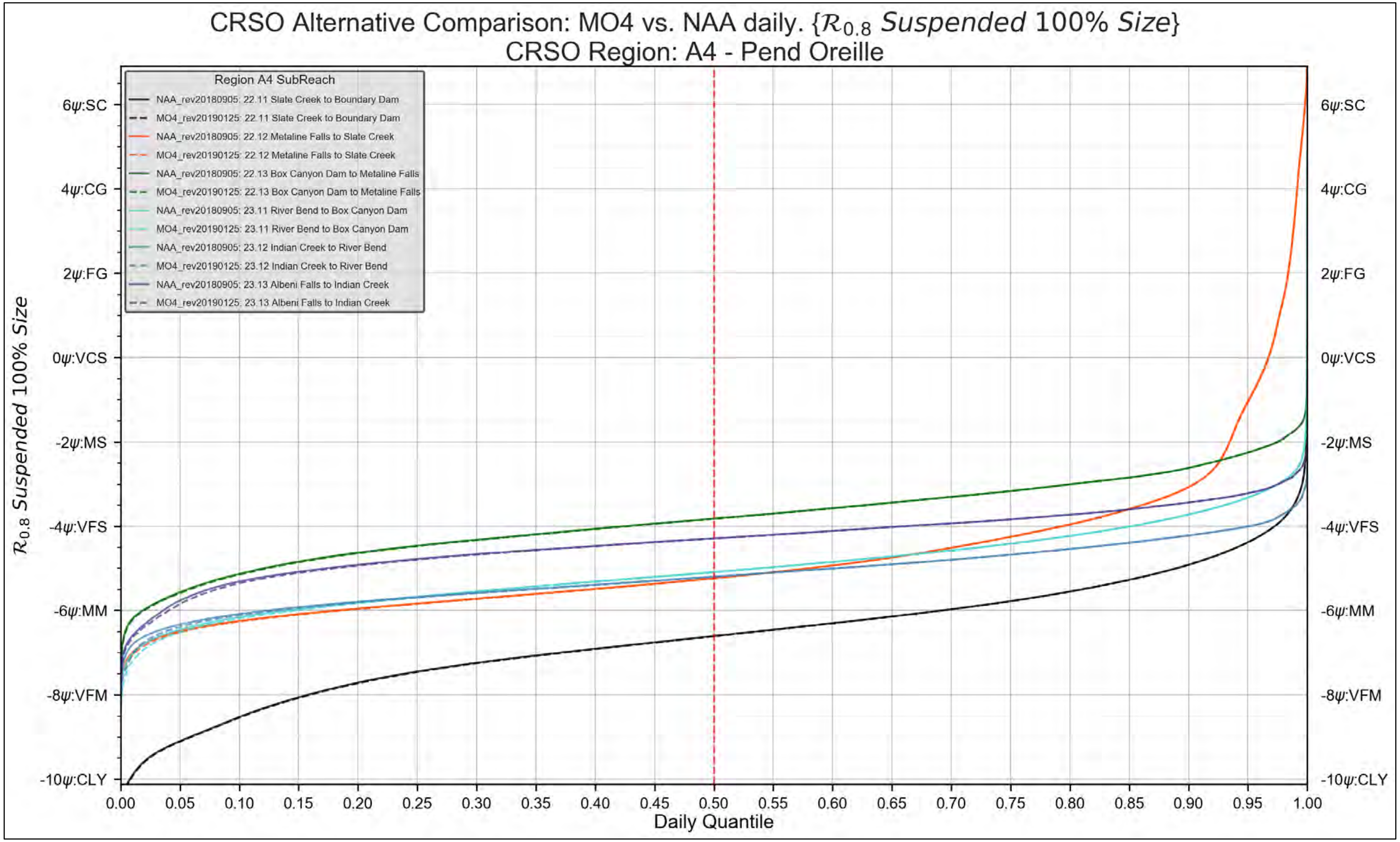
Figure 4-80. Region A4 – Pend Oreille. MO3 vs. NAA. Critical Grain-Size Threshold



2133

2134 **Figure 4-81. Region A4 – Pend Oreille. MO3 vs. NAA. Width/Hydraulic Depth Ratio**

2135 **REGION A4. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE**



2136

2137 **Figure 4-82. Region A4 – Pend Oreille. MO4 vs. NAA. 100% Suspended Grain-Size Threshold**

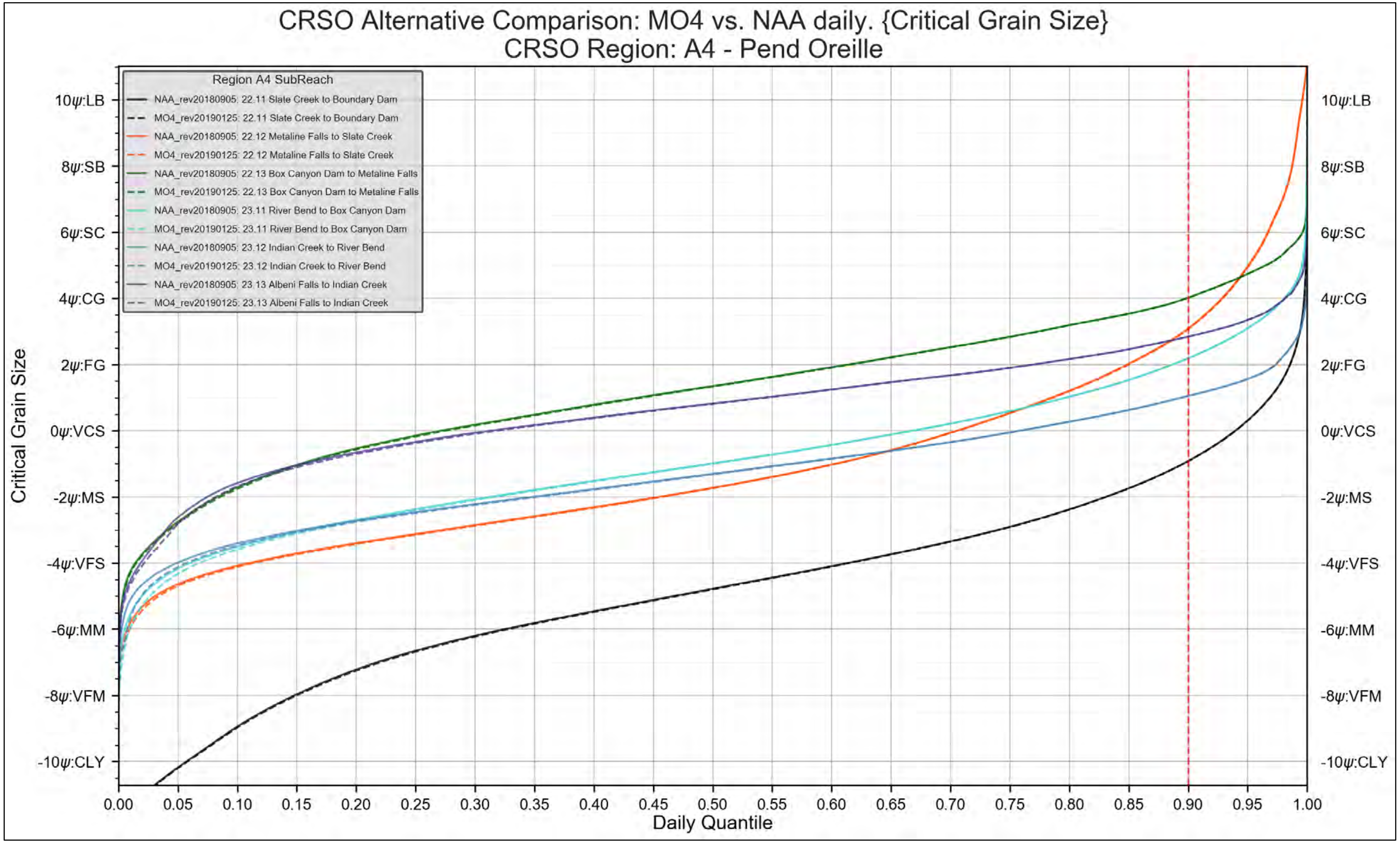
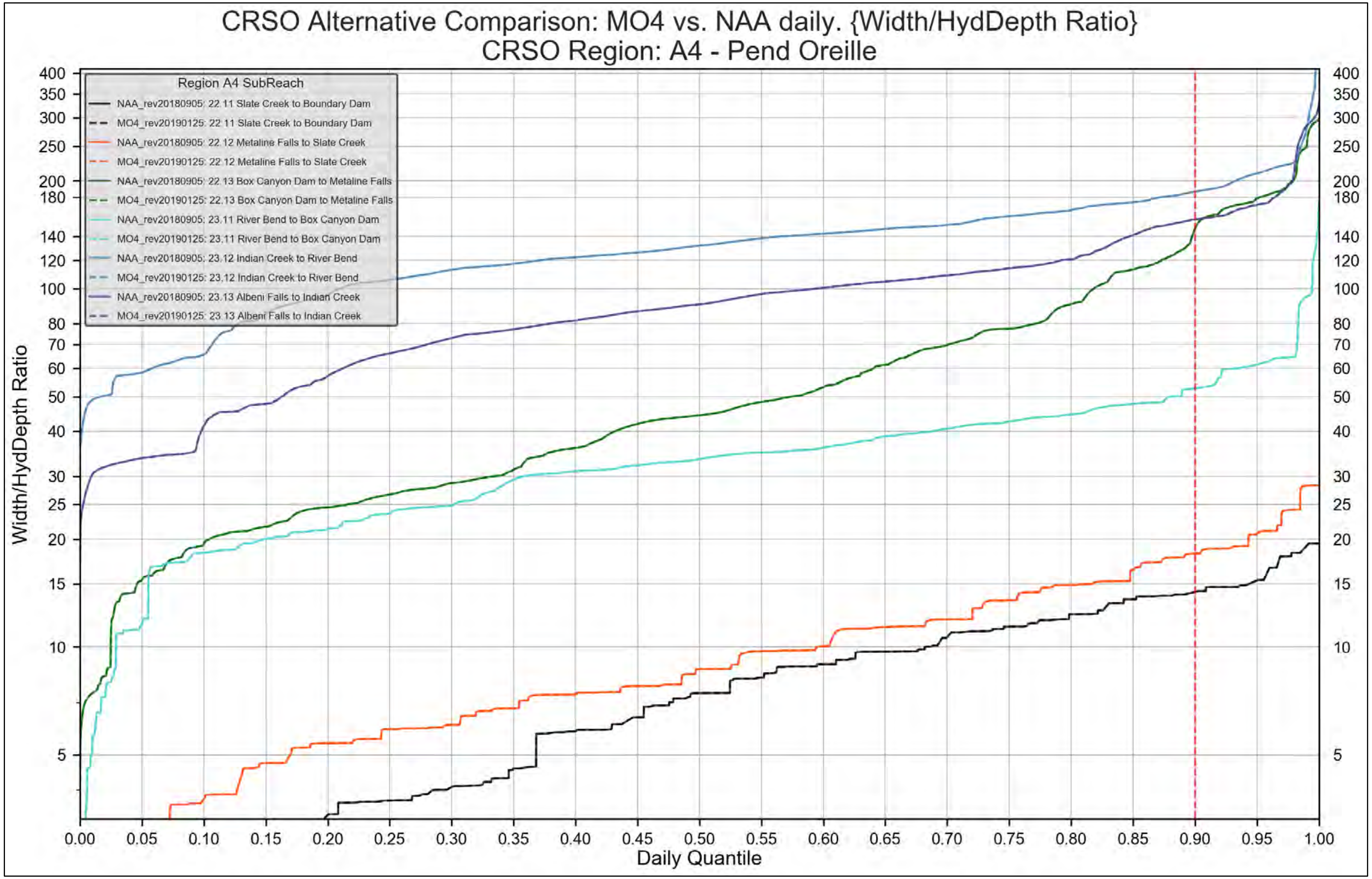


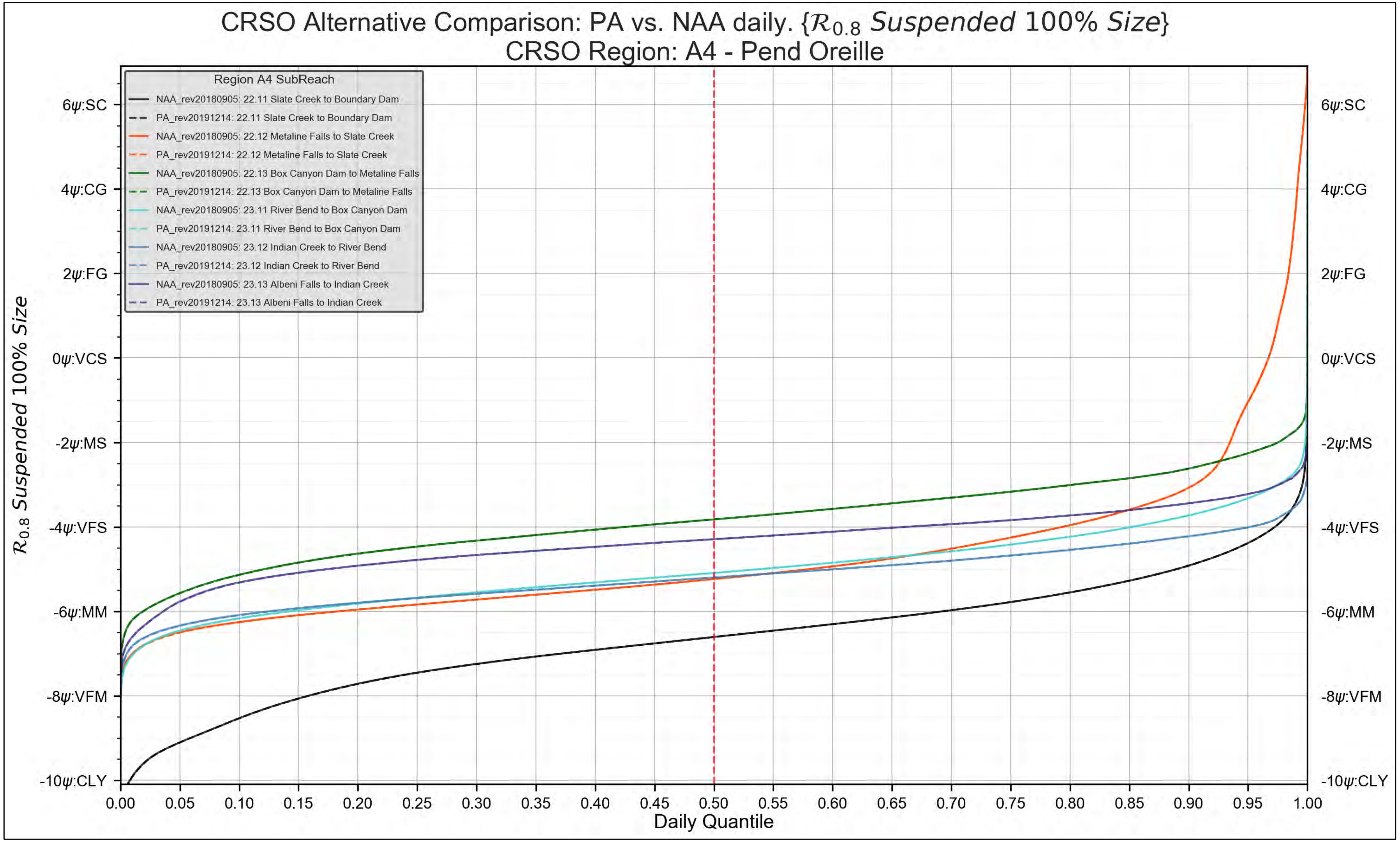
Figure 4-83. Region A4 – Pend Oreille. MO4 vs. NAA. Critical Grain-Size Threshold



2140

2141 **Figure 4-84. Region A4 – Pend Oreille. MO4 vs. NAA. Width/Hydraulic Depth Ratio**

2142 **REGION A4. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE**



2143

2144 **Figure 4-85 Region A4 – Pend Oreille. PA vs. NAA. 100% Suspended Grain-Size Threshold**

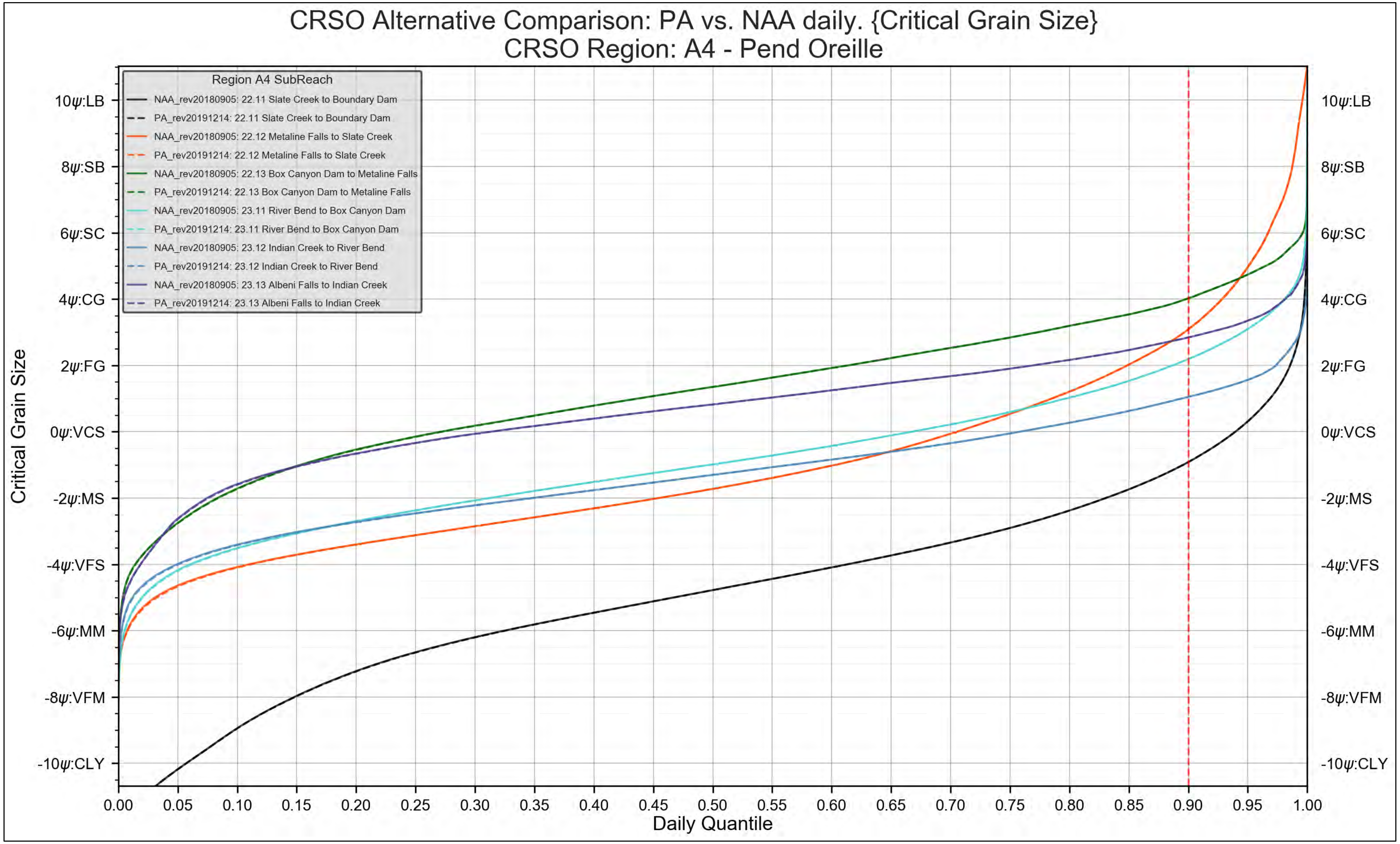
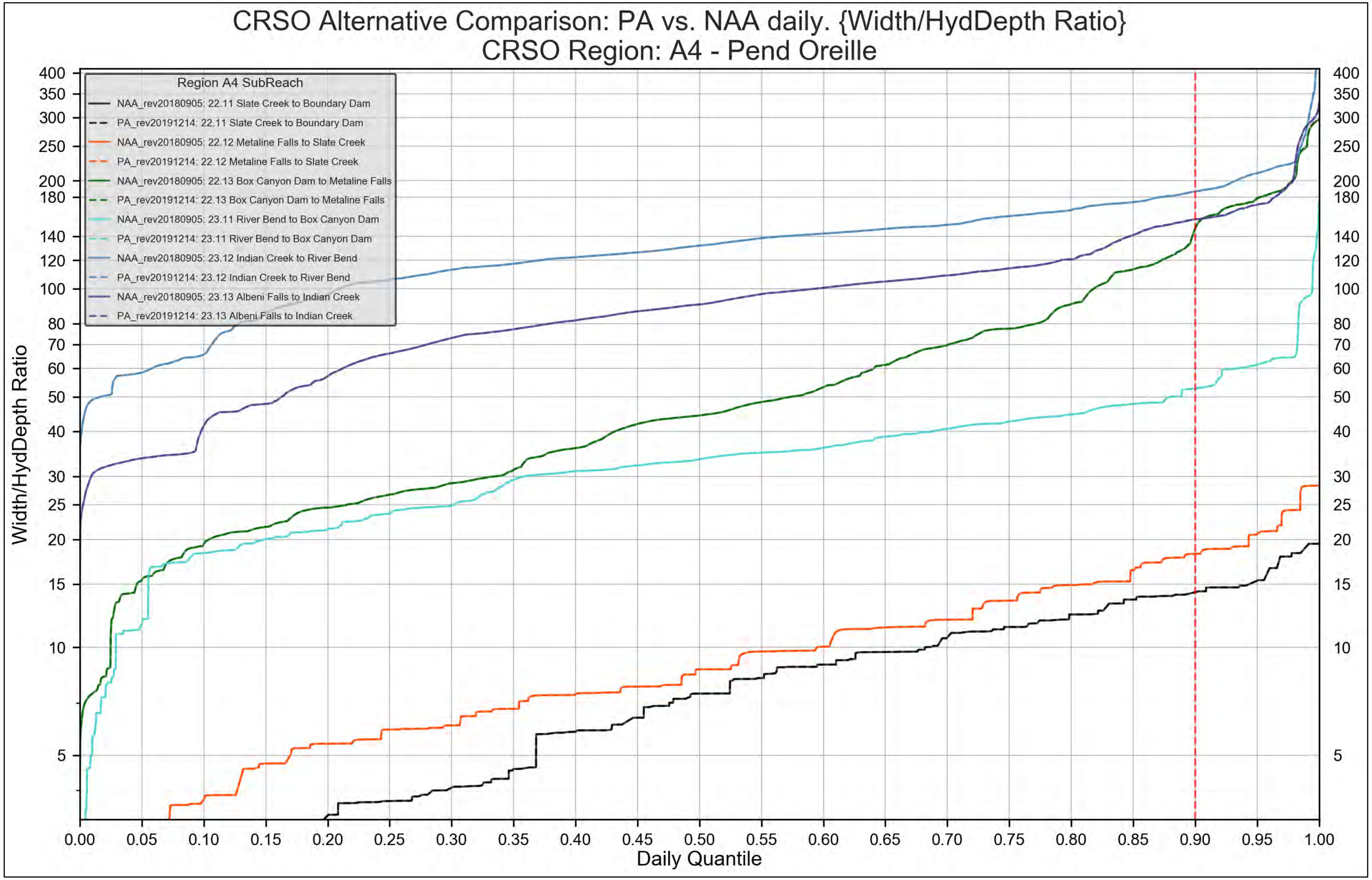


Figure 4-86 Region A4 – Pend Oreille. PA vs. NAA. Critical Grain-Size Threshold



2148 **Figure 4-87 Region A4 – Pend Oreille. PA vs. NAA. Width/Hydraulic Depth Ratio**

4.2.4 Region B: Middle Columbia Reach – U.S.-Canada Border to Richland, Washington

4.2.4.1 Region B: Middle Columbia Reach Comparison Tables

Table 4-11. Region B: Middle Columbia Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**
Columbia – U.S. Canada border to Richland, Washington	21.14	Northport Reach	5.8%	4.4%	3.0%	7.0%	5.3%	2.9%	-0.9%	-0.6%	-0.3%	**16.7%**	**15.0%**	2.4%	0.2%	0.2%	0.1%
	21.13	Lake Roosevelt Upper Reach	5.6%	**13.5%**	0.8%	**7.9%**	15.9%	0.8%	-0.8%	2.4%	0.1%	**19.1%**	**45.5%**	-2.1%	0.2%	1.6%	0.2%
	21.12	Lake Roosevelt Middle Reach	2.5%	6.6%	0.4%	3.5%	5.7%	0.5%	-0.5%	-1.7%	0.0%	8.6%	**22.5%**	1.5%	0.2%	0.2%	-0.1%
	21.11	Lake Roosevelt Lower Reach	1.3%	2.0%	0.1%	1.9%	0.9%	0.1%	-0.5%	-3.0%	0.0%	4.6%	**11.3%**	0.2%	0.1%	-0.7%	0.0%
	20.12	Upper Chief Joseph Pool	-2.5%	-5.2%	0.0%	0.5%	-0.9%	0.0%	-2.0%	-5.6%	0.0%	-3.4%	-2.1%	0.1%	-0.2%	-0.4%	0.0%
	20.11	Lower Chief Joseph Pool	-2.9%	-6.3%	0.0%	-1.0%	-0.4%	0.0%	-2.8%	-7.9%	0.0%	-5.3%	-1.0%	0.0%	0.0%	-0.9%	0.0%
	19.12	Upper Wells Pool	-3.0%	-6.1%	0.1%	-0.5%	-1.8%	0.0%	-3.0%	-6.8%	0.1%	-4.3%	-5.3%	0.0%	-0.2%	-0.5%	0.0%
	19.11	Lower Wells Pool	-2.2%	-7.2%	0.0%	0.6%	-2.1%	0.0%	-2.1%	-7.7%	0.0%	-1.6%	-3.0%	0.0%	-0.3%	-0.6%	0.0%
	18.12	Upper Rocky Reach Pool	-1.9%	-5.1%	0.6%	0.7%	-1.5%	0.1%	-1.7%	-5.4%	0.7%	-1.3%	-2.5%	0.6%	-0.3%	-0.3%	0.0%
	18.11	Lower Rocky Reach Pool	-2.9%	-5.7%	0.0%	-0.5%	-0.1%	0.0%	-2.6%	-6.6%	0.0%	-3.0%	-1.3%	0.0%	-0.2%	-0.7%	0.0%
	17.12	Upper Rock Island Pool	-2.3%	-3.5%	1.2%	0.4%	-0.5%	0.3%	-2.9%	-5.0%	1.3%	-0.8%	-0.6%	0.0%	-0.3%	-0.4%	0.1%
	17.11	Lower Rock Island Pool	-2.6%	-6.6%	0.0%	0.3%	-1.8%	0.0%	-2.4%	-7.4%	0.0%	-2.7%	-2.2%	0.0%	-0.2%	-0.6%	0.0%
	16.12	Upper Wanapum Pool	-2.2%	-7.1%	-0.1%	0.2%	-1.3%	0.0%	-2.4%	-7.1%	-0.1%	-1.5%	-5.8%	0.0%	-0.3%	-0.5%	0.0%
	16.11	Lower Wanapum Pool	-2.0%	-6.5%	0.0%	0.5%	-1.7%	0.0%	-1.9%	-7.3%	0.0%	-2.0%	-2.9%	0.0%	-0.2%	-0.5%	0.0%
	15.11	Priest Rapids Pool	-2.2%	-4.8%	0.0%	-0.1%	0.0%	0.0%	-2.6%	-5.3%	0.0%	-2.6%	0.0%	0.0%	-0.2%	-0.5%	0.0%
	14.12	Hanford Reach	-0.9%	-1.7%	0.7%	0.0%	-0.6%	0.1%	-0.9%	-1.7%	0.7%	-0.3%	-0.9%	0.3%	-0.1%	-0.2%	0.0%
	14.11	Richland Reach	-1.9%	-3.7%	0.3%	0.3%	-1.1%	0.0%	-1.6%	-3.7%	0.4%	1.1%	9.6%	1.1%	-0.3%	-0.3%	0.0%

Table 4-12. Region B: Middle Columbia Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**
Columbia – U.S.-Canada border to Richland, Washington	21.14	Northport Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	**Minor**	**Minor**	Negligible	Negligible	Negligible	Negligible
	21.13	Lake Roosevelt Upper Reach	Negligible	**Minor**	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	Negligible	**Minor**	**Minor**	Negligible	Negligible	Negligible	Negligible
	21.12	Lake Roosevelt Middle Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	**Minor**	Negligible	Negligible	Negligible	Negligible
	21.11	Lake Roosevelt Lower Reach	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect
	20.12	Upper Chief Joseph Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	20.11	Lower Chief Joseph Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	19.12	Upper Wells Pool	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	19.11	Lower Wells Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	18.12	Upper Rocky Reach Pool	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	18.11	Lower Rocky Reach Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	17.12	Upper Rock Island Pool	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible
	17.11	Lower Rock Island Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	16.12	Upper Wanapum Pool	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	16.11	Lower Wanapum Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	15.11	Priest Rapids Pool	Negligible	Negligible	No Effect	Negligible	No Effect	No Effect	Negligible	Negligible	No Effect	Negligible	No Effect	No Effect	Negligible	Negligible	No Effect
	14.12	Hanford Reach	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	14.11	Richland Reach	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect

4.2.4.2 Region B1: Middle Columbia Reach (above Chief Joseph Dam) Comparison Figures

REGION B1: MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

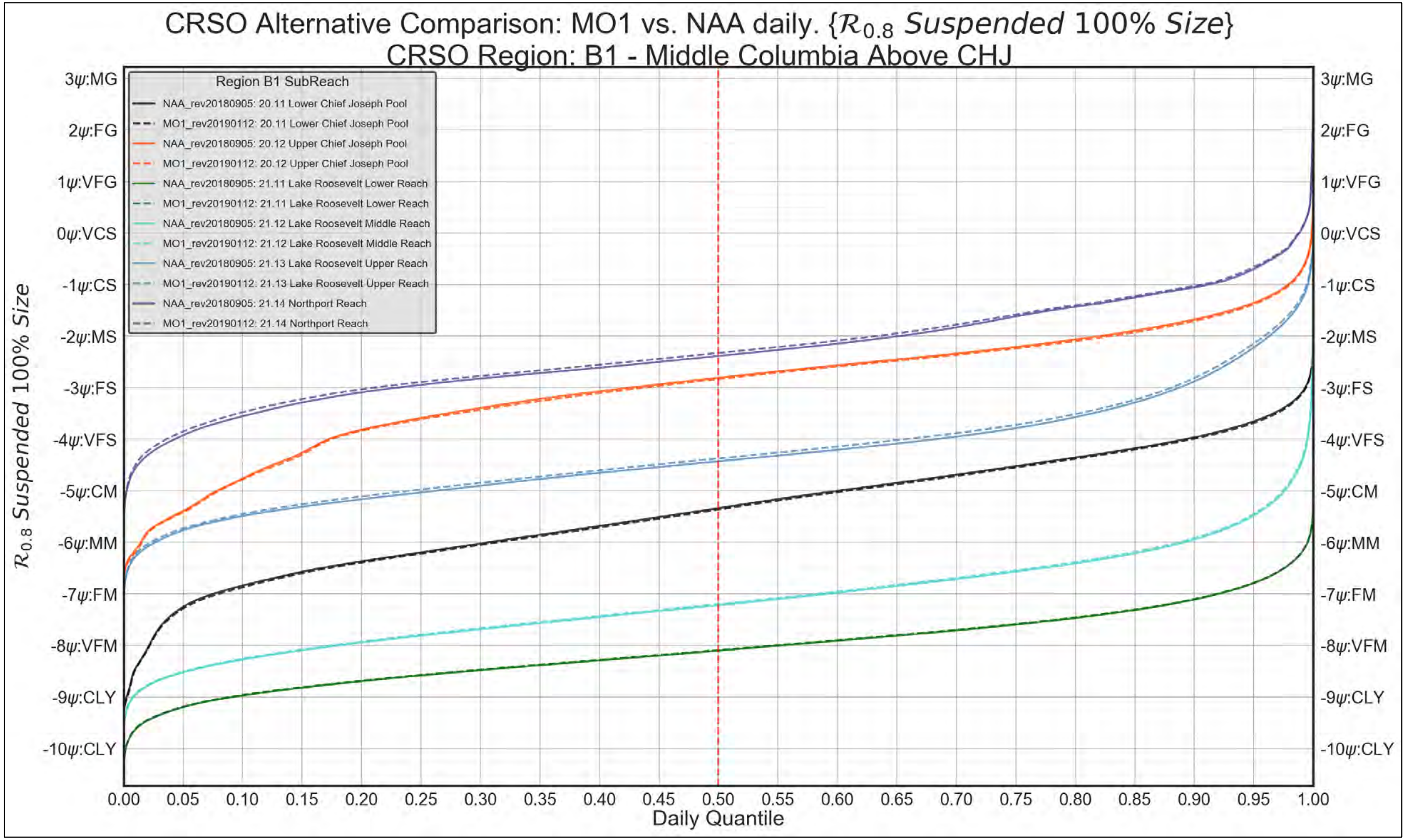
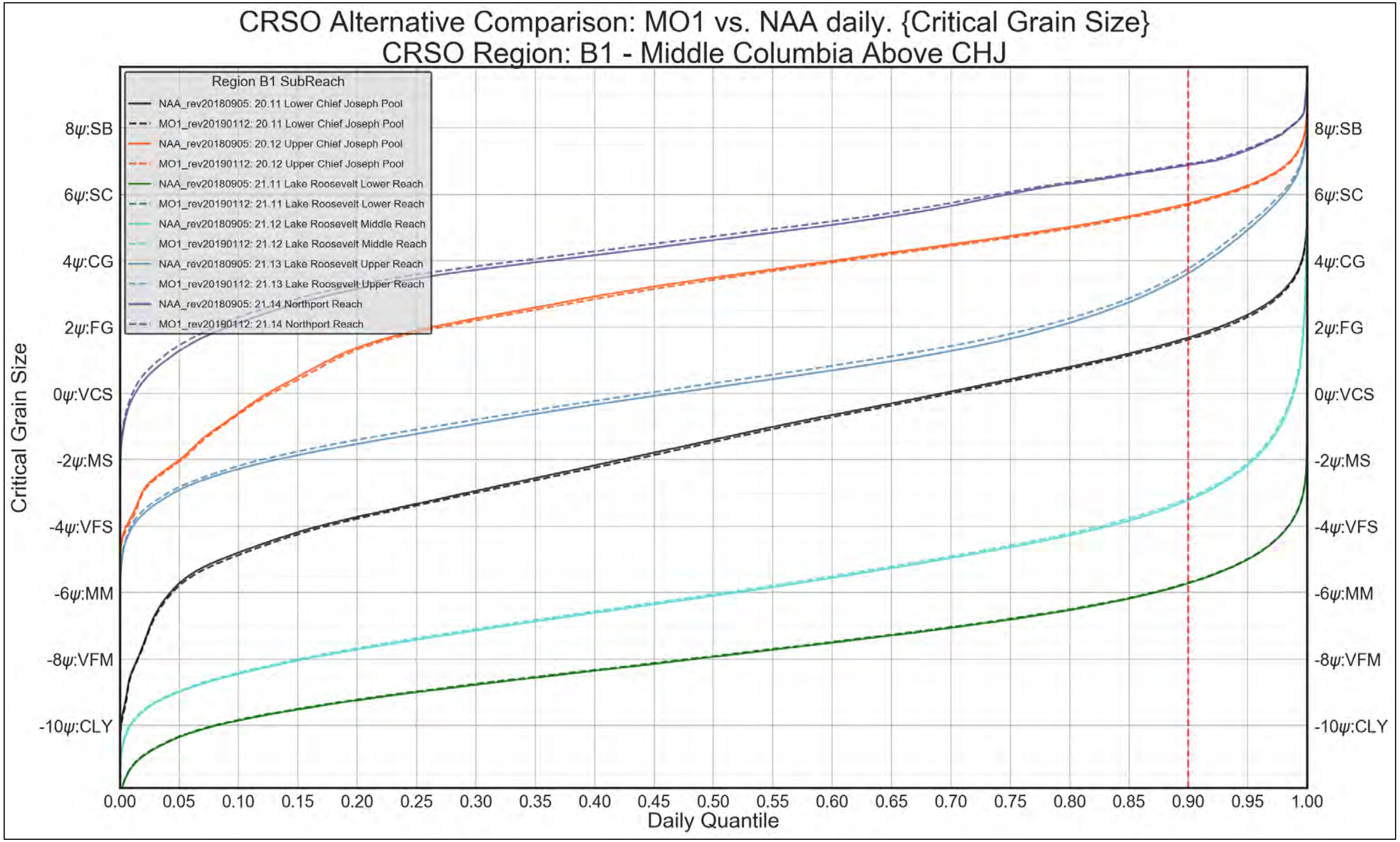
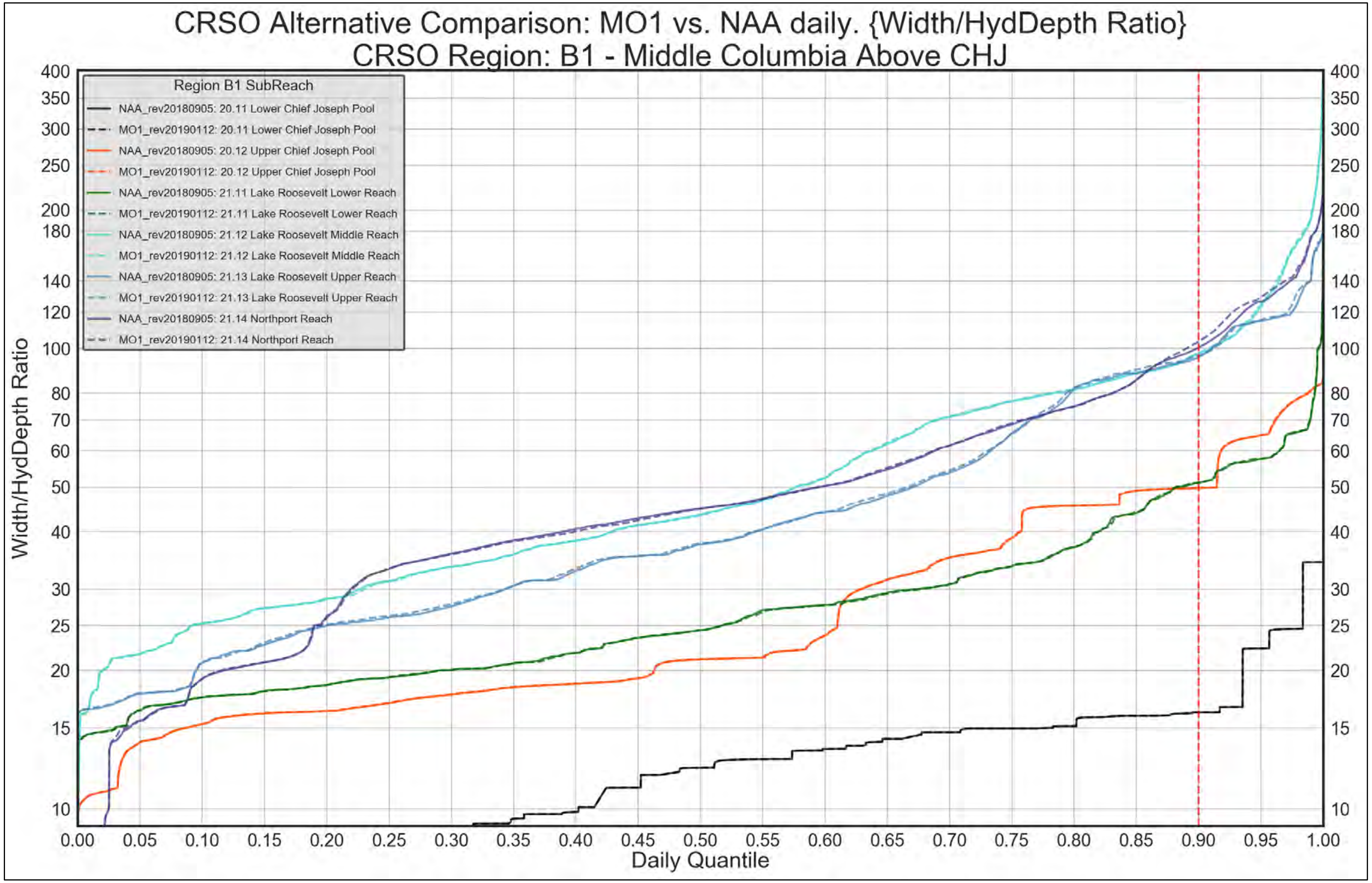


Figure 4-88. Region B1 – Middle Columbia above CHJ. MO1 vs. NAA. 100% Suspended Grain-Size Threshold



2157

2158 **Figure 4-89. Region B1 – Middle Columbia above CHJ. MO1 vs. NAA. Critical Grain-Size Threshold**



2159
2160 **Figure 4-90. Region B1 – Middle Columbia above CHJ. MO1 vs. NAA. Width/Hydraulic Depth Ratio**

REGION B1. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

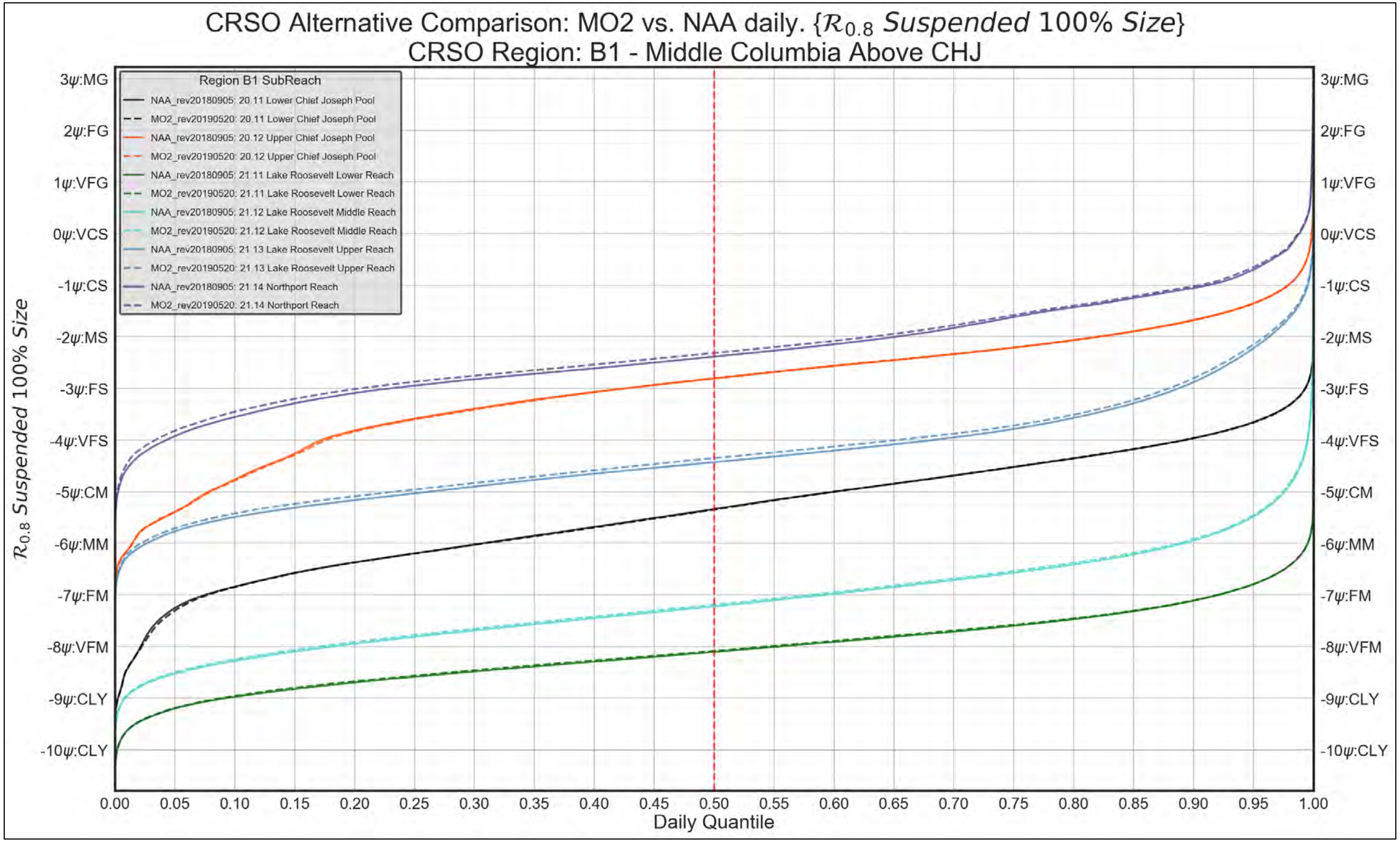


Figure 4-91. Region B1 – Middle Columbia above CHJ. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

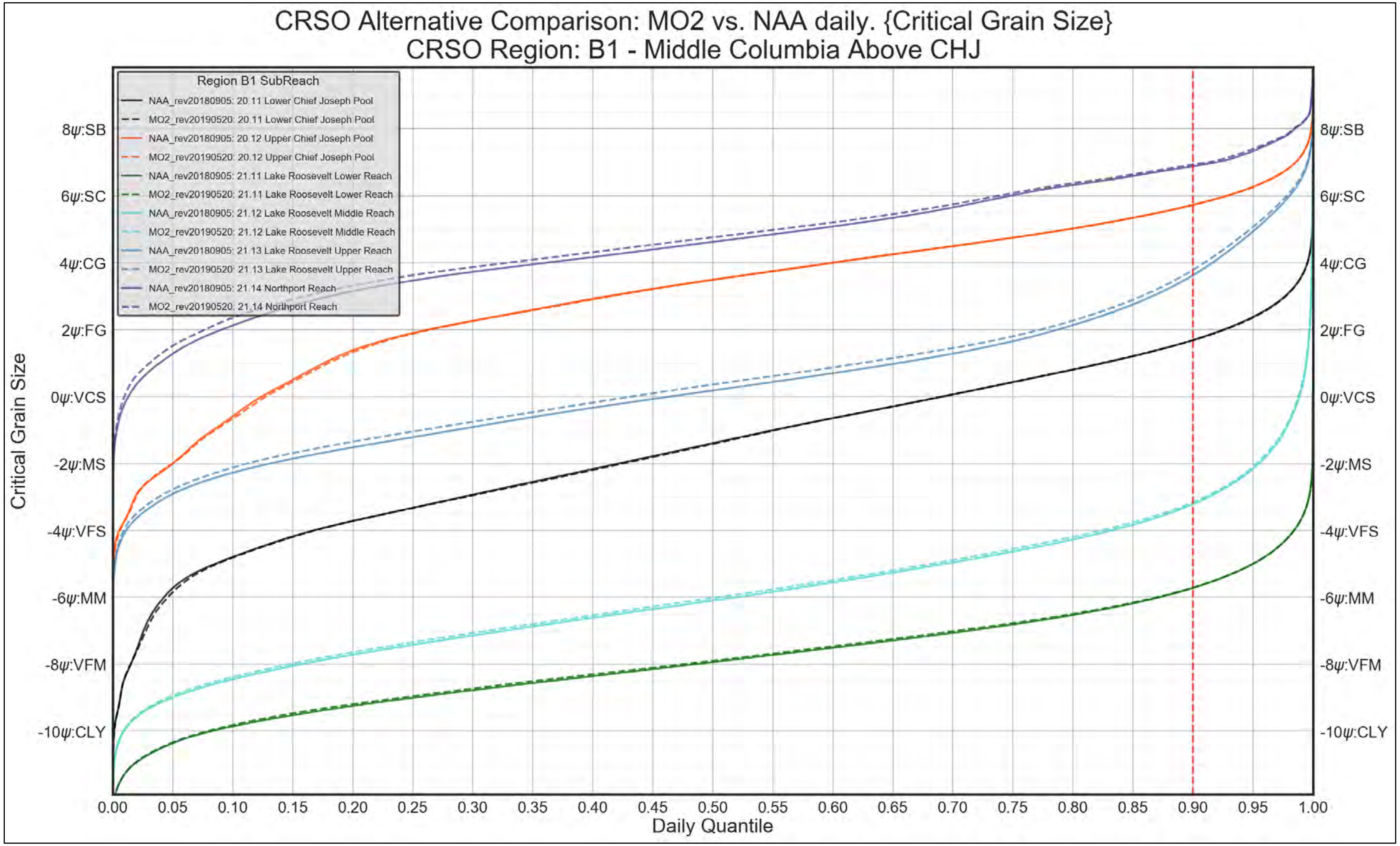


Figure 4-92. Region B1 – Middle Columbia above CHJ. MO2 vs. NAA. Critical Grain-Size Threshold

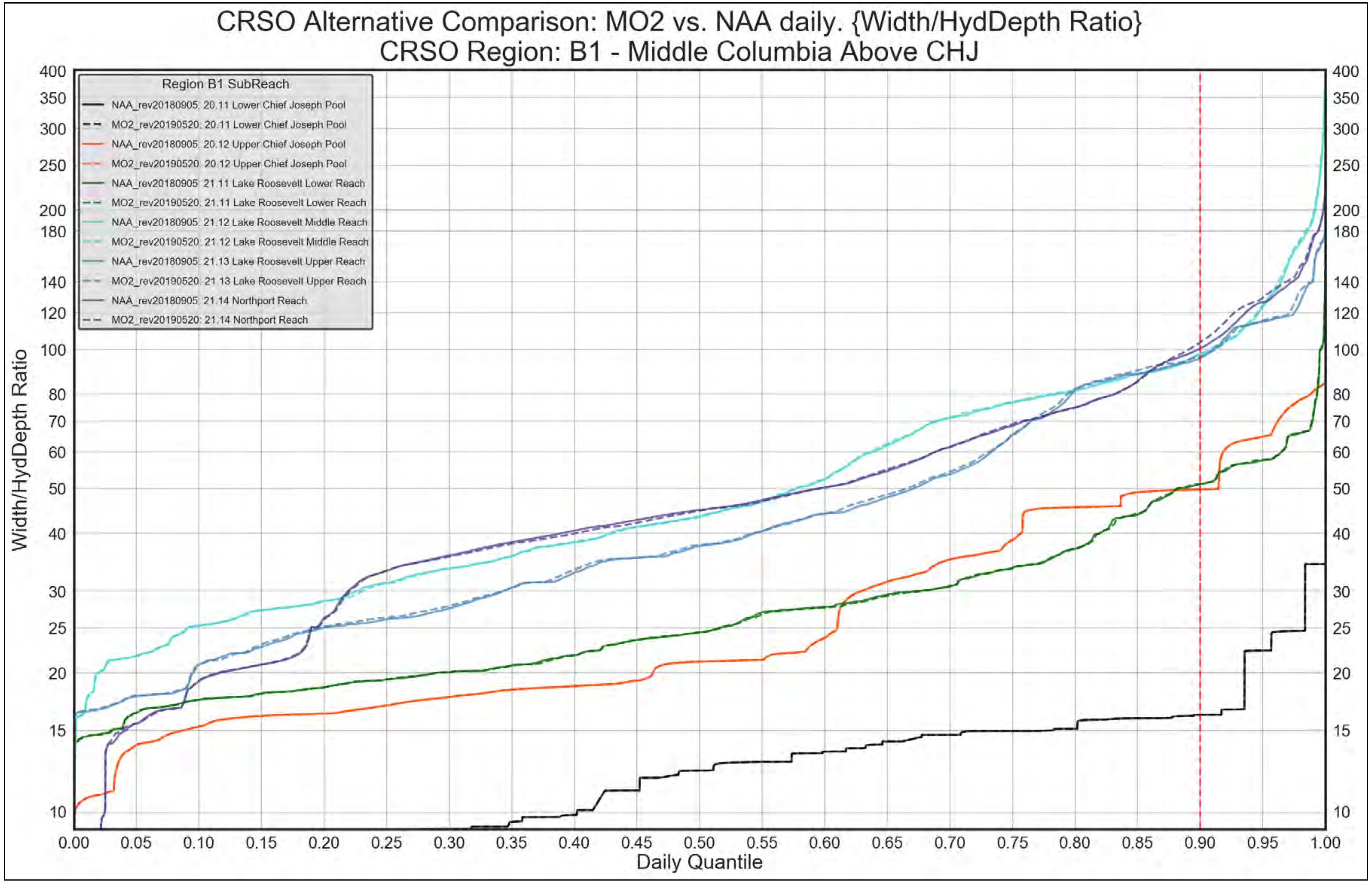
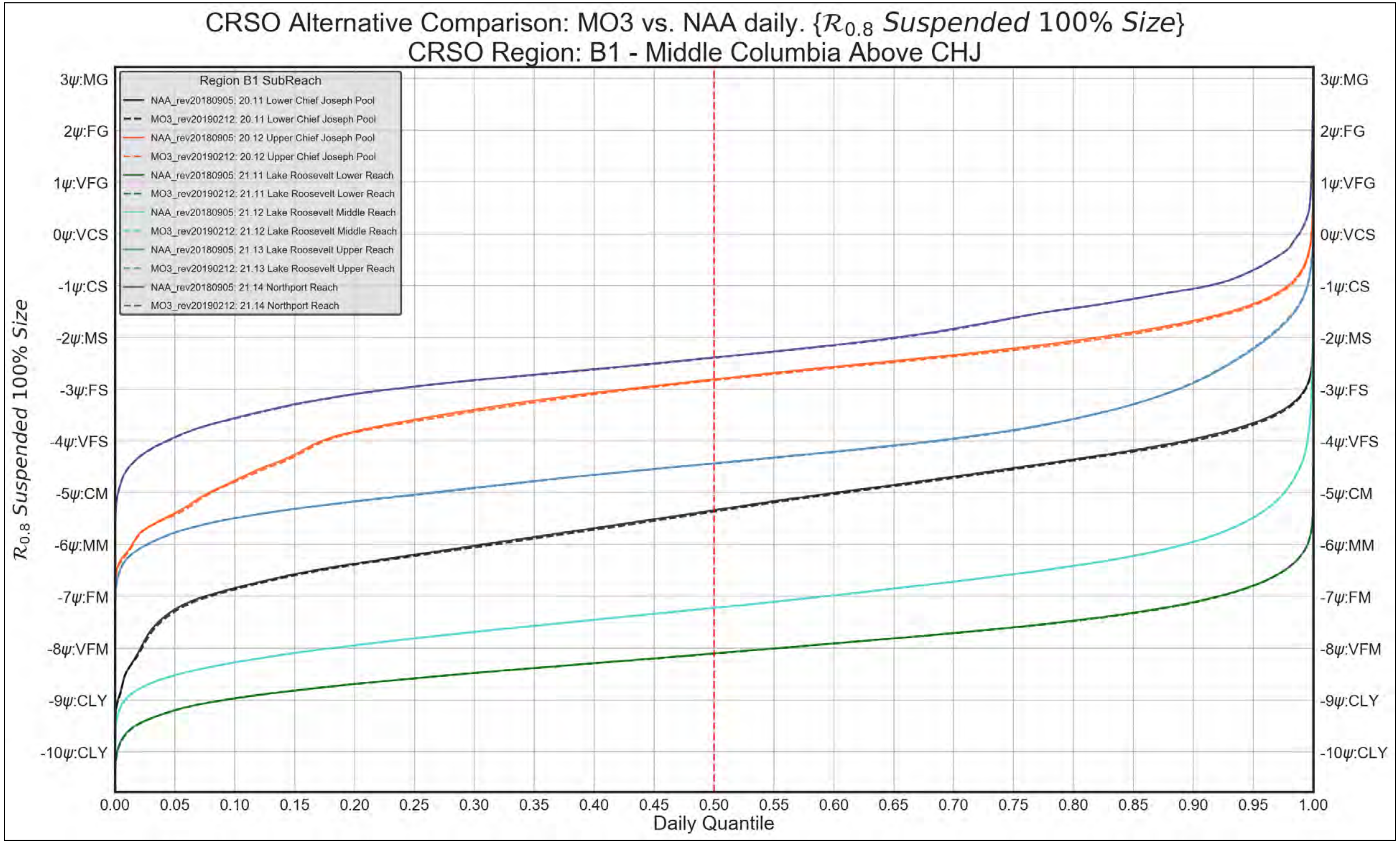


Figure 4-93. Region B1 – Middle Columbia above CHJ. MO2 vs. NAA. Width/Hydraulic Depth Ratio

2168 **REGION B1. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE**



2169

2170 Figure 4-94. Region B1 – Middle Columbia above CHJ. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

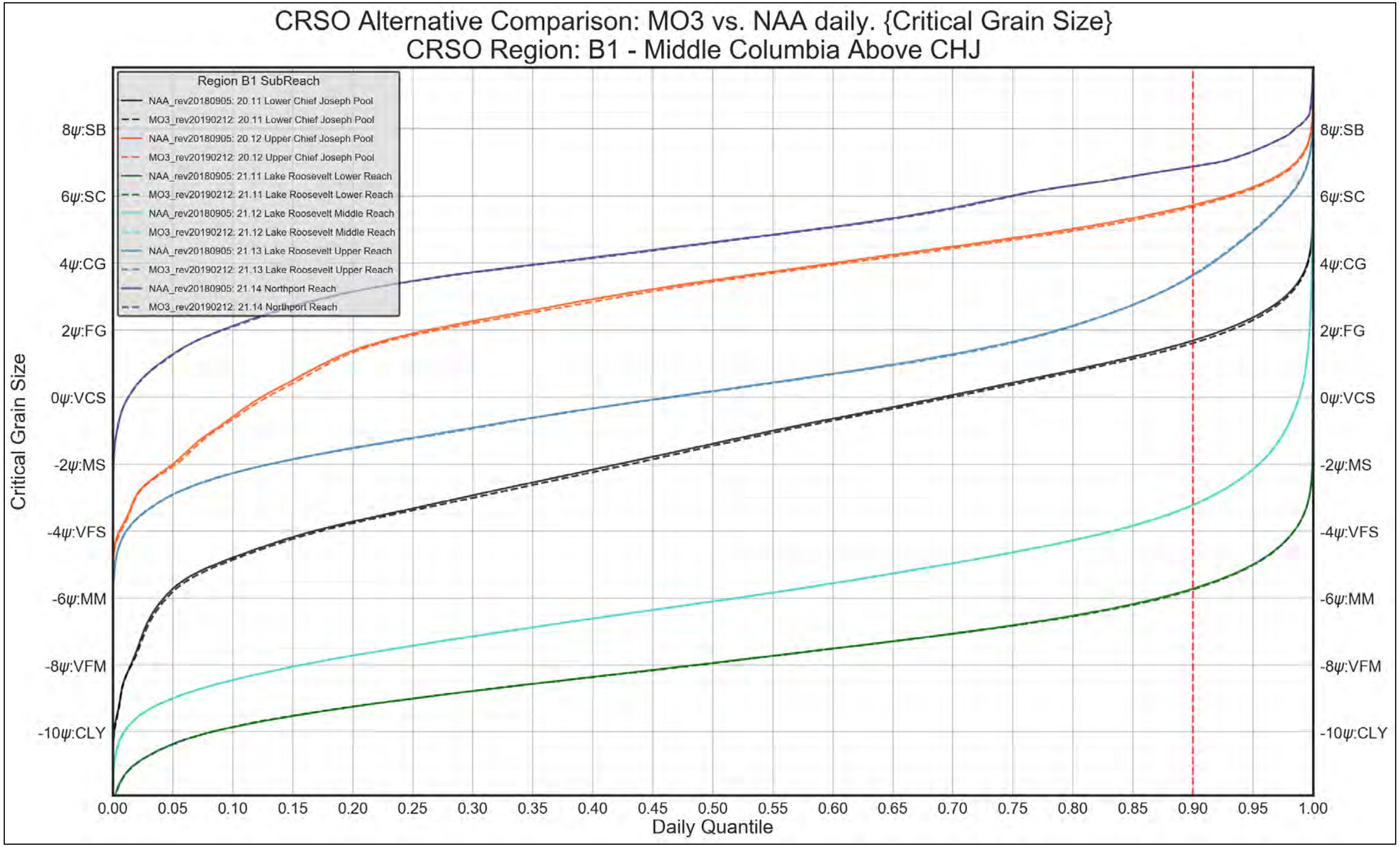


Figure 4-95. Region B1 – Middle Columbia above CHJ. MO3 vs. NAA. Critical Grain-Size Threshold

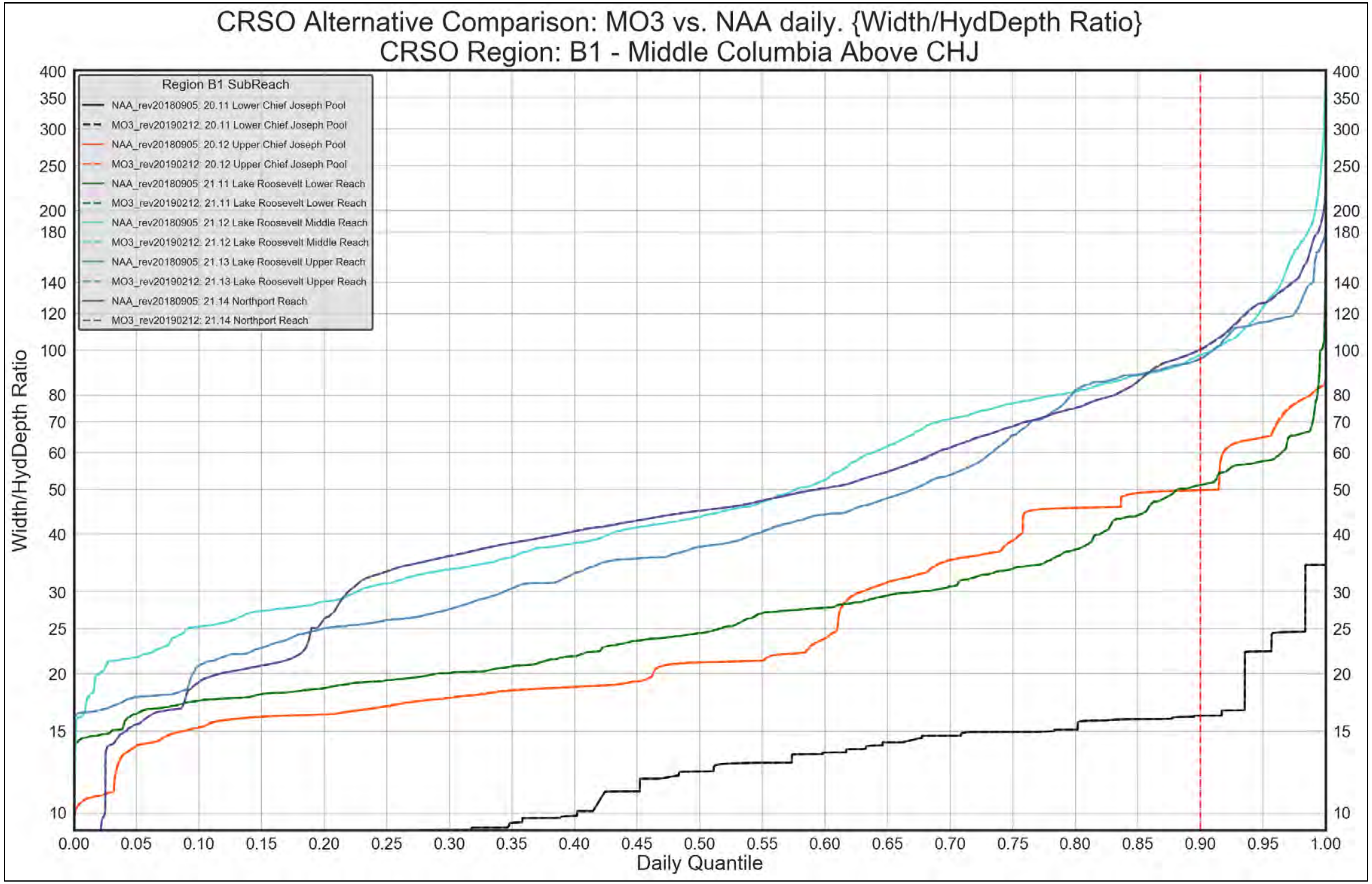


Figure 4-96. Region B1 – Middle Columbia above CHJ. MO3 vs. NAA. Width/Hydraulic Depth Ratio

REGION B1. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE

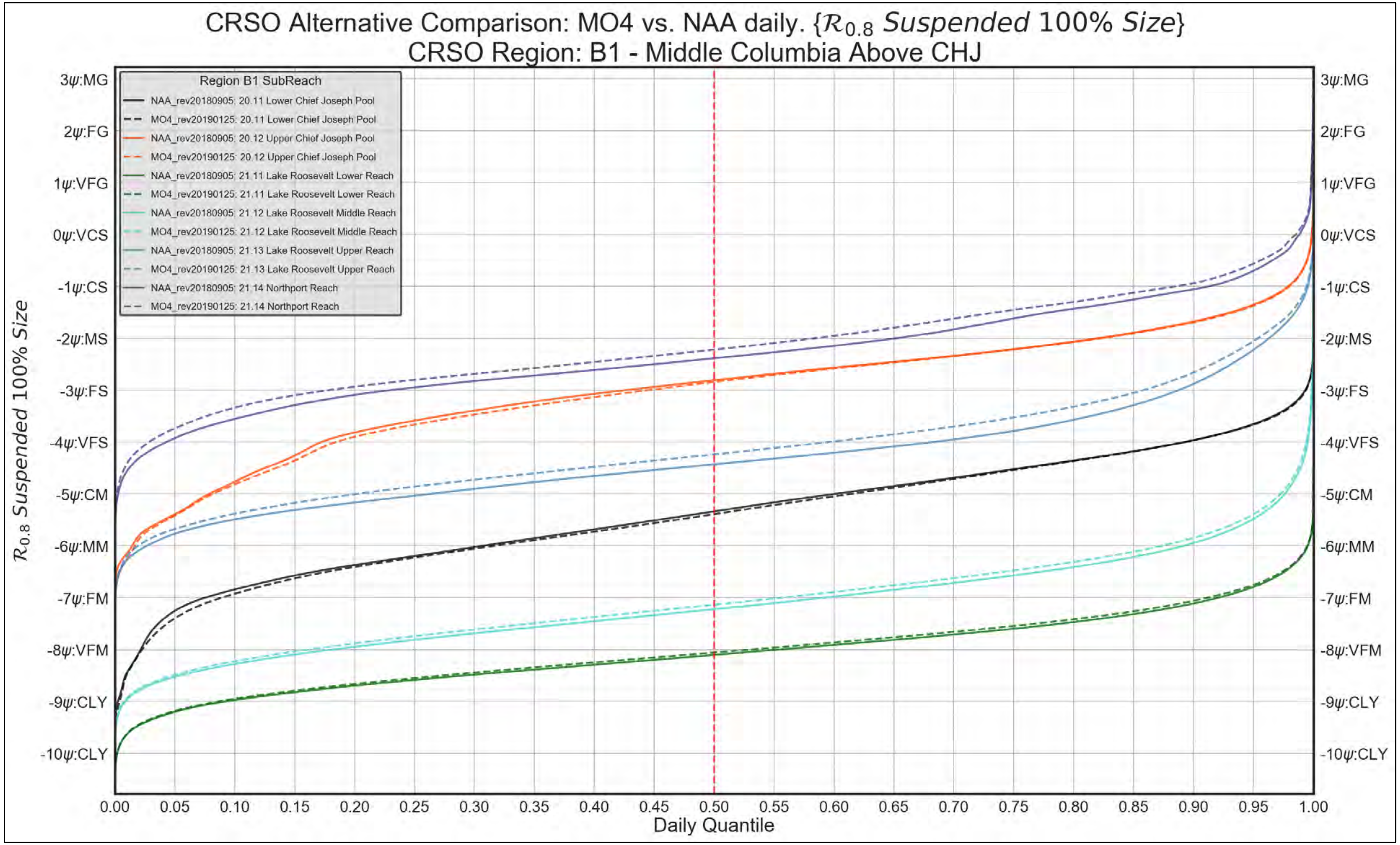


Figure 4-97. Region B1 – Middle Columbia above CHJ. MO4 vs. NAA. 100% Suspended Grain-Size Threshold

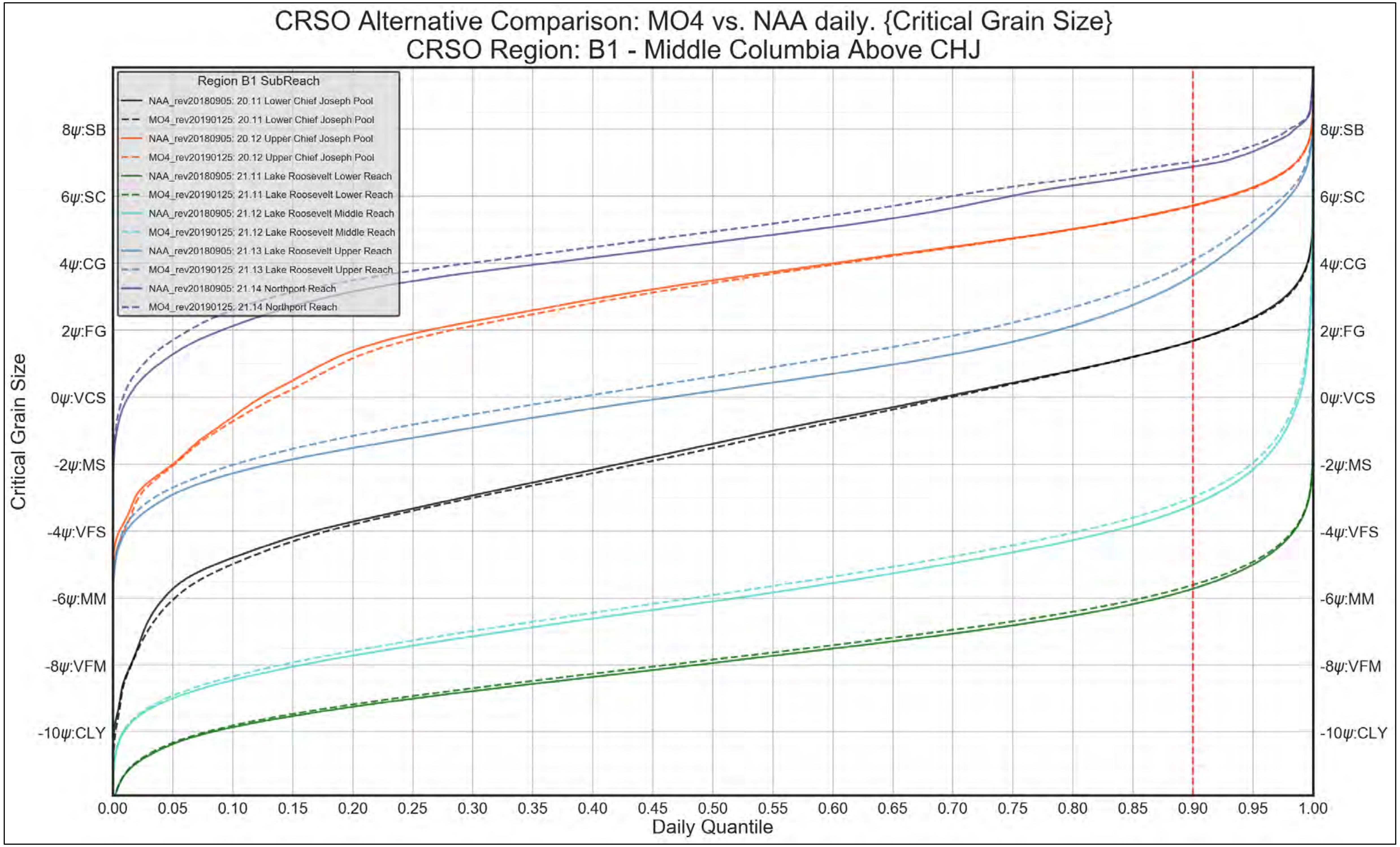
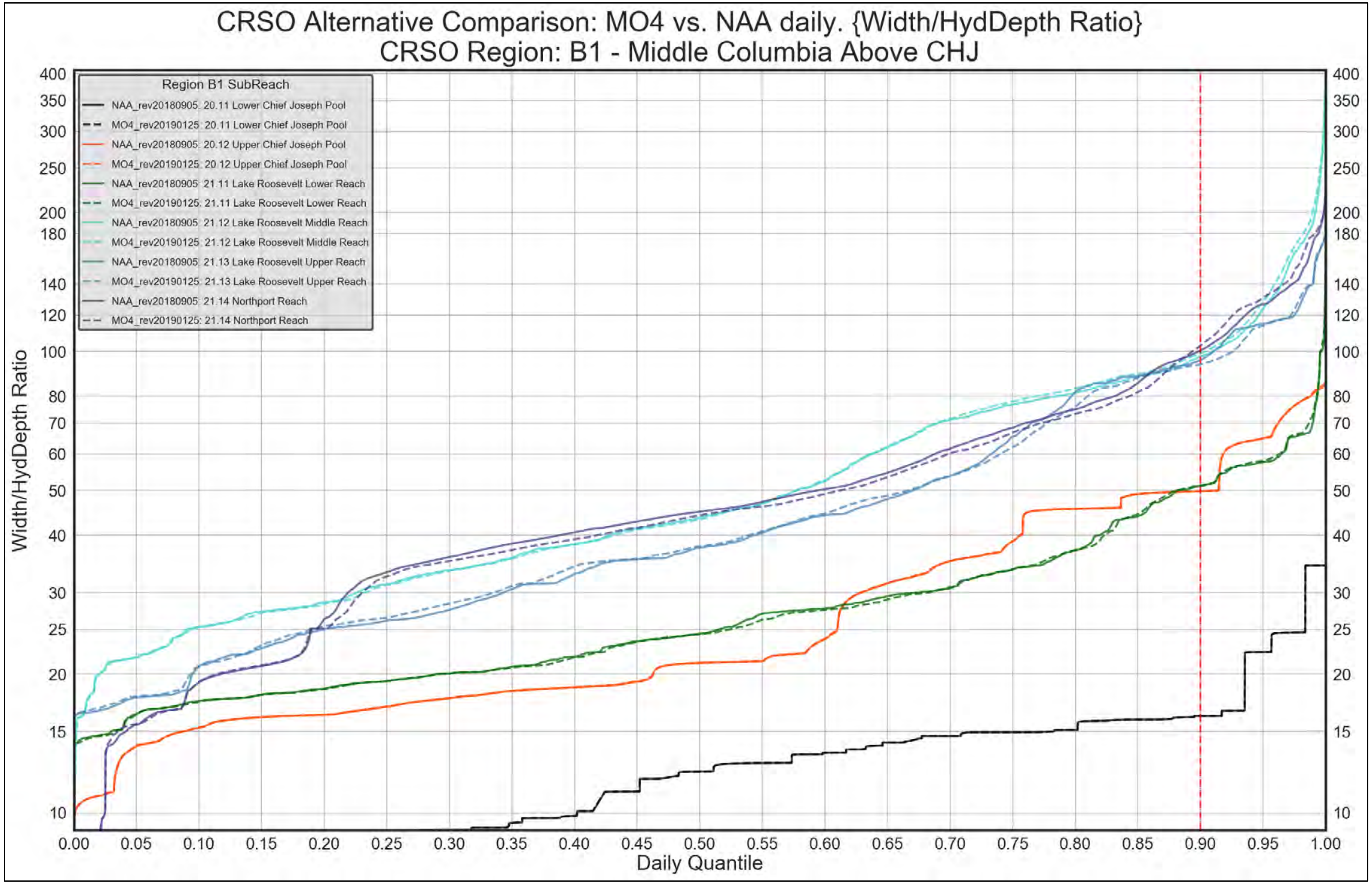
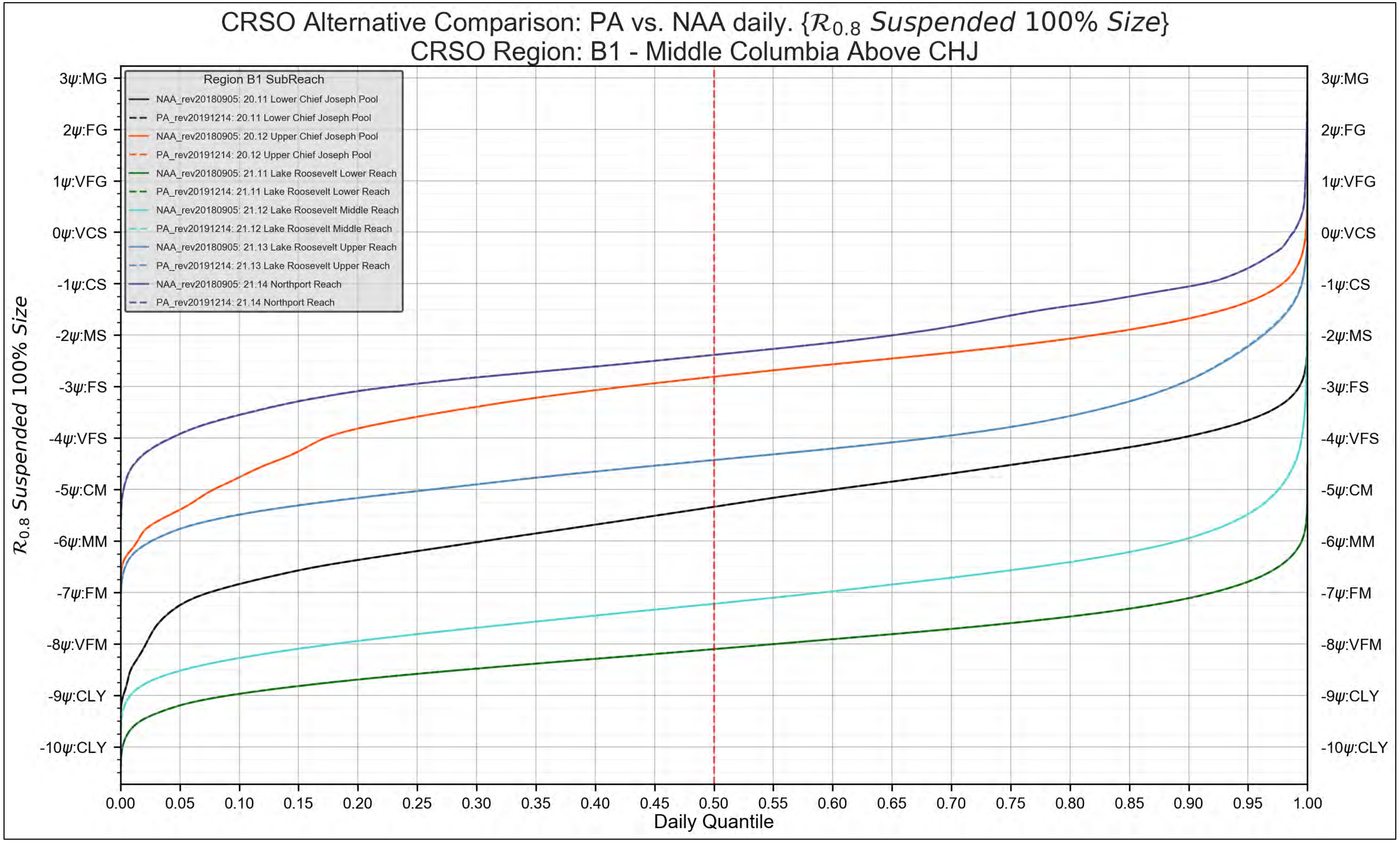


Figure 4-98. Region B1 – Middle Columbia above CHJ. MO4 vs. NAA. Critical Grain-Size Threshold



2180
2181 **Figure 4-99. Region B1 – Middle Columbia above CHJ. MO4 vs. NAA. Width/Hydraulic Depth Ratio**

2182 **REGION B1. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE**



2183
2184 **Figure 4-100 Region B1 – Middle Columbia above CHJ. PA vs. NAA. 100% Suspended Grain-Size Threshold**

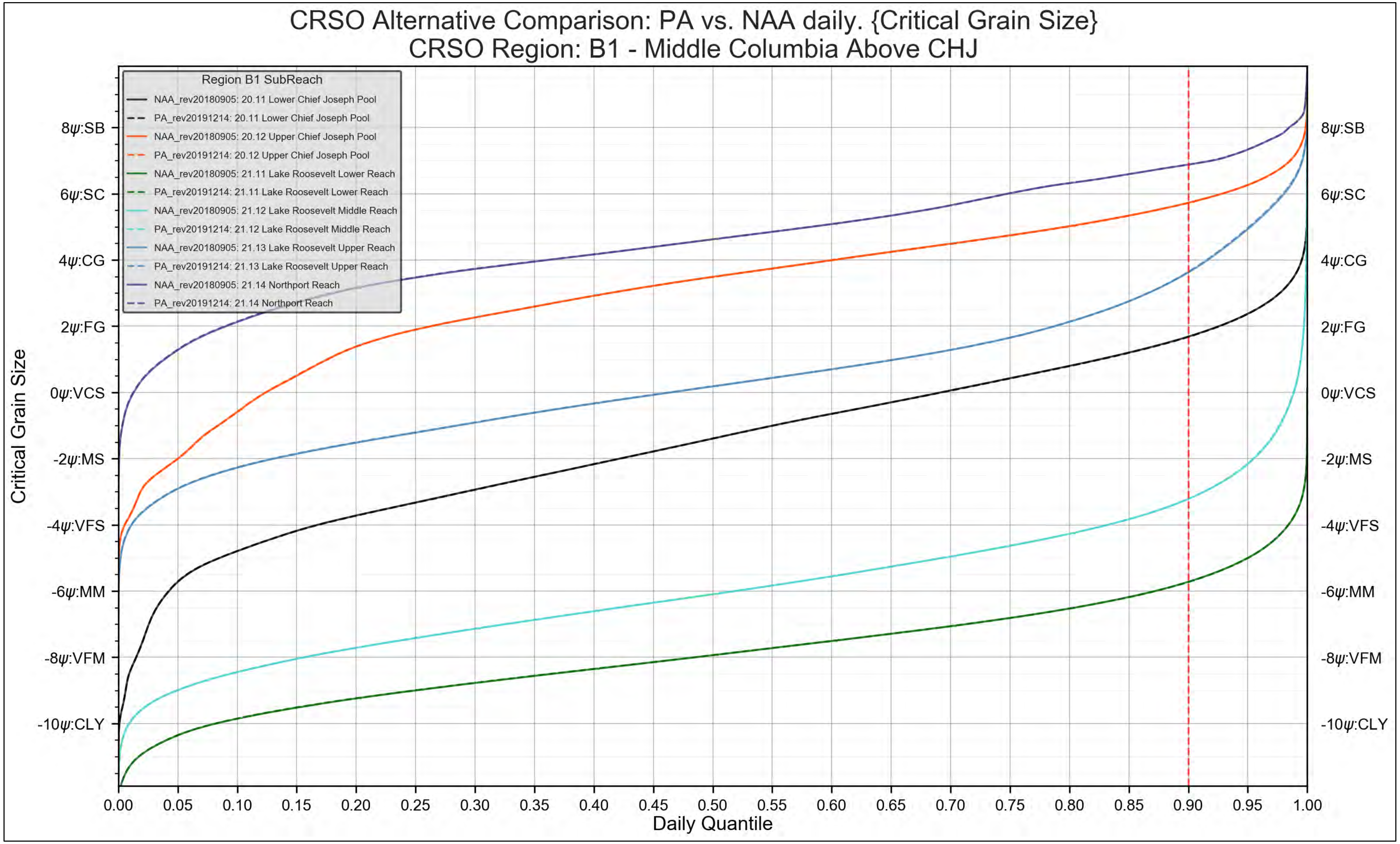
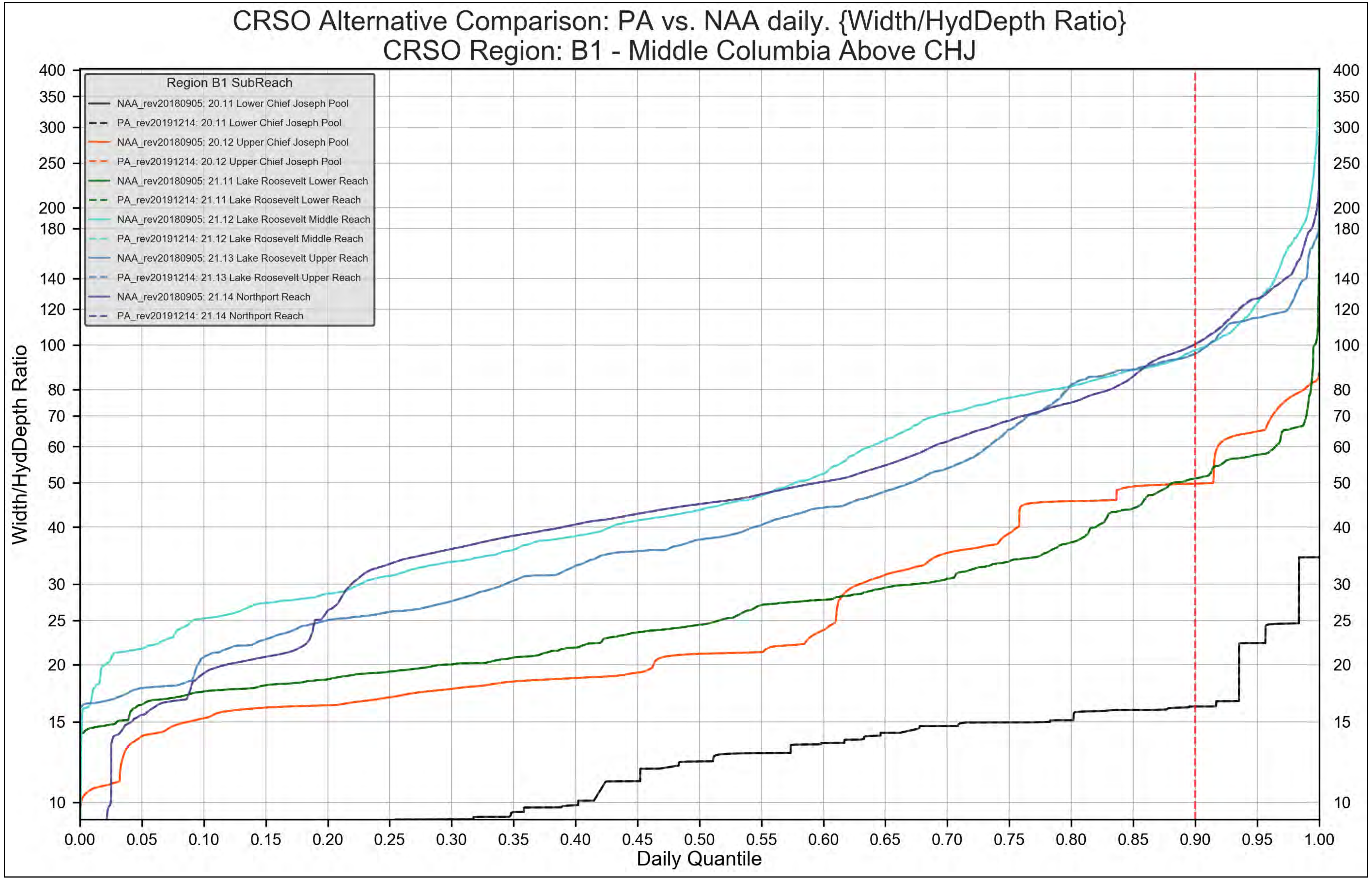


Figure 4-101 Region B1 – Middle Columbia above CHJ. PA vs. NAA. Critical Grain-Size Threshold



2187

2188 **Figure 4-102 Region B1 – Middle Columbia above CHJ. PA vs. NAA. Width/Hydraulic Depth Ratio**

4.2.4.3 Region B2. Middle Columbia Reach (Below CHJ). Comparison Figures

REGION B2. MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

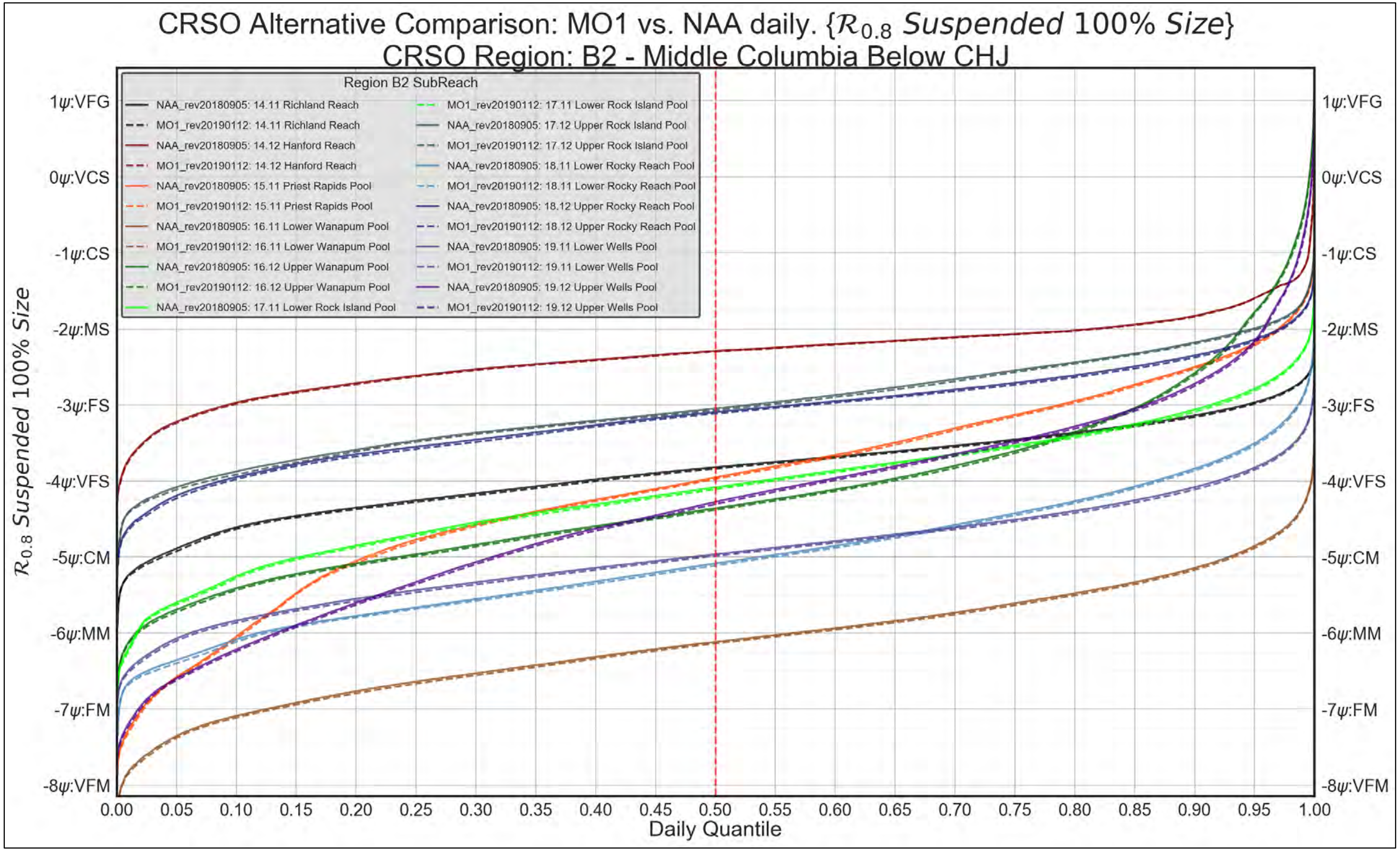


Figure 4-103 Region B2 – Middle Columbia below CHJ. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

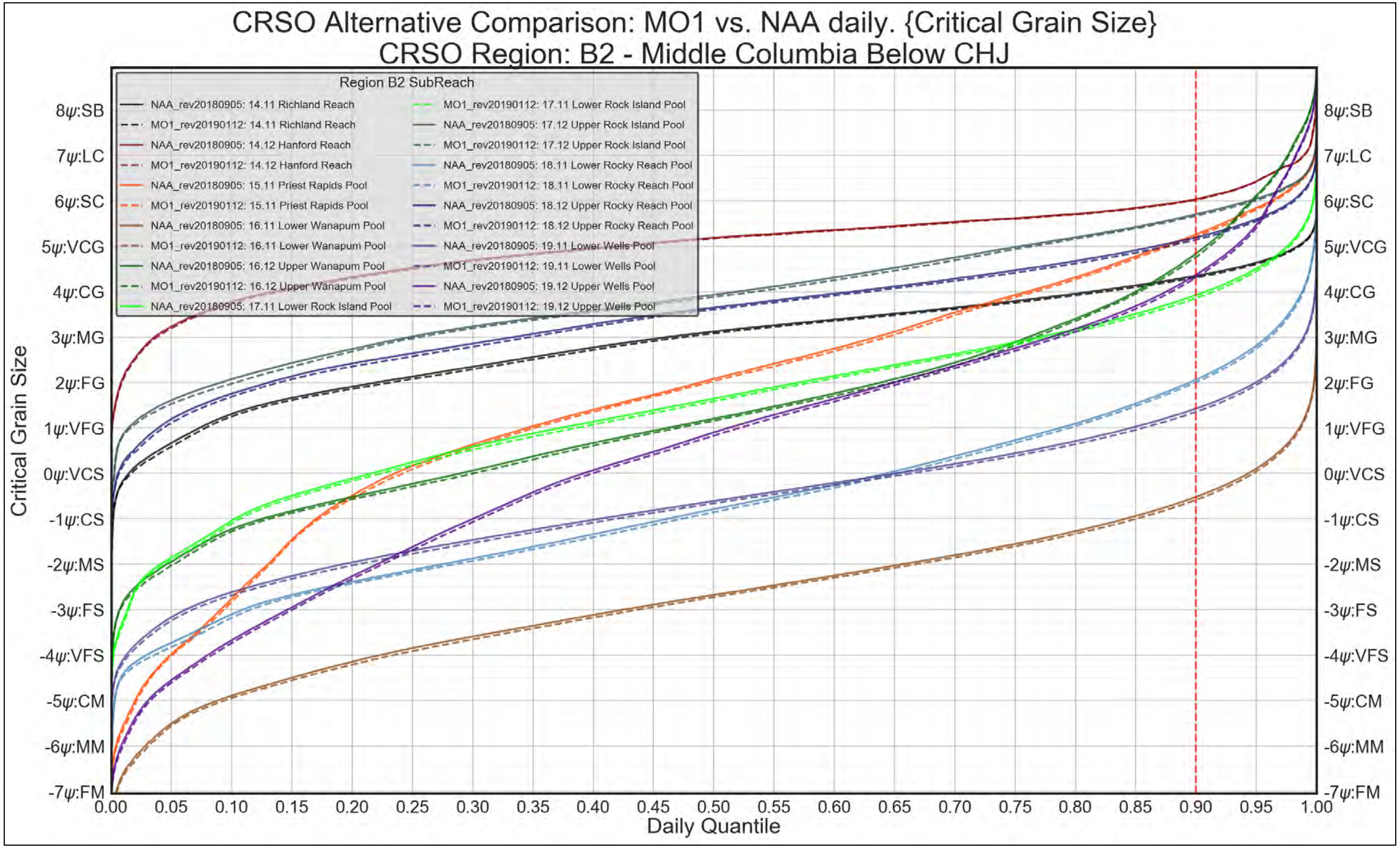


Figure 4-104. Region B2 – Middle Columbia below CHJ. MO1 vs. NAA. Critical Grain-Size Threshold

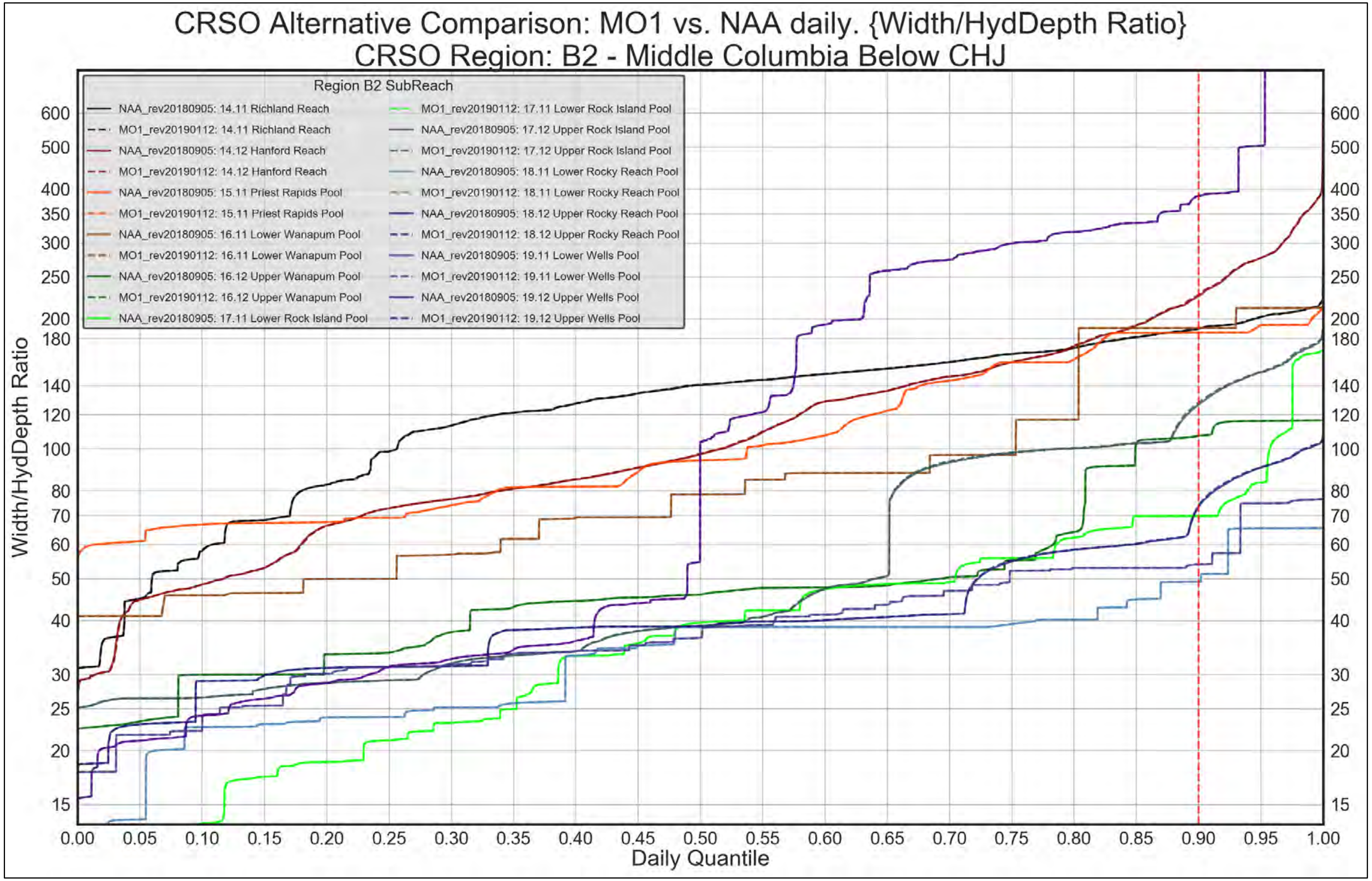


Figure 4-105. Region B2 – Middle Columbia below CHJ. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION B2. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

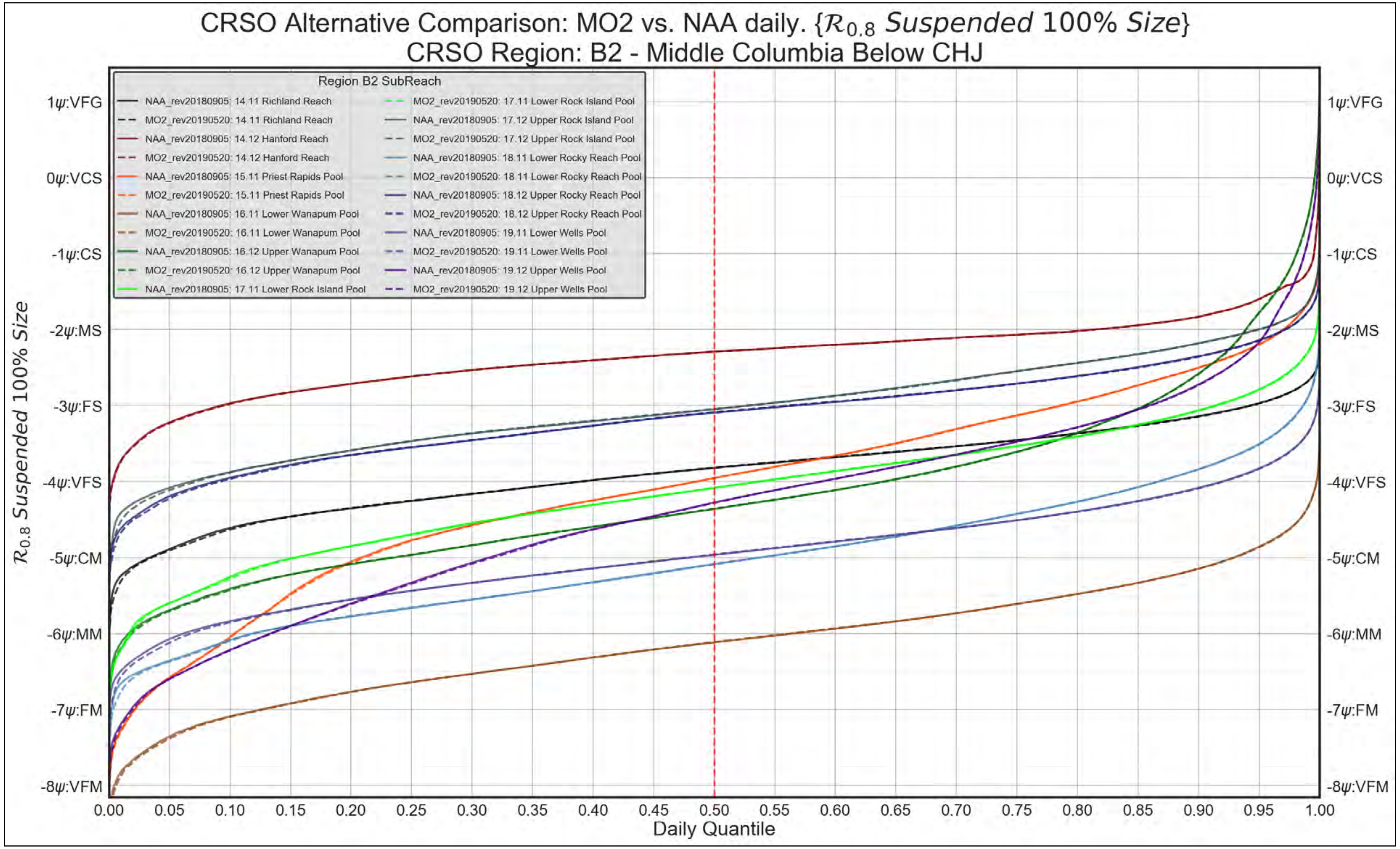


Figure 4-106. Region B2 – Middle Columbia below CHJ. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

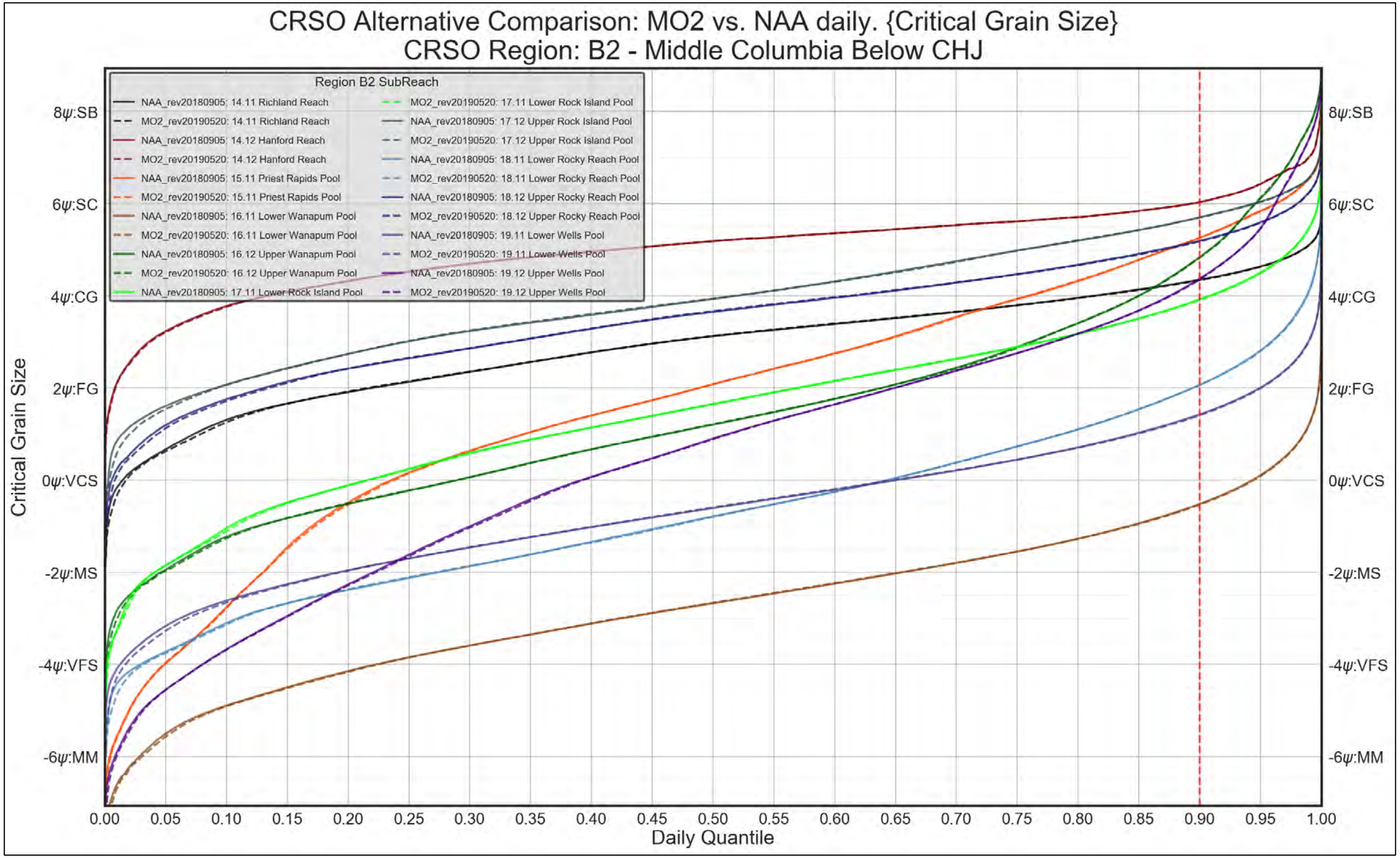


Figure 4-107. Region B2 – Middle Columbia below CHJ. MO2 vs. NAA. Critical Grain-Size Threshold

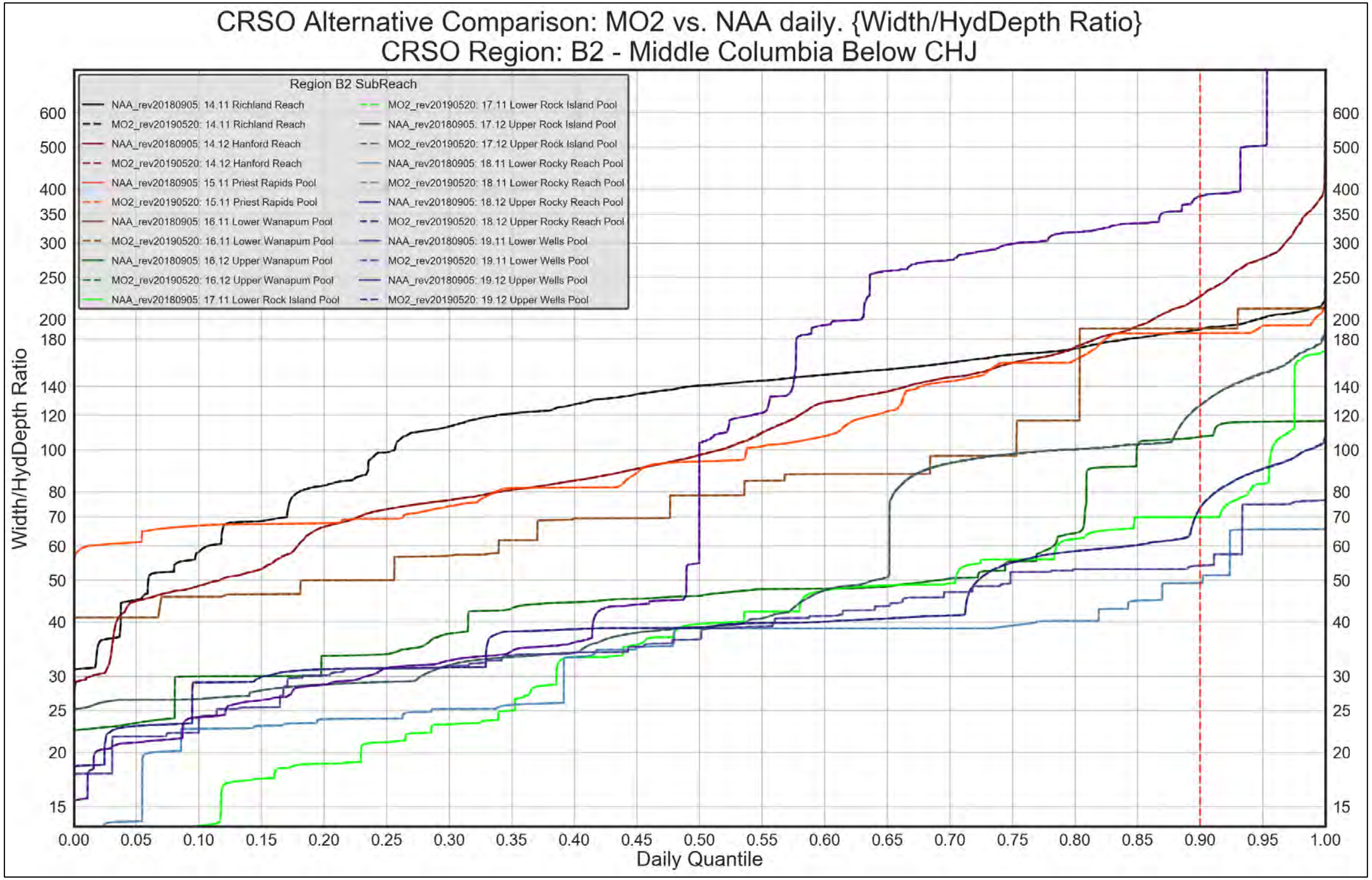


Figure 4-108 Region B2 – Middle Columbia below CHJ. MO2 vs. NAA. Width/Hydraulic Depth Ratio

REGION B2. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

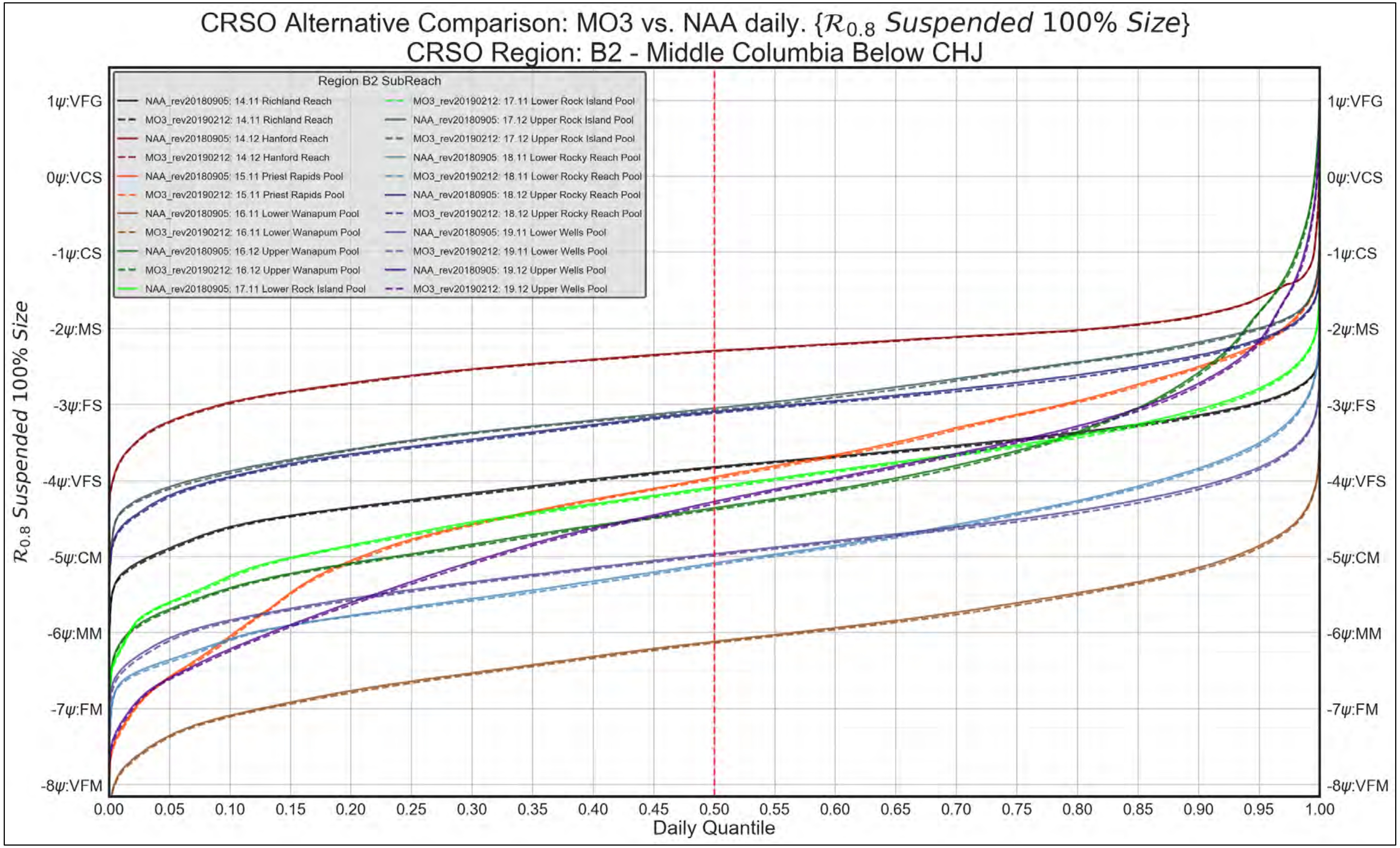


Figure 4-109 Region B2 – Middle Columbia below CHJ. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

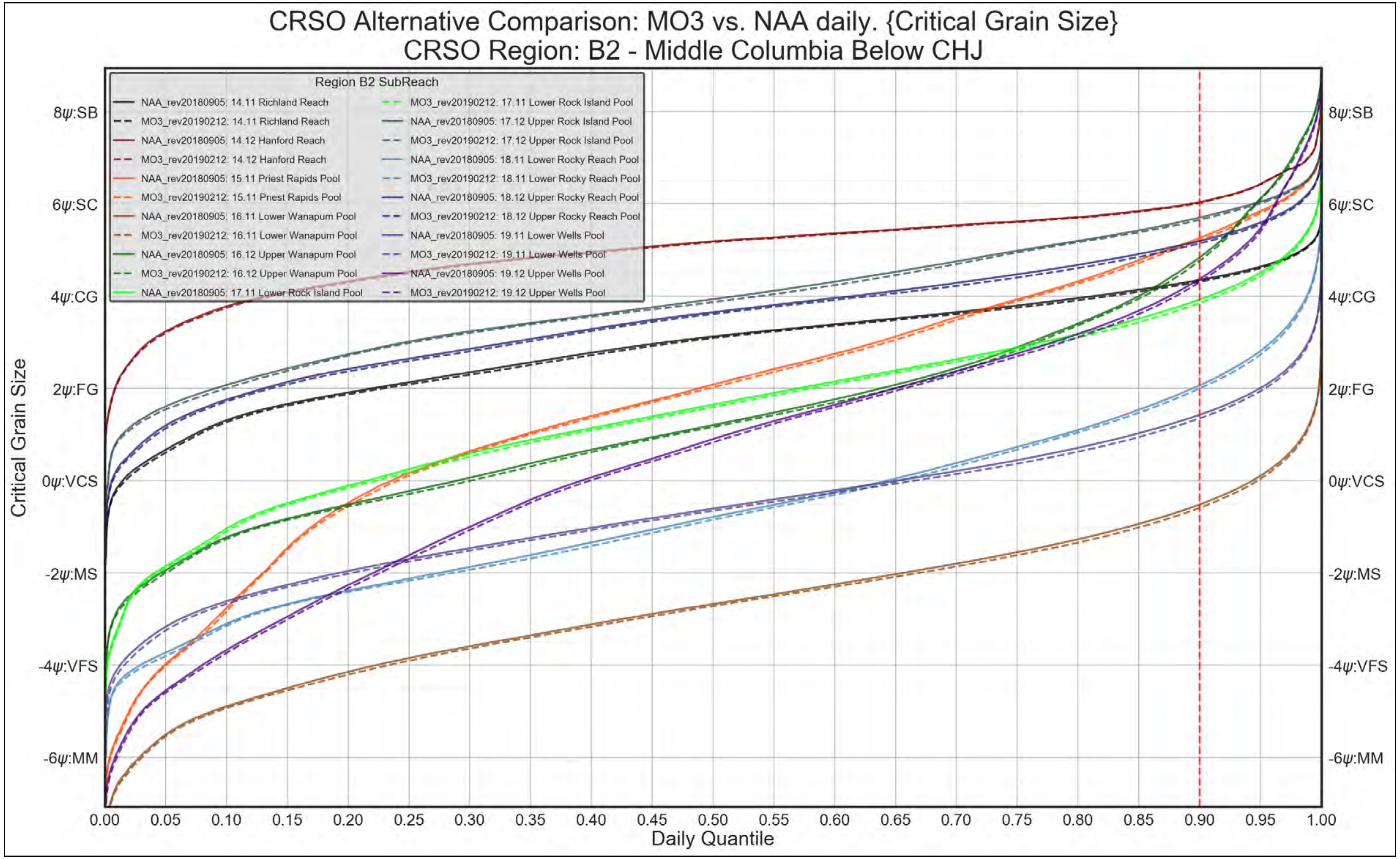


Figure 4-110 Region B2 – Middle Columbia below CHJ. MO3 vs. NAA. Critical Grain-Size Threshold

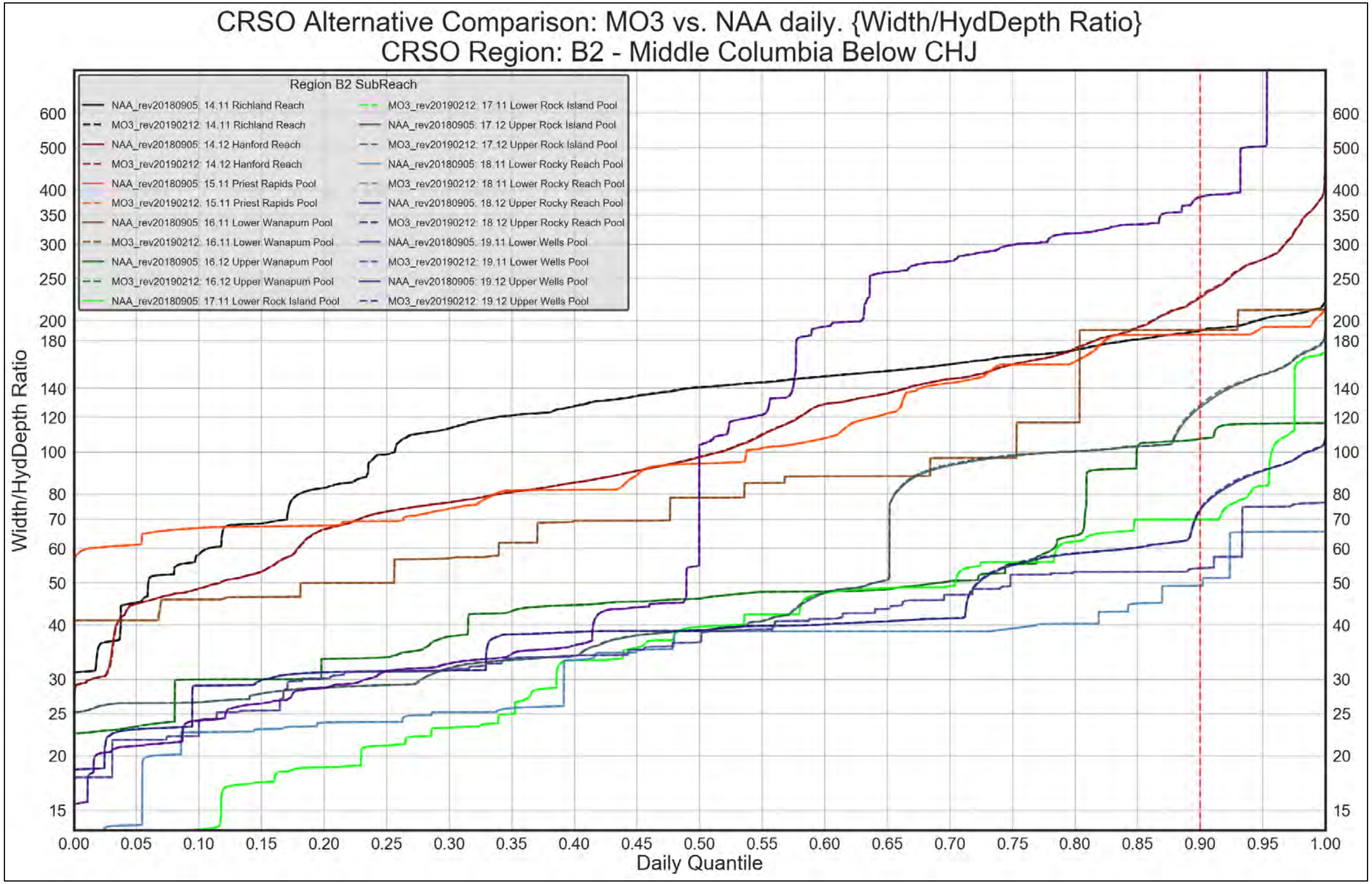
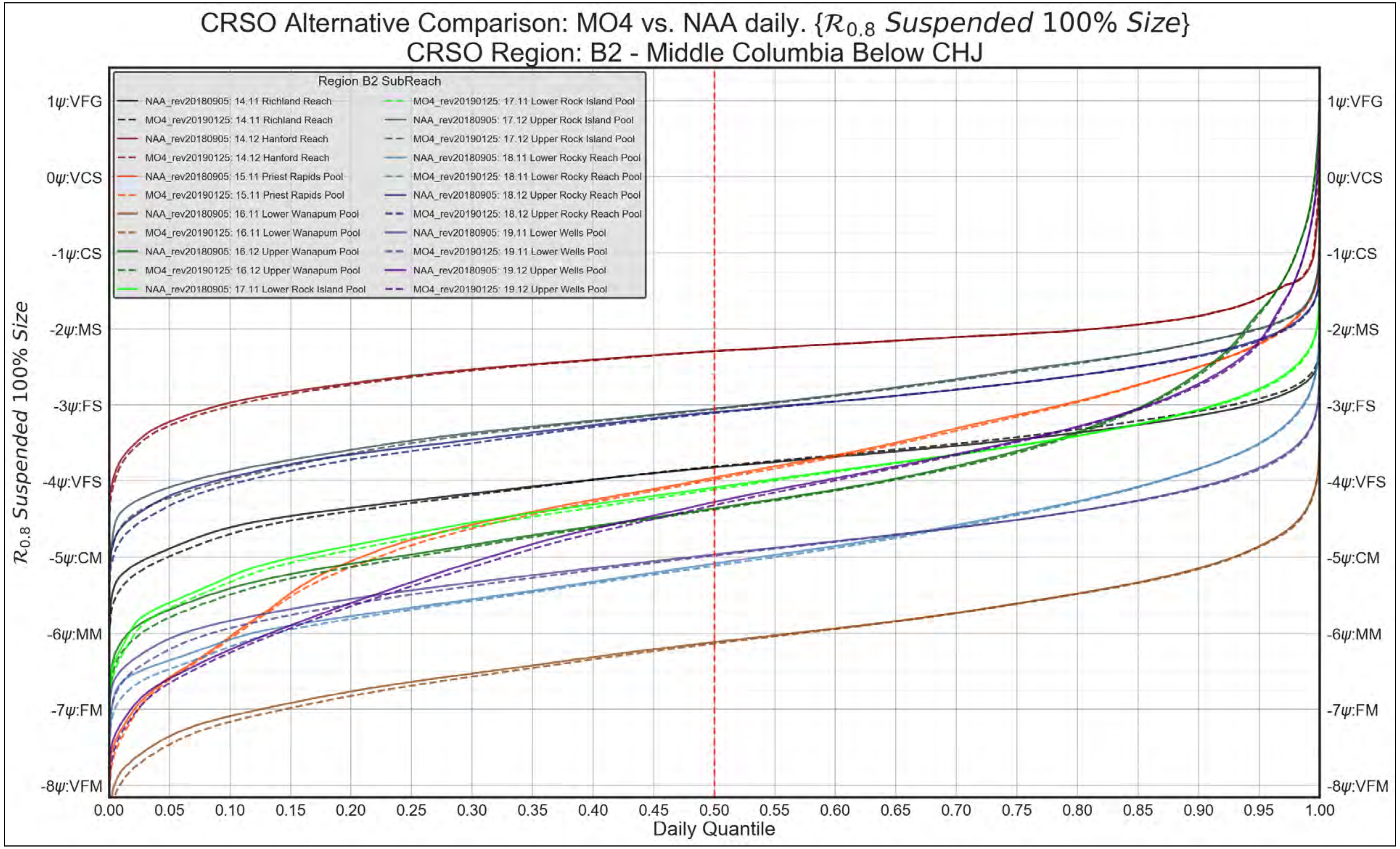


Figure 4-111. Region B2 – Middle Columbia below CHJ. MO3 vs. NAA. Width/Hydraulic Depth Ratio

2211 REGION B2. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE



2212

2213 **Figure 4-112. Region B2 – Middle Columbia below CHJ. MO4 vs. NAA. 100% Suspended Grain-Size Threshold**

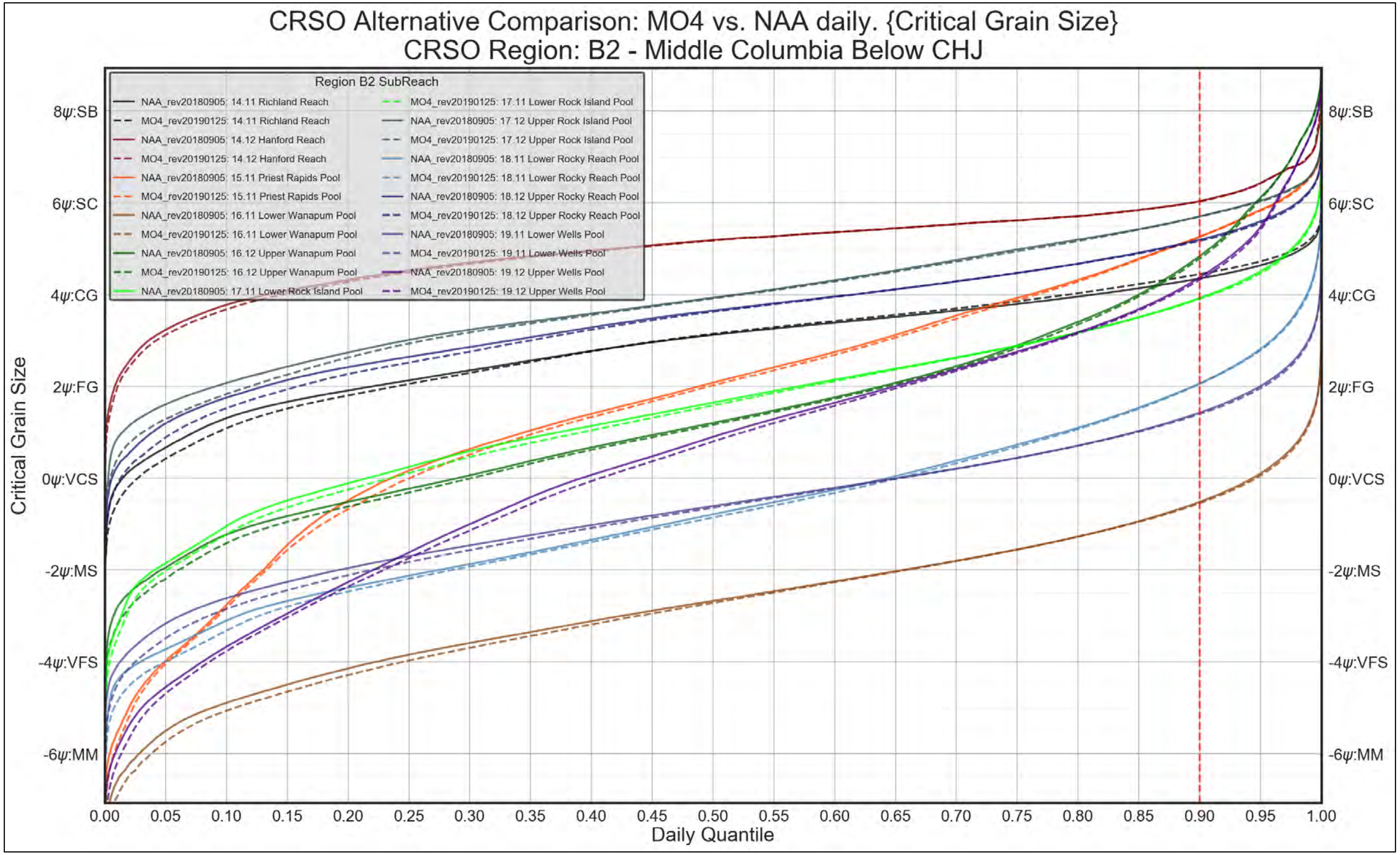


Figure 4-113. Region B2 – Middle Columbia below CHJ. MO4 vs. NAA. Critical Grain-Size Threshold

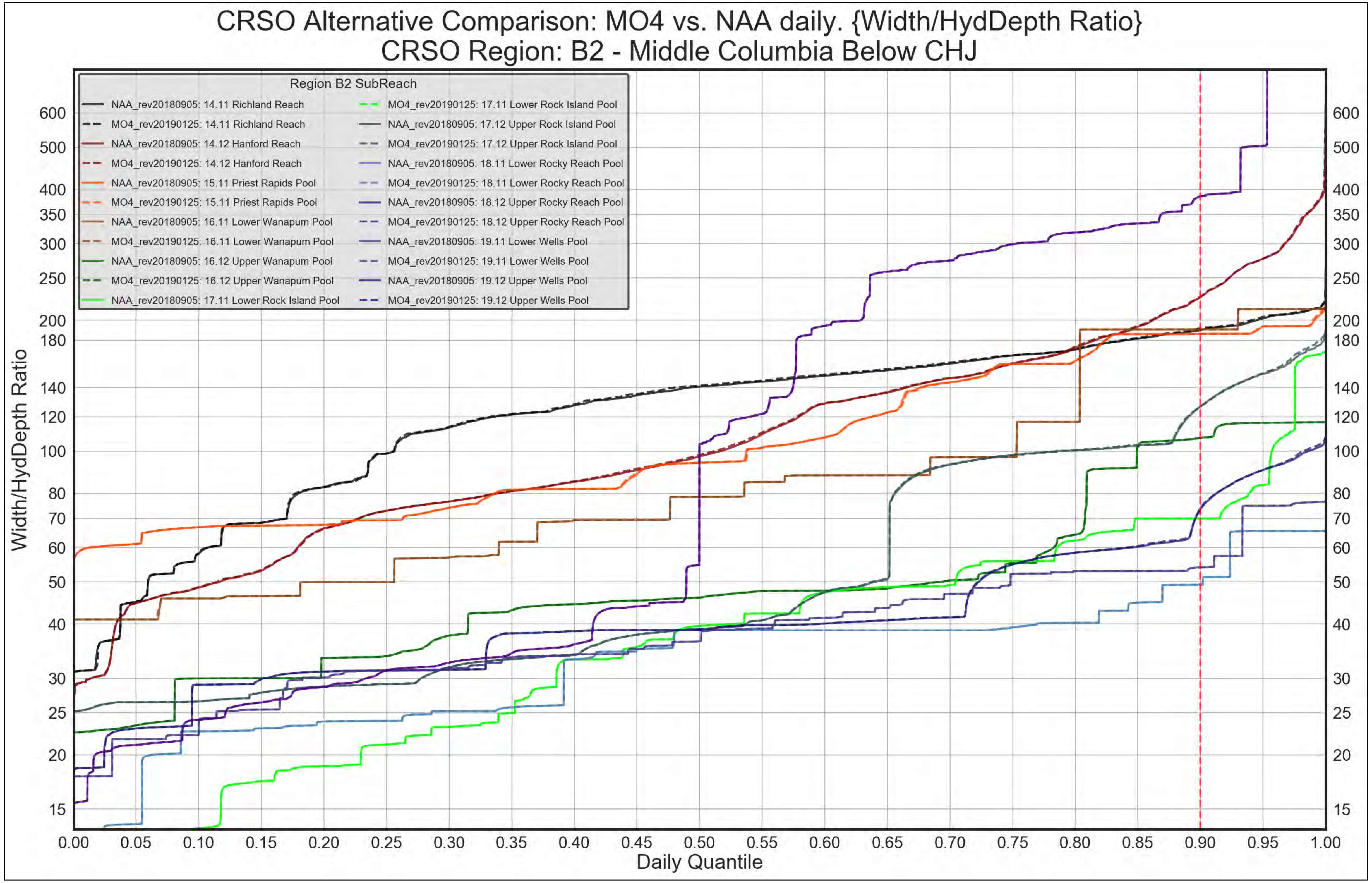
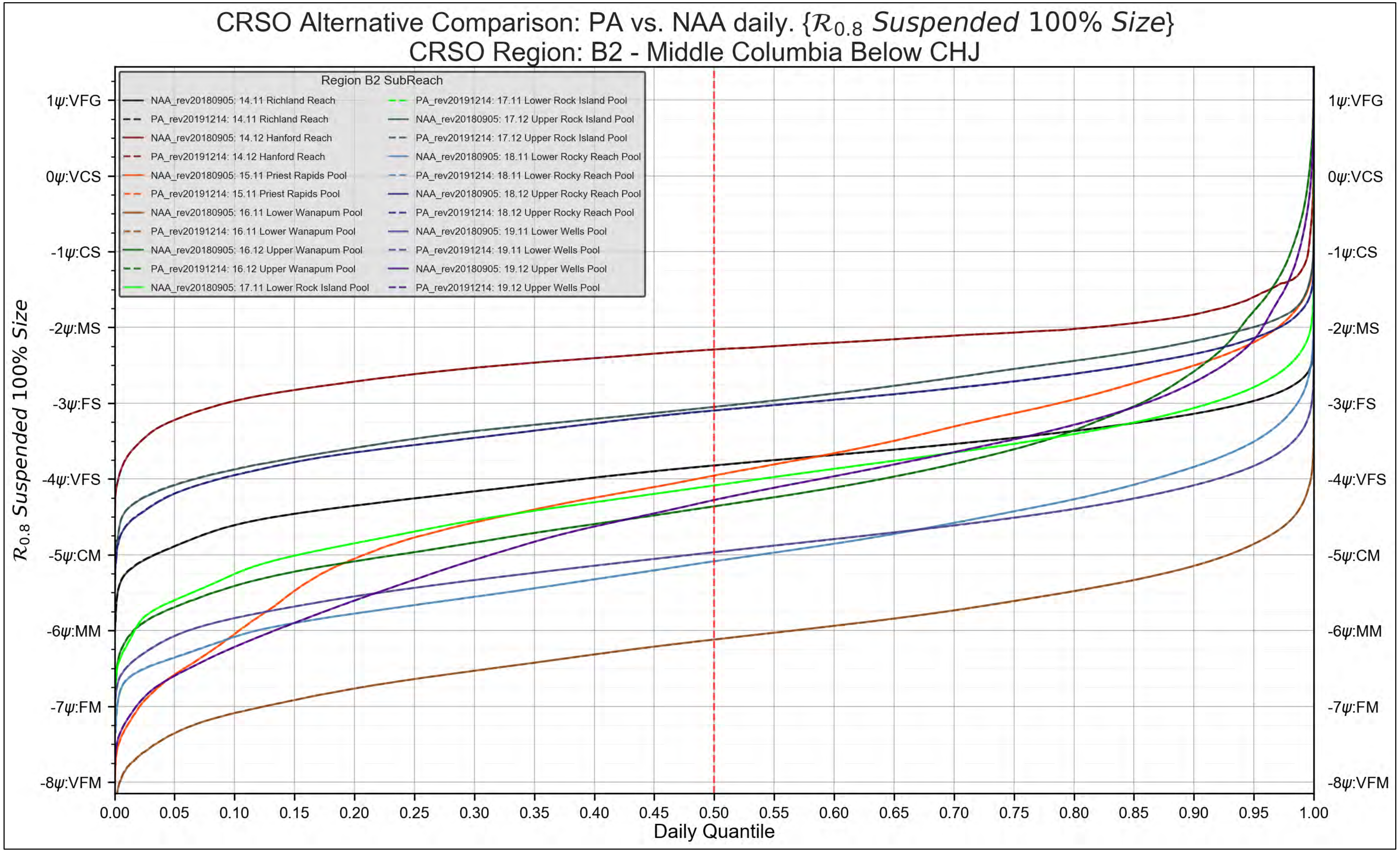


Figure 4-114 Region B2 – Middle Columbia below CHJ. MO4 vs. NAA. Width/Hydraulic Depth Ratio

2218 **REGION B2. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE**



2219

2220 **Figure 4-115 Region B2 – Middle Columbia below CHJ. PA vs. NAA. 100% Suspended Grain-Size Threshold**

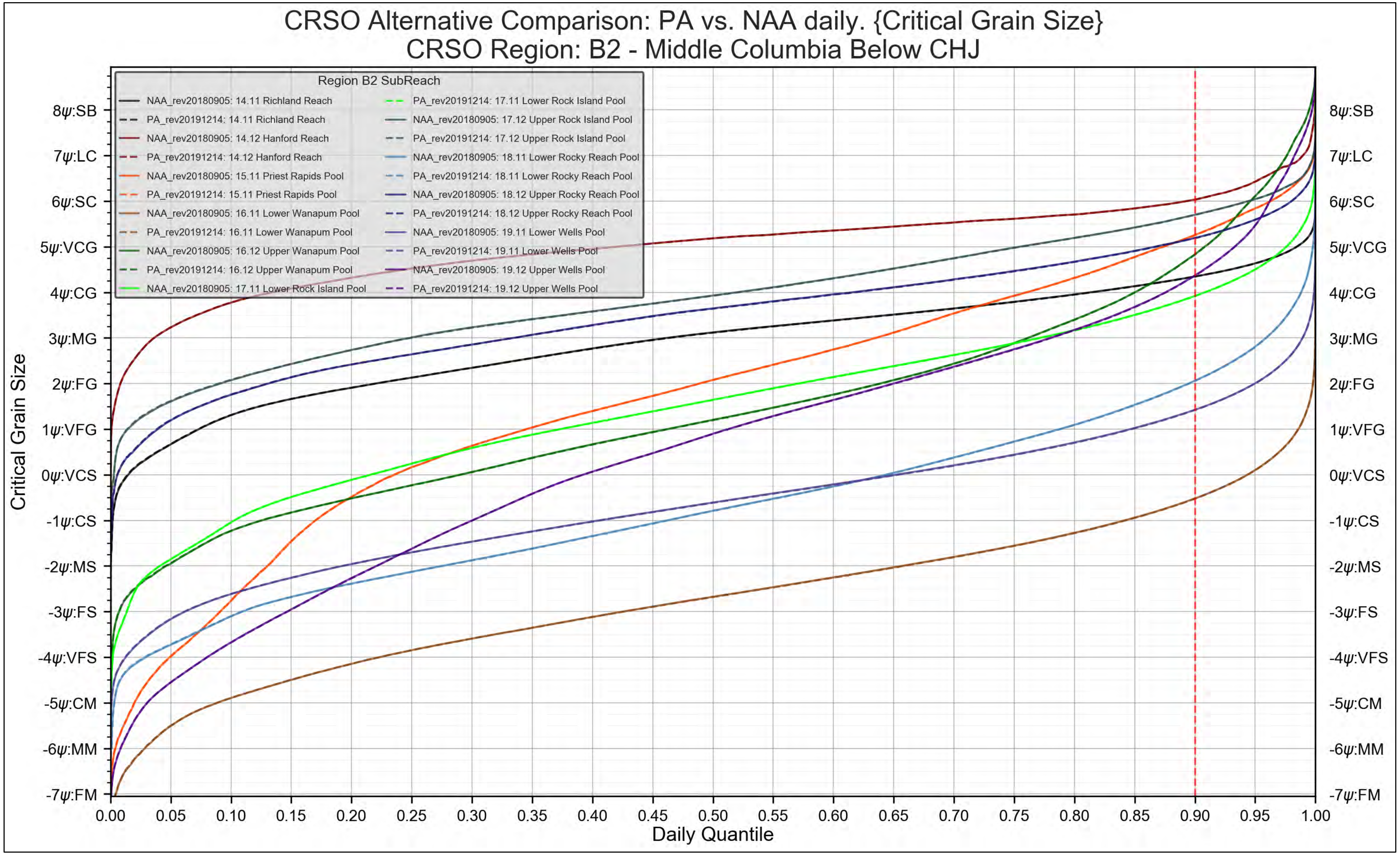
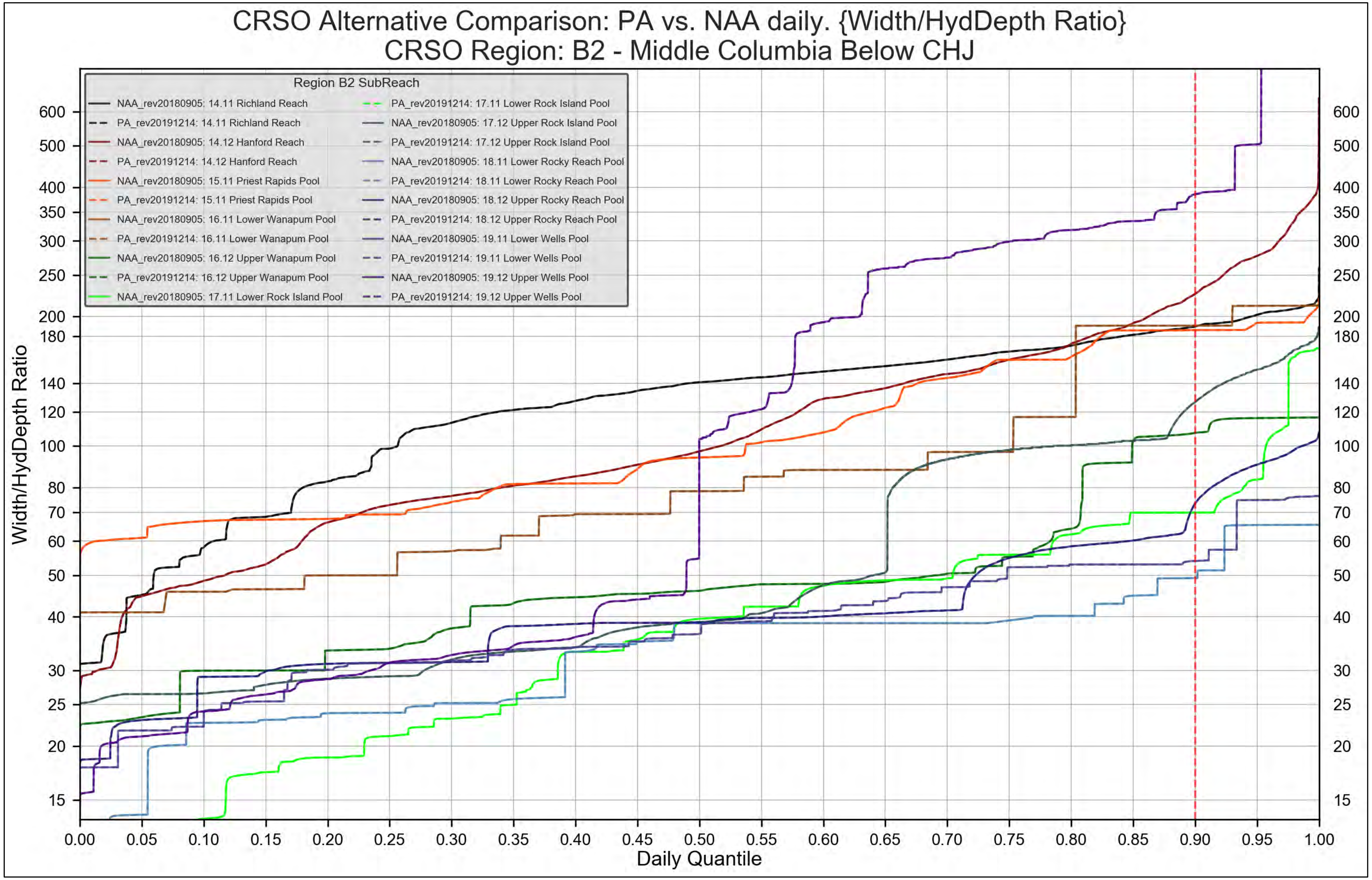


Figure 4-116 Region B2 – Middle Columbia below CHJ. PA vs. NAA. Critical Grain-Size Threshold



2223
2224 **Figure 4-117 Region B2 – Middle Columbia below CHJ. PA vs. NAA. Width/Hydraulic Depth Ratio**

4.2.5 Region C: Clearwater and Lower Snake Reach

4.2.5.1 Region C: Clearwater and Lower Snake Reach Comparison Tables

Table 4-13. Region C: Clearwater and Lower Snake Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
Major Reach	**ID #**	**Name**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**	**% Change 100% Suspended Grain-Size Class at 50% Excd**	**% Change in Grain-Size Class at 90% Excd**	**% Change in Width/Hyd Depth Ratio at 90% Excd**
Clearwater and Lower Snake	11.13	Above Grande Ronde Confluence	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	2.6%	3.3%	-0.3%	0.1%	0.2%	0.0%	0.3%	0.5%	0.0%
	11.12	Grande Ronde Confluence to Tenmile Rapids	0.0%	0.0%	0.0%	0.2%	0.1%	-0.2%	7.4%	3.8%	-0.7%	0.4%	0.7%	-0.2%	-2.9%	-1.9%	-1.3%
	11.11	Tenmile Rapids to Clearwater Confluence	0.1%	0.0%	0.0%	0.7%	0.2%	-0.1%	**201.0%**	**114.2%**	**44.1%**	0.6%	0.2%	-0.2%	0.3%	-0.2%	-0.5%
	10.23	Middle Clearwater - above NF Confluence	-1.7%	0.9%	2.1%	1.3%	-1.4%	-3.2%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	-0.5%
	10.22	Lower Clearwater – North Fork Confluence to Lenore	-1.0%	-0.1%	2.9%	0.3%	-0.1%	-1.8%	1.8%	-0.1%	-0.5%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.4%
	10.21	Lower Clearwater - Lenore to Spalding	0.0%	0.4%	0.5%	-0.2%	-1.1%	-2.2%	4.1%	4.4%	-2.3%	0.0%	0.1%	0.0%	0.0%	0.0%	-0.4%
	10.12	Lower Clearwater - Spalding to Lewiston	-0.3%	0.0%	-1.6%	0.1%	-0.3%	-1.2%	1.0%	3.3%	2.9%	0.0%	0.0%	0.0%	-2.2%	-2.9%	-3.9%
	10.11	Lower Clearwater - above Snake Confluence	**-10.6%**	3.1%	0.0%	1.6%	-7.5%	0.0%	**335.8%**	**572.1%**	**86.9%**	-0.5%	-0.5%	0.8%	-1.0%	-1.3%	-0.2%
	9.12	Clearwater Confluence to Silcott Island	-1.5%	1.1%	0.0%	1.7%	-2.6%	0.0%	**326.7%**	**534.8%**	**74.4%**	0.3%	-0.3%	0.0%	-0.5%	-0.9%	-0.3%
	9.11	Lower Granite to Silcott Island	-1.0%	1.1%	0.0%	1.6%	-2.8%	0.0%	**504.3%**	**839.4%**	**91.7%**	0.7%	0.1%	0.0%	-1.8%	-4.2%	-0.3%
	8.12	Lower Granite Tailrace	-1.6%	1.1%	0.0%	1.8%	-2.5%	0.0%	**214.1%**	**193.1%**	**66.0%**	0.5%	-1.8%	-0.1%	-0.8%	-2.3%	-0.5%
	8.11	Little Goose Pool	-0.7%	1.5%	0.0%	1.3%	-2.3%	0.0%	**436.1%**	**716.4%**	**82.9%**	0.5%	-0.8%	-0.3%	-0.6%	-2.6%	0.0%
	7.12	Little Goose Tailrace	-1.0%	0.9%	0.0%	1.9%	-2.3%	0.0%	**349.5%**	**470.6%**	**122.5%**	0.5%	-1.8%	0.0%	-0.2%	-1.4%	-0.3%
	7.11	Lower Monumental Pool	-0.9%	1.2%	0.0%	1.5%	-2.4%	0.0%	**483.9%**	**760.3%**	**122.9%**	0.5%	-0.8%	-0.3%	-0.2%	-3.3%	0.0%
	6.22	Lower Monumental Tailrace	-0.6%	1.2%	0.0%	0.7%	-2.8%	0.0%	**241.3%**	**286.0%**	**91.9%**	0.4%	-2.6%	0.0%	0.0%	-2.1%	0.0%
	6.21	Ice Harbor Pool	-1.5%	1.1%	0.0%	1.5%	-3.0%	0.0%	**415.3%**	**730.7%**	**61.0%**	0.7%	-1.4%	0.0%	0.2%	-0.2%	0.0%
	6.11	Ice Harbor Tailrace	-0.8%	1.3%	0.0%	0.8%	-1.3%	0.0%	0.5%	-2.1%	-2.0%	3.4%	**19.2%**	0.0%	0.3%	0.5%	0.0%

Table 4-14. Region C: Clearwater and Lower Snake Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	Name	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change
Clearwater and Lower Snake	11.13	Above Grande Ronde Confluence	No Effect	No Effect	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	No Effect	No Effect
	11.12	Grande Ronde Confluence to Tenmile Rapids	No Effect	No Effect	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	11.11	Tenmile Rapids to Clearwater Confluence	Negligible	No Effect	No Effect	Negligible	Negligible	Negligible	**Major**	**Major**	**Major**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	10.23	Middle Clearwater - above NF Confluence	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect	No Effect	Negligible	Negligible	Negligible
	10.22	Lower Clearwater - NF Confluence to Lenore	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	No Effect	Negligible	No Effect	Negligible
	10.21	Lower Clearwater - Lenore to Spalding	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	No Effect	No Effect	Negligible	Negligible
	10.12	Lower Clearwater - Spalding to Lewiston	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect	No Effect	No Effect	No Effect	Negligible
	10.11	Lower Clearwater - above Snake Confluence	**Minor**	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	9.12	Clearwater Confluence to Silcott Island	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible
	9.11	Lower Granite to Silcott Island	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible
	8.12	Lower Granite Tailrace	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	8.11	Little Goose Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	7.12	Little Goose Tailrace	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	7.11	Lower Monumental Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	6.22	Lower Monumental Tailrace	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	6.21	Ice Harbor Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	**Major**	**Major**	**Major**	Negligible	Negligible	No Effect	No Effect	Negligible	No Effect
	6.11	Ice Harbor Tailrace	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	**Minor**	No Effect	Negligible	Negligible	No Effect

4.2.5.2 Region C1: Clearwater Reach Comparison Figures

REGION C1: MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

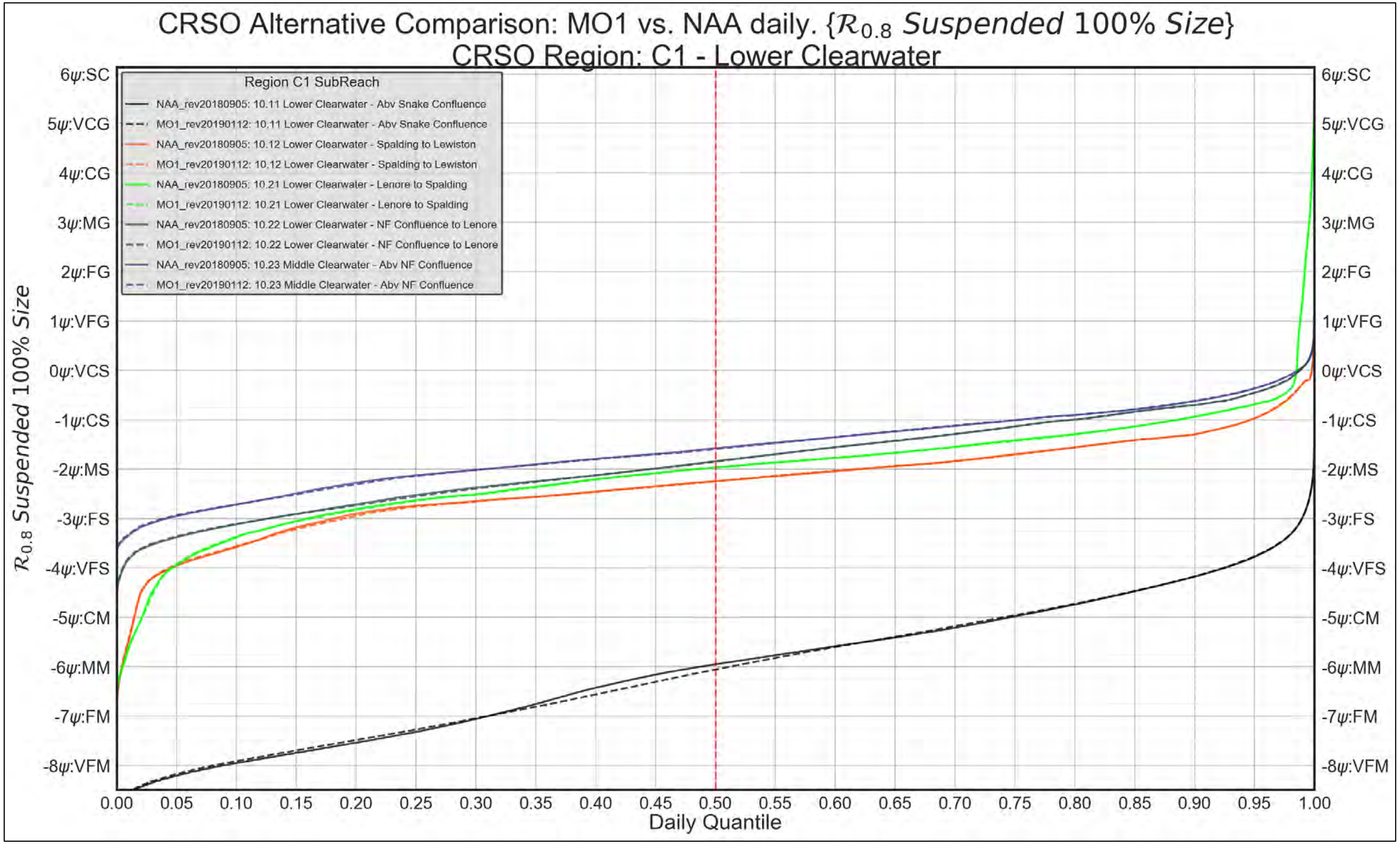


Figure 4-118. Region C1 – Lower Clearwater. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

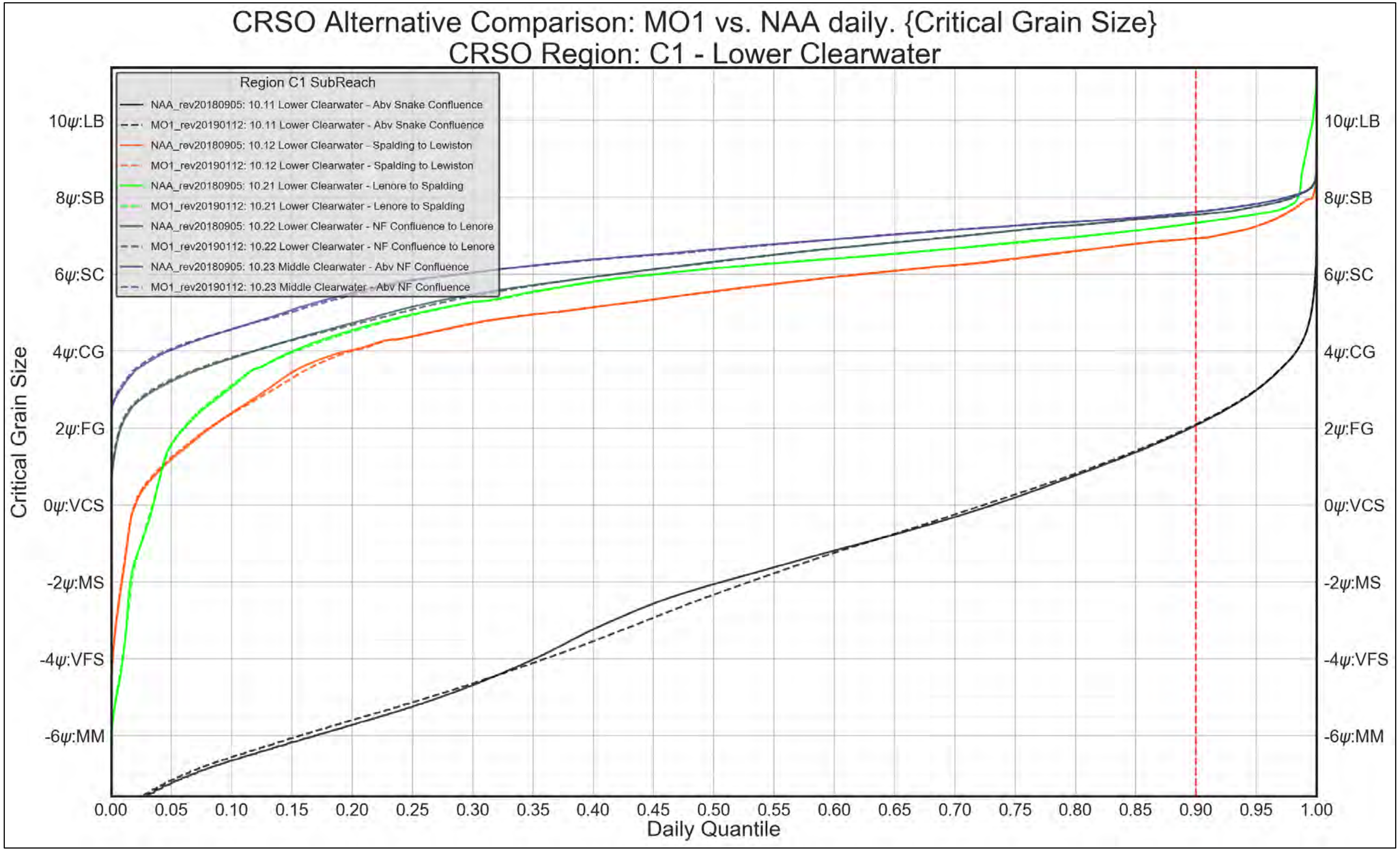


Figure 4-119. Region C1 – Lower Clearwater. MO1 vs. NAA. Critical Grain-Size Threshold

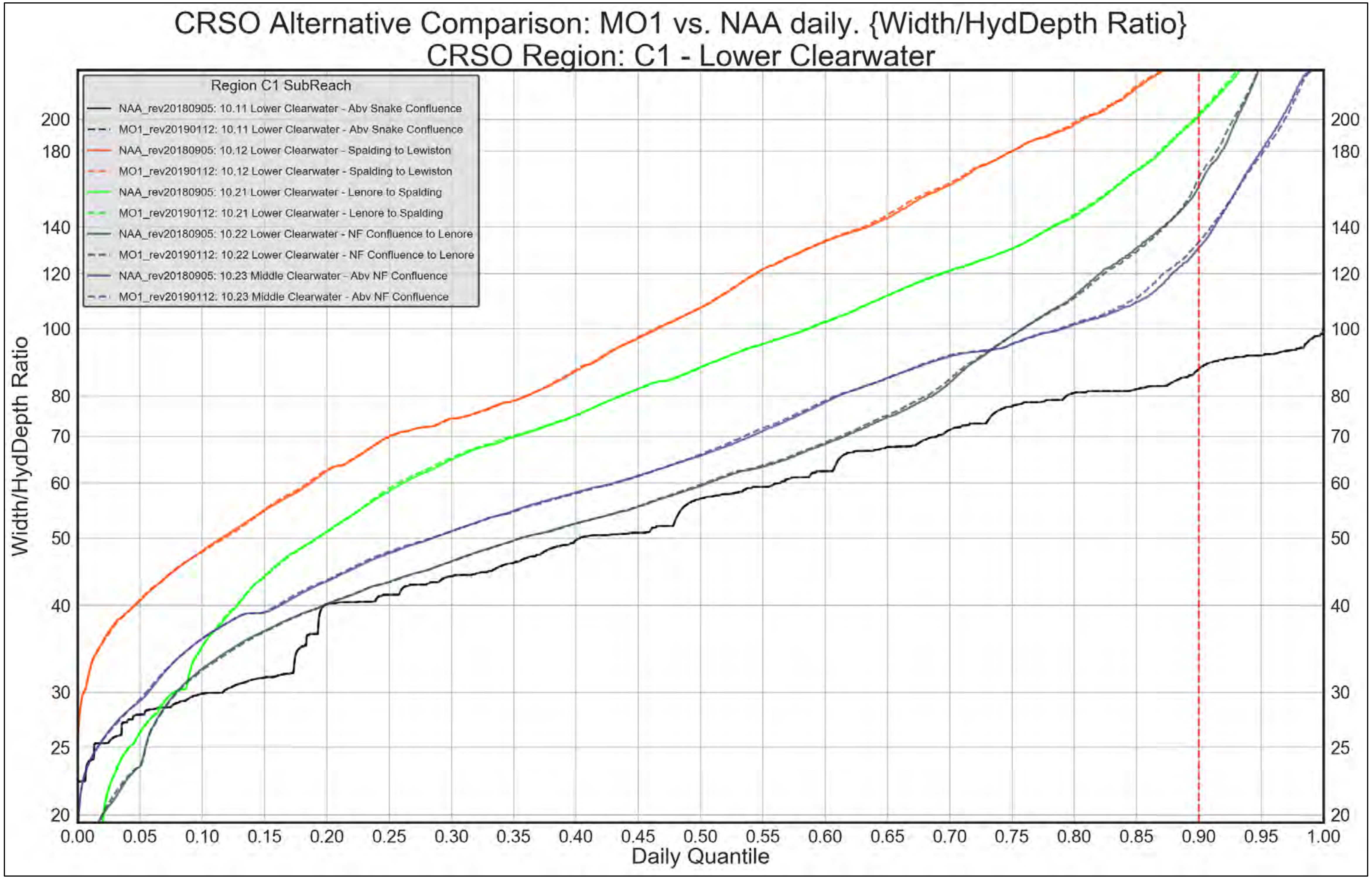
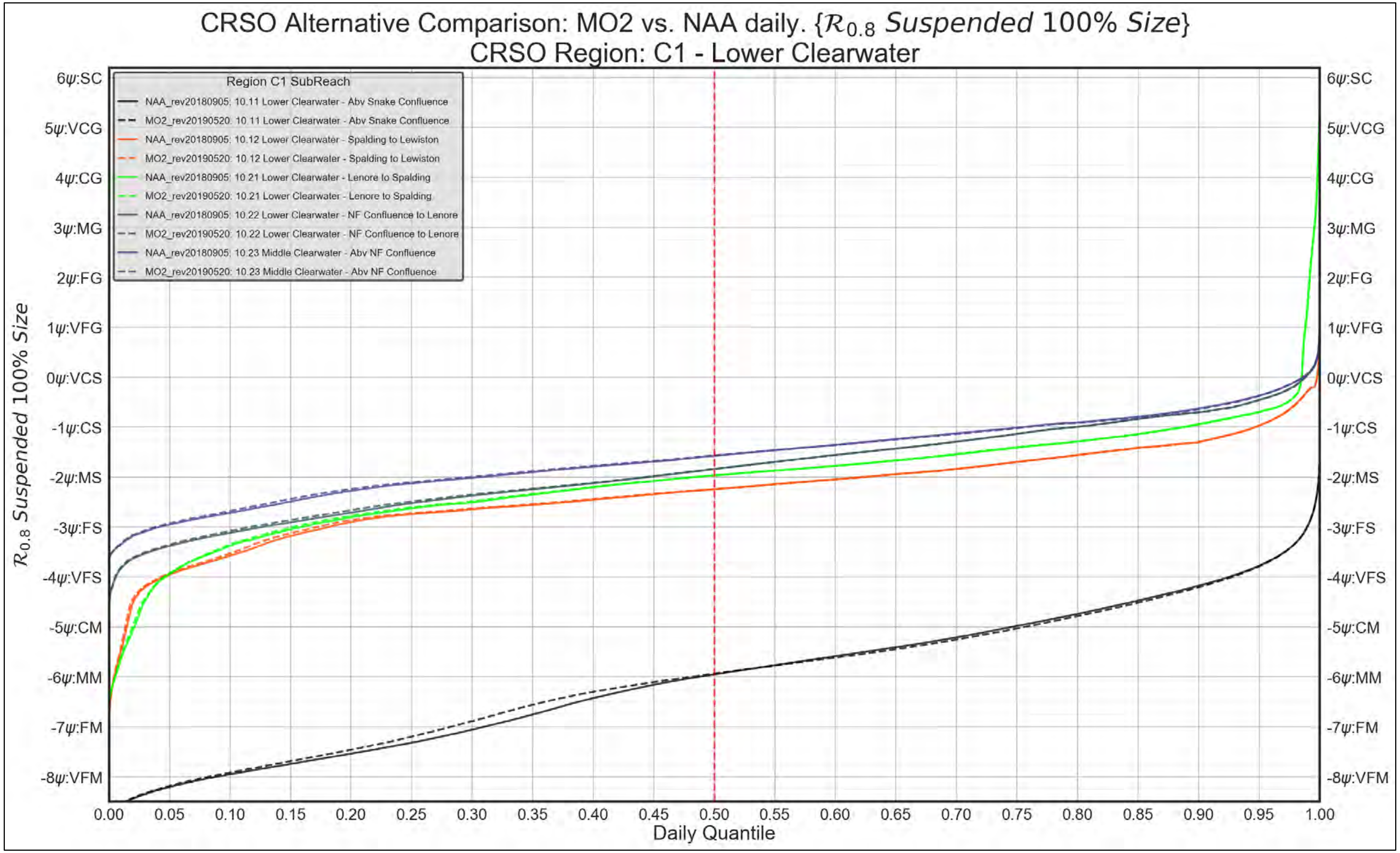


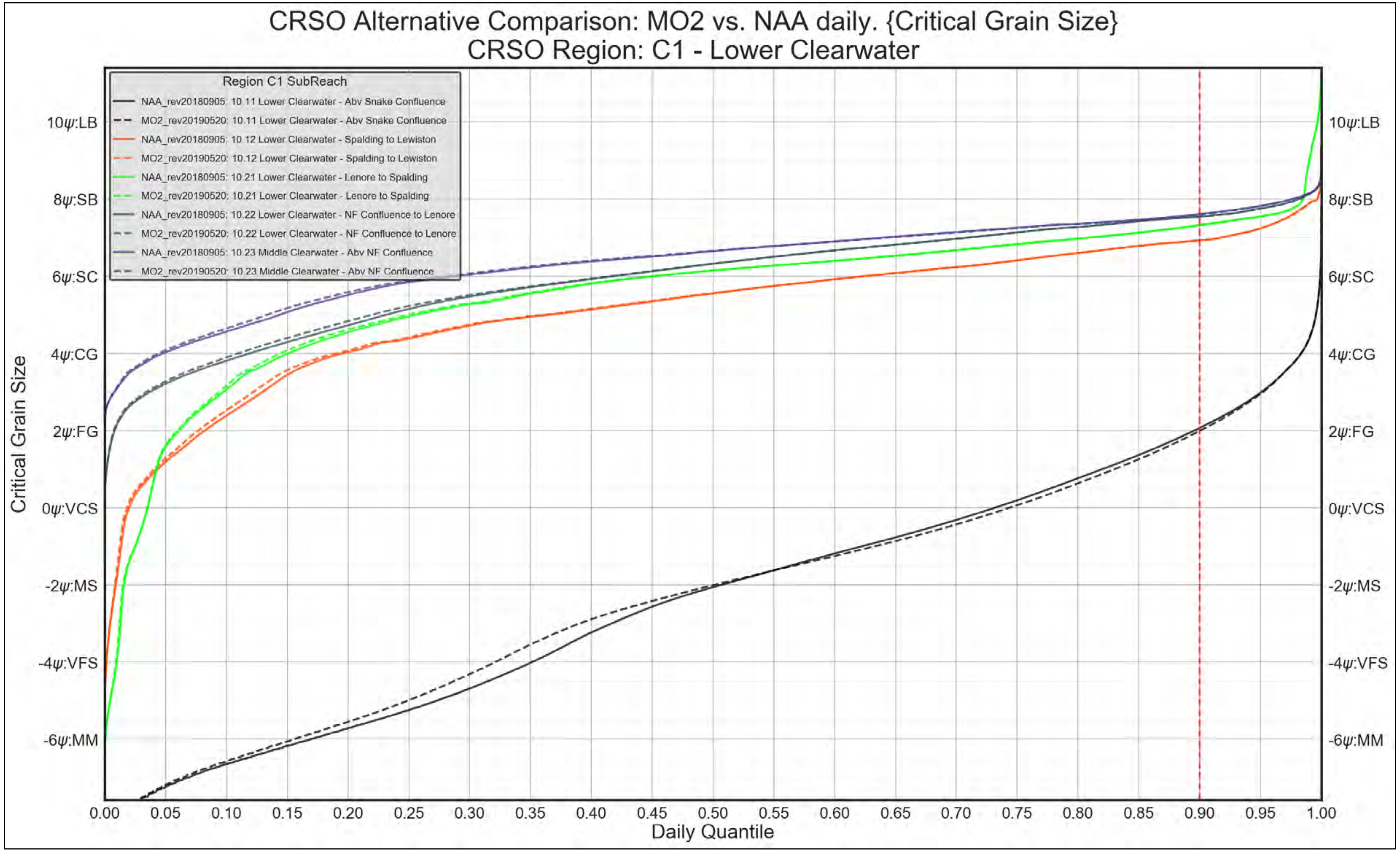
Figure 4-120. Region C1 – Lower Clearwater. MO1 vs. NAA. Width/Hydraulic Depth Ratio

2237 **REGION C1. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE**



2238

2239 **Figure 4-121. Region C1 – Lower Clearwater. MO2 vs. NAA. 100% Suspended Grain-Size Threshold**



2240

2241 Figure 4-122. Region C1 – Lower Clearwater. MO2 vs. NAA. Critical Grain-Size Threshold

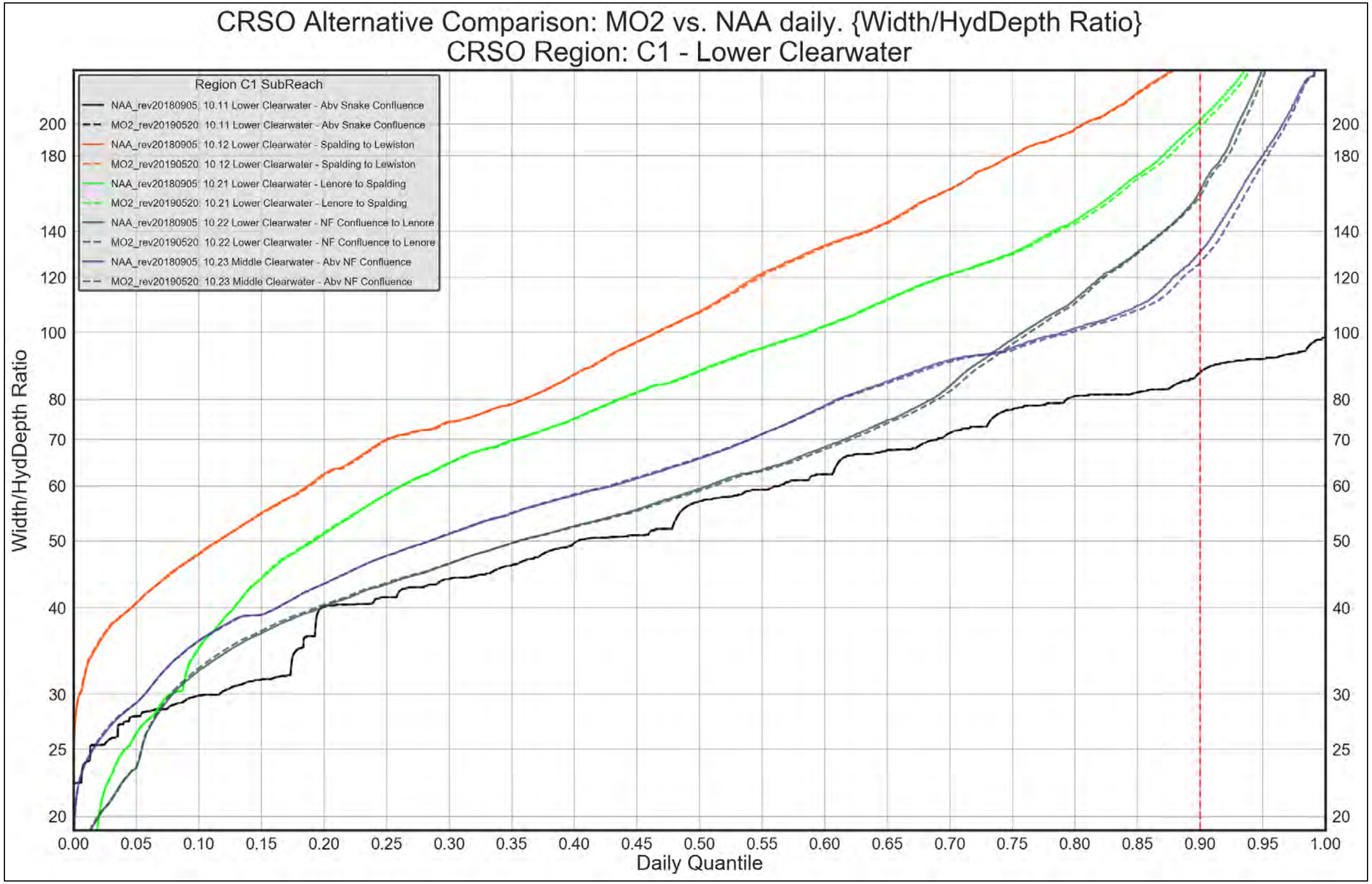
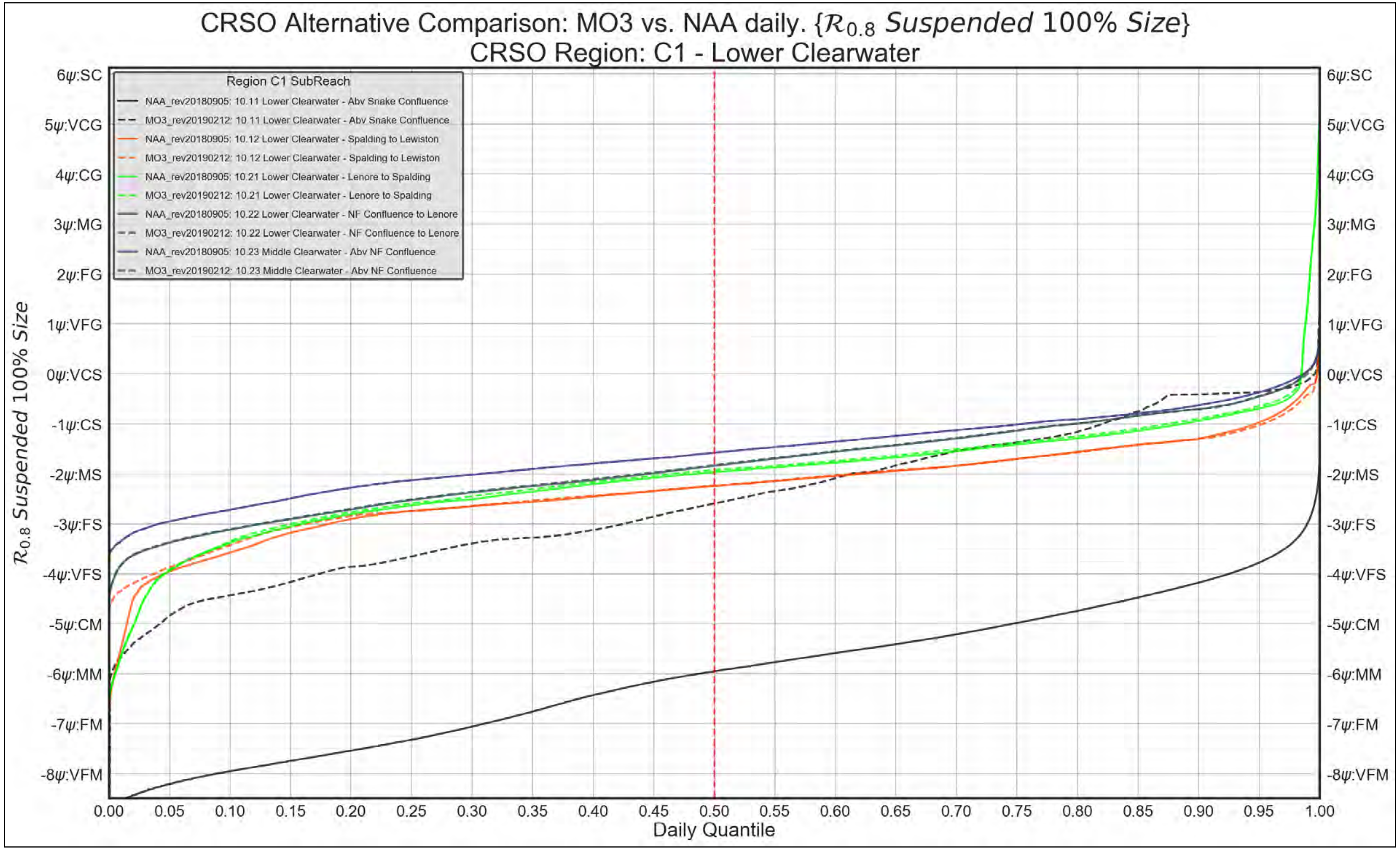


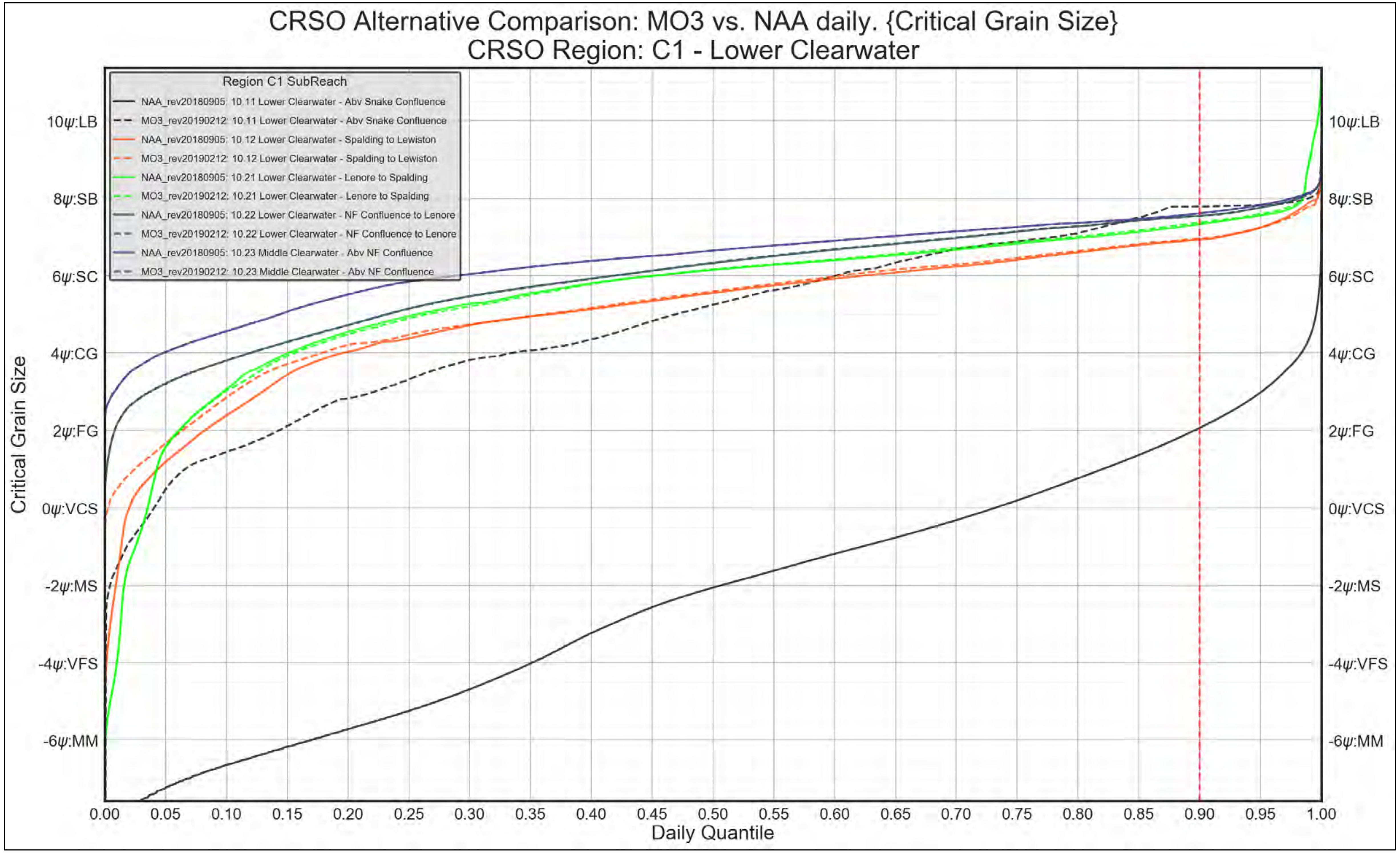
Figure 4-123. Region C1 – Lower Clearwater. MO2 vs. NAA. Width/Hydraulic Depth Ratio

2244 **REGION C1. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE**



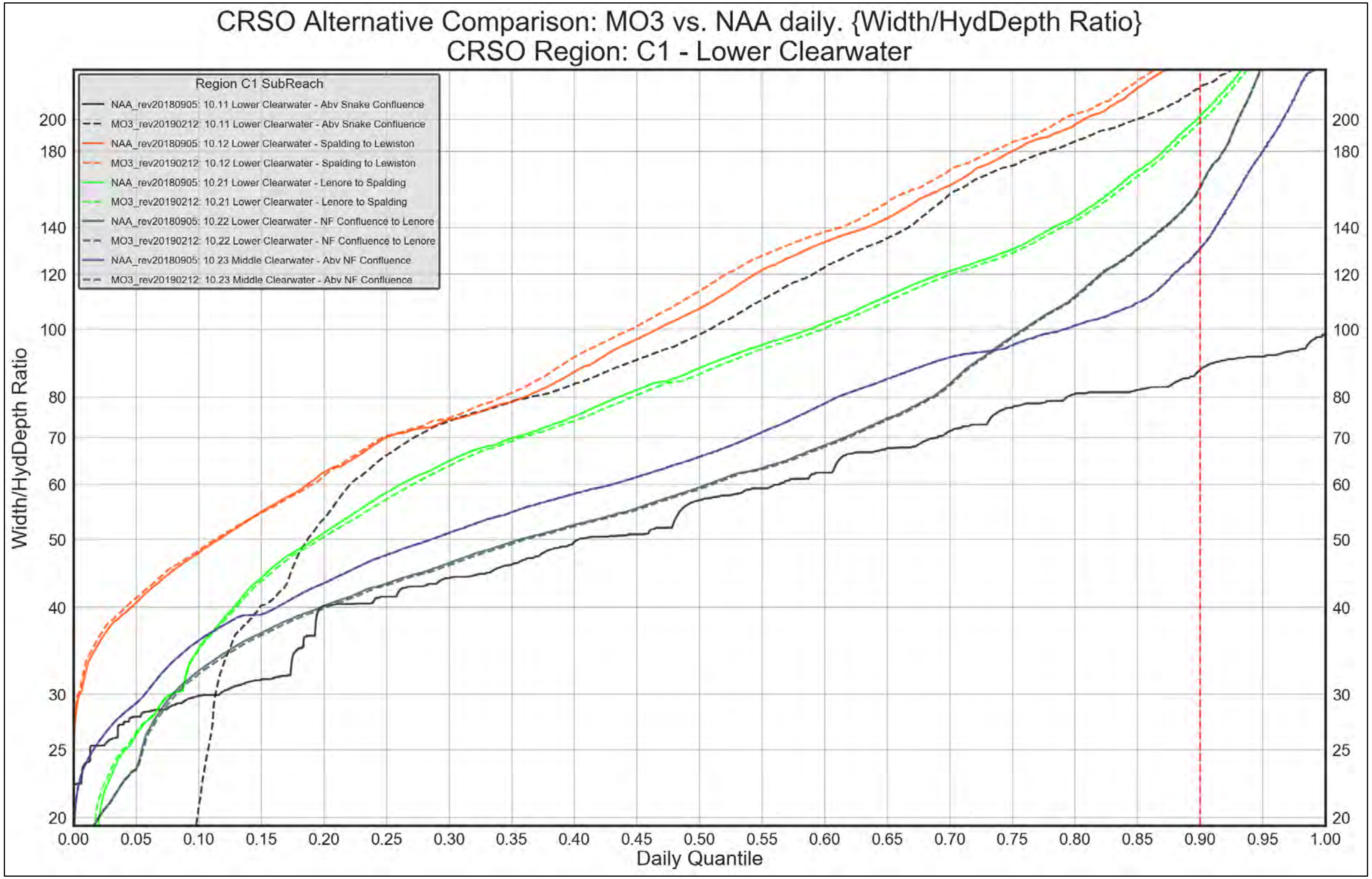
2245

2246 **Figure 4-124. Region C1 – Lower Clearwater. MO3 vs. NAA. 100% Suspended Grain-Size Threshold**



2247

2248 **Figure 4-125. Region C1 – Lower Clearwater. MO3 vs. NAA. Critical Grain-Size Threshold**



2249
2250 **Figure 4-126. Region C1 – Lower Clearwater. MO3 vs. NAA. Width/Hydraulic Depth Ratio**

REGION C1. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE

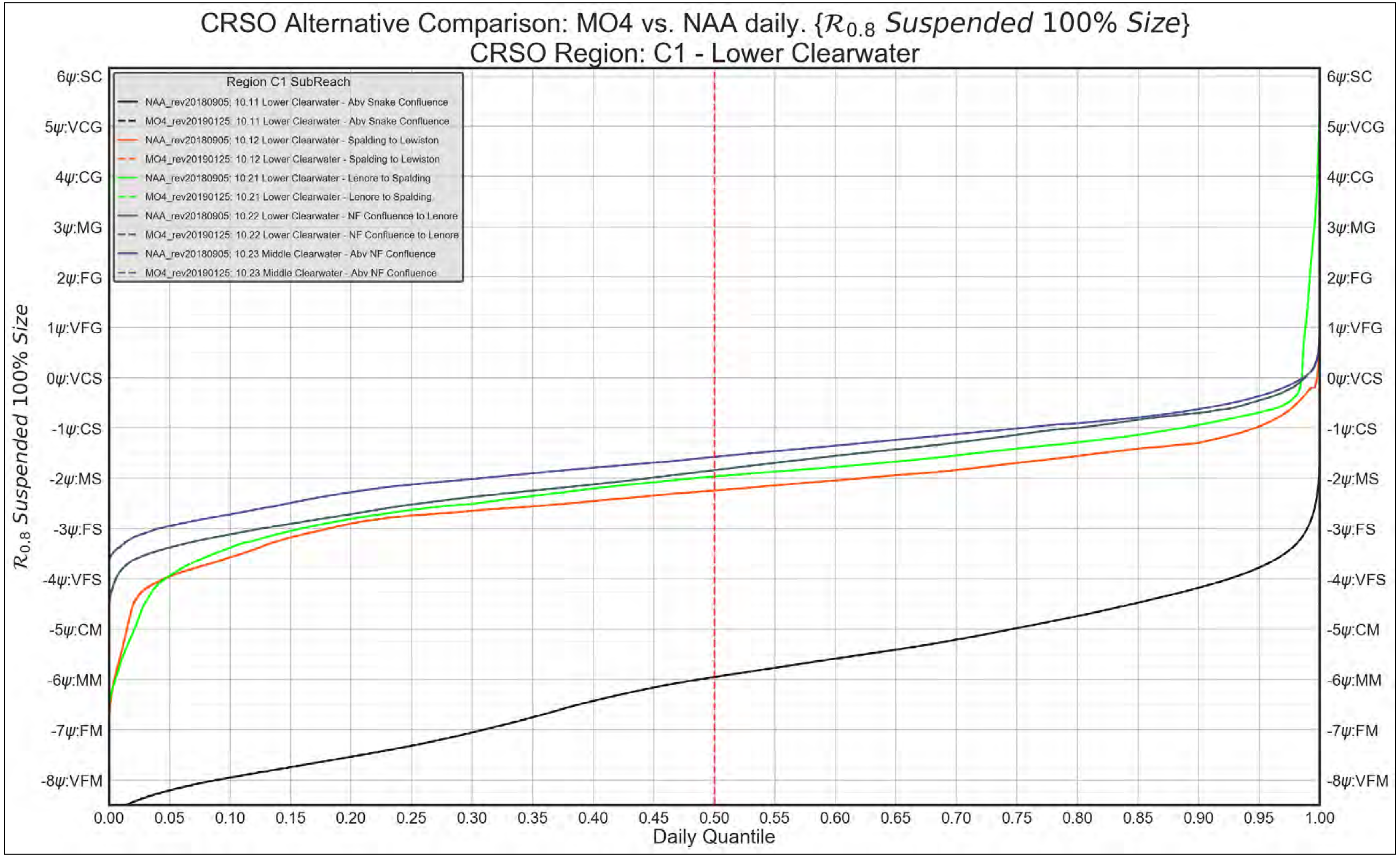


Figure 4-127. Region C1 – Lower Clearwater. MO4 vs. NAA. 100% Suspended Grain-Size Threshold

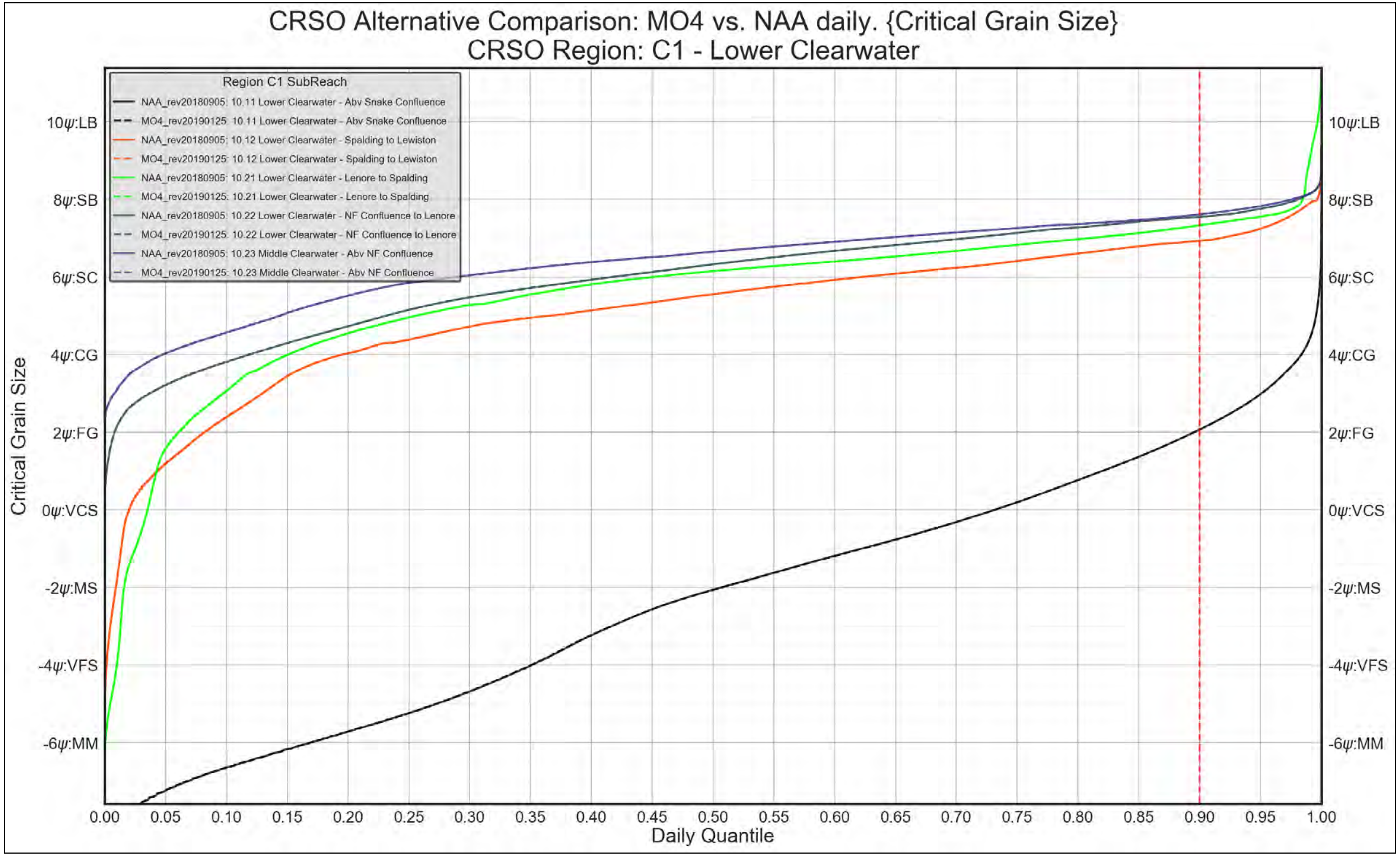
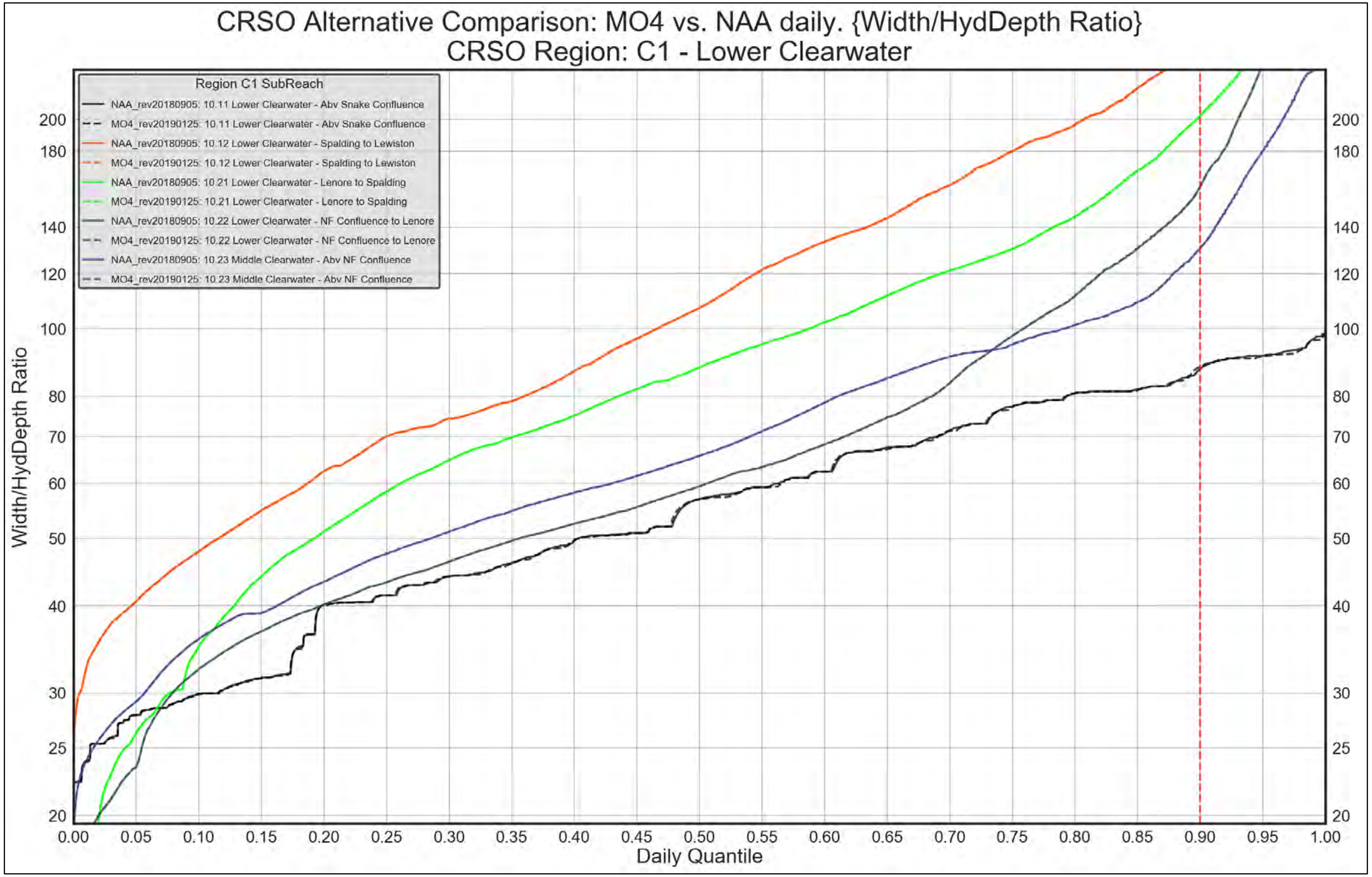
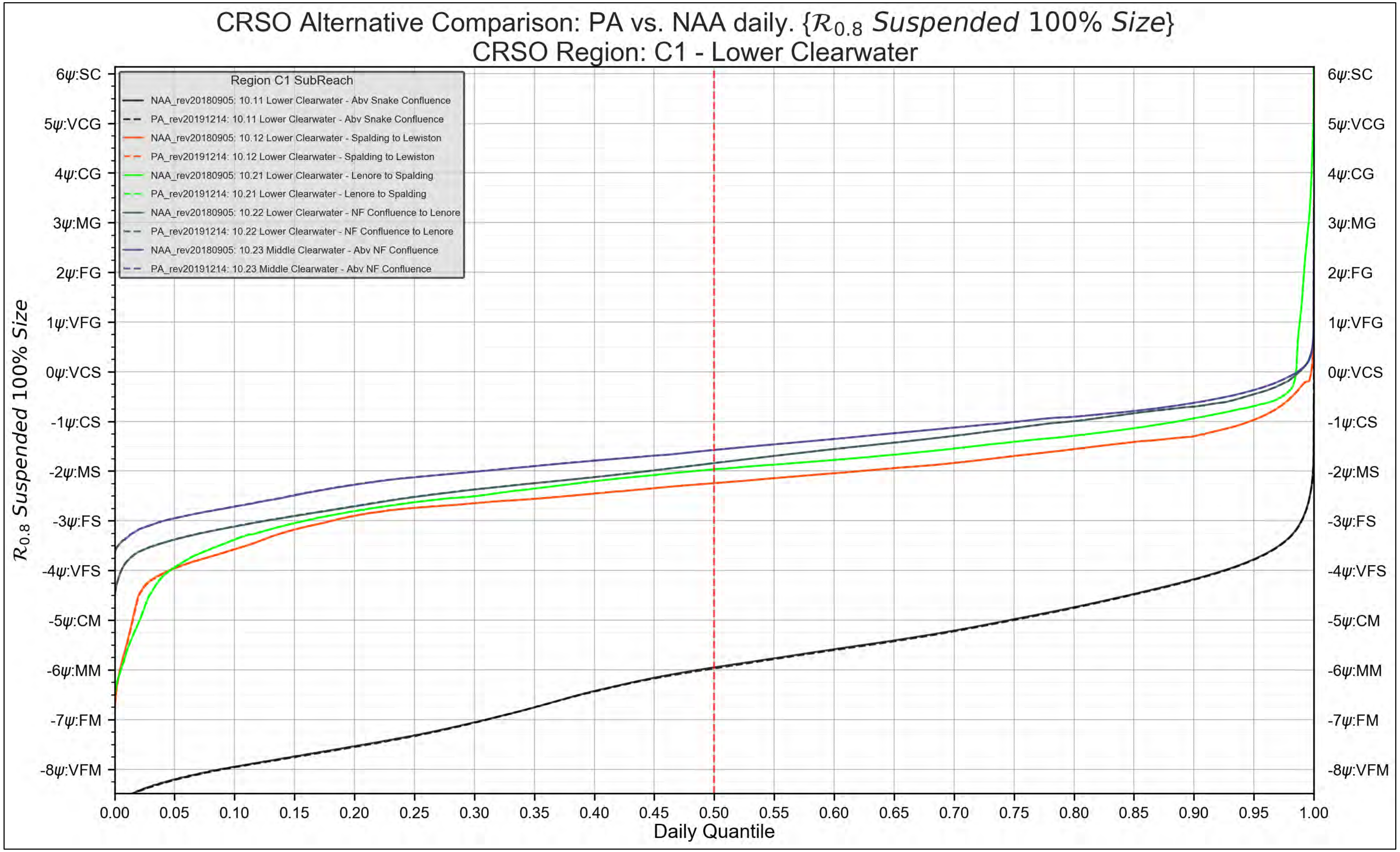


Figure 4-128. Region C1 – Lower Clearwater. MO4 vs. NAA. Critical Grain-Size Threshold



2256
2257 **Figure 4-129. Region C1 – Lower Clearwater. MO4 vs. NAA. Width/Hydraulic Depth Ratio**

2258 **REGION C1. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE**



2259

2260 **Figure 4-130 Region C1 – Lower Clearwater. PA vs. NAA. 100% Suspended Grain-Size Threshold**

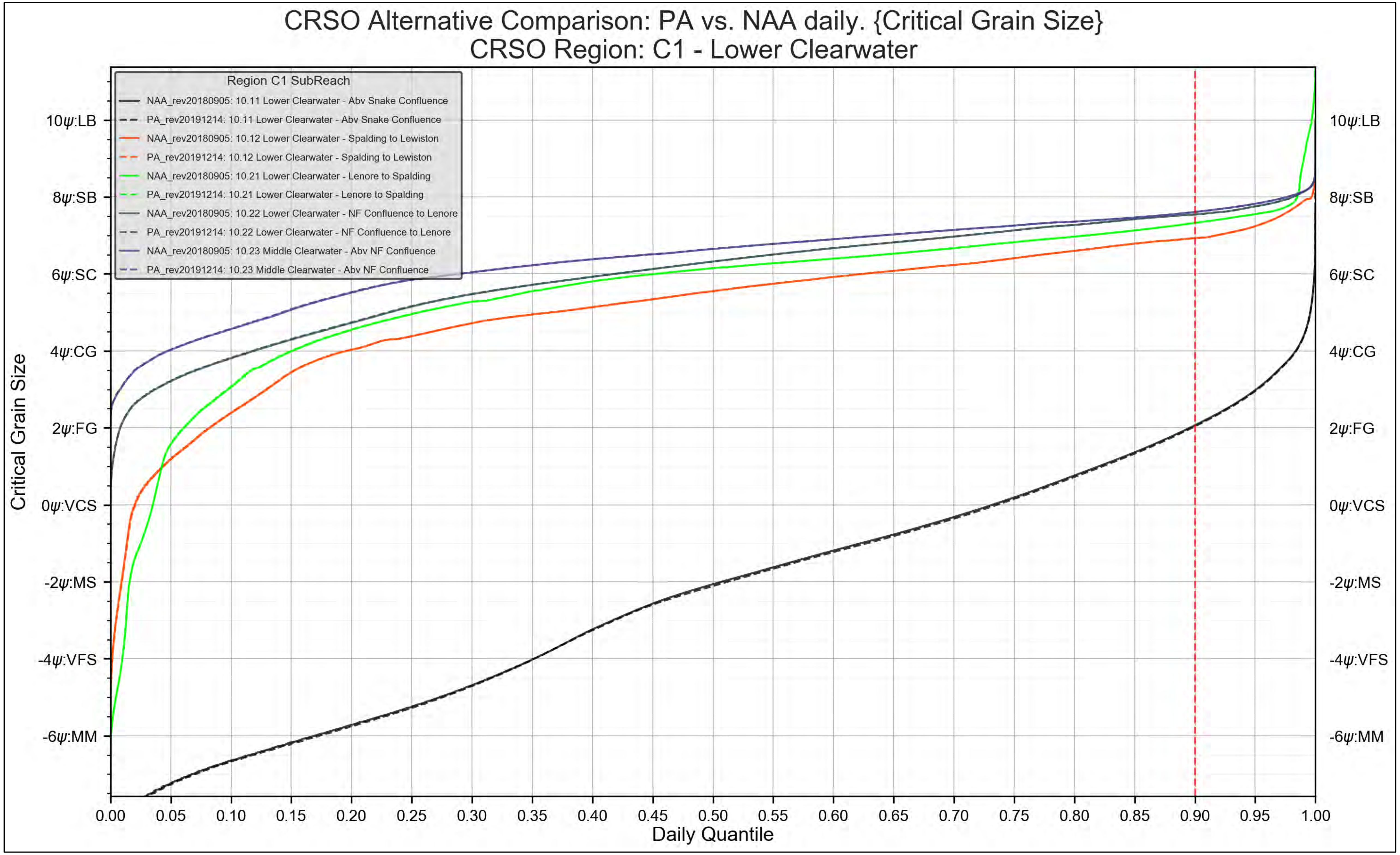
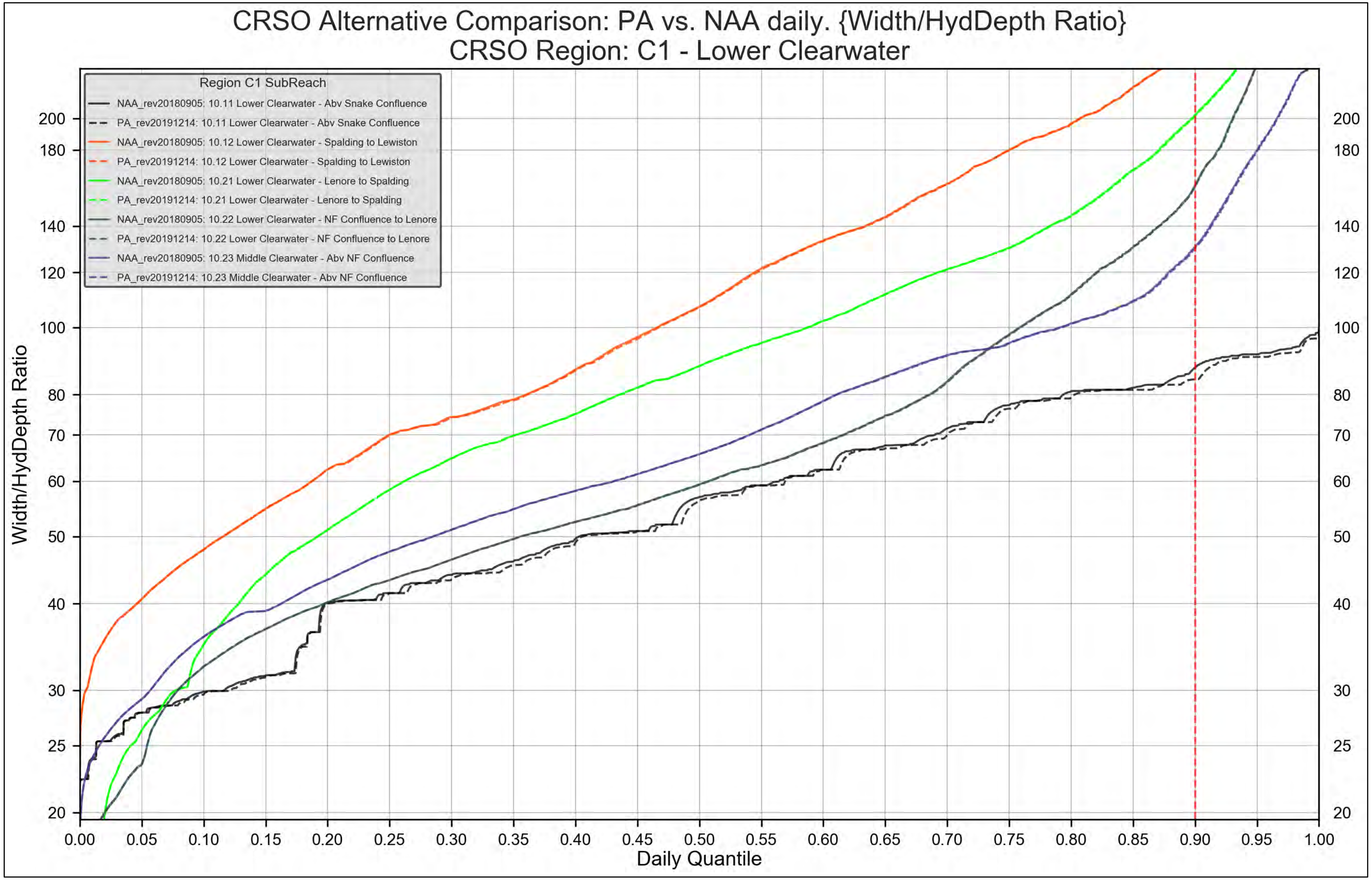


Figure 4-131 Region C1 – Lower Clearwater. PA vs. NAA. Critical Grain-Size Threshold



2263
2264 **Figure 4-132 Region C1 – Lower Clearwater. PA vs. NAA. Width/Hydraulic Depth Ratio**

4.2.5.3 Region C2. Lower Snake Reach. Comparison Figures

REGION C2. MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

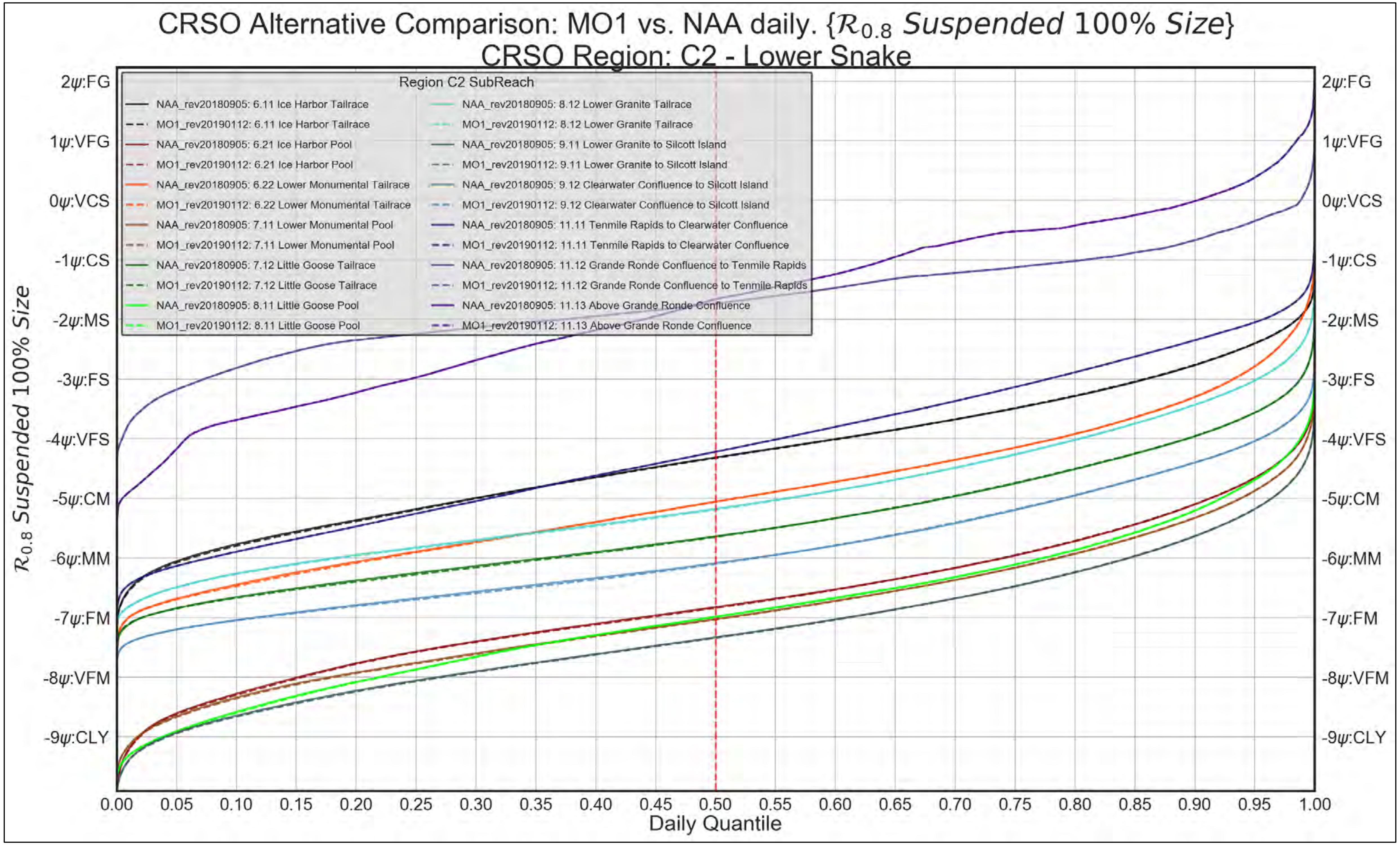


Figure 4-133. Region C2 – Lower Snake. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

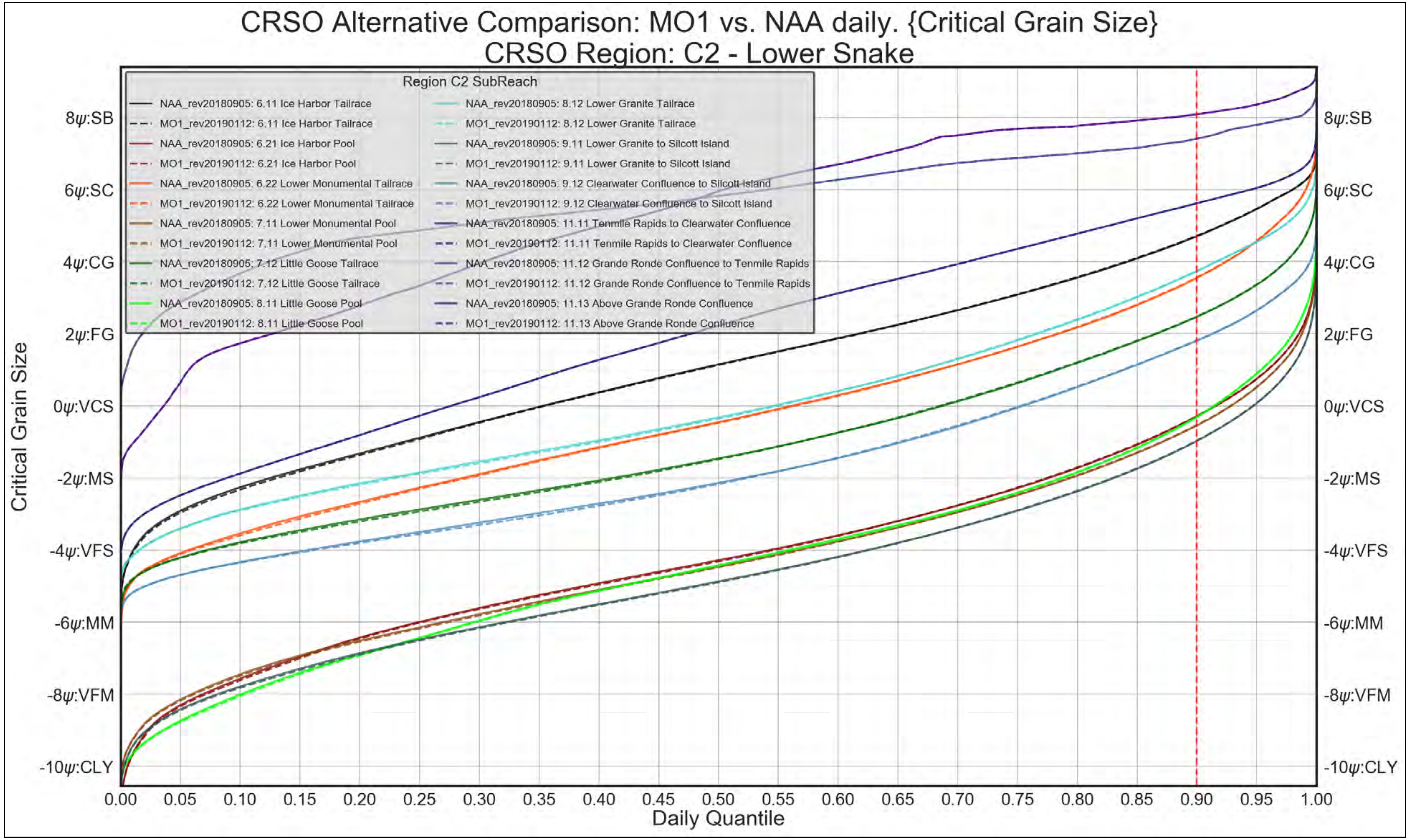


Figure 4-134. Region C2 – Lower Snake. MO1 vs. NAA. Critical Grain-Size Threshold

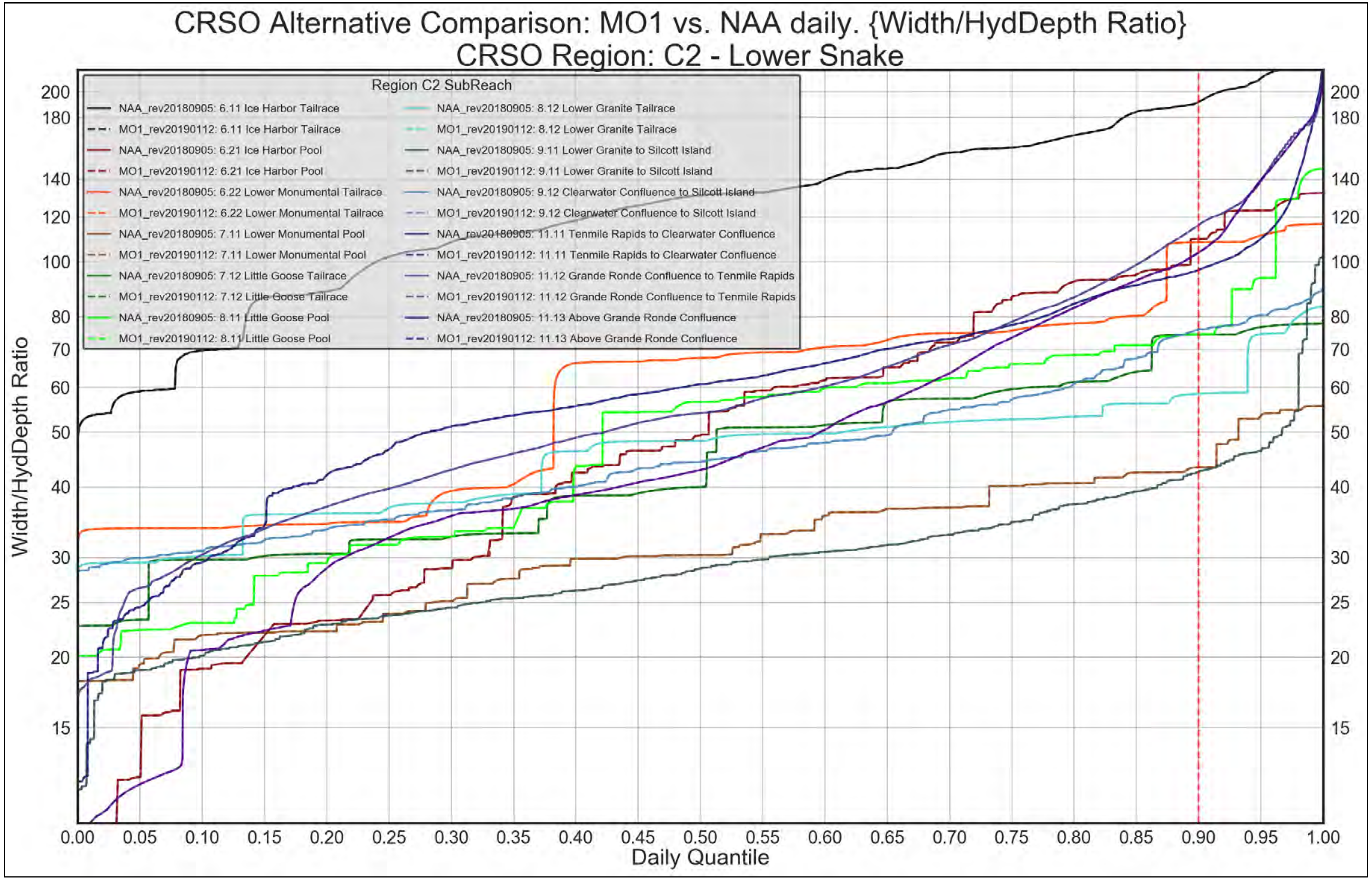


Figure 4-135. Region C2 – Lower Snake. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION C2. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

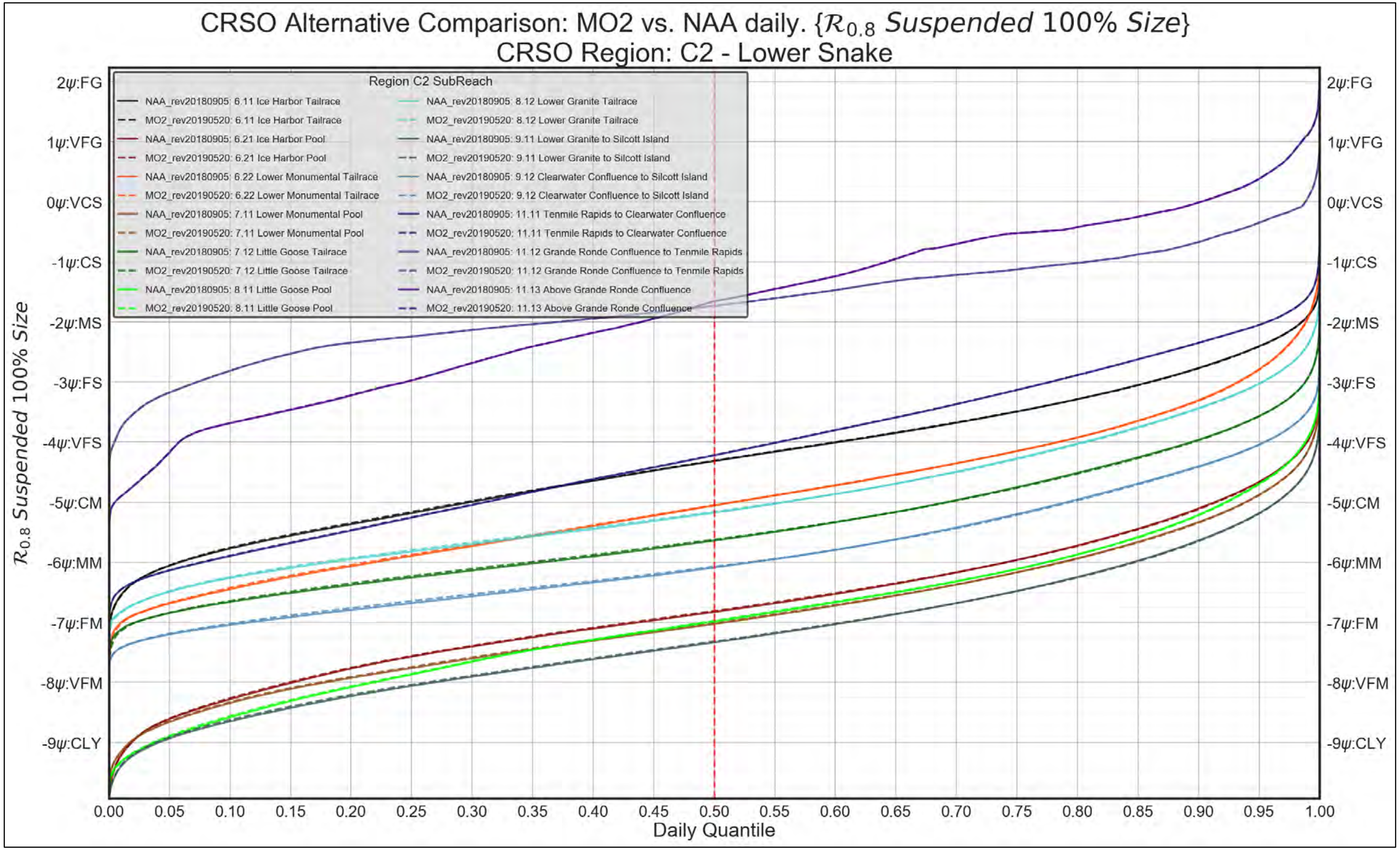


Figure 4-136. Region C2 – Lower Snake. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

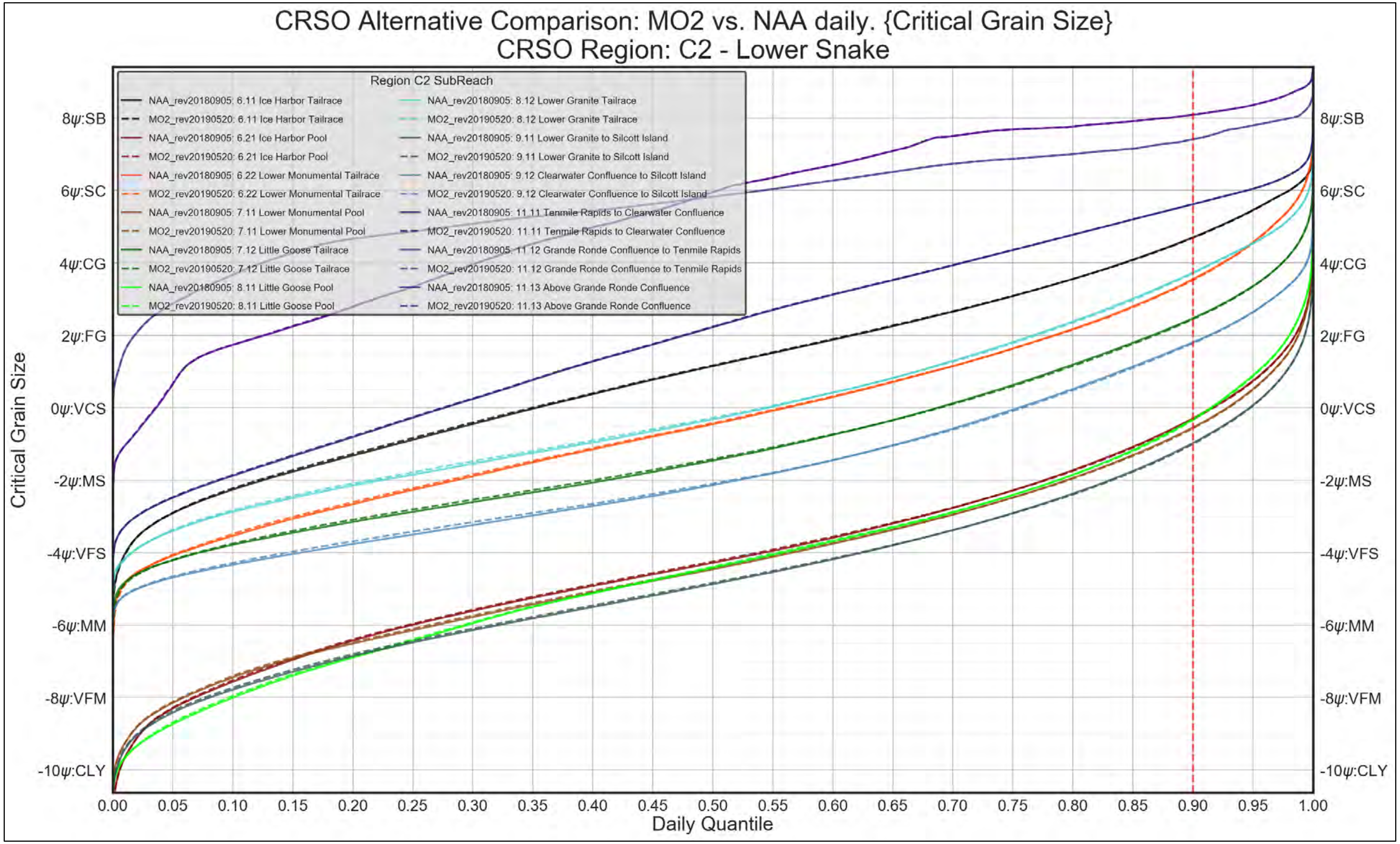


Figure 4-137. Region C2 – Lower Snake. MO2 vs. NAA. Critical Grain-Size Threshold

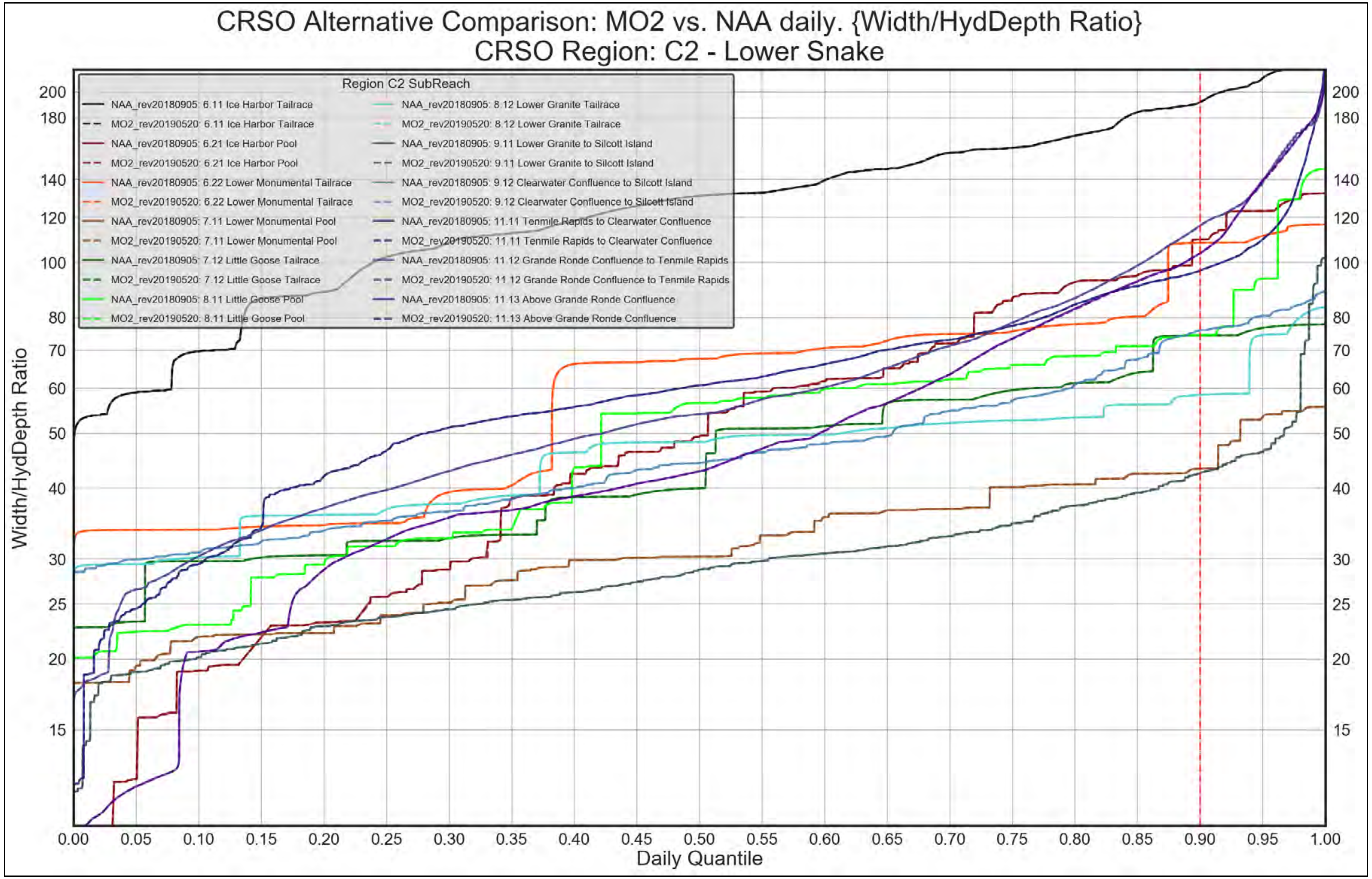


Figure 4-138. Region C2 – Lower Snake. MO2 vs. NAA. Width/Hydraulic Depth Ratio

REGION C2. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

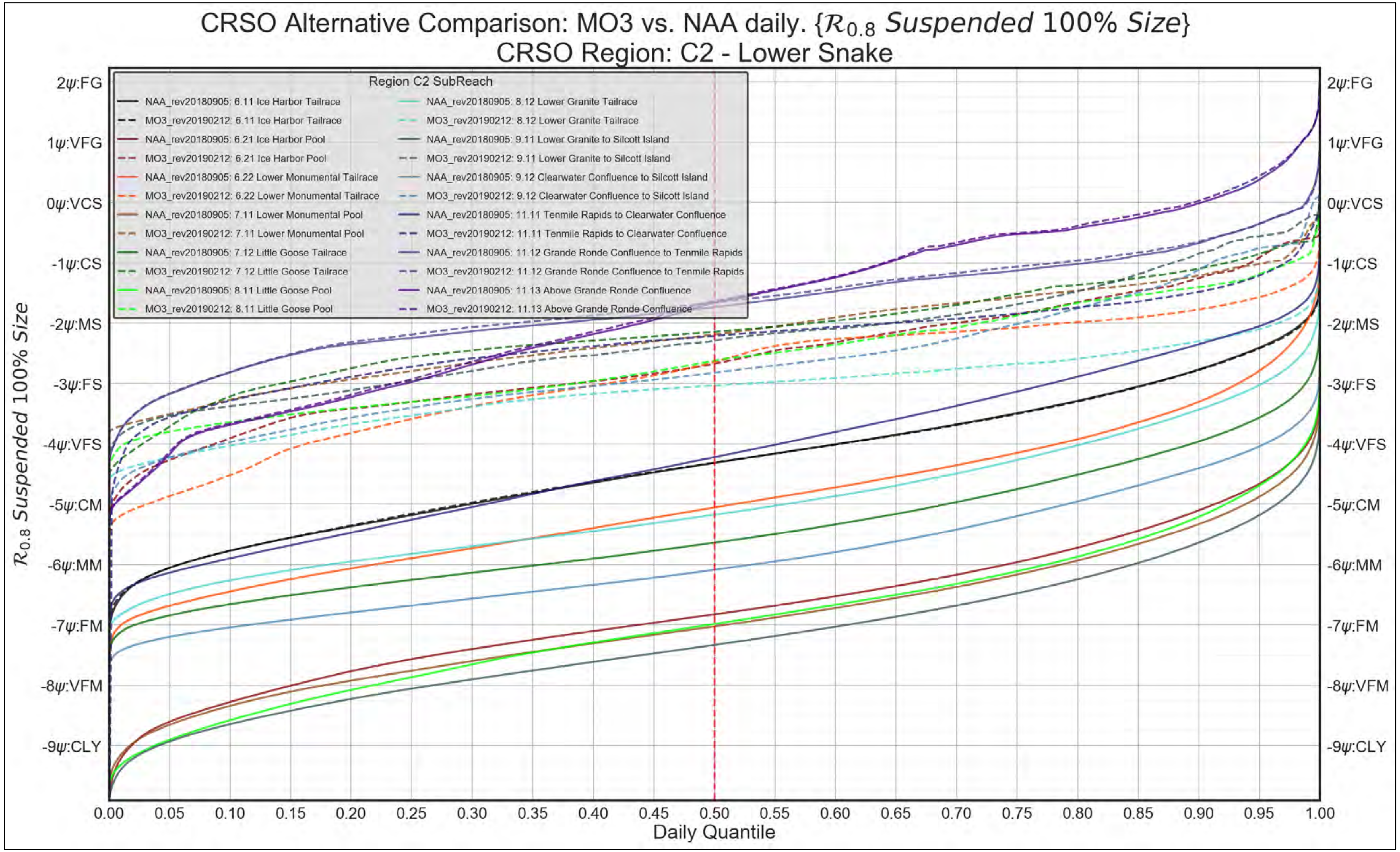


Figure 4-139. Region C2 – Lower Snake. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

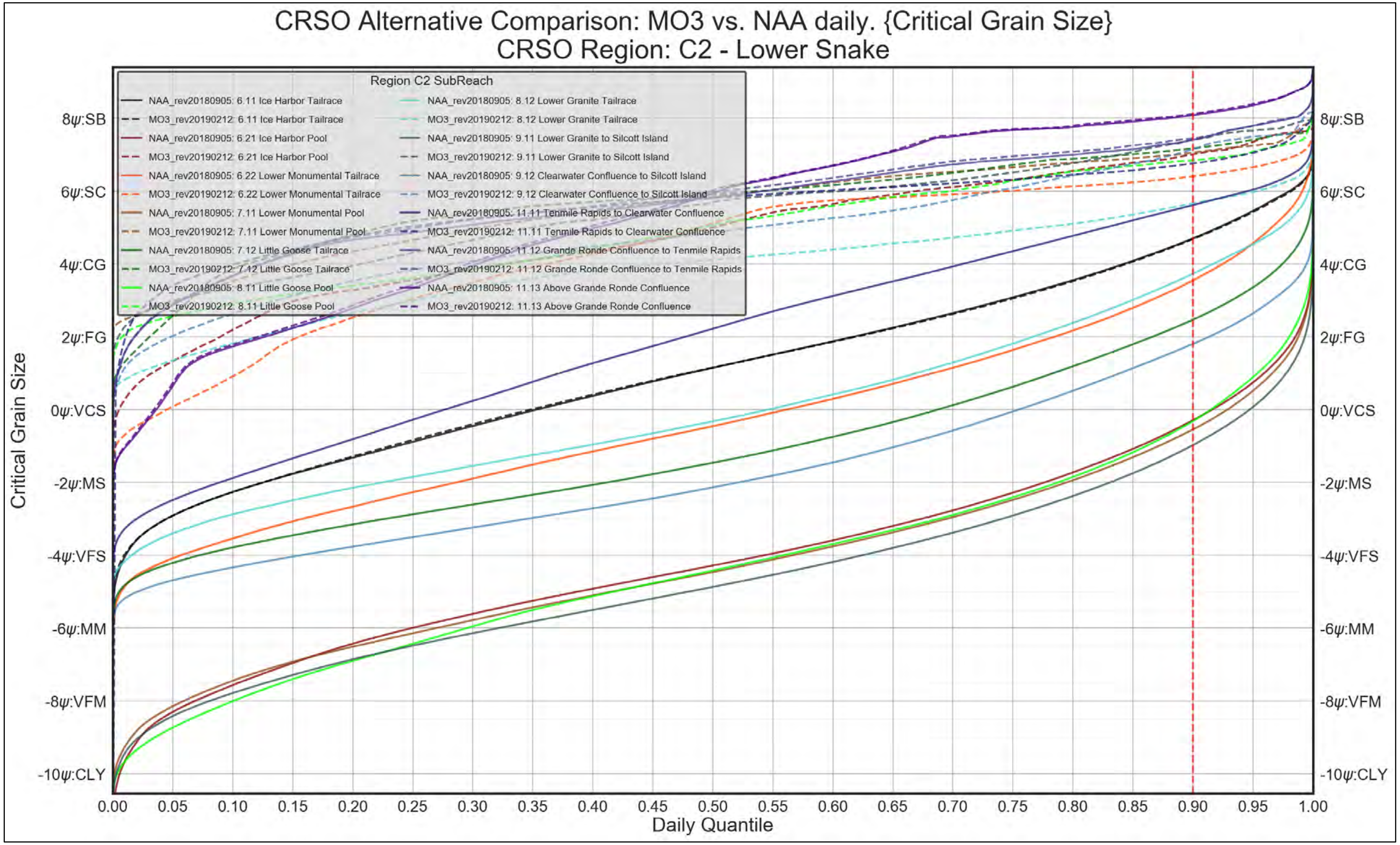


Figure 4-140. Region C2 – Lower Snake. MO3 vs. NAA. Critical Grain-Size Threshold

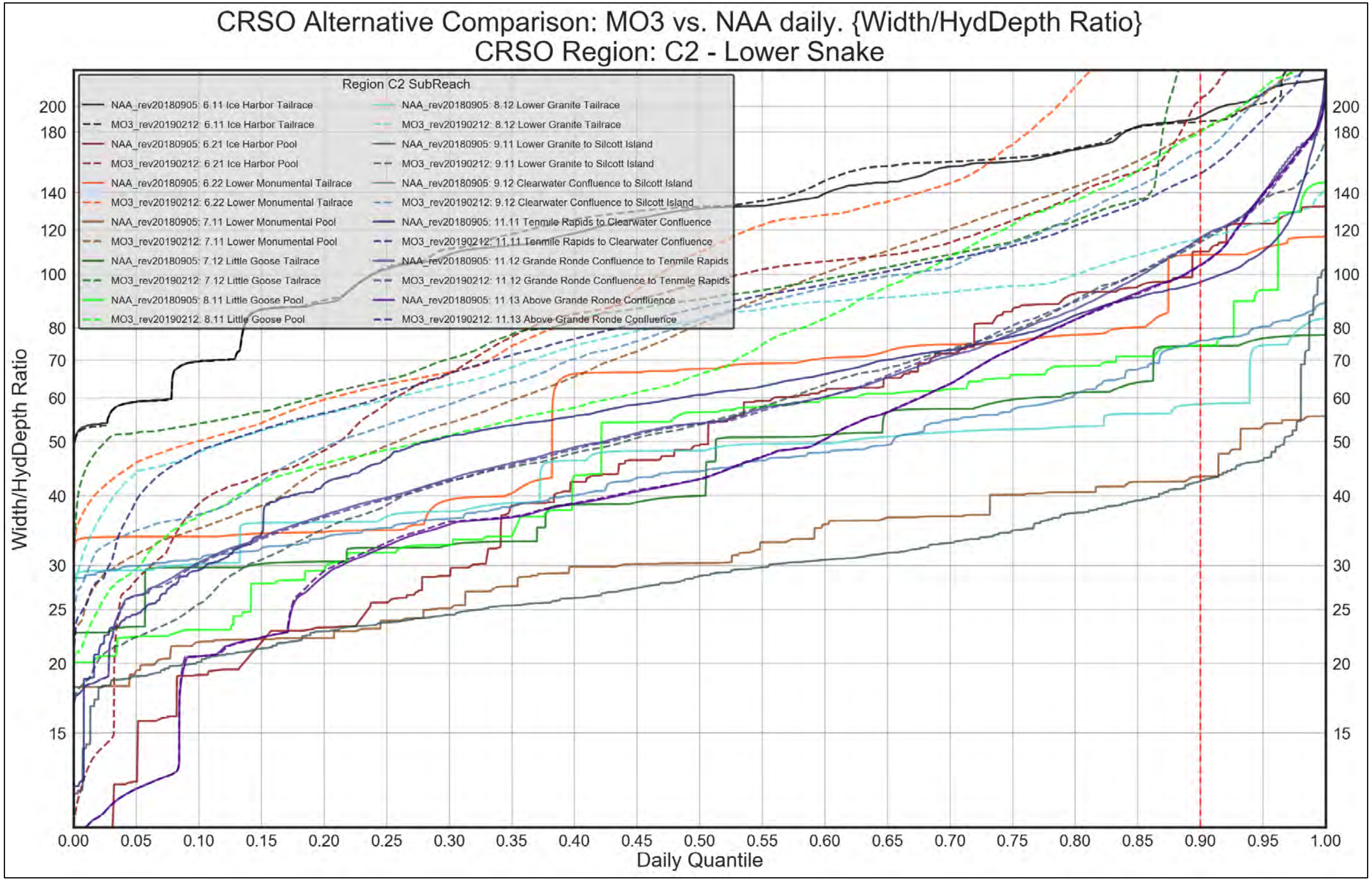
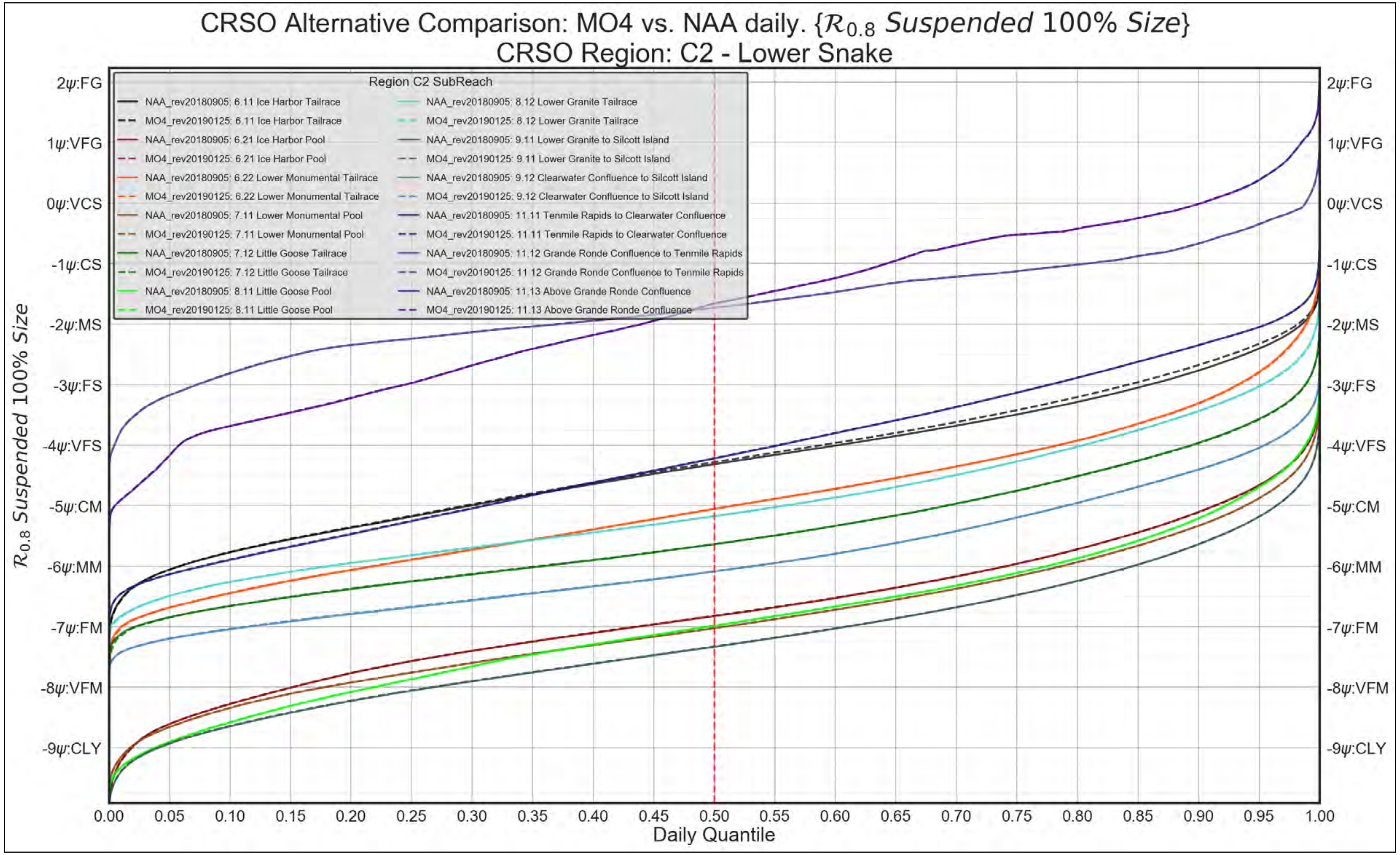


Figure 4-141. Region C2 – Lower Snake. MO3 vs. NAA. Width/Hydraulic Depth Ratio

2287 **REGION C2. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE**



2288

2289 **Figure 4-142. Region C2 – Lower Snake. MO4 vs. NAA. 100% Suspended Grain-Size Threshold**

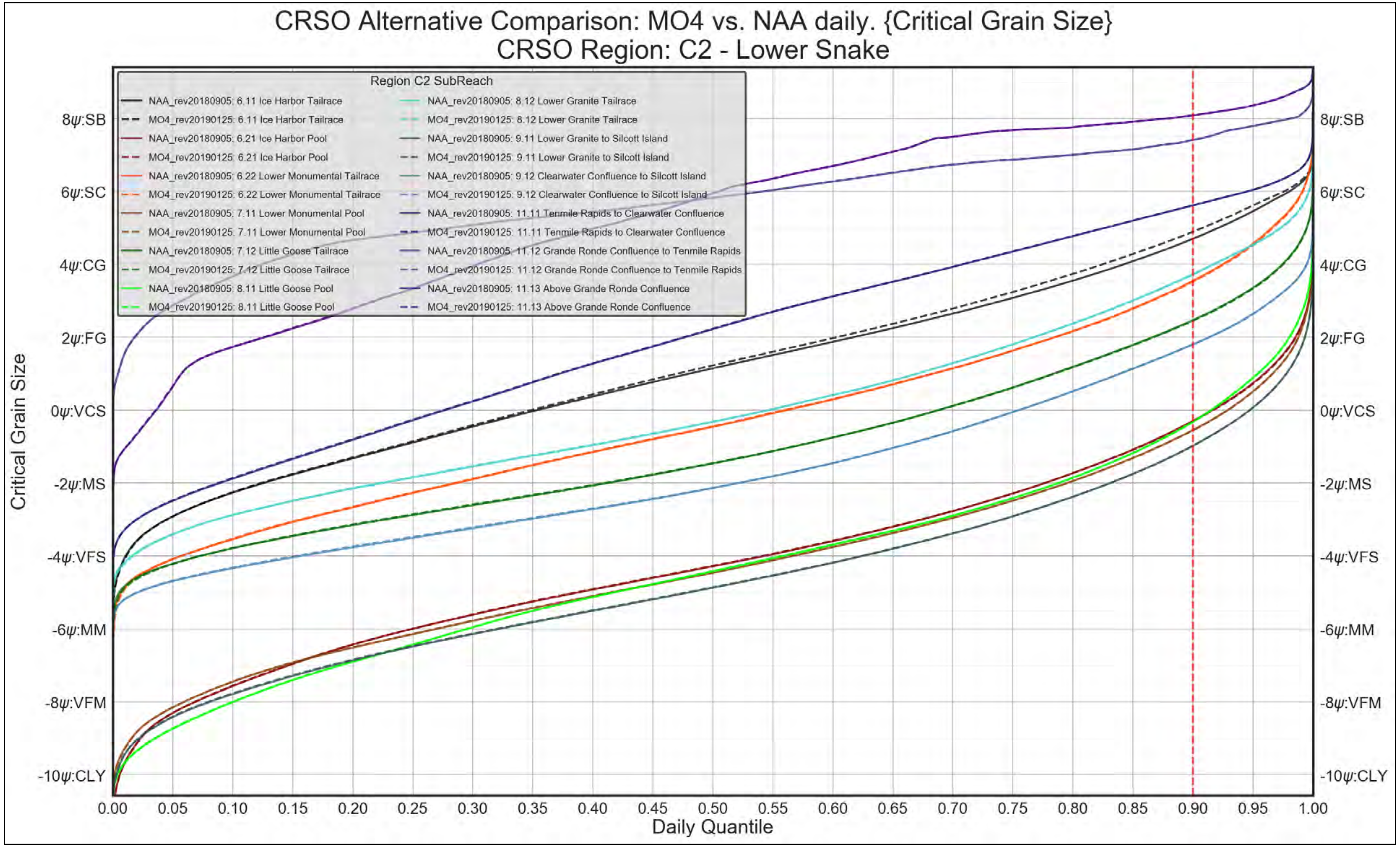


Figure 4-143. Region C2 – Lower Snake. MO4 vs. NAA. Critical Grain-Size Threshold

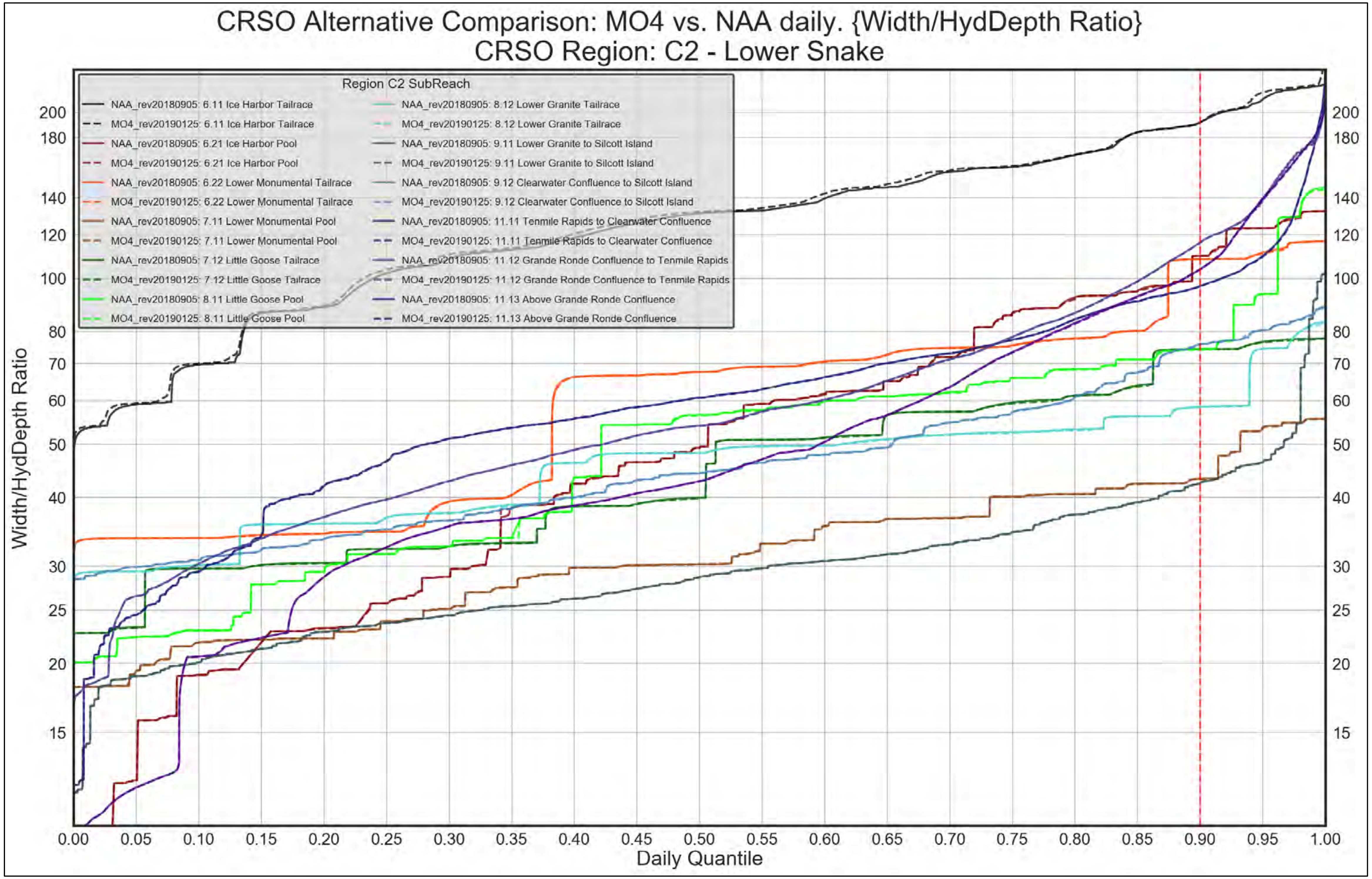


Figure 4-144. Region C2 – Lower Snake. MO4 vs. NAA. Width/Hydraulic Depth Ratio

REGION C2. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE

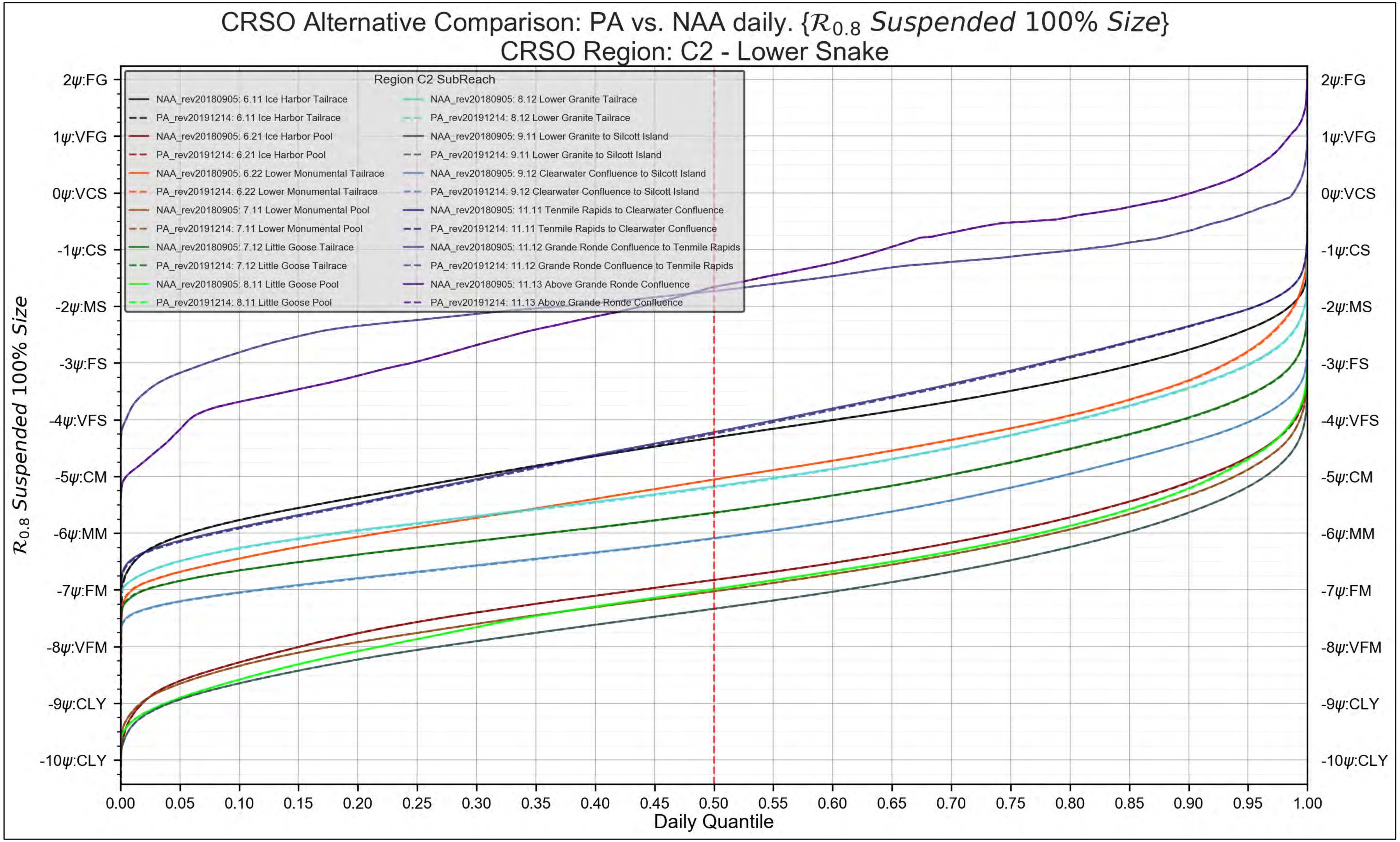


Figure 4-145 Region C2 – Lower Snake. PA vs. NAA. 100% Suspended Grain-Size Threshold

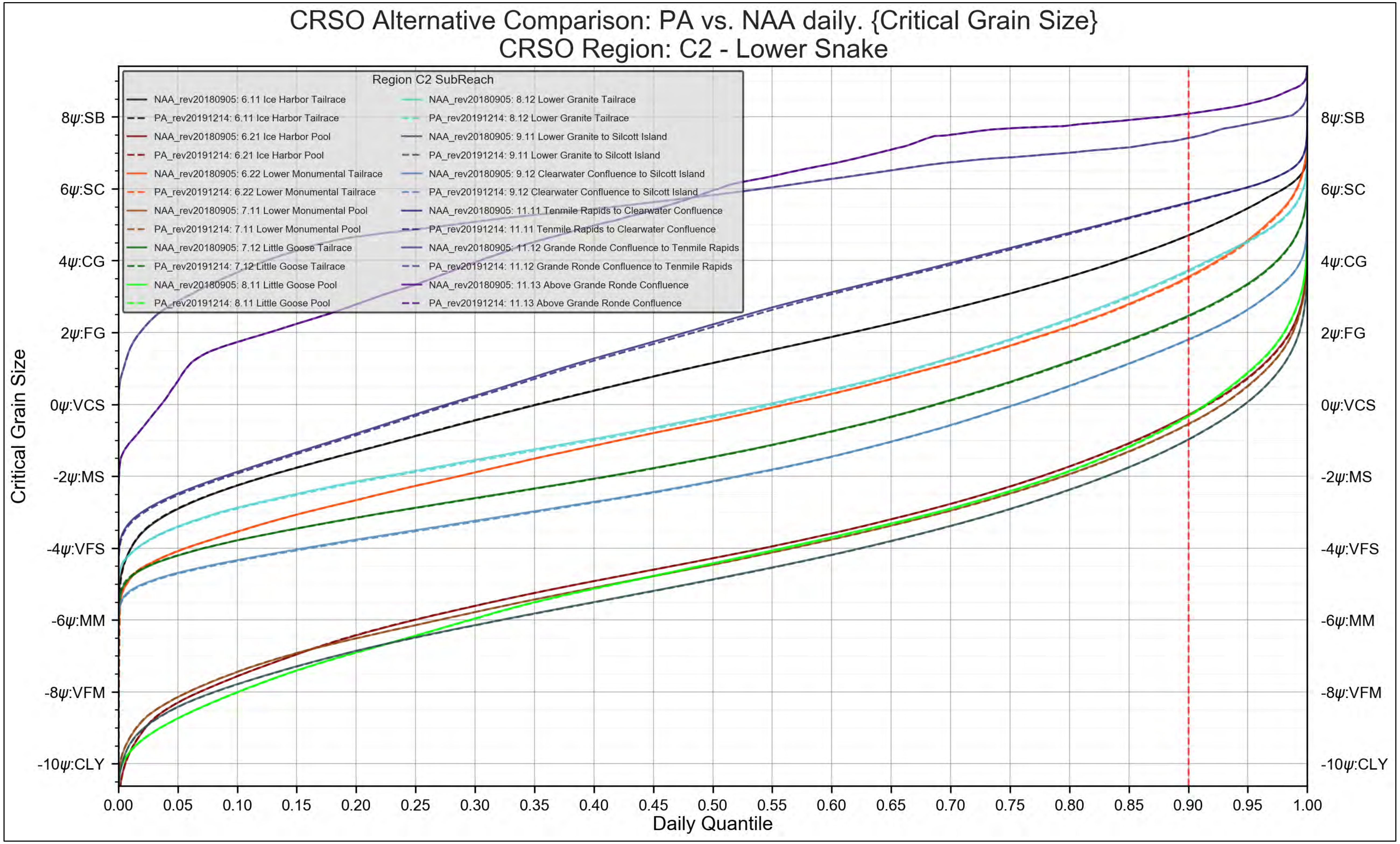


Figure 4-146 Region C2 – Lower Snake. PA vs. NAA. Critical Grain-Size Threshold

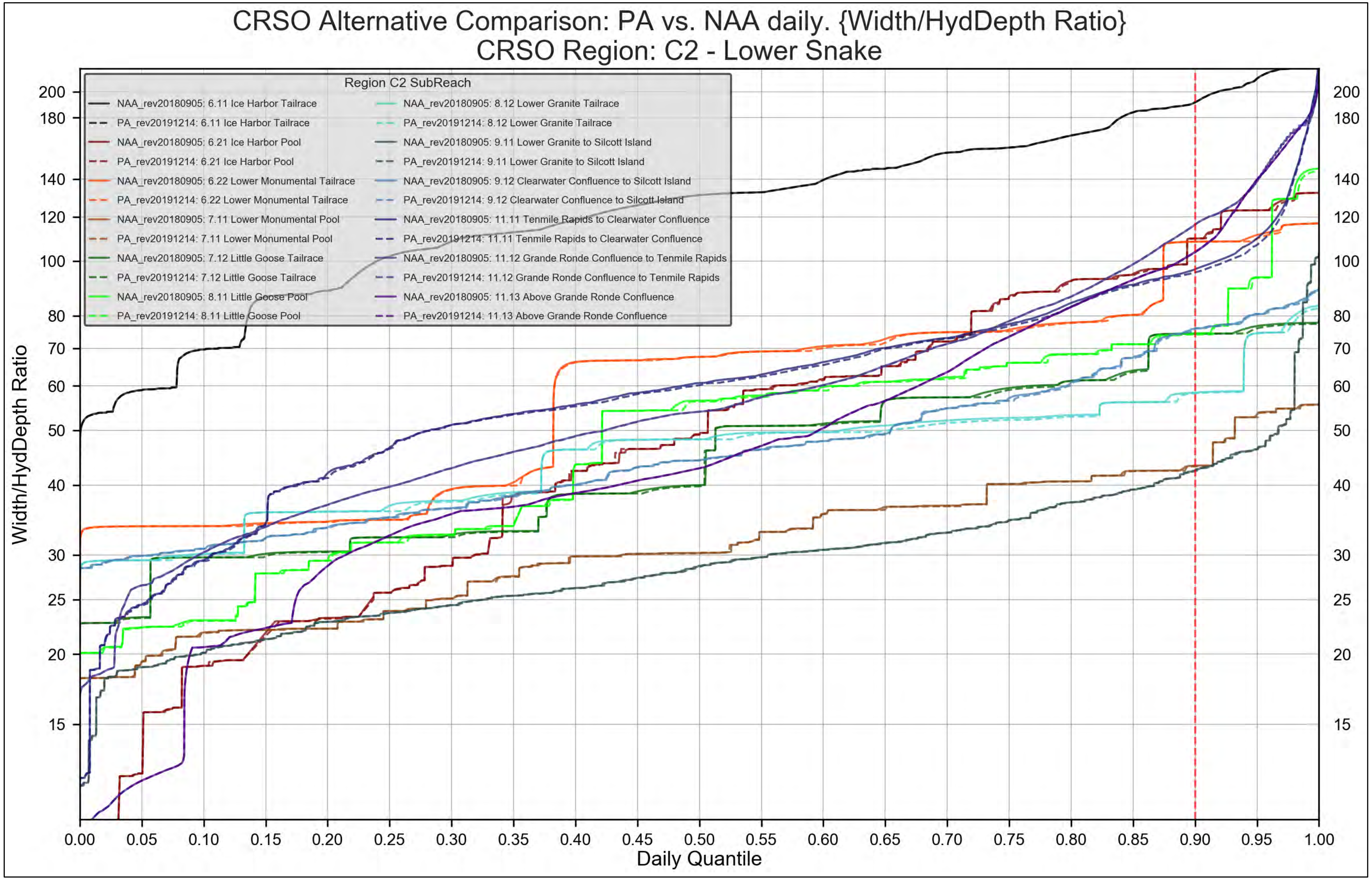


Figure 4-147 Region C2 – Lower Snake. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.5.4 Region C2: Snake River Navigation

Table 4-15. Region C2: Lower Snake River Navigation

Alternative	Average Annual Watershed Sediment Yield above Lower Granite Dam - Bed Material Load (Ktons)				Estimated Change in Average Annual Dredging Volume (Cubic yards per year)
	Clearwater at Spalding	Snake at Anatone	Total (Snake + Clearwater)	Percent Change	
No Action (NAA)	178.8	803.3	982.1	Baseline	Baseline
MO1	180.1	803.3	983.3	0.31%	387
MO2	179.3	803.9	983.1	0.10%	185
MO3	178.9	803.9	982.7	0.10%	**n/a***
MO4	178.9	803.9	982.7	0.05%	61
PA	177.6	803.3	980.9	-0.30%	-371

* Under MO3, dredging of the Snake River FNC would be discontinued. Under MO3, watershed sediment yield would be routed to the Columbia River as noted further in Section 4.2.6.4

4.2.6 Region D: Lower Columbia Reach – Richland, Washington, to Astoria, Oregon

4.2.6.1 Region D: Lower Columbia Reach Comparison Tables

Table 4-16. Region D: Lower Columbia Run-of-River Reservoir and Free-Flowing River Metrics Quantitative Analysis Summary

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	Name	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change In Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd
Lower Columbia Below Richland, Washington	5.13	Pasco to Kennewick Reach	-1.9%	-4.9%	0.0%	0.7%	-1.3%	0.1%	-2.2%	-8.1%	2.1%	1.2%	7.8%	0.2%	-0.3%	-0.3%	0.0%
	5.12	Snake River Confluence to Wallula	-1.8%	-4.7%	0.0%	0.2%	-2.4%	0.0%	0.8%	-0.6%	0.0%	3.8%	**15.6%**	2.0%	-0.1%	-0.7%	0.0%
	5.11	Wallula to McNary Dam	-1.7%	-4.6%	0.0%	0.8%	-2.7%	0.0%	0.4%	-1.5%	1.3%	1.2%	3.9%	0.1%	-0.1%	-0.7%	0.0%
	4.12	Upper John Day Pool	-2.5%	-9.0%	-1.3%	0.6%	-2.2%	0.0%	-2.0%	-8.7%	-0.8%	1.1%	**11.4%**	4.1%	-6.0%	**-17.3%**	-4.4%
	4.11	Lower John Day Pool	-2.0%	-7.3%	-0.2%	0.8%	-2.6%	0.0%	-1.7%	-7.2%	-0.1%	0.7%	3.5%	0.3%	-2.3%	-9.2%	-1.0%
	3.12	Upper Dalles Dam Pool	-1.6%	-3.7%	0.0%	0.8%	-2.0%	0.0%	-1.2%	-4.5%	0.1%	3.7%	**17.8%**	0.8%	-0.3%	-0.3%	0.0%
	3.11	Lower Dalles Dam Pool	-1.8%	-4.5%	0.0%	0.2%	-2.4%	0.0%	-1.8%	-5.0%	0.0%	2.2%	**13.4%**	3.8%	-0.3%	-0.4%	0.0%
	2.13	The Dalles Dam to Memaloose Island	-1.5%	-3.4%	-0.1%	0.5%	-1.6%	-0.1%	-1.5%	-4.0%	-0.1%	3.7%	**15.1%**	-4.7%	-0.2%	-0.3%	0.0%
	2.12	Memaloose Island to Cascade Falls	-1.4%	-3.4%	0.1%	0.9%	-1.9%	0.0%	-1.5%	-4.2%	0.1%	5.1%	**23.1%**	2.0%	-0.3%	-0.2%	0.0%
	2.11	Cascade Falls to Bonneville Dam	-1.7%	-4.3%	0.0%	1.0%	-2.6%	0.0%	-1.3%	-5.3%	0.0%	3.8%	**16.7%**	0.0%	-0.4%	-0.5%	0.0%

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	Name	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change In Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd	% Change 100% Suspended Grain-Size Class at 50% Excd	% Change in Grain-Size Class at 90% Excd	% Change in Width/Hyd Depth Ratio at 90% Excd
	1.23	Bonneville Dam to Skamania	-1.1%	-1.6%	0.1%	-0.4%	-0.3%	0.1%	-1.3%	-1.5%	0.1%	-1.2%	-0.1%	0.1%	0.0%	-0.2%	0.0%
	1.22	Skamania to Washougal	-0.8%	-2.3%	0.3%	0.7%	-1.4%	-0.1%	-0.8%	-2.7%	0.3%	-0.5%	-1.1%	-0.3%	-0.2%	-0.2%	0.1%
	1.21	Washougal to Vancouver	-0.9%	-2.1%	0.0%	0.6%	-0.9%	0.1%	-0.8%	-2.3%	0.0%	-1.0%	-1.0%	0.0%	-0.1%	-0.2%	0.0%
	1.12	Columbia between Willamette and Cowlitz	-1.0%	-2.1%	-0.2%	0.4%	-0.8%	0.0%	-1.1%	-2.4%	-0.2%	0.9%	-2.1%	-0.2%	-0.3%	0.0%	0.0%
	1.11	Columbia below Cowlitz	-1.2%	-2.2%	0.0%	0.2%	-0.5%	0.0%	-1.1%	-2.6%	0.0%	-0.3%	-2.2%	0.0%	-0.2%	-0.1%	0.0%

Table 4-17. Region D: Lower Columbia Run-of-River Reservoir and Free-Flowing River Metrics Qualitative Analysis Summary

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	Name	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change	Potential for Sediment Passing Reservoirs and Reaches	Potential for Bed Material Change	Potential for Geomorphic Change
Lower Columbia below Richland, WA	5.13	Pasco to Kennewick Reach	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	5.12	Snake River Confluence to Wallula	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect
	5.11	Wallula to McNary Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect
	4.12	Upper John Day Pool	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	**Minor**	Negligible
	4.11	Lower John Day Pool	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	3.12	Upper Dalles Dam Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect
	3.11	Lower Dalles Dam Pool	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect
	2.13	The Dalles Dam to Memaloose Island	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect
	2.12	Memaloose Island to Cascade Falls	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	**Minor**	Negligible	Negligible	Negligible	No Effect

Major Reach	Subreach		M01 vs. NAA			M02 vs. NAA			M03 vs. NAA			M04 vs. NAA			PA vs. NAA		
	ID #	**Name**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**	**Potential for Sediment Passing Reservoirs and Reaches**	**Potential for Bed Material Change**	**Potential for Geomorphic Change**
	2.11	Cascade Falls to Bonneville Dam	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	**Minor**	No Effect	Negligible	Negligible	No Effect
	1.23	Bonneville Dam to Skamania	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	No Effect
	1.22	Skamania to Washougal	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	1.21	Washougal to Vancouver	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect
	1.12	Columbia between Willamette and Cowlitz	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	No Effect	No Effect
	1.11	Columbia below Cowlitz	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect	Negligible	Negligible	No Effect

4.2.6.2 Region D1: Lower Columbia Reach above Bonneville Dam Comparison Figures

REGION D1: MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

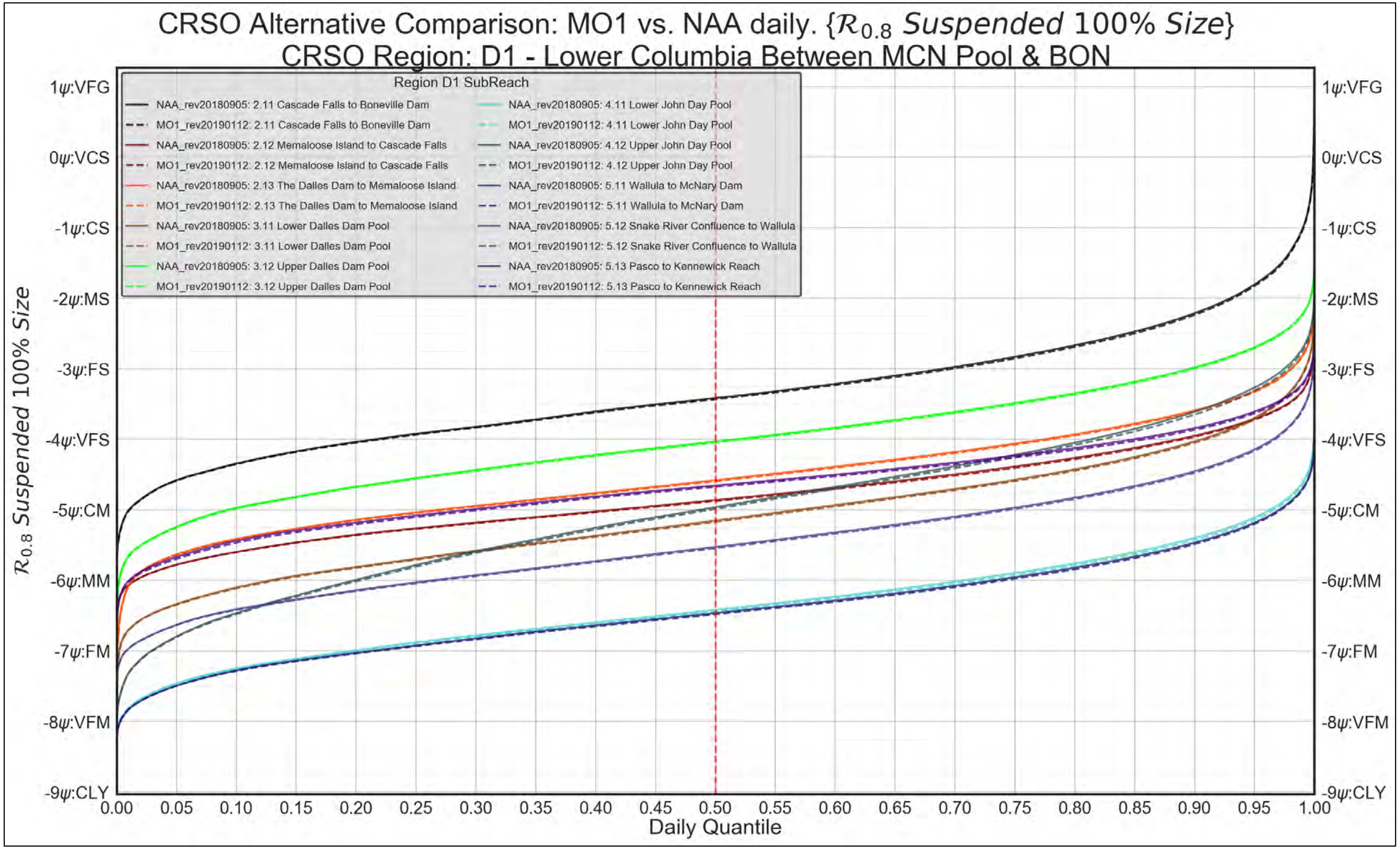


Figure 4-148. Region D1 – Lower Columbia between MCN Pool & BON. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

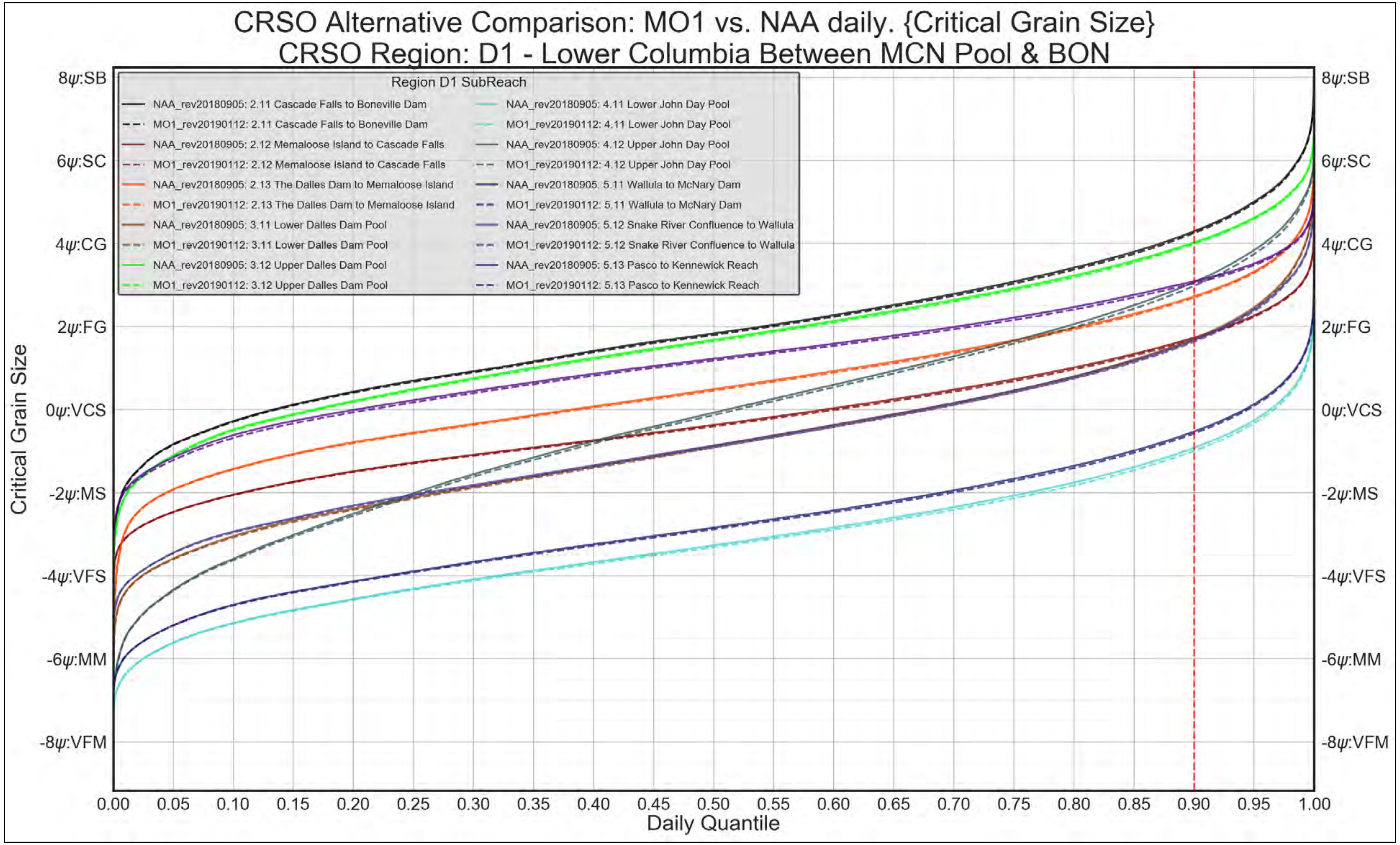


Figure 4-149. Region D1 – Lower Columbia between MCN Pool & BON. MO1 vs. NAA. Critical Grain-Size Threshold

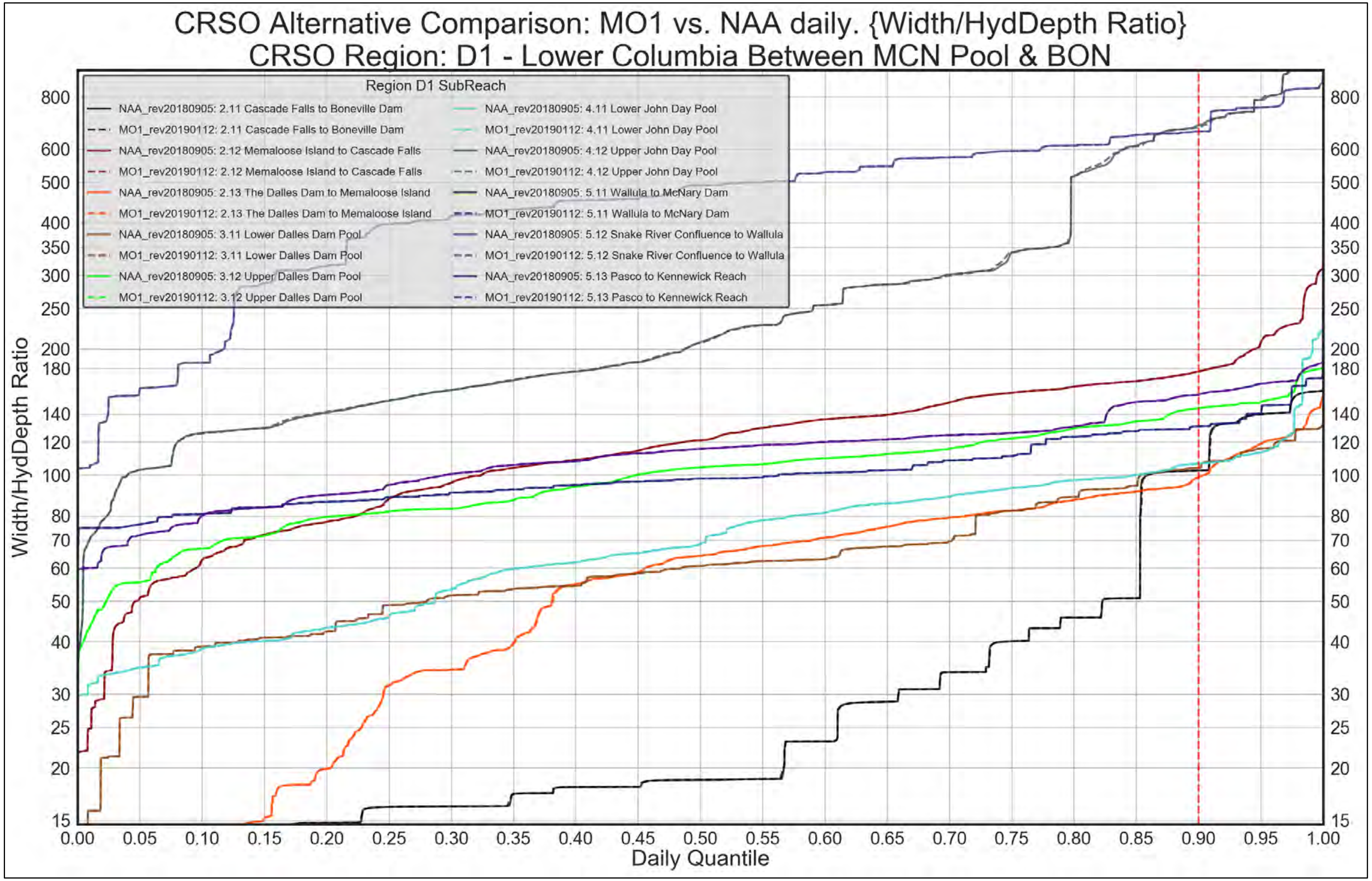


Figure 4-150. Region D1 – Lower Columbia between MCN Pool & BON. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION D1. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

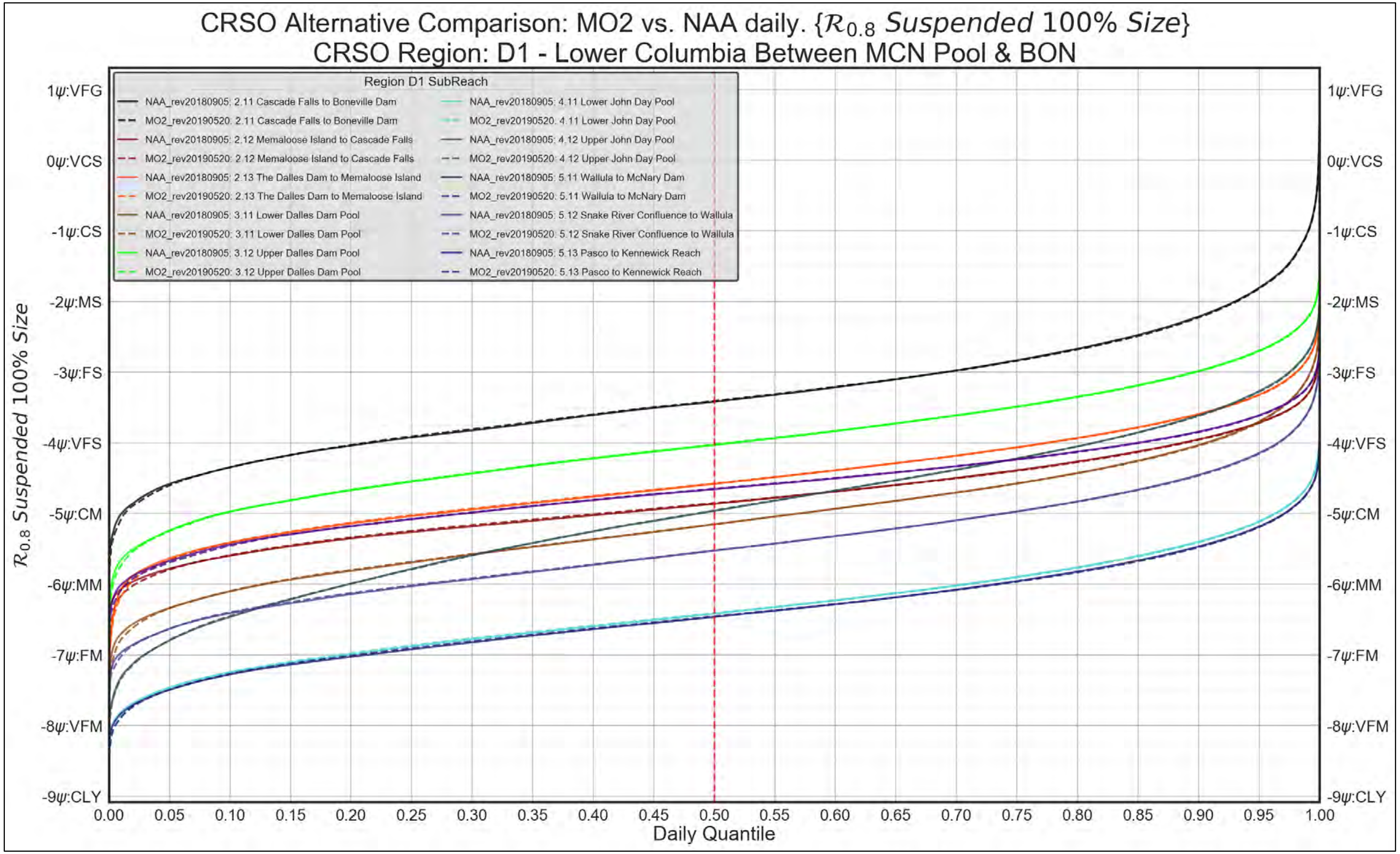


Figure 4-151. Region D1 – Lower Columbia between MCN Pool & BON. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

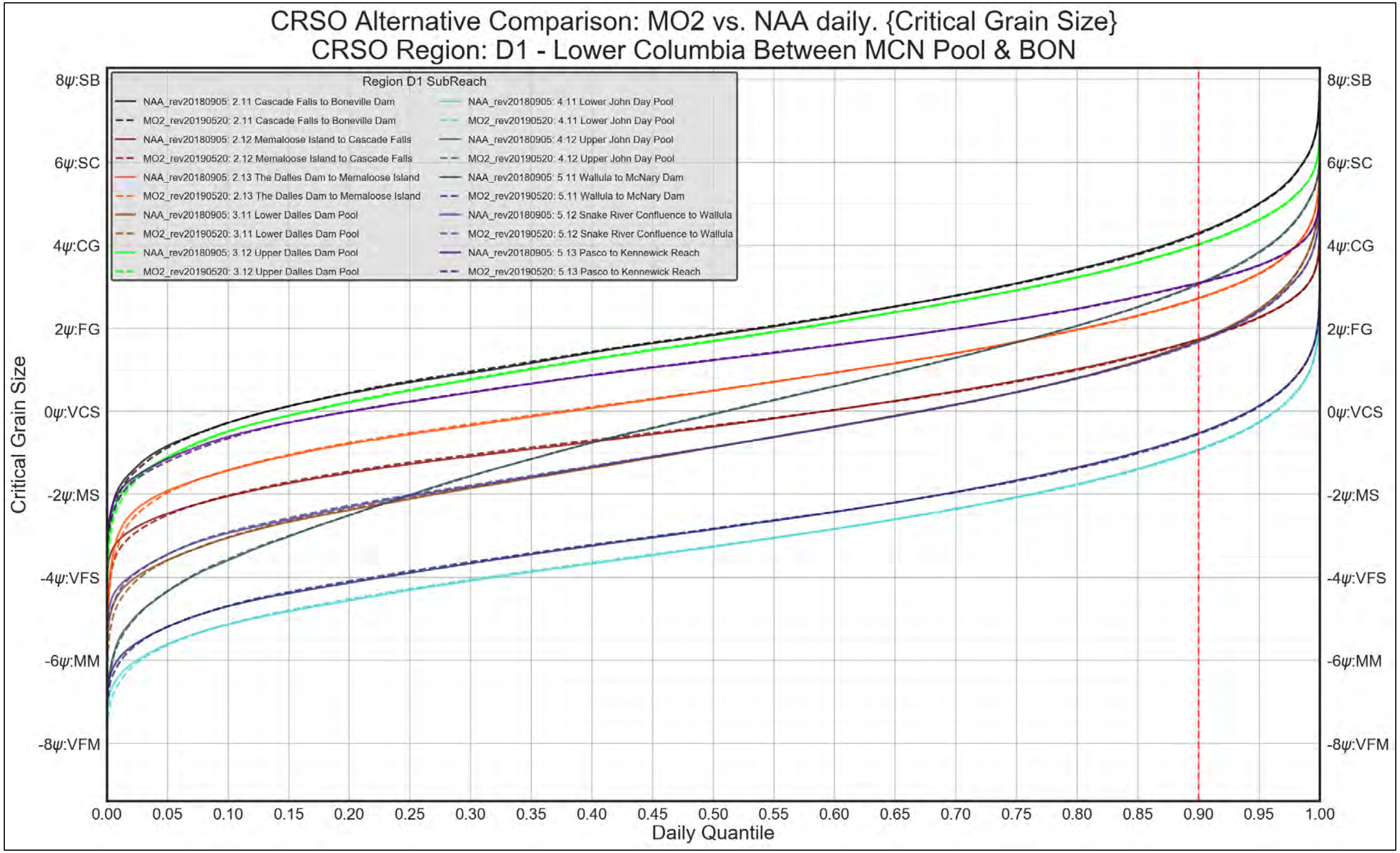
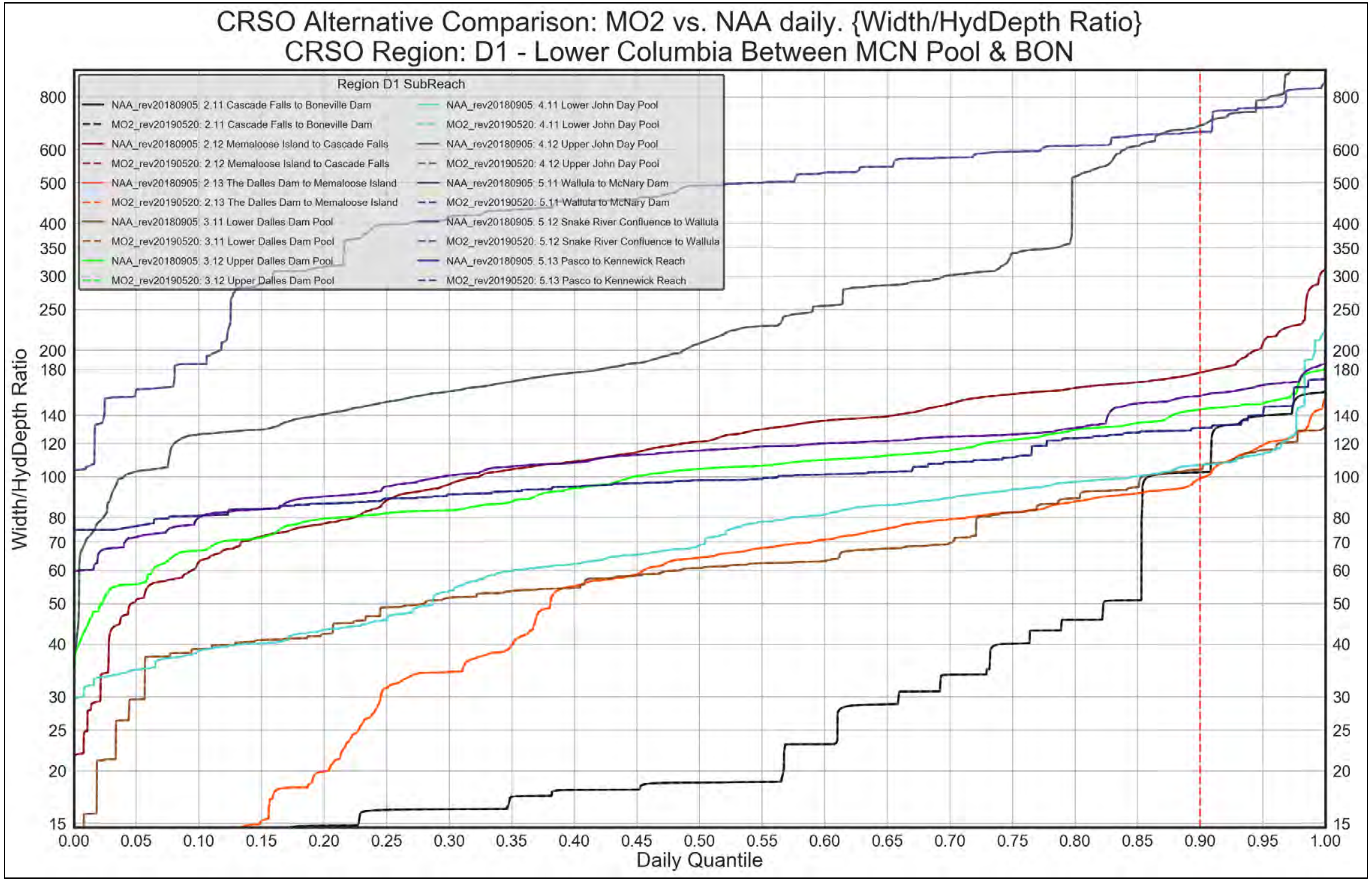


Figure 4-152. Region D1 – Lower Columbia between MCN Pool & BON. MO2 vs. NAA. Critical Grain-Size Threshold



2321

2322 **Figure 4-153. Region D1 – Lower Columbia between MCN Pool & BON. MO2 vs. NAA. Width/Hydraulic Depth Ratio**

REGION D1. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE

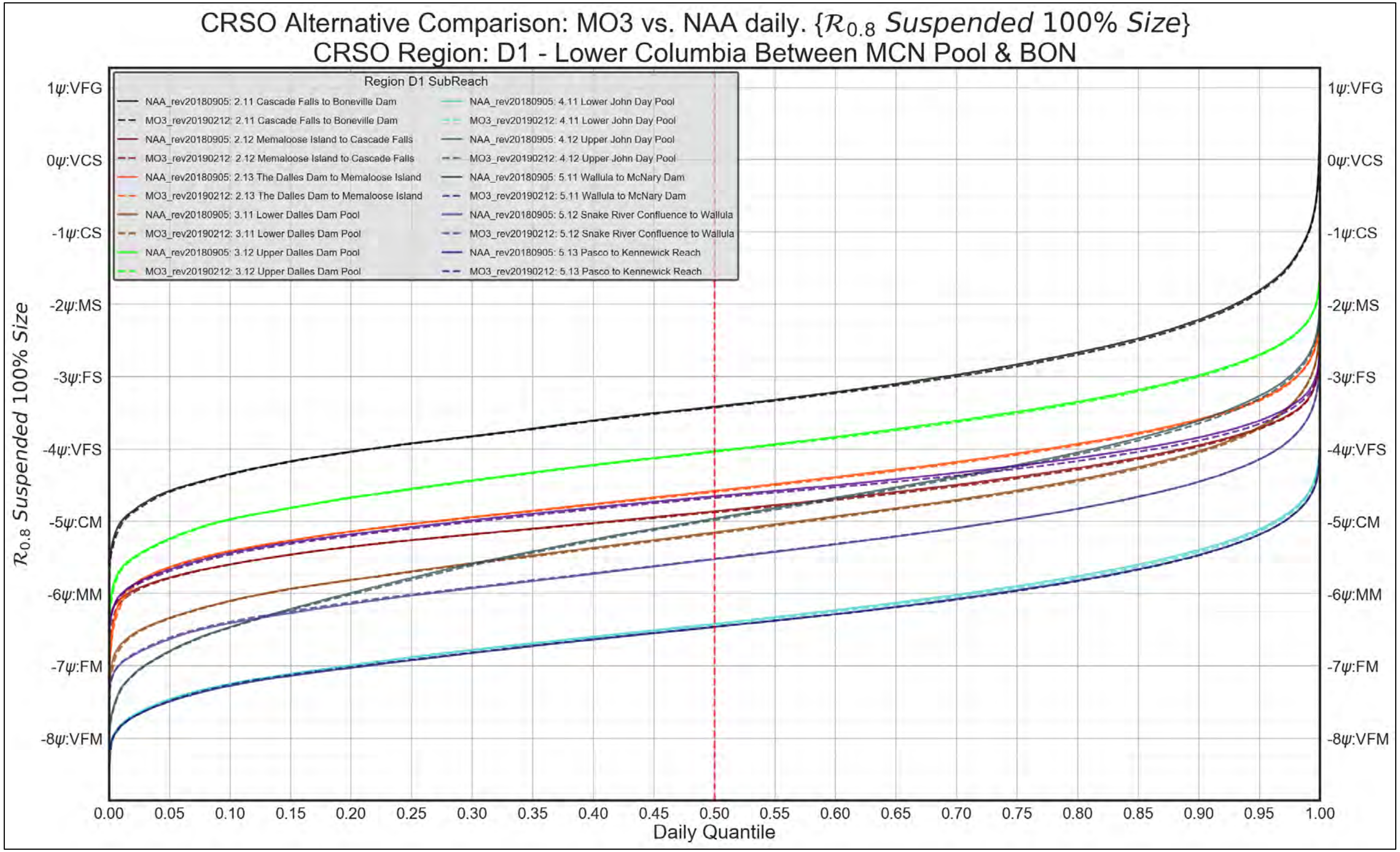


Figure 4-154. Region D1 – Lower Columbia between MCN Pool & BON. MO3 vs. NAA. 100% Suspended Grain-Size Threshold

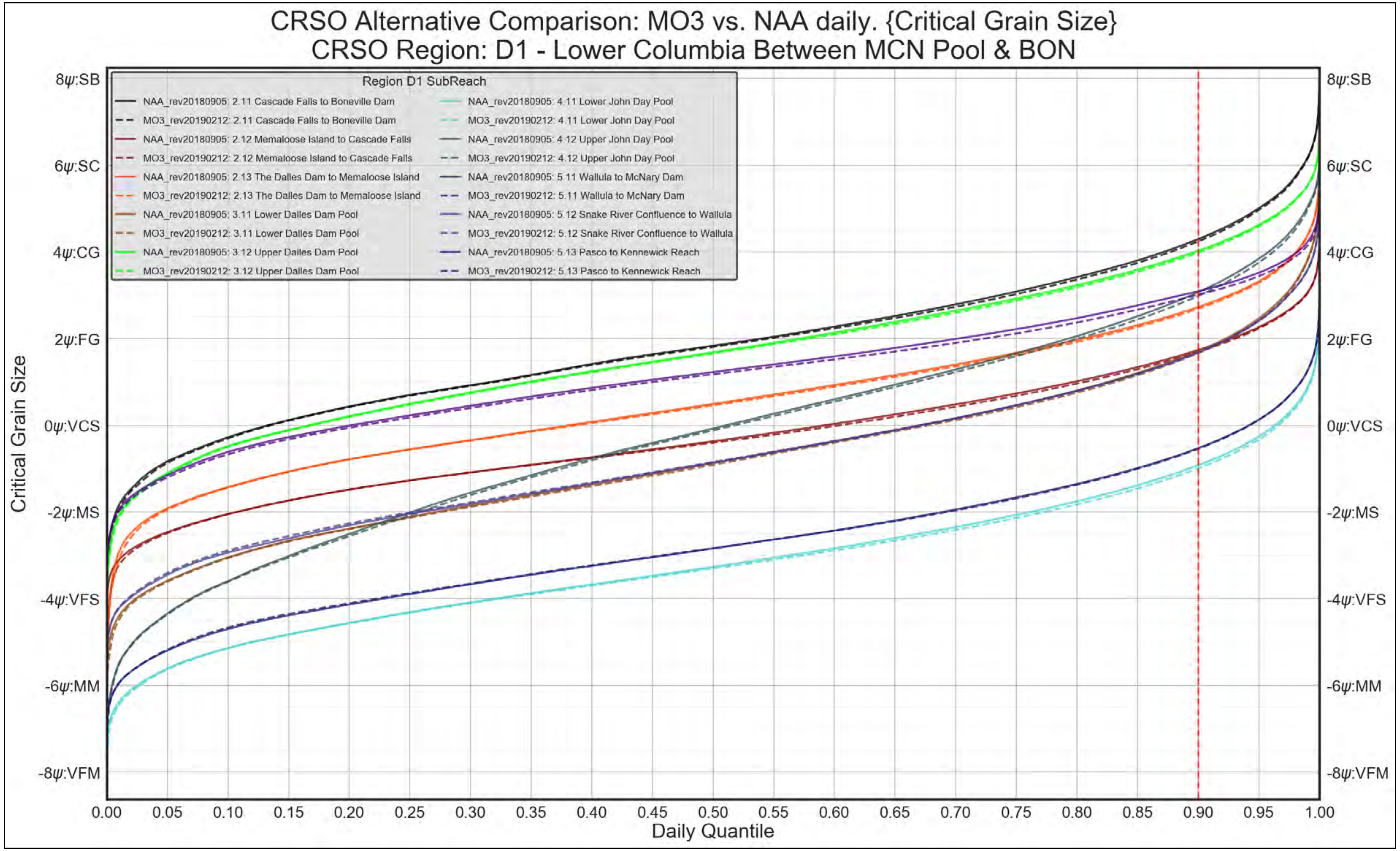


Figure 4-155. Region D1 – Lower Columbia between MCN Pool & BON. MO3 vs. NAA. Critical Grain-Size Threshold

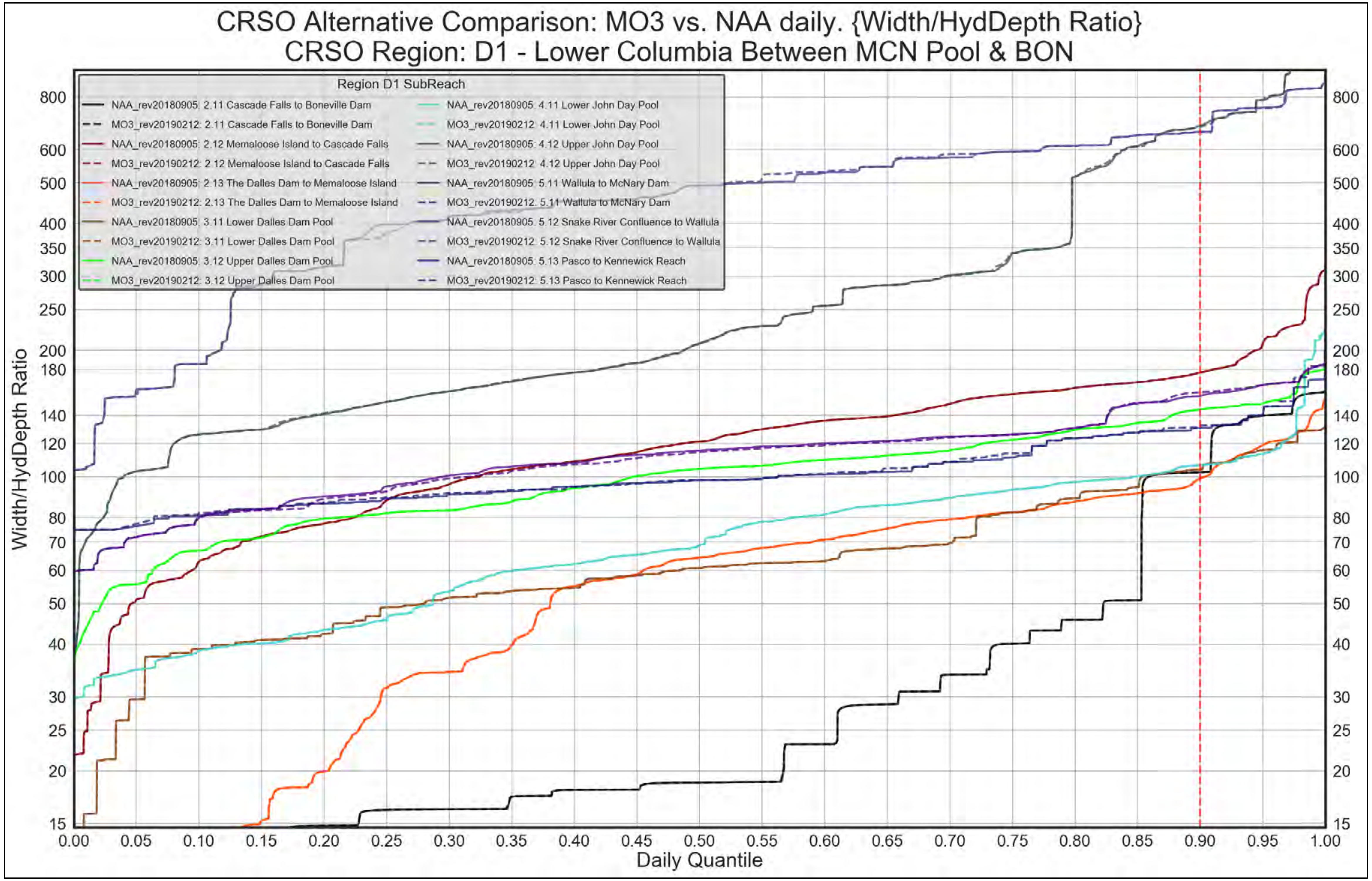
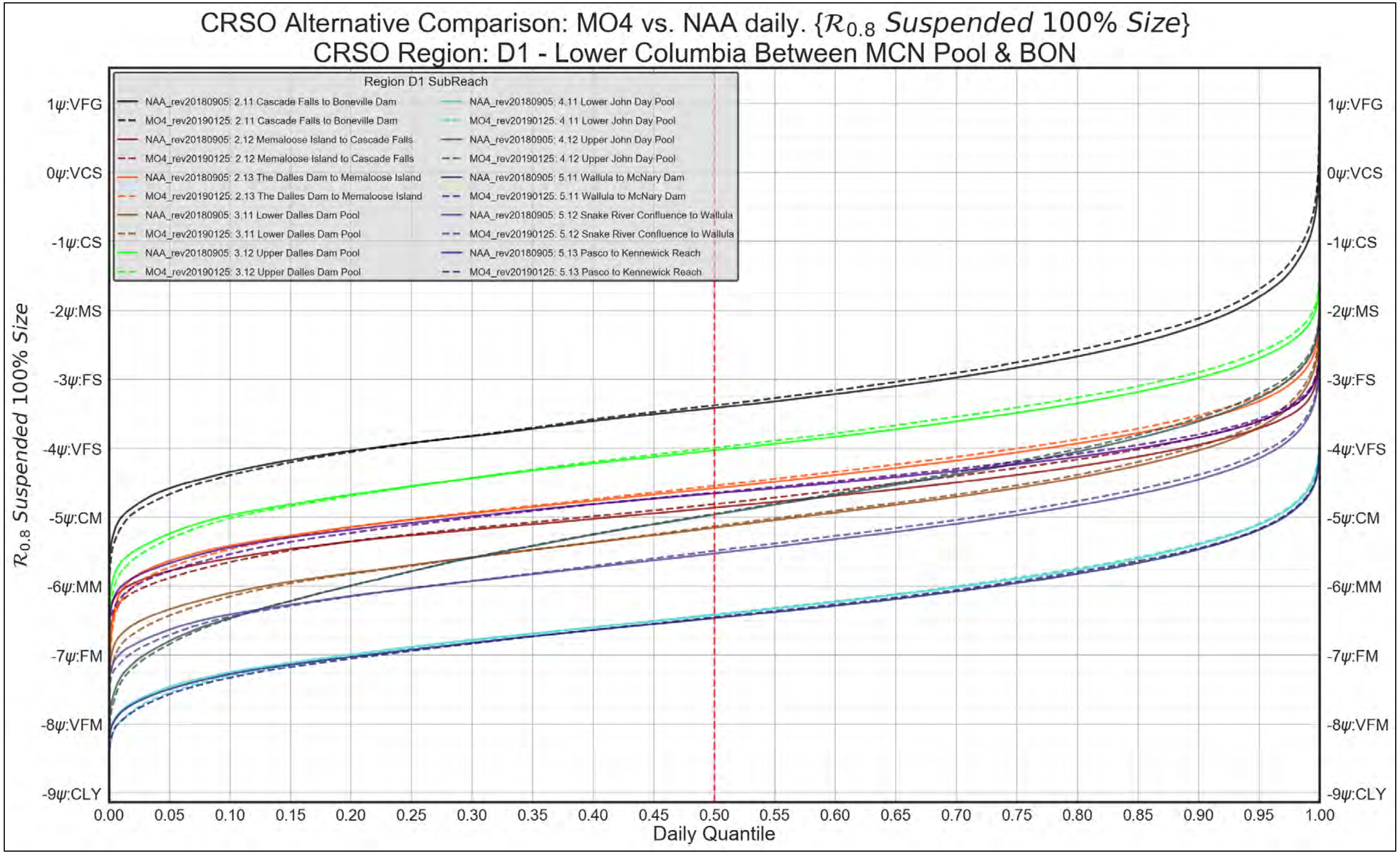


Figure 4-156. Region D1 – Lower Columbia between MCN Pool & BON. MO3 vs. NAA. Width/Hydraulic Depth Ratio

2330 **REGION D1. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE**



2331

2332 **Figure 4-157. Region D1 – Lower Columbia between MCN Pool & BON. MO4 vs. NAA. 100% Suspended Grain-Size Threshold**

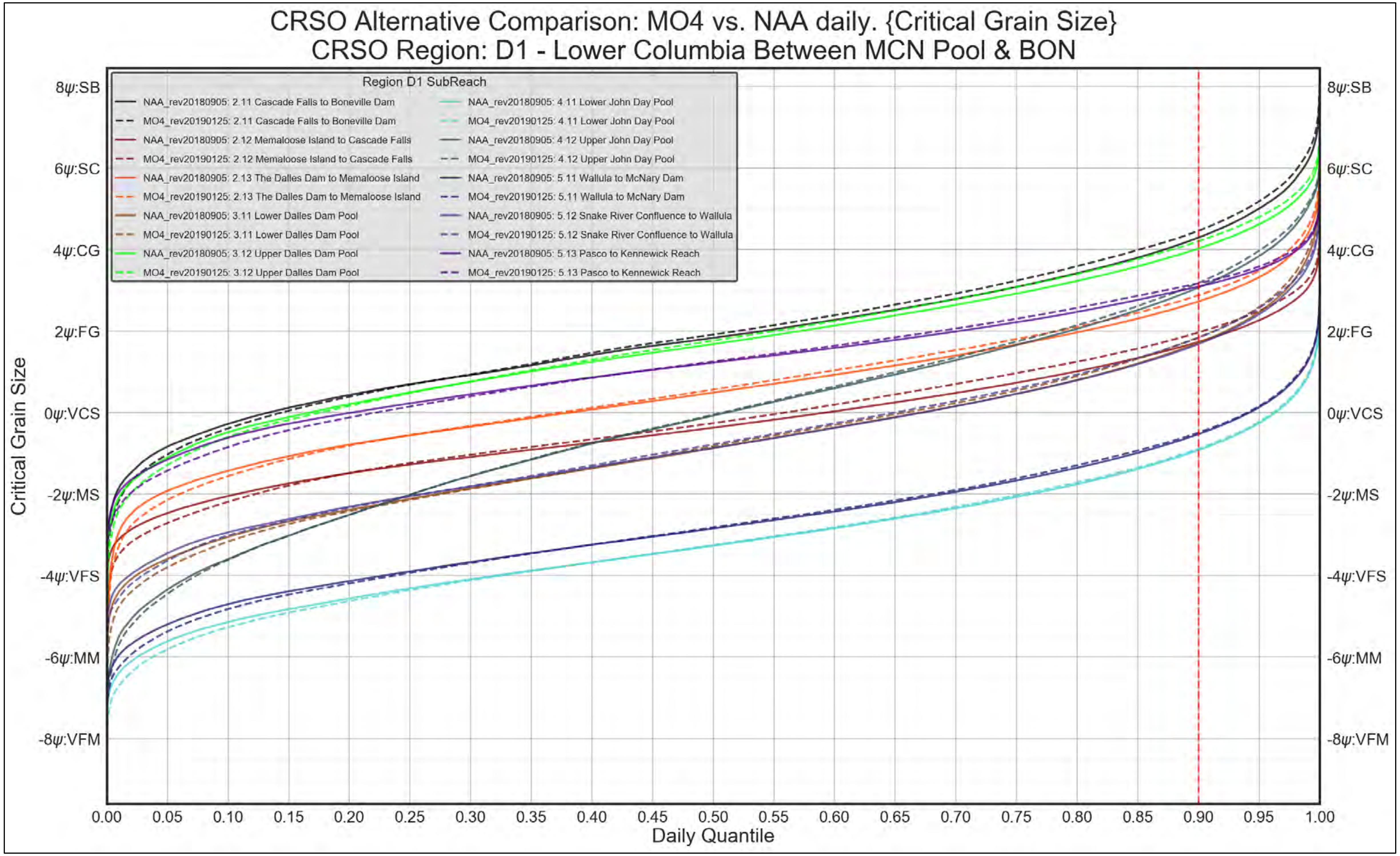


Figure 4-158. Region D1 – Lower Columbia between MCN Pool & BON. MO4 vs. NAA. Critical Grain-Size Threshold

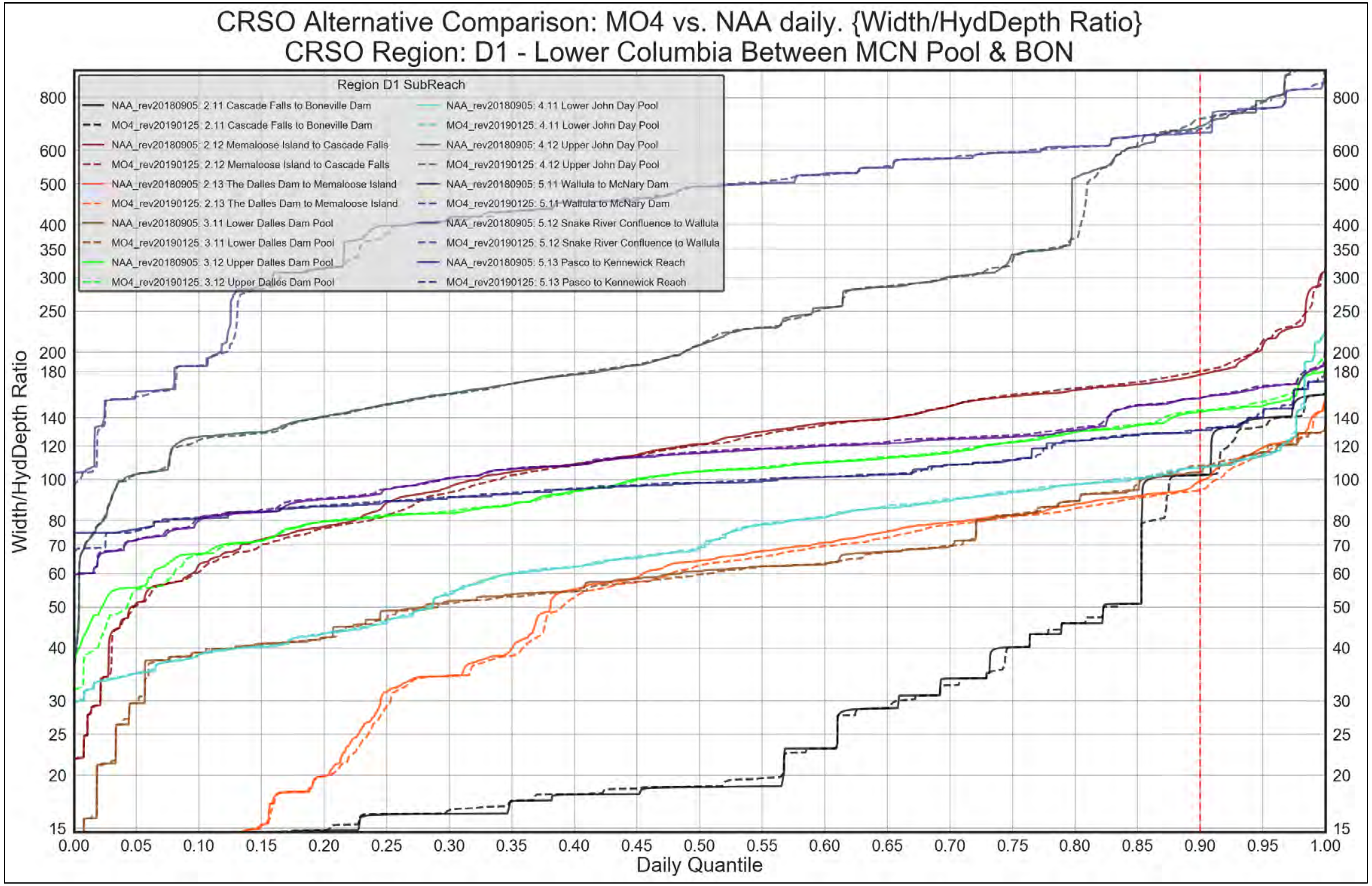
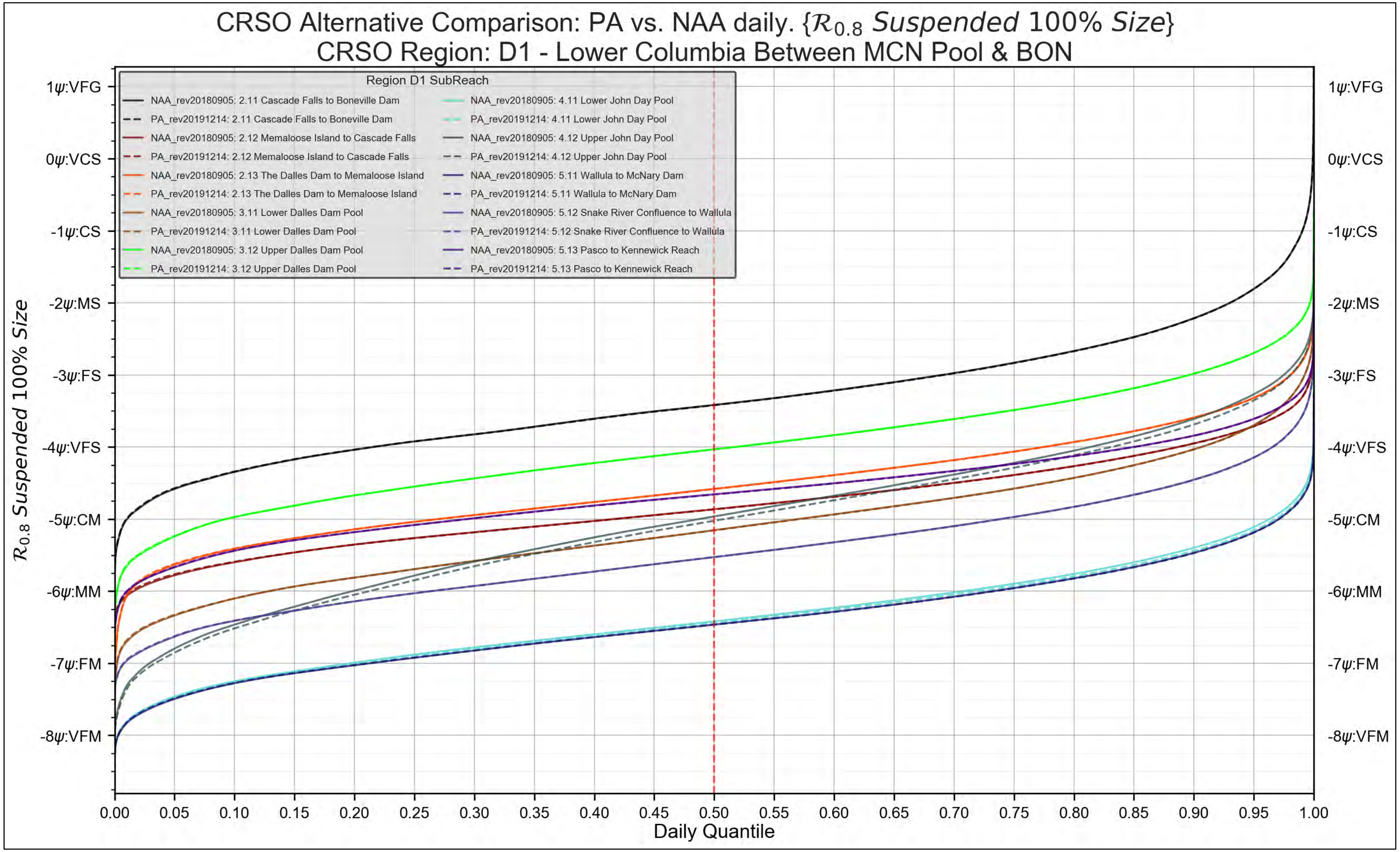


Figure 4-159. Region D1 – Lower Columbia between MCN Pool & BON. MO4 vs. NAA. Width/Hydraulic Depth Ratio

2337 **REGION D1. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE**



2338
2339 **Figure 4-160 Region D1 – Lower Columbia between MCN Pool & BON. PA vs. NAA. 100% Suspended Grain-Size Threshold**

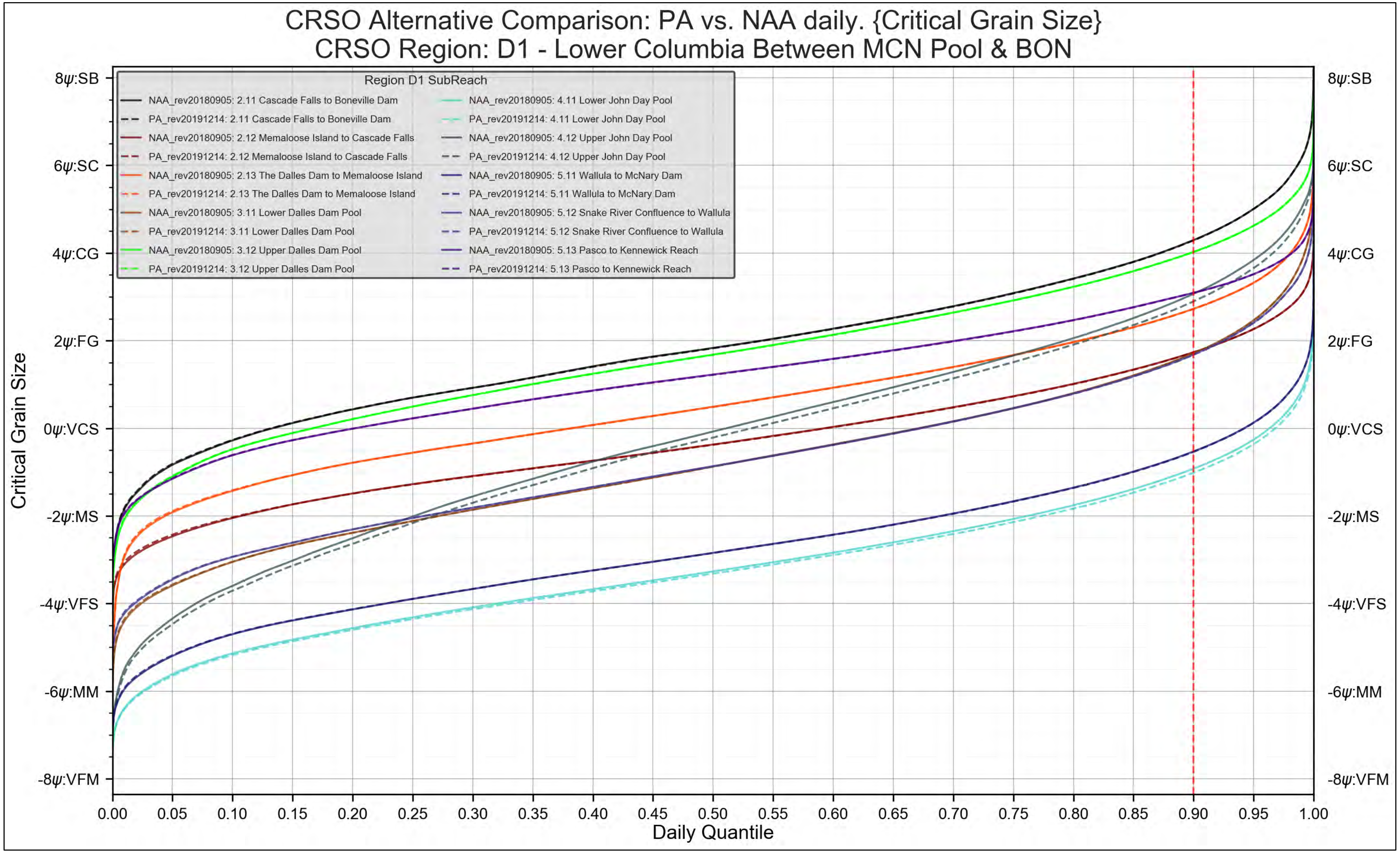


Figure 4-161 Region D1 – Lower Columbia between MCN Pool & BON. PA vs. NAA. Critical Grain-Size Threshold

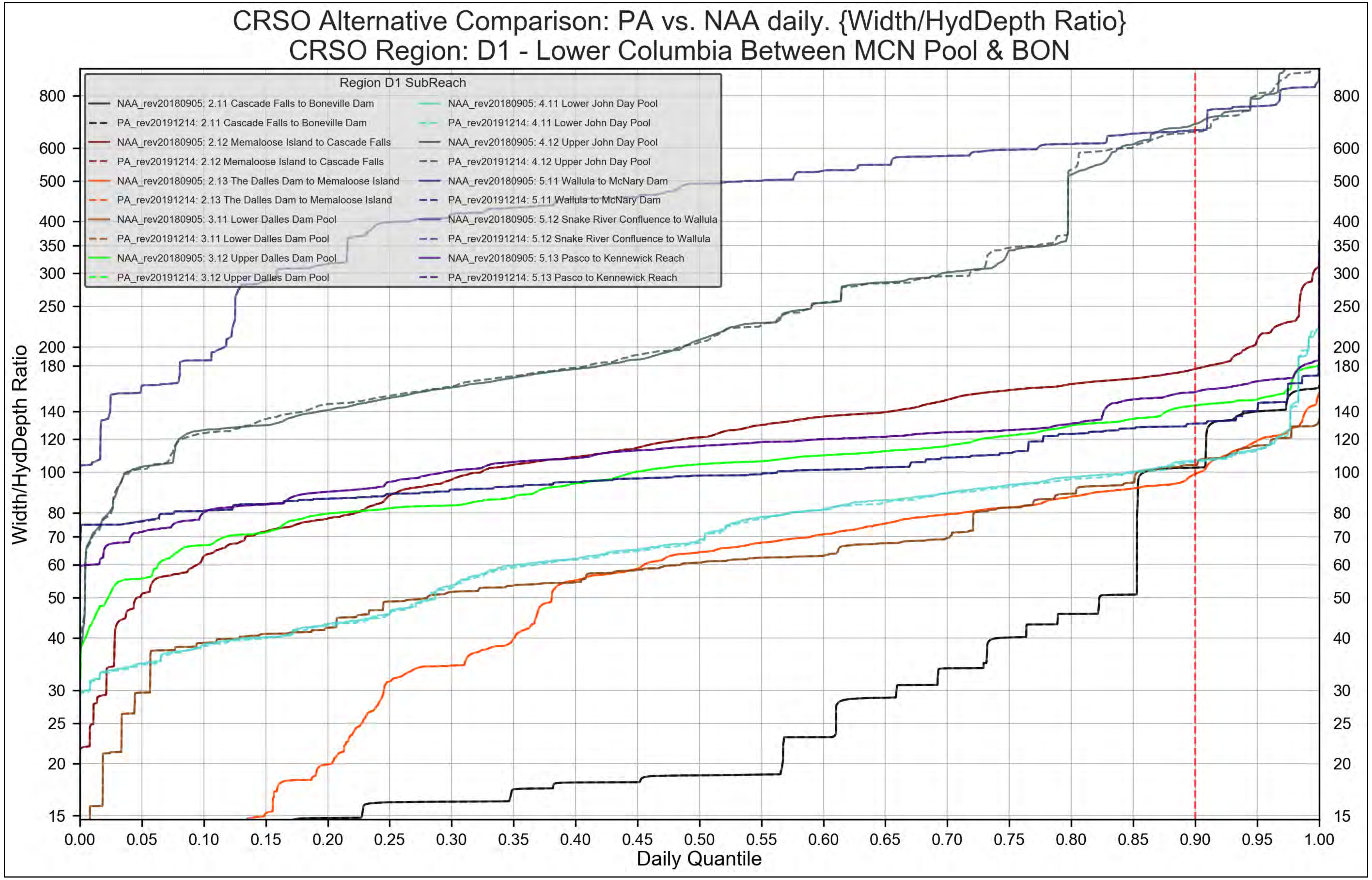


Figure 4-162 Region D1 – Lower Columbia between MCN Pool & BON. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.6.3 Region D2. Lower Columbia Reach below BON. Comparison Figures

REGION D2. MULTIPLE OBJECTIVE ALTERNATIVE 1 VERSUS NO ACTION ALTERNATIVE

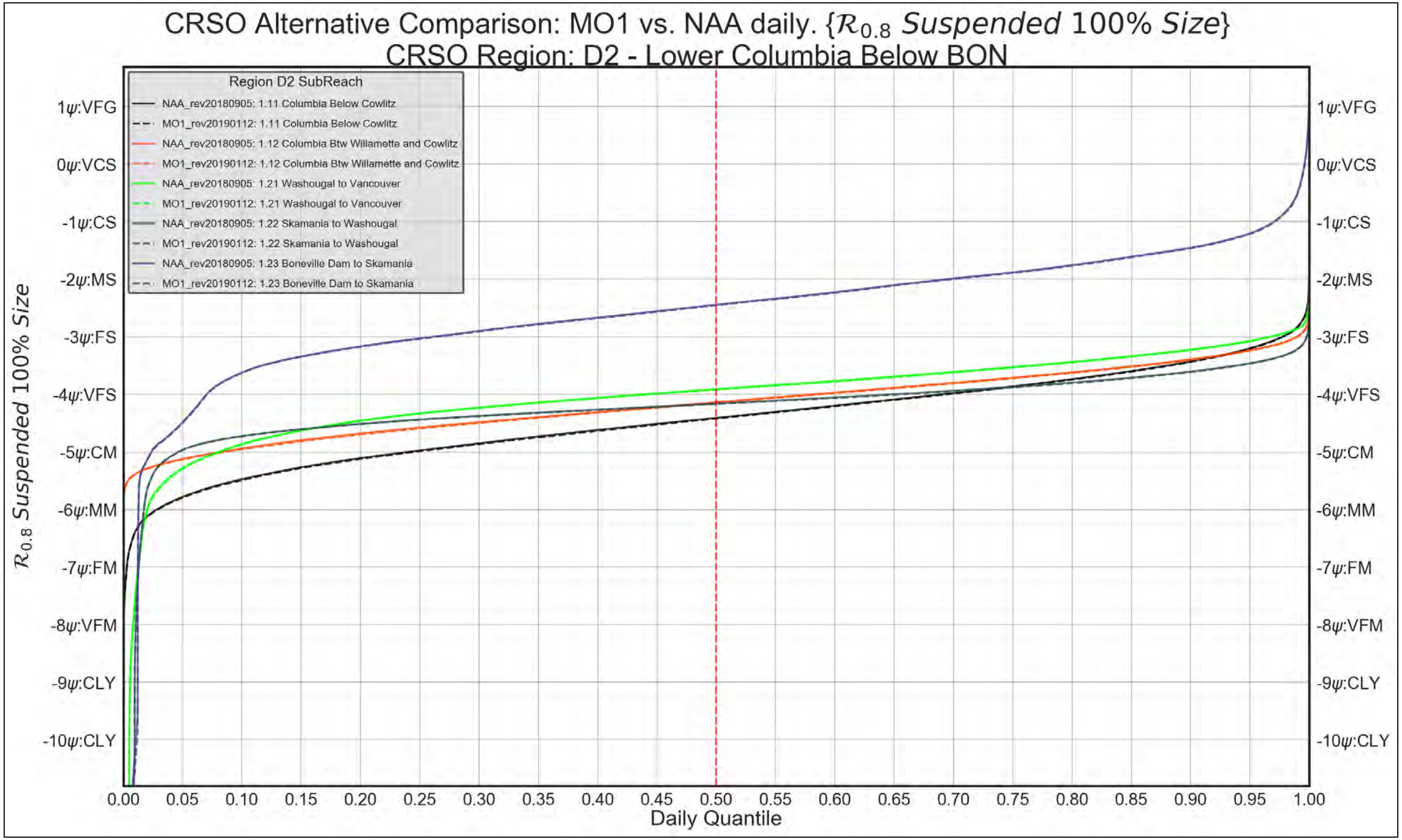
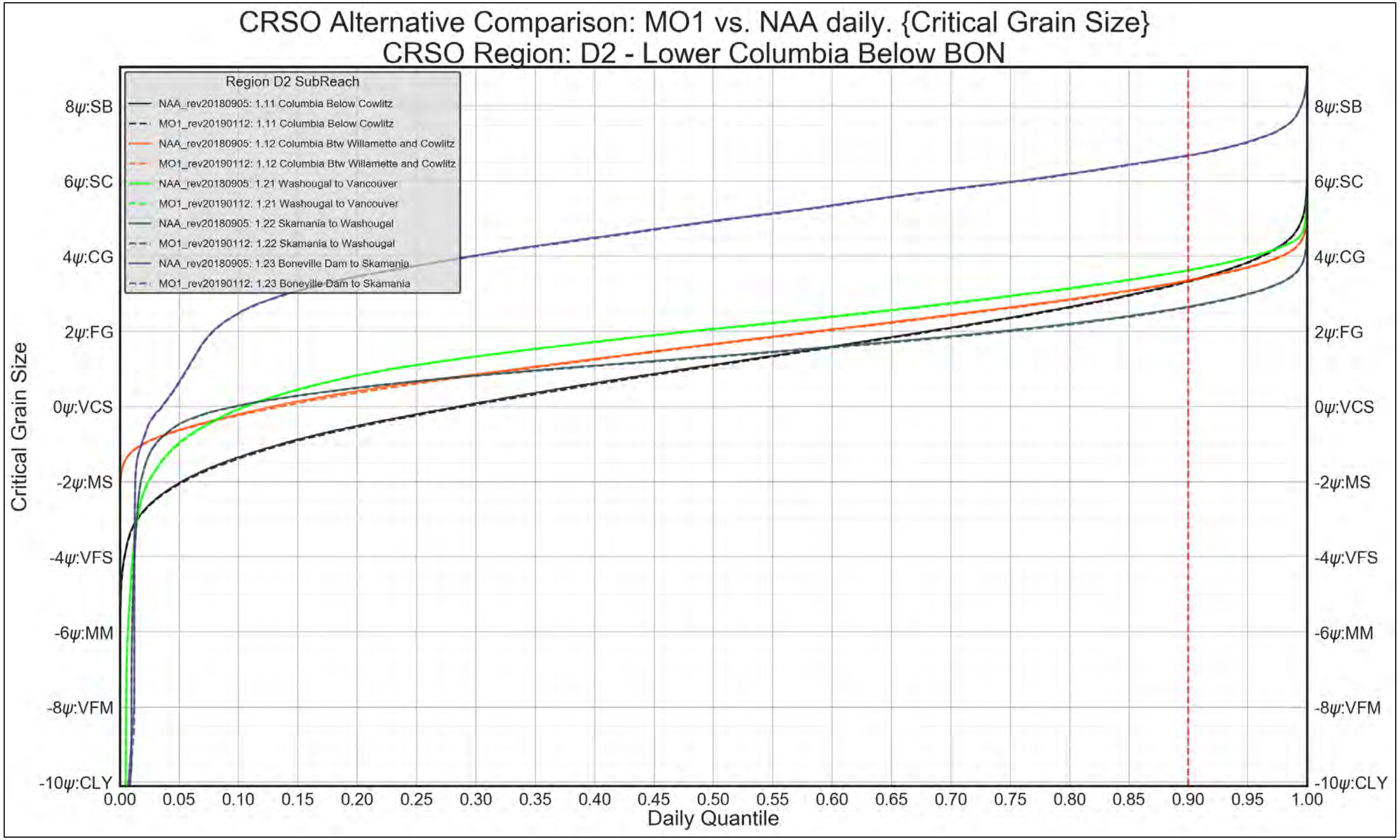


Figure 4-163. Region D2 – Lower Columbia below BON. MO1 vs. NAA. 100% Suspended Grain-Size Threshold

2348



2349 **Figure 4-164. Region D2 – Lower Columbia below BON. MO1 vs. NAA. Critical Grain-Size Threshold**

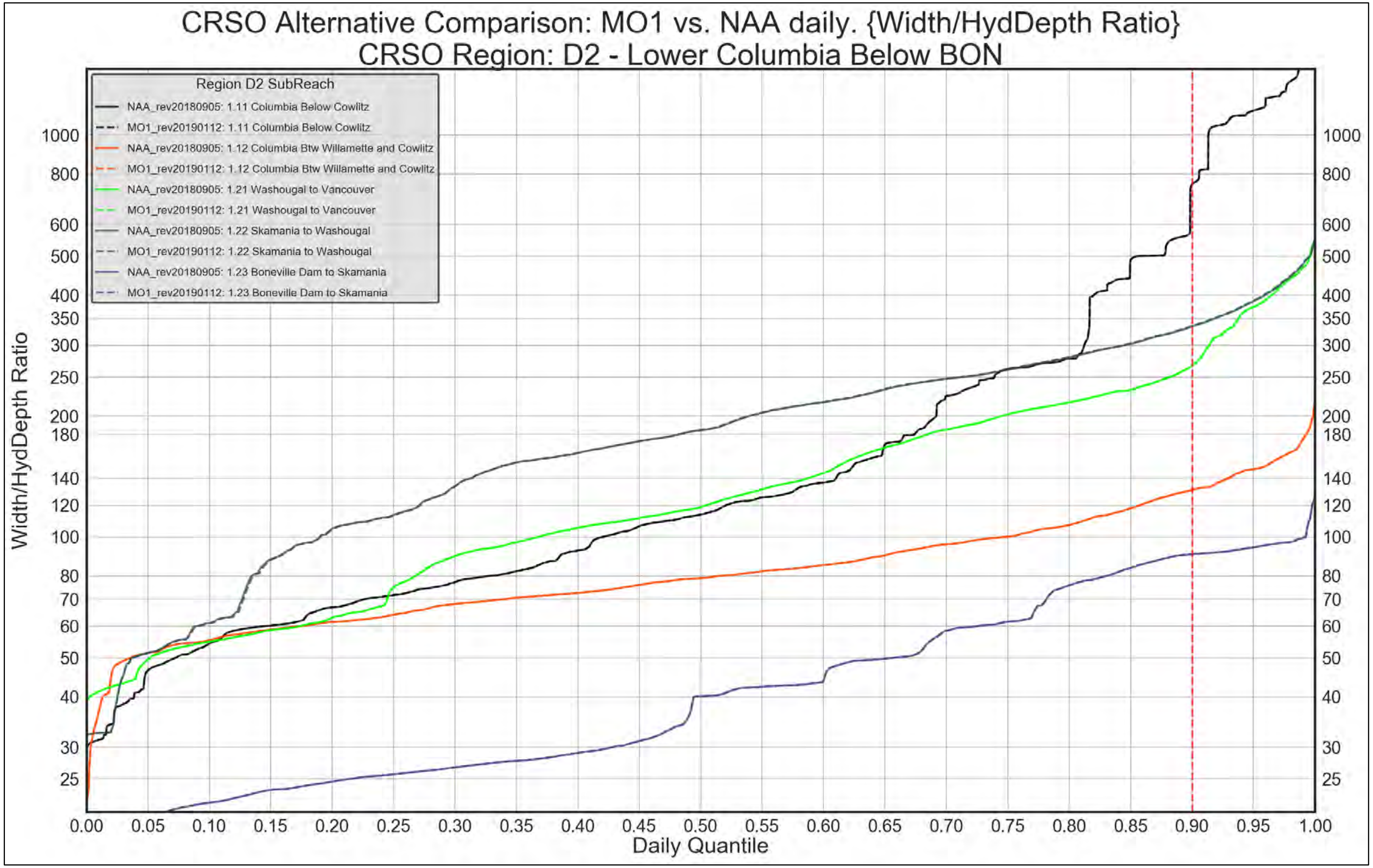


Figure 4-165. Region D2 – Lower Columbia below BON. MO1 vs. NAA. Width/Hydraulic Depth Ratio

REGION D2. MULTIPLE OBJECTIVE ALTERNATIVE 2 VERSUS NO ACTION ALTERNATIVE

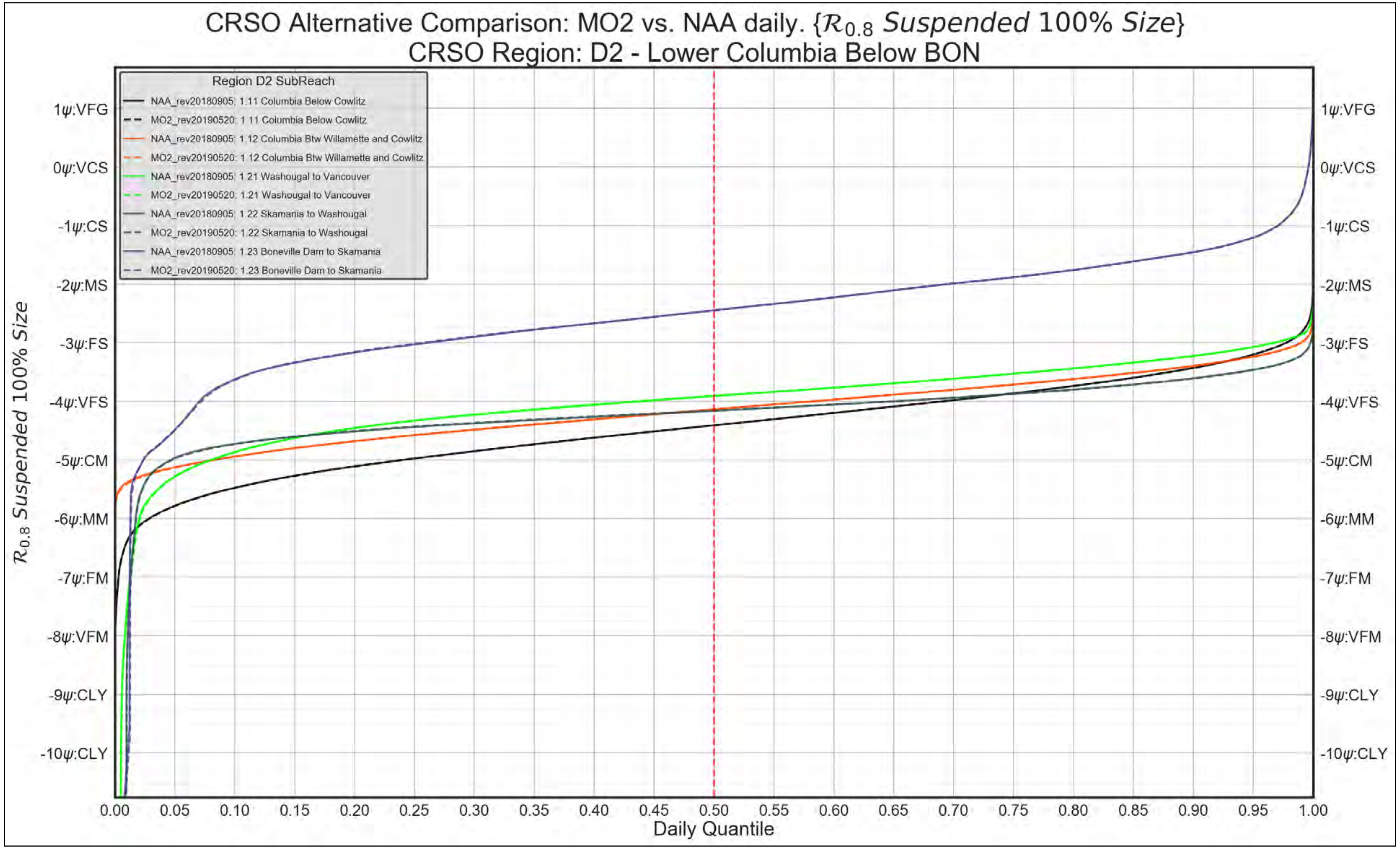


Figure 4-166. Region D2 – Lower Columbia below BON. MO2 vs. NAA. 100% Suspended Grain-Size Threshold

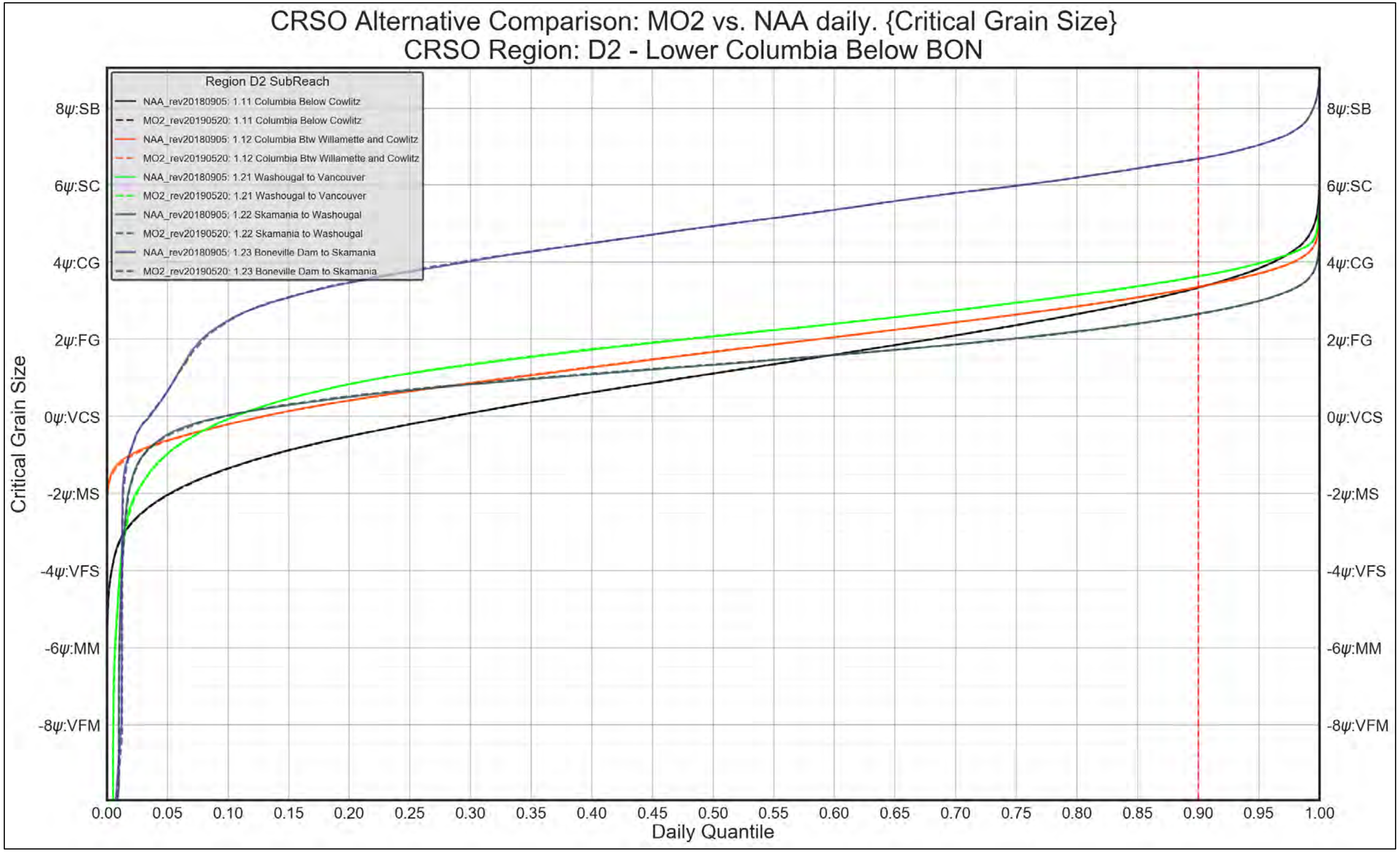


Figure 4-167. Region D2 – Lower Columbia below BON. MO2 vs. NAA. Critical Grain-Size Threshold

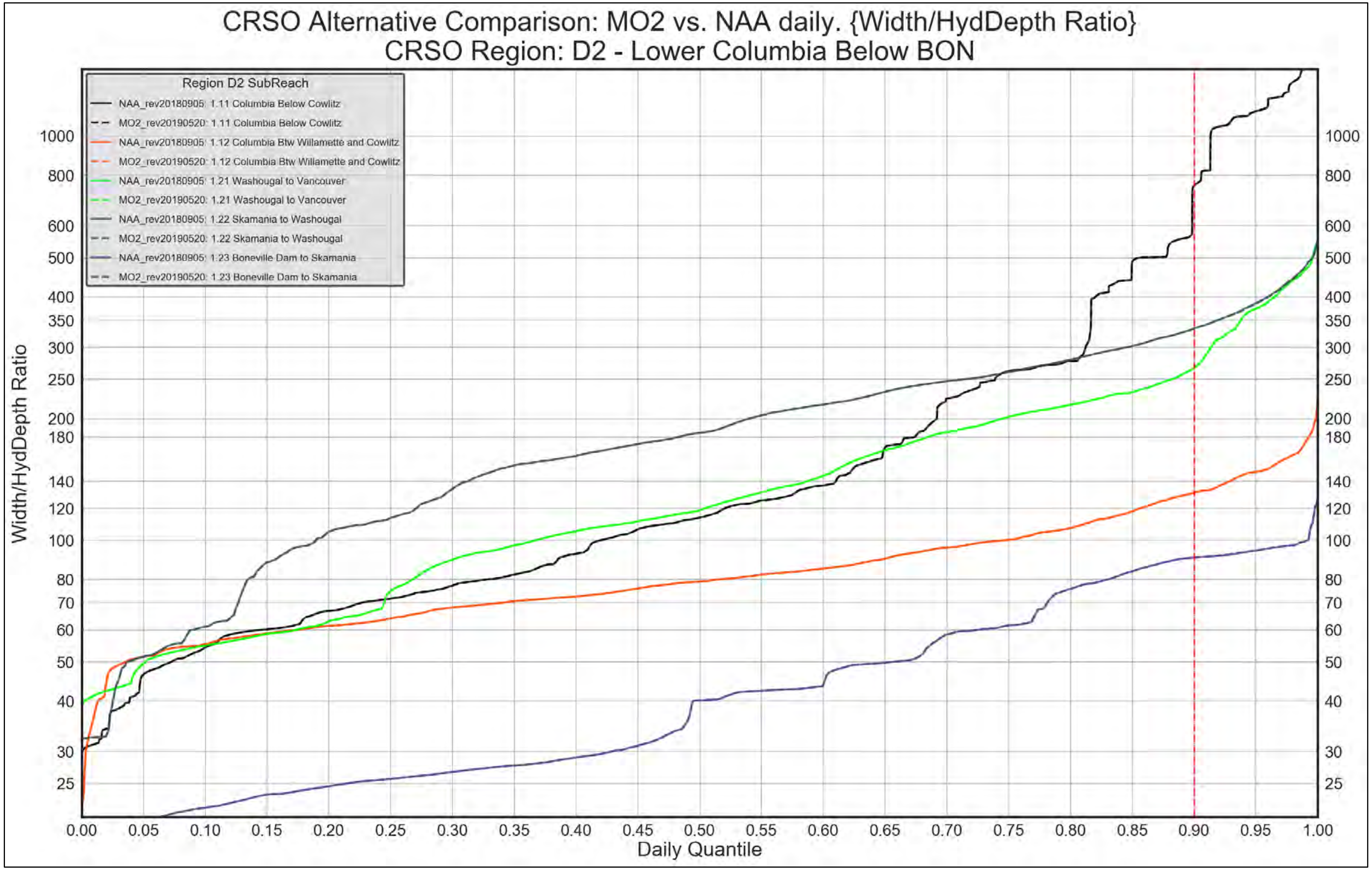
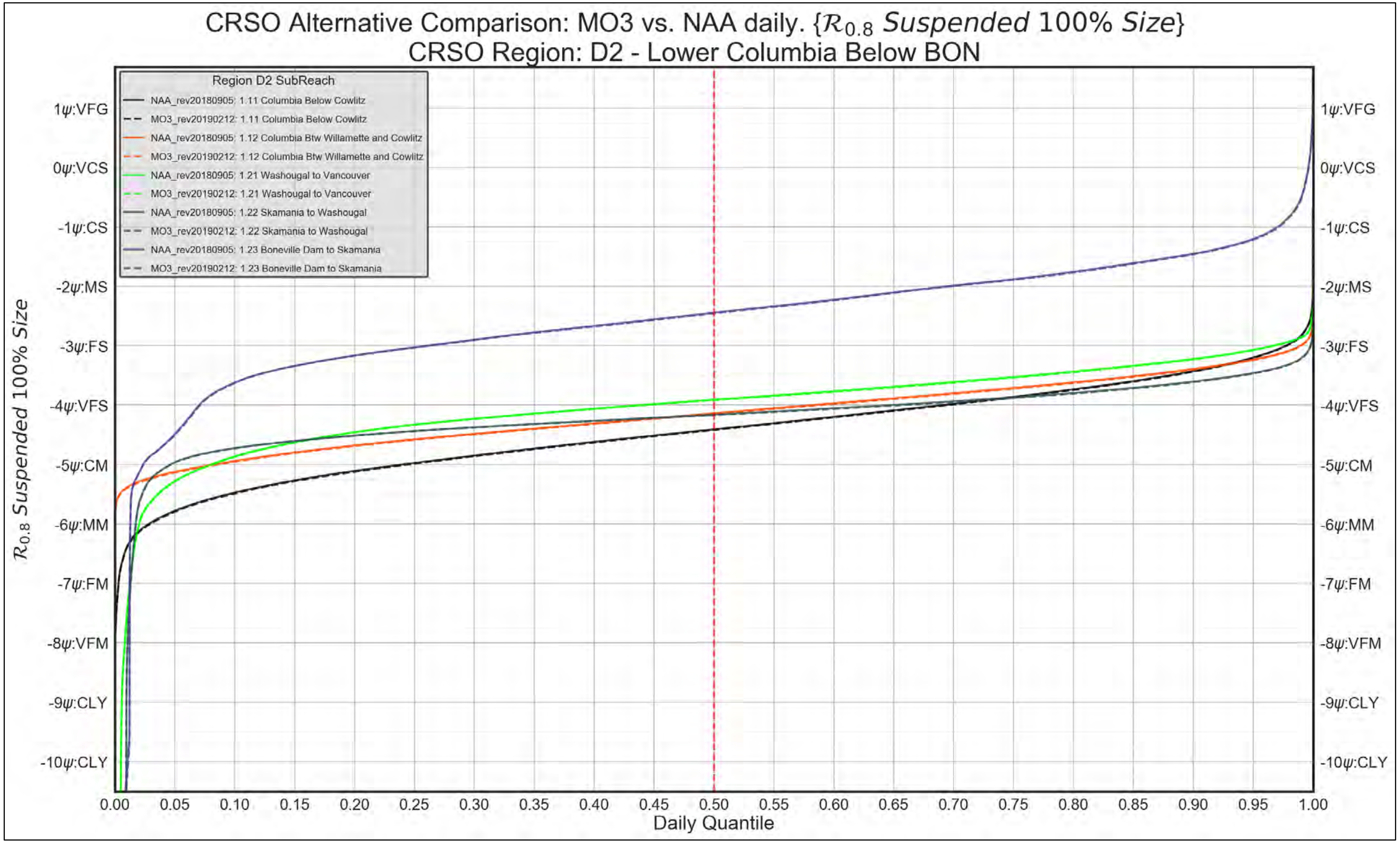


Figure 4-168. Region D2 – Lower Columbia below BON. MO2 vs. NAA. Width/Hydraulic Depth Ratio

2359 **REGION D2. MULTIPLE OBJECTIVE ALTERNATIVE 3 VERSUS NO ACTION ALTERNATIVE**



2360

2361 **Figure 4-169. Region D2 – Lower Columbia below BON. MO3 vs. NAA. 100% Suspended Grain-Size Threshold**

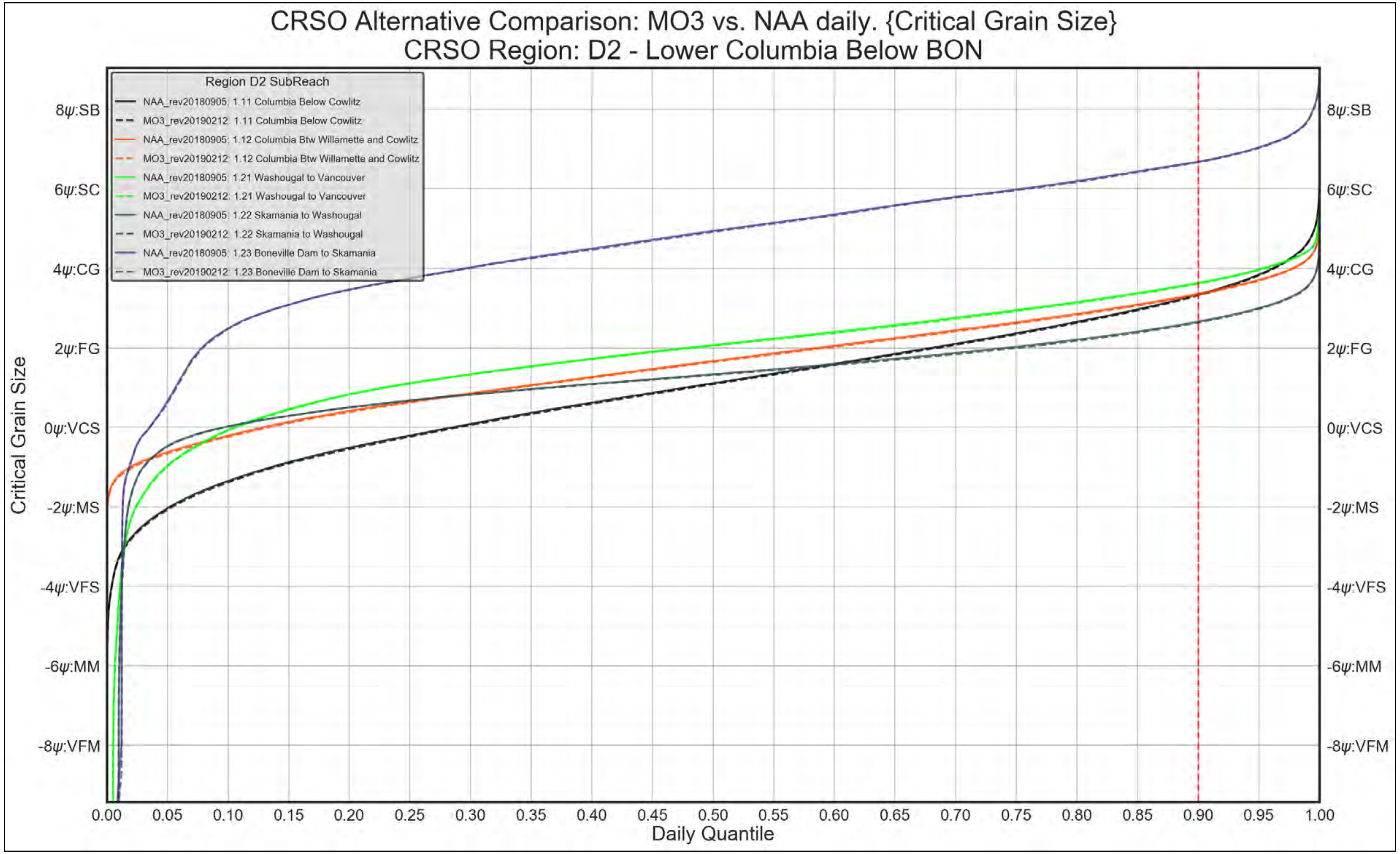


Figure 4-170. Region D2 – Lower Columbia below BON. MO3 vs. NAA. Critical Grain-Size Threshold

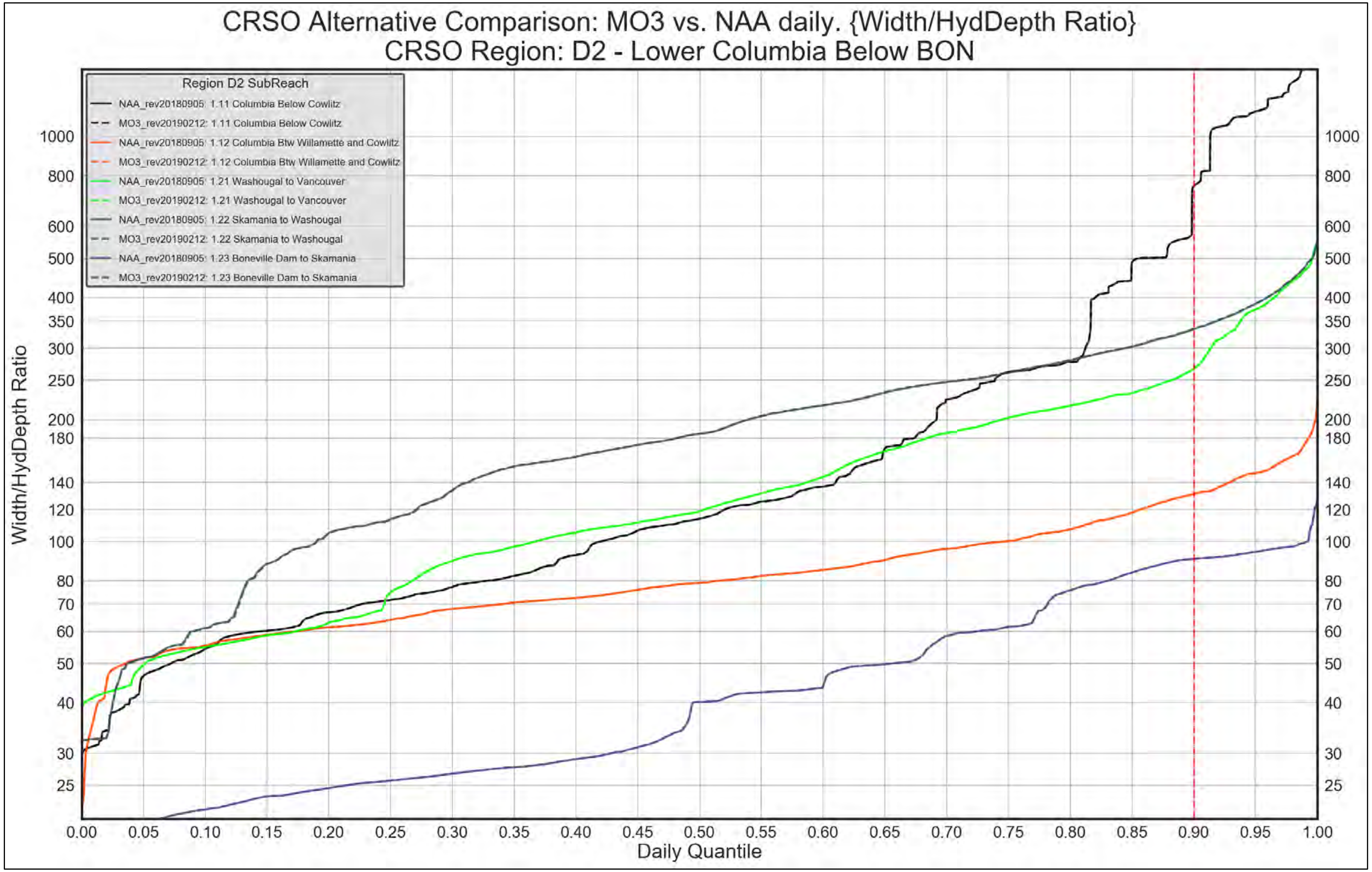
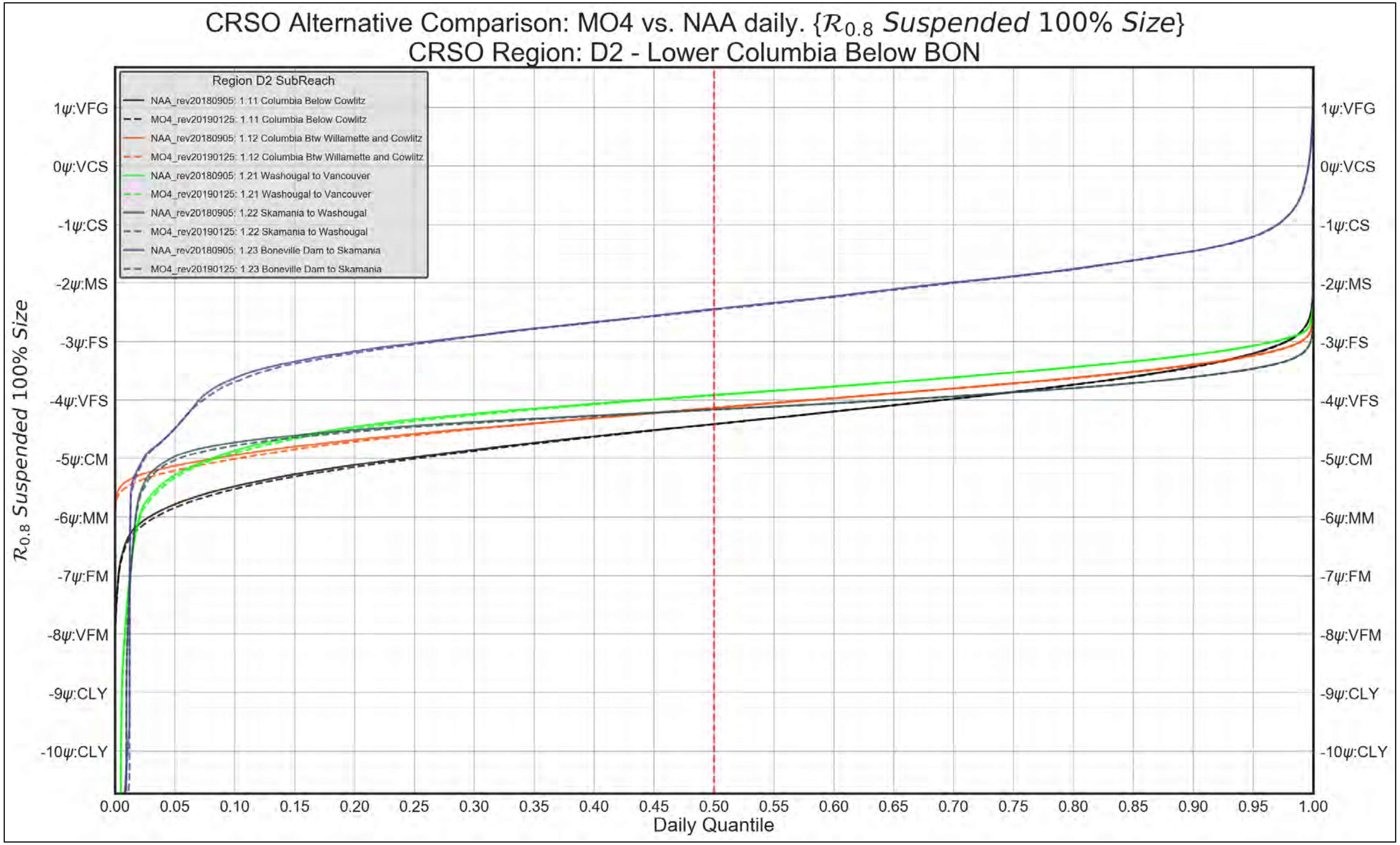


Figure 4-171. Region D2 – Lower Columbia below BON. MO3 vs. NAA. Width/Hydraulic Depth Ratio

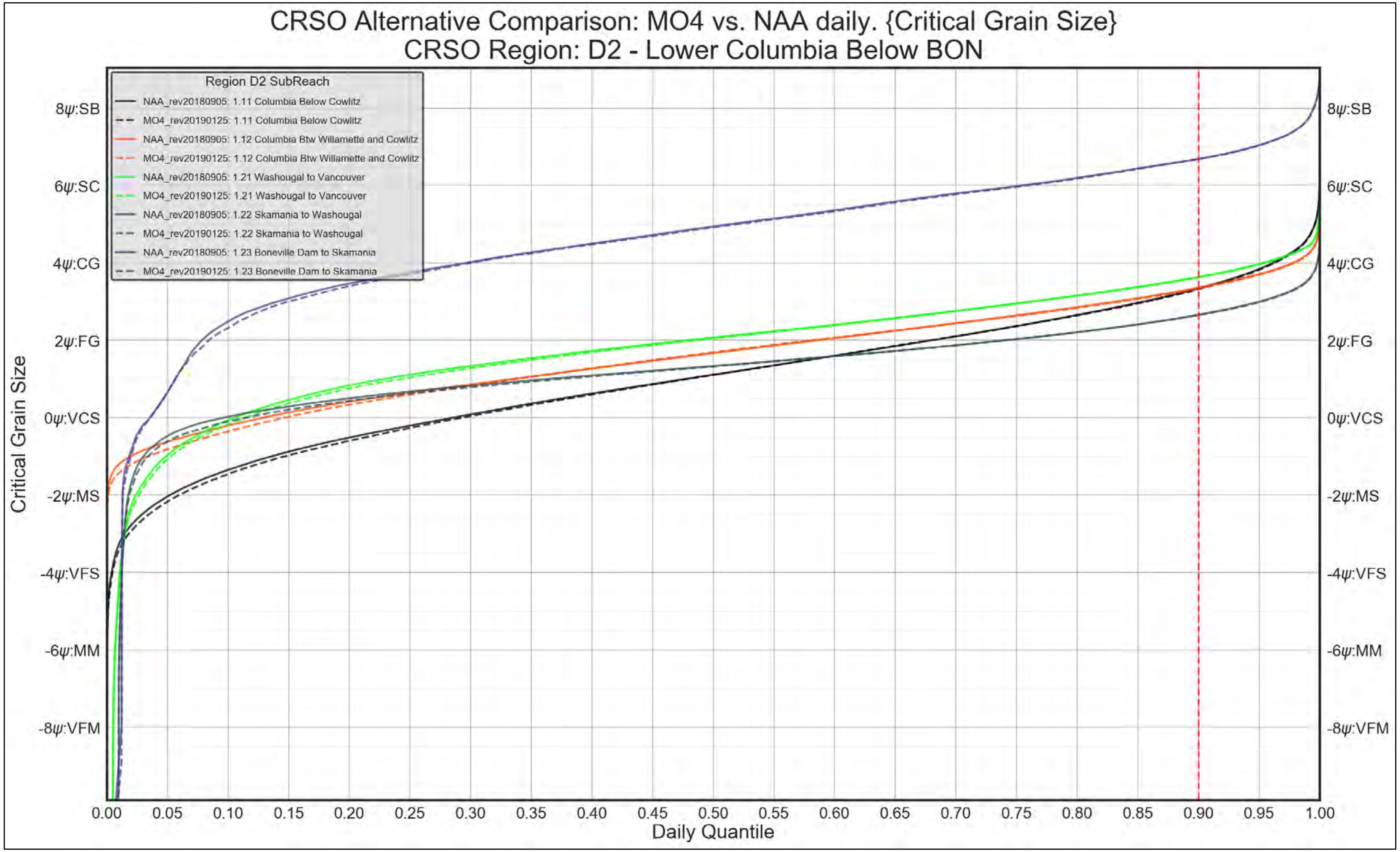
2366 **REGION D2. MULTIPLE OBJECTIVE ALTERNATIVE 4 VERSUS NO ACTION ALTERNATIVE**



2367

2368 **Figure 4-172. Region D2 – Lower Columbia below BON. MO4 vs. NAA. 100% Suspended Grain-Size Threshold**

2369



2370 **Figure 4-173. Region D2 – Lower Columbia below BON. MO4 vs. NAA. Critical Grain-Size Threshold**

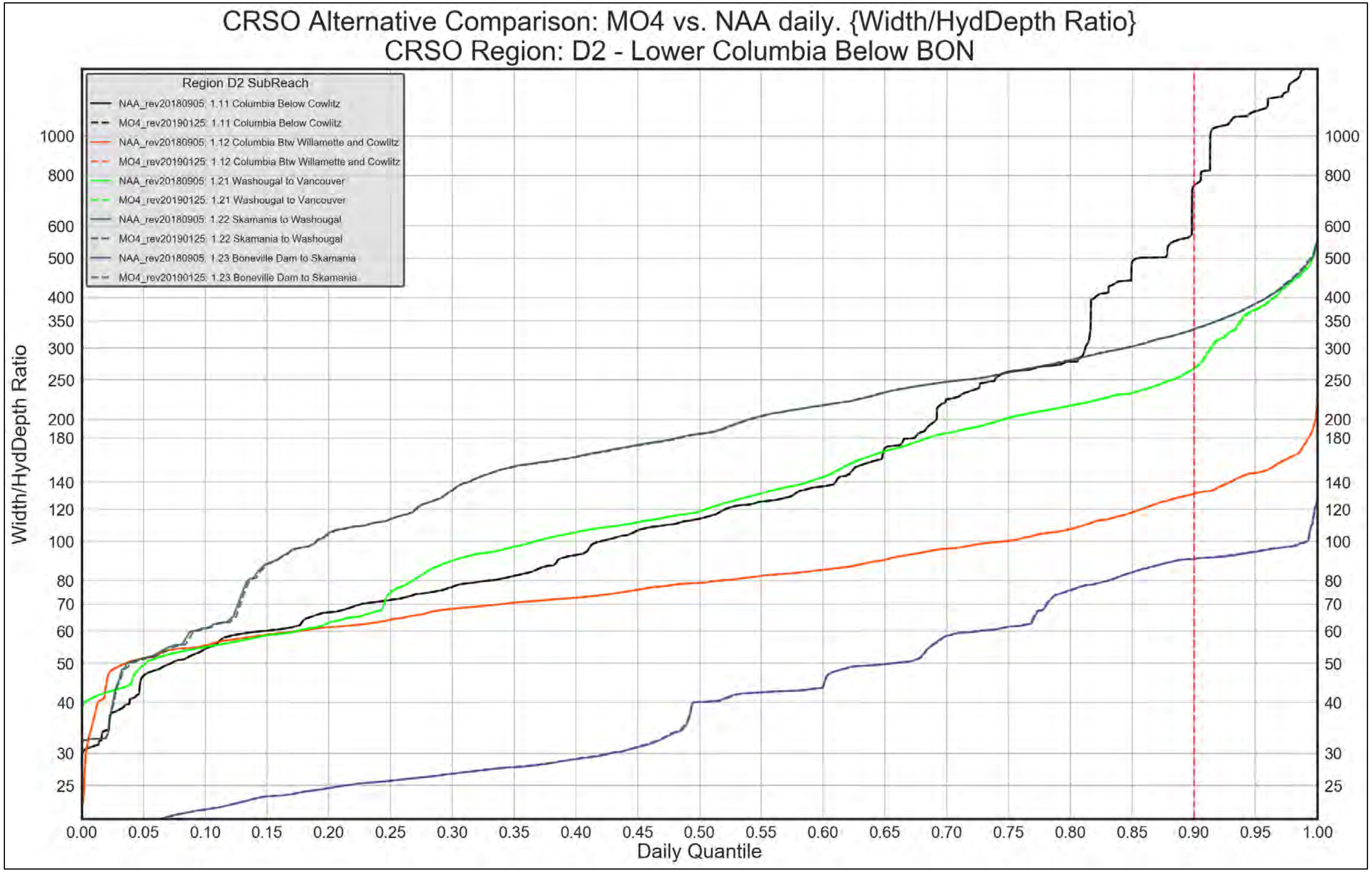


Figure 4-174. Region D2 – Lower Columbia below BON. MO4 vs. NAA. Width/Hydraulic Depth Ratio

REGION D2. PREFERRED ALTERNATIVE VERSUS NO ACTION ALTERNATIVE

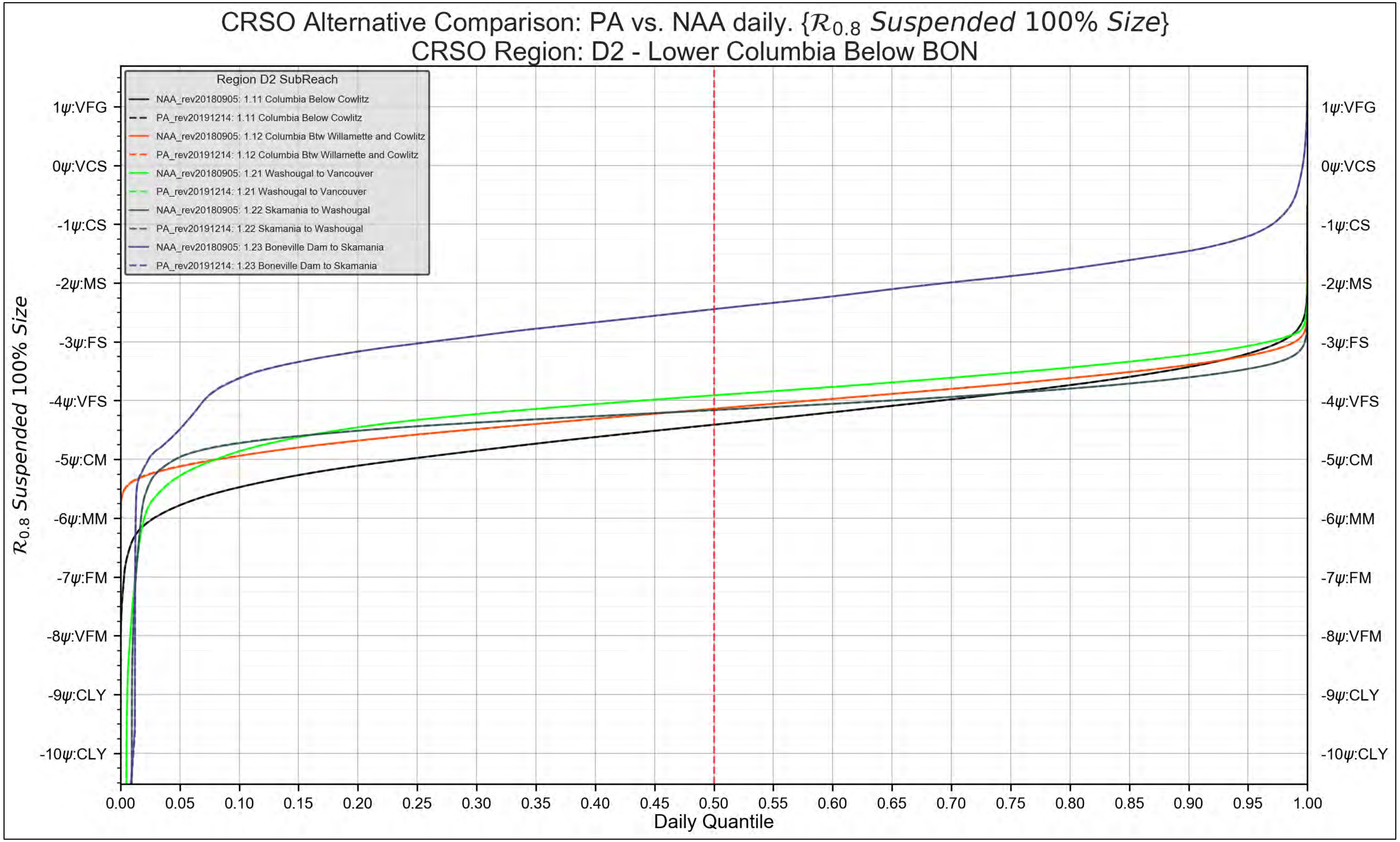
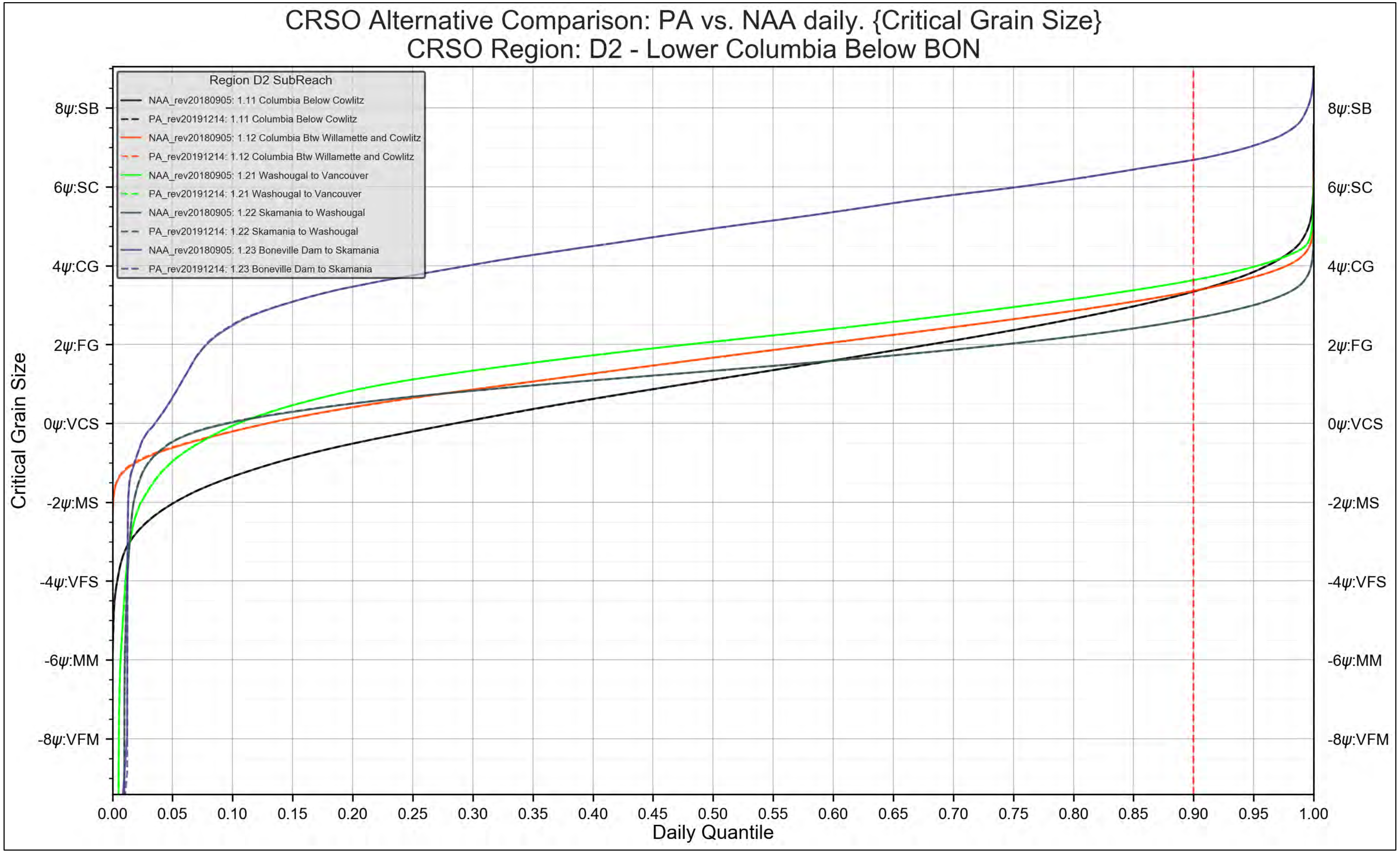


Figure 4-175 Region D2 – Lower Columbia below BON. PA vs. NAA. 100% Suspended Grain-Size Threshold



2376

2377 **Figure 4-176 Region D2 – Lower Columbia below BON. PA vs. NAA. Critical Grain-Size Threshold**

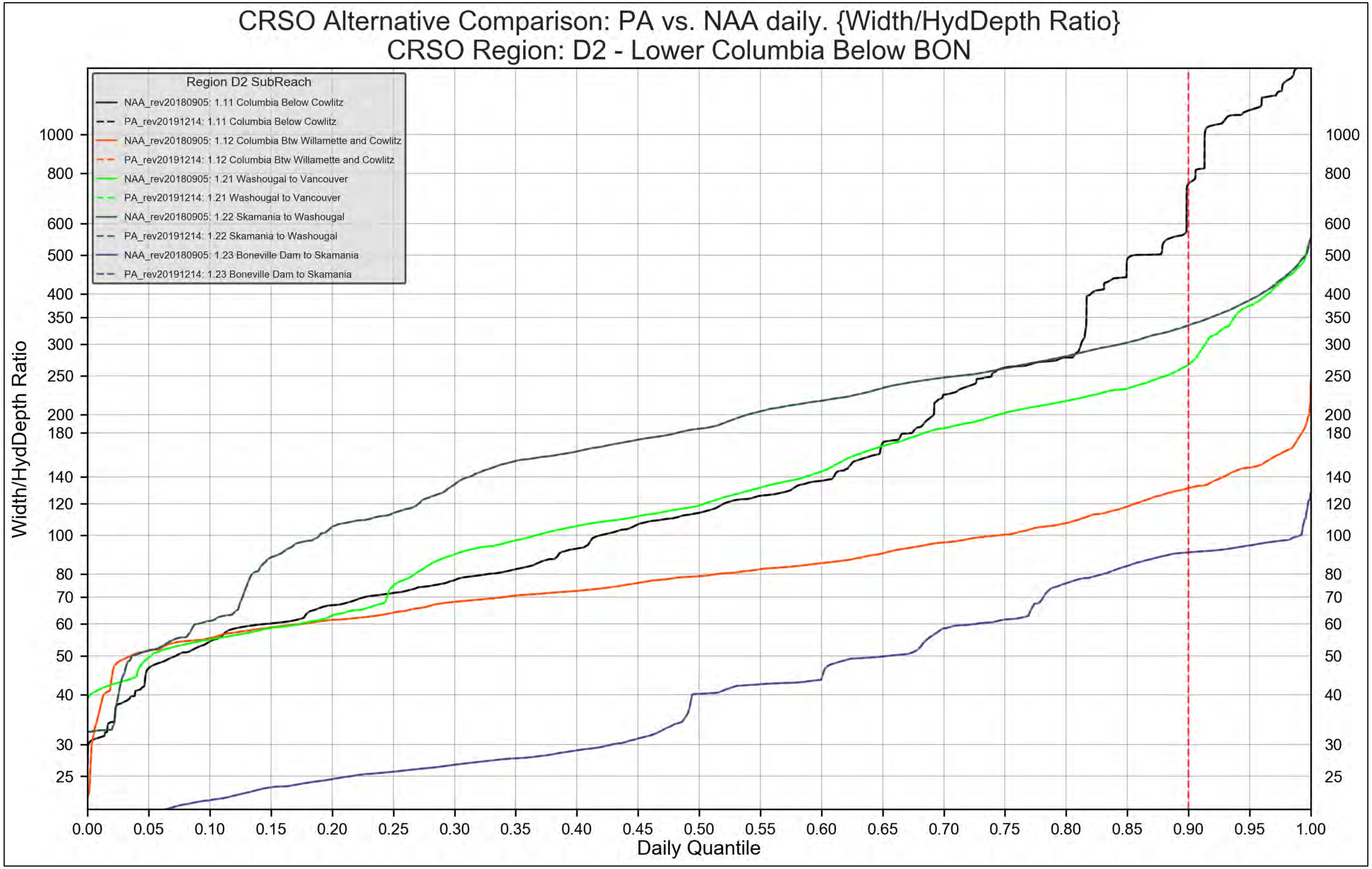


Figure 4-177 Region D2 – Lower Columbia below BON. PA vs. NAA. Width/Hydraulic Depth Ratio

4.2.6.4 Region D: Lower Columbia River Navigation

Table 4-18. Lower Columbia River Navigation Dredging Comparison

	Expected O&M Dredging for Lower Columbia River FNC	Difference in O&M Dredging from No Action Alternative	
CRSO Alternative	**CY/year**	**CY/year**	**%**
No Action Alternative	6,682,305	Baseline	Baseline
MO1	6,665,523	-16,782	-0.3%
MO2	6,737,766	55,462	0.8%
MO3*	6,654,331	-27,974	-0.4%
MO4	6,627,343	-54,962	-0.8%
PA	6,696,101	13,796	0.2%

* Under MO3, watershed sediment loads from the Snake River will be routed to the Columbia River and the coarse bed material load fractions that cause shoaling are not expected to pass downstream of McNary Dam. Near-term sedimentation effects upstream of McNary Dam following lower Snake River dam embankment breaching are expected to last 2 to 7 years as legacy sediment deposits within the historical dam pools are incrementally eroded. The near-term sedimentation effects are expected to be spatially biased towards the quiescent areas left of the FNC in the upstream end of Lake Wallula above McNary Dam that are prone to shoaling; however the FNC in Lake Wallula may still require some episodic maintenance dredging within this near-term timeframe. Long-term sedimentation effects would include continued deposition in quiescent areas prone to shoaling as a result of annual watershed sediment delivery that had previously been trapped by the lower Snake River dams, but is not expected to result in long-term shoaling impacts to the FNC.

CY = Cubic Yards.

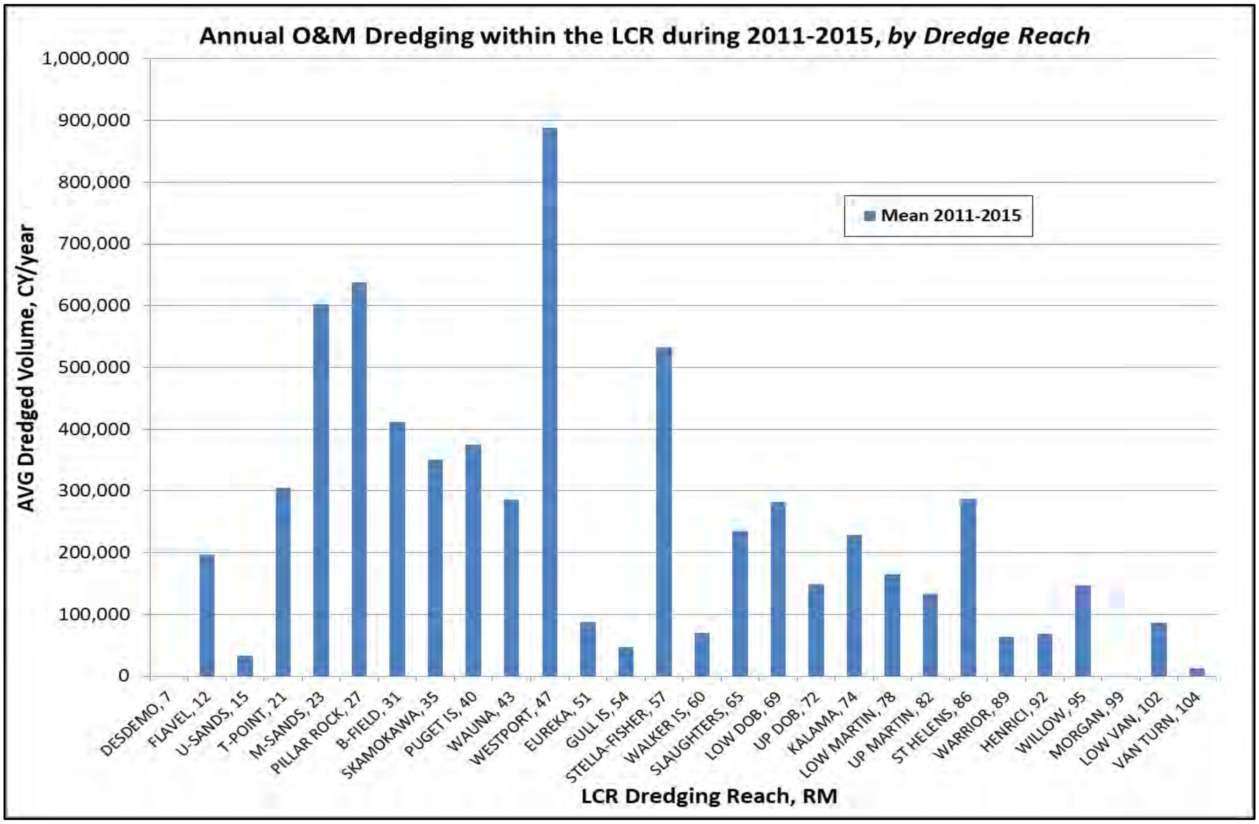


Figure 4-178. Annual O&M Dredging within the LCR during 2011-2015

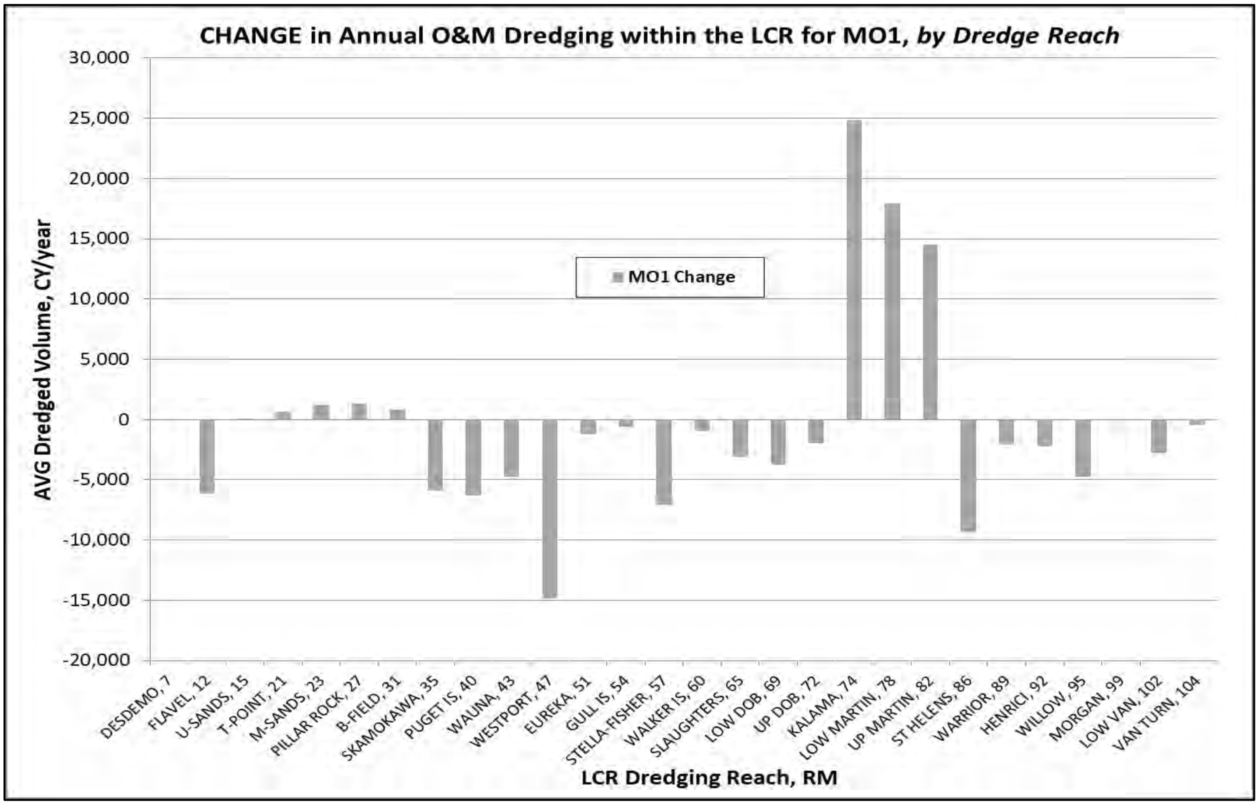


Figure 4-179. Change in Annual O&M Dredging within the LCR for MO1

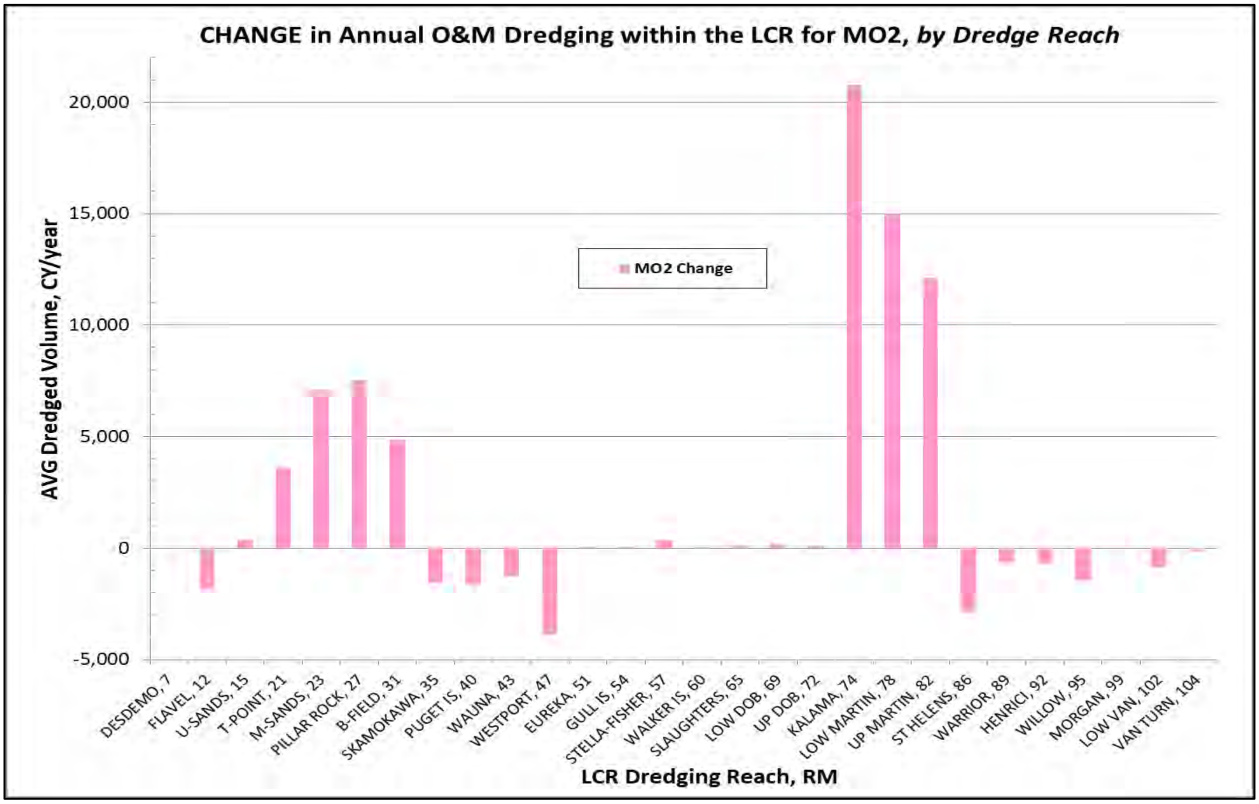


Figure 4-180. Change in Annual O&M Dredging within the LCR for MO2

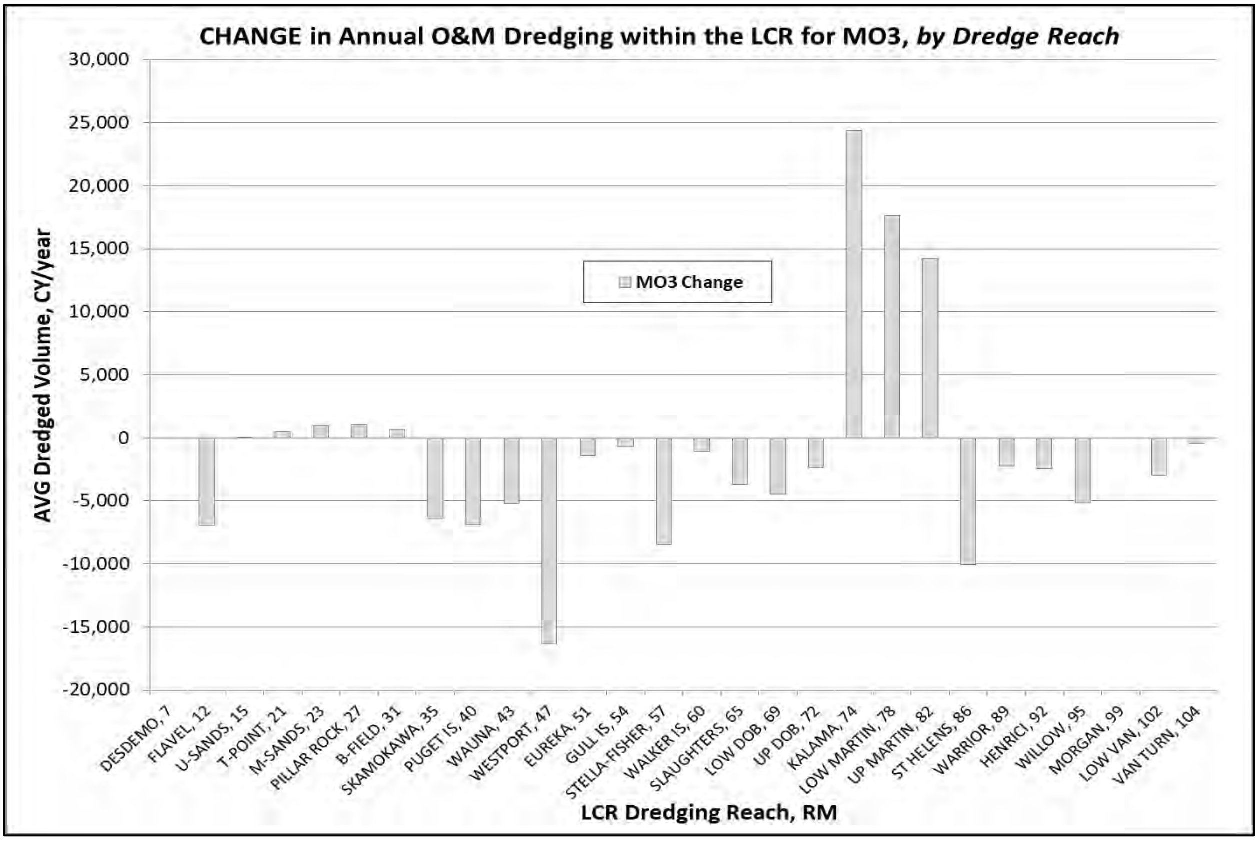


Figure 4-181. Change in Annual O&M Dredging within the LCR for MO3

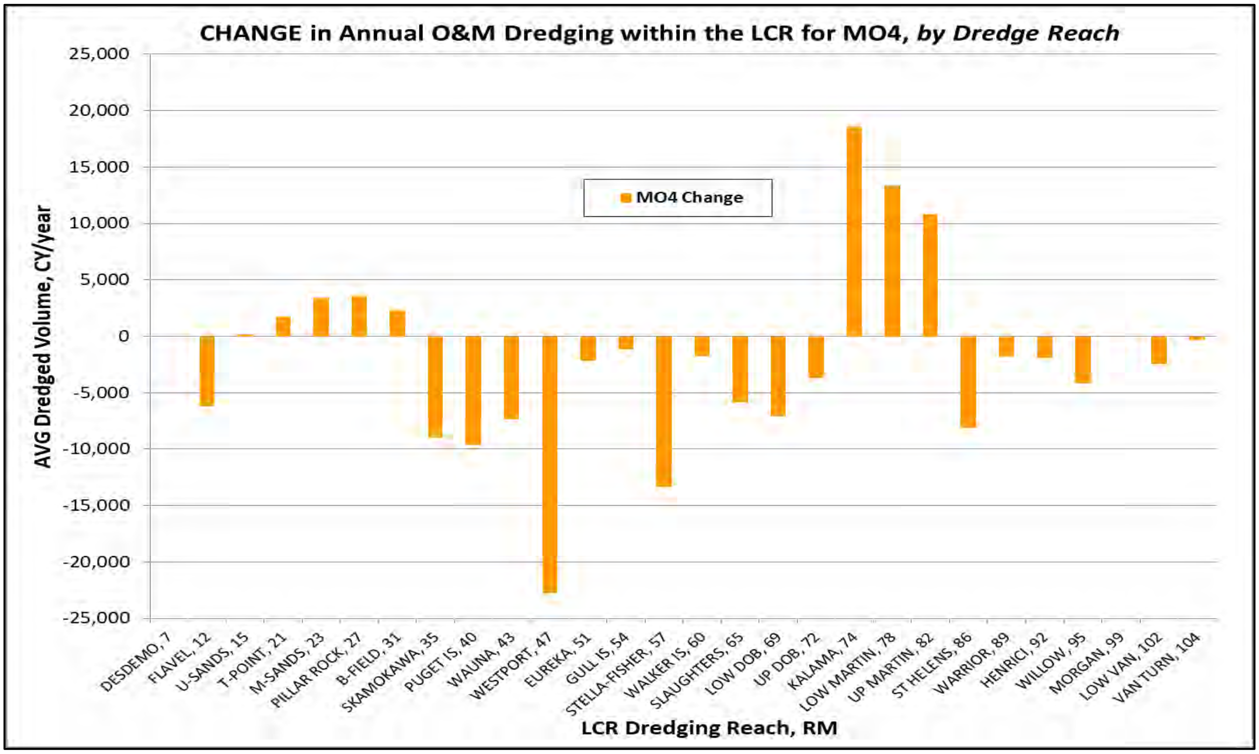


Figure 4-182. Change in Annual O&M Dredging within the LCR for MO4

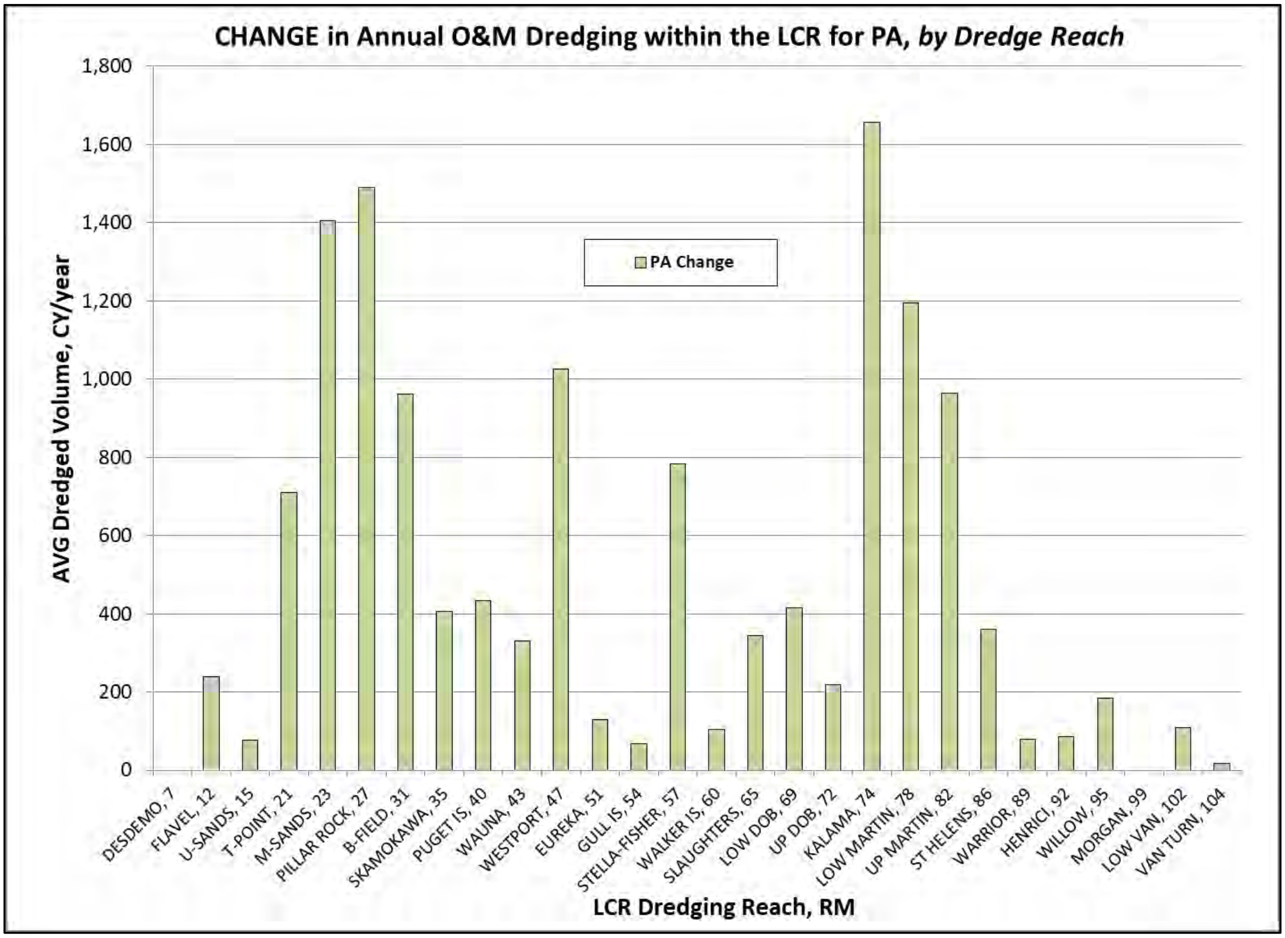


Figure 4-183. Change in Annual O&M Dredging within the LCR for PA

CHAPTER 5 - REFERENCES

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