1.0 FED HYDRO STRATEGY

The FCRPS Capital Investment program uses Copperleaf's C55 Asset Investment Planning and Management tool to plan and manage the Capital program. The benefits and costs associated with ongoing and prospective investments are tracked in the system. In addition to the Capital portfolio management capabilities, C55 also inventories and forecasts equipment condition, probability of failure and outage consequences. When an investment is created in the system, assets that are impacted are attached to the investment and future condition from the replacement or refurbishment activity is forecasted. With this information, C55 is able to calculate mitigated risk and associate it with its respective investment. The strategy alternatives presented in Section 11.1 were developed using the analysis capabilities within C55. In general, these capabilities can be broken down as follows:

Asset Analytics: Identifies the optimal replacement date for each asset in the FCRPS Asset Registry by minimizing lifecycle cost within budget constraints. The optimal replacement dates produced by Asset Analytics are intended to be directional. FCRPS Asset Planning processes use the results from Asset Analytics to develop executable projects.

Value Framework (Portfolio Management and Optimization): The costs and benefits associated with the projects developed to address the Asset Analytics recommendations as well as other projects brought forward by the Corps and Reclamation are managed in C55. These projects, which make up the Asset Plan, are optimized to maximize the value of the portfolio using C55's Portfolio Optimizer. This can result in projects being deferred if the value is higher in a future year in favor of projects that deliver a higher value now.

Asset Analytics

A risk-based approach is taken to identifying the optimal timing for investment, consistent with the approach used in previous strategies. C55 Asset Analytics calculate optimal replacement dates by:

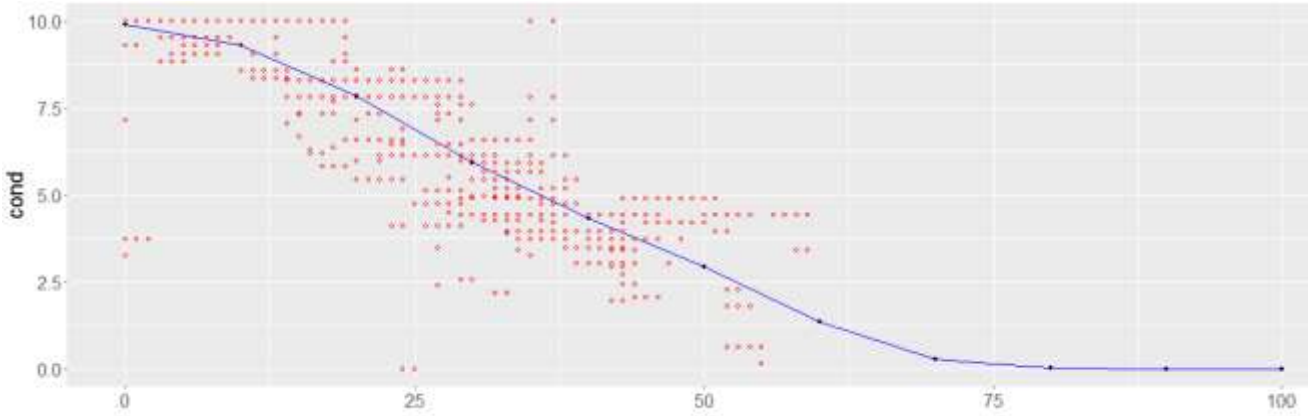
- Assessing current condition and forecasting how it changes over time;
- Relating asset condition to an effective age and probability of failure for each asset type;
- Multiplying the consequence of failure by the probability of failure for each respective asset to determine the risk it poses in a given year; and
- Minimizing the sum of the present value risk costs and replacement cost.

Condition

The Corps and Reclamation assess equipment condition for powertrain and critical auxiliary components annually and balance of plant equipment every two years. Equipment Condition is assessed using the hydroAMP Condition Assessment framework, described in detail in section 8.2.3.

Future condition is forecast using expected degradation rates developed using regression analyses on hydroAMP condition data relating equipment condition to equipment age. The analysis groups condition scores into eleven buckets, rounding conditions scores to 0 through 10. Probit regressions then give the probability that a piece of equipment falls into each of the 11 buckets at a given age. The expected condition decay curve is built up from these regressions, which are the expected values at each age.

Example Equipment Condition Degradation Curve



The chart above illustrates an expected degradation curve with each individual point representing a condition assessment at a specific equipment age.

Probability of Failure

Failure Curves for Powertrain and critical auxiliary equipment were updated in 2016 using an Expert Opinion Elicitation processes facilitated by the Army Corps of Engineers' Risk Management Center. The curves were developed for twenty eight major hydropower assets using the opinion of Subject Matter Experts from the Corps, including the Hydroelectric Design Center, Bonneville Power Administration, US Bureau of Reclamation, Tennessee Valley Administration, Chelan Power and Western Area Power Administration. These baseline Weibull curves will be continually updated using Bayesian techniques as additional failure data is collected in the Corps' maintenance management system.

This task was initiated to replace existing failure curves that relied on empirical data containing both equipment replacements and retirements. Since the existing failure curves included retirement data that did not necessarily result from equipment failure, the curves likely overstated probability of failure and understated reliability as assets age.

Risks and Costs

Lost Generation Risk (LGR): Equipment failure may also result in longer outages and, thus, more lost generation than if replaced on a planned basis. LGR also increases as equipment condition degrades over time.

Direct Cost Risk (DCR): If equipment fails during the deferral period, intervention costs may be incrementally higher for collateral damage and planning, procurement, and scheduling inefficiencies (overtime, emergency hiring, contract premiums, etc.). This cost risk increases as equipment condition degrades over time and is estimated for each component.

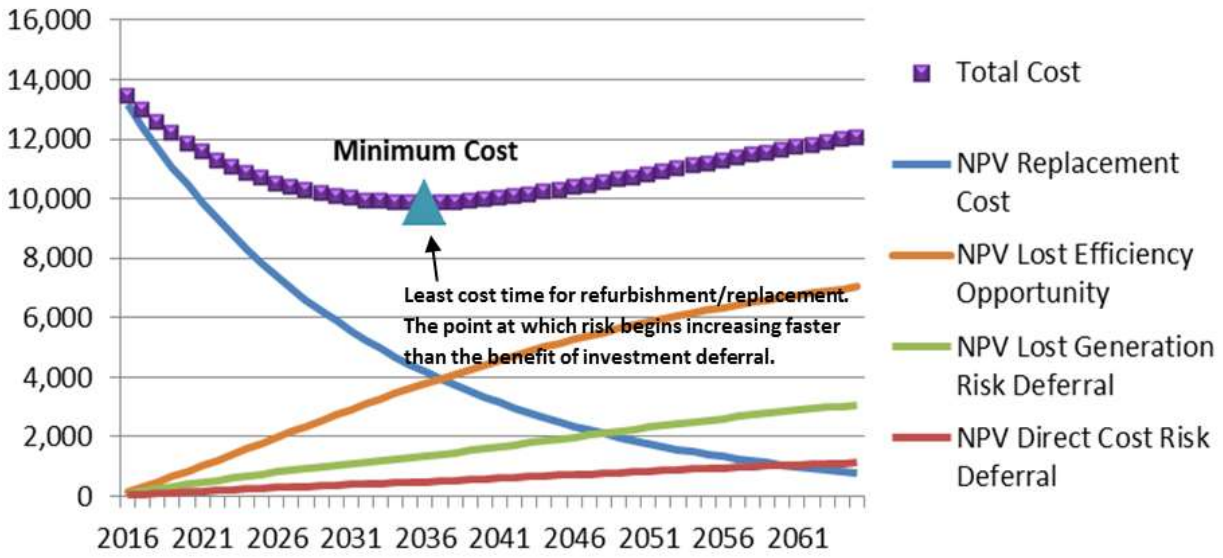
Lost Efficiency Opportunity (LEO): Some equipment replacements (turbine runners, transformers and generator windings) reduce efficiency losses. Deferring replacement results in a lost opportunity to capture increased generation from higher efficiency equipment.

Project Cost: The cost of the replacement or refurbishment activity.

Lifecycle Cost Minimization

To determine the optimal timing for replacement, each equipment component is evaluated in yearly time steps. In each year, the present value of accumulated financial risk cost is added to the present value cost of replacing the equipment in that year. The sum of these present value costs is the Total Cost related to a decision to delay equipment replacement until that year. This algorithm is described graphically below.

FCRPS Equipment Lifecycle Cost Minimization Methodology



The optimal time to plan on equipment replacement is at the low point (cost minimum) of the Total Cost curve. The cost minimum is the point in time at which the sum of financial risk costs and potential lost efficiency opportunity begin growing faster than the benefit of deferring the investment. Up until that time the value of investment deferral is greater than the expected increase in financial risk and lost efficiency opportunity costs, so it makes financial sense to continue deferring equipment replacement.

When a constraint is introduced, Asset Analytics prioritizes all assets at or passed their respective optimal replacement dates based on their cost of deferral. Assets are chosen for replacement ranked by their respective deferral cost until there is no longer room within the budget. The analytics will then seek to replace the next highest deferral cost asset that remains within the budget constraint until either the constraint is reached in full or no further assets can be selected while remaining within constraints.

Value Framework

After optimal replacement dates are established, the Asset Planning Team, in coordination with other Corps and Reclamation planning functions, develop projects to address the risks identified by Asset Analytics. These projects, along with other needs identified by the plants, are entered into the Portfolio Management module of C55 with a forecast for their annual spend and a preliminary assessment of their risks and benefits.

Benefits and risks associated with investment activities are evaluated using the Value Framework component of C55. The establishment of the FCRPS Value Framework was one of the first outcomes of the Asset Investment Excellence Initiative. The value measures upon which investments are assessed are summarized in the table below.

FCRPS Value Framework

Value Measure Categories	Value Measures	Organizational Goals
Financial	Financial Benefits	Maximize cost savings and increase efficiency to ensure low cost power Maintain ability to reliably supply energy to the grid
	Generation Efficiency Benefits	
	Direct Cost Risk	
	Lost Generation Risk	
Trusted Stewardship	Compliance Risk	Reduce Safety, Environmental and Compliance risks to as low as reasonably practicable. Ensure employee and public safety Maintain mandate to operate
	Environmental Risk	
	Productive Workplace Benefit	
Safety	Safety Risk	
Community	Public Perception Risk	

Financial Risks are assessed in dollars while Trusted Stewardship, Safety and Community value measures are assessed qualitatively. These qualitative measures are assessed using a 5 by 5 risk matrix that aligns the consequence scales of the qualitative measures to the quantified financial risks and benefits. This creates a method of assigning value to qualitative benefits and risks. For optimization purposes, Safety and Environmental risk receive weightings of 2.0 and 1.5 respectively. This means that Safety risks are weighted twice as heavily as an equivalent Lost Generation risk and Environmental risks are weighted 1.5 times as heavily as an equivalent Lost Generation risk.

FCRPS Risk Matrix Consequence Descriptions

Consequence	Insignificant	Minor	Moderate	Major	Extreme
Financial Risk	<$10k	$10k - $100k	$100k - $1M	$1M - $10M	>$10M
Lost Generation Risk	< 280 MWh	280 MWh - 2,800 MWh	2,800 MWh - 28,000 MWh	28,000 MWh - 280,000 MWh	> 280,000 MWh
Compliance Risk	No or insignificant effect on operations or administrative flexibility or annual mandated costs < $10k	Change in operations or administrative flexibility or inability or annual mandated costs < $100k	Adverse impact on beneficial legal principles or precedents; project operations noticeably affected for compliance; inability to maintain system frequency or voltage or annual mandated costs < $1M	Adverse effect on existing beneficial legal principles or precedents; substantial changes needed in project operations or administration or annual mandated costs < $10M	Extremely difficult to meet fundamental statutory obligations; extremely unreliable system; extreme changes needed in project operations or administration or annual mandated costs > $10M
Environmental Risk	No impact	Impact to on-site environment (simple remediation) or where the remediation costs < $100k	Limited impact off-site (localized remediation required) or where the remediation costs < $1M	Detrimental impact on- or off-site (long-term remediation required) or where the remediation costs < $10M	Detrimental or catastrophic impact off-site (mitigation impossible) or or where the remediation costs > $10M
Safety Risk	No or minor injury, first aid	Treatment by medical professional	Lost time accident - temporary disability	Permanent disability	Fatality
Public Perception Risk	No or isolated internal complaints	Local media attention; widespread internal complaints; some public embarrassment	Transitory local media / federal / customer attention and criticism; some damage control; congressional enquiry; short duration loss of power to islanded community	Ongoing media / federal / customer attention; major damage control; significant impact on staff morale; congressional enquiry; extended duration loss of power to islanded community	Adverse and ongoing media / federal / customer attention, criticism and agency intervention; extreme damage control; parliamentary secretary called to congress; permanent duration loss of power to islanded community

Lost Generation Risk and Direct Cost Risk (captured by "Financial Risk" above) are automatically calculated for assets that are attached to investments using the same analysis performed in Asset Analytics described above. Investment impact dates and resulting condition scores from replacement or refurbishment are forecast and the mitigated Lost Generation and Direct Cost risks are calculated between the baseline and investment scenarios. For the remaining Value Measures, risk is calculated by multiplying the consequences selected from the matrix above by the assessed probability of occurrence. Mitigated risk is the difference between the assessed probabilities of occurrence with and without an investment as well as any change in future consequence that may result from an investment alternative. The risk matrix below displays the interaction of probability and consequence scales.

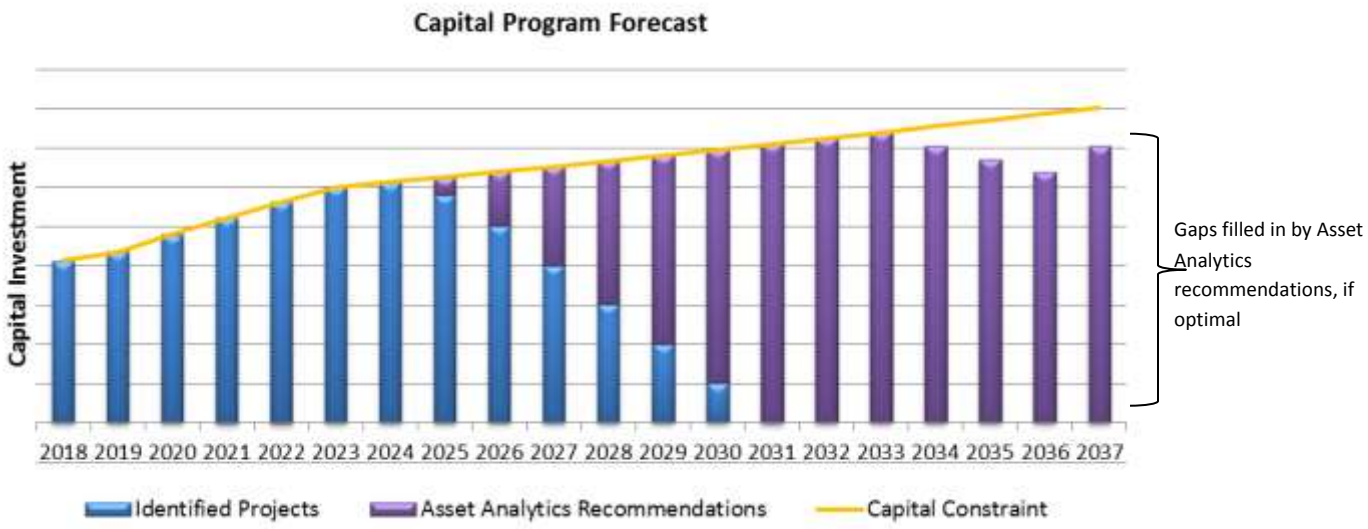
FCRPS Risk Matrix

Probability						
	Almost Certain This event could occur within the next 2 years					
	Likely This event could occur within the next 5 years					
	Possible This event could occur within the next 13 years					
	Unlikely This event could occur within the next 50 years					
	Rare This event could occur within the next 100 years					
		Insignificant	**Minor**	**Moderate**	**Major**	**Extreme**
		Consequence				

Risk Level	Low	Medium	High

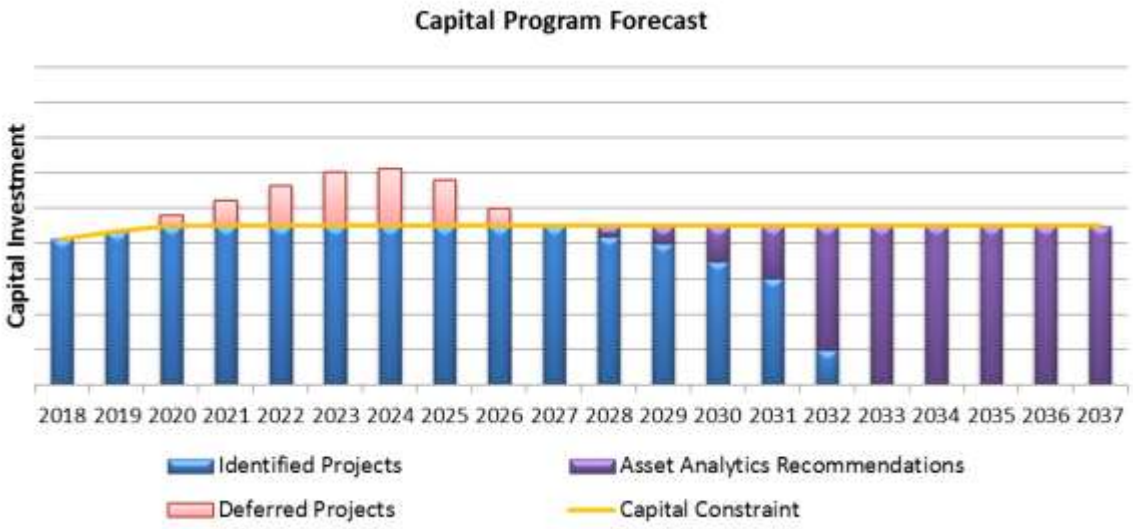
The Asset Plan is constructed through iterative optimizations of the FCRPS capital investment portfolio. For development of the SAMP, planned investments from the Asset Plan are optimized under the planning levels identified in each respective Strategy Alternative. If identified projects exceed the planning levels identified in the strategy alternatives, the optimization will defer investments in order to maximize the value of available Capital funding. In future years in which the Asset Plan is not fully programmed up to the budget constraint, Asset Analytics will identify assets for which it is optimal to plan a replace but a project has yet to be identified. However, if there are not assets at or passed their optimal replacement dates, Asset Analytics is not required to spend all available funds. The long term

strategies presented in Sections 11.1 and 11.2 are a result of these iterative analytics. The example below illustrates how optimization defers projects to stay within constraints.



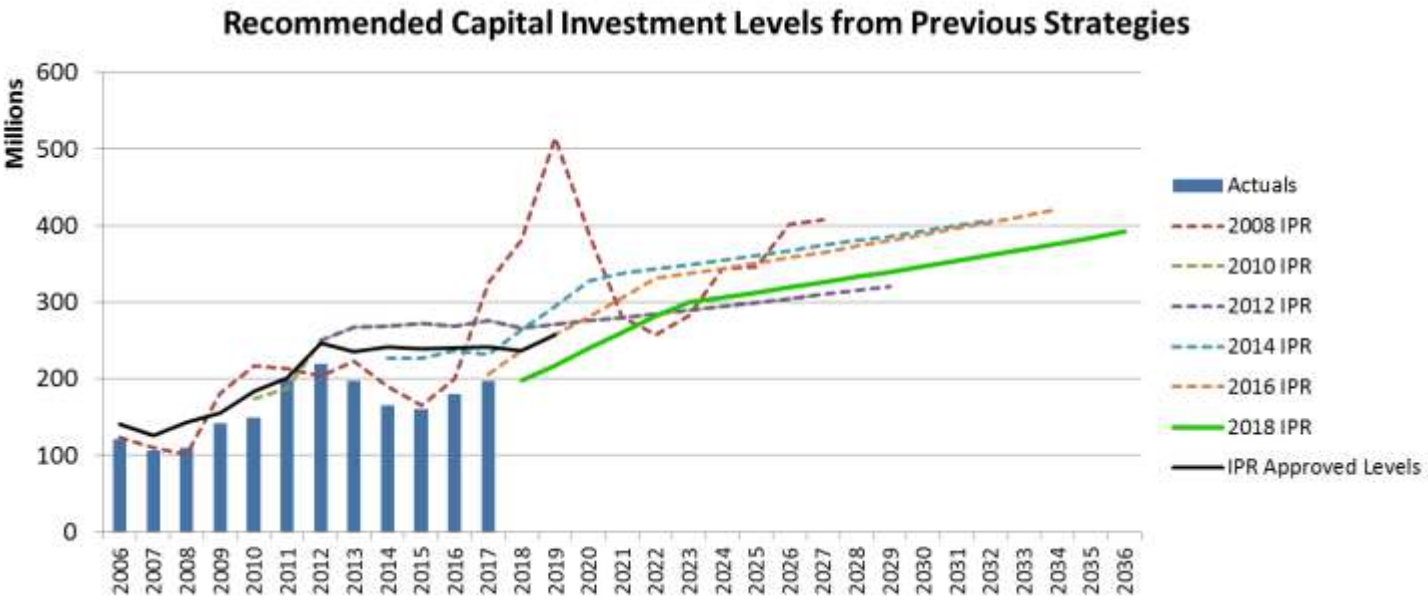
The chart above shows Capital investment for planned projects in Blue which represent mature investments that are tracked in C55. As the capital forecast associated with planned projects declines, Asset Analytics fills in gaps by selecting assets to replace, if optimal. In some cases, it may not be optimal to spend the entire budget.

When a more constrained budget is introduced, the existing portfolio of identified investments is optimized resulting in a number of projects moving to a later date. The forecast associated with deferred investment is highlighted in red in the example below. A lower constraint results in planned projects lasting farther into the future before Asset Analytics is required to fill in gaps in the long term plan.


Capital Program Forecast
Capital Investment
2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037
Identified Projects
Asset Analytics Recommendations
Deferred Projects
Capital Constraint

1.1 Strategy Alternative #1

The need to increase investment in the hydro system in order to minimize total lifecycle cost was identified as early as the Asset Strategy presented in the 2008 IPR. Subsequent Asset Strategies continued to identify an increasing need for investment, especially in the 2020s. Between 2007 and 2011 the capital investment program doubled from $100 million per year to around $200 million per year. Despite the analysis showing an increasing investment need from an economic perspective and the Corps and Reclamation mirroring similar concerns from an engineering perspective, actual investment levels and Start-of-Year budget requests began to decline after 2012. This disconnect lead to creation of the Asset Investment Excellence Initiative, which had an early focus on planning and execution of the Capital investment program.



In 2017, Capital Investment increased back up to the $200 million level. The previous IPR called for Capital Investment to begin increasing above the $200 million level in 2018 to $236 million. However, Start-of-Year budget requests from the Corps and Reclamation remained at the $200 million level.

Strategy Alternative #1 is a revision of the recommended strategy presented in the 2016 Capital Investment Review. Investments, planning levels and objectives are largely unchanged but the ramp up to a $300 million investment level is delayed and less aggressive. Investment at Grand Coulee and McNary dams represent the majority of the Capital investment program over the next decade. The ability to ramp up to the identified investment level is closely tied to the schedules for the various projects at these two plants.

Over the next 20 years, this alternative is forecast to slow the decline in average condition of all equipment, improve the average condition of power train equipment, reduce current Lost Generation Risk levels by more than half and improve efficiency with Turbine replacements at Grand Coulee, McNary and John Day dams. Relative to Strategy Alterative #2, this strategy has a Net Present Value of $1.2 billion.

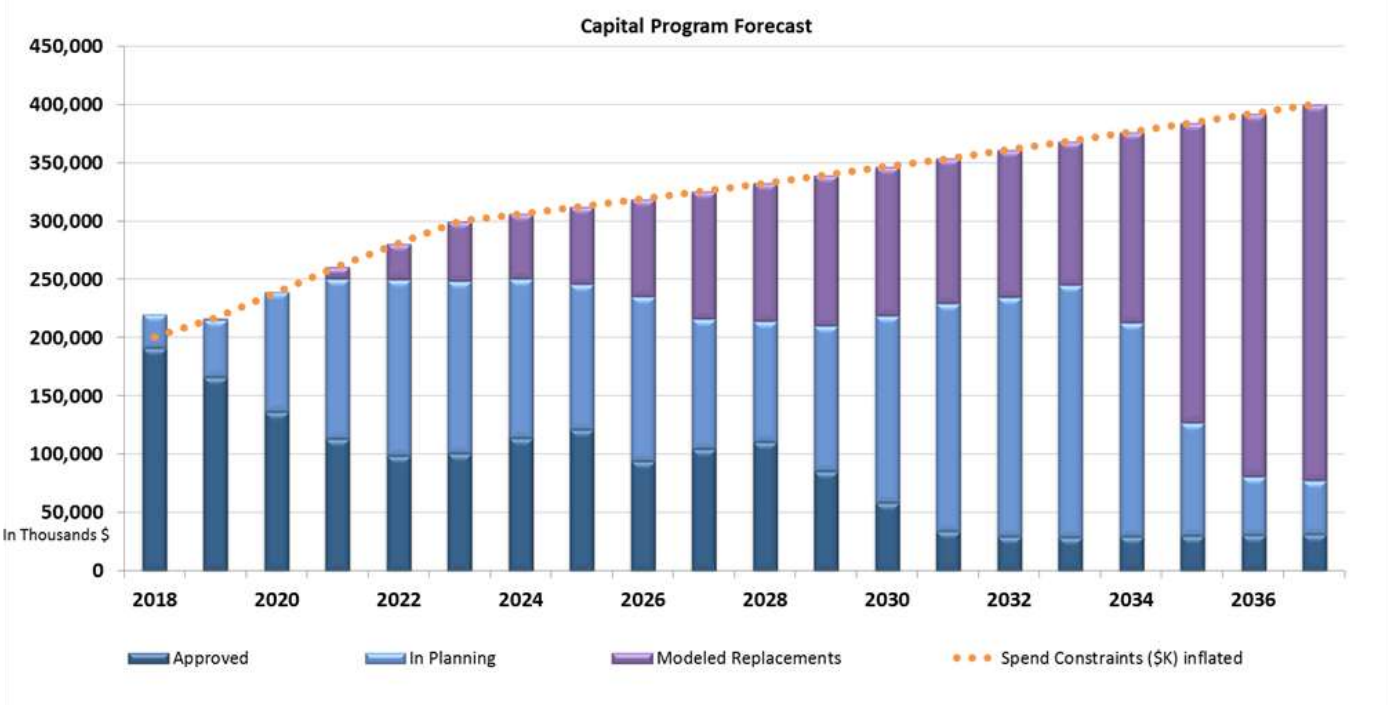
1.1.1 Planning Levels

For this alternative, the capital program ramps up to $300 million dollars by 2023 and then increases with inflation. This is a delayed ramp up from the 2016 IPR recommendation to reflect a more executable investment program. The baseline Routine and Non-Routine expense programs are forecast through 2021 and increase with inflation in subsequent years.

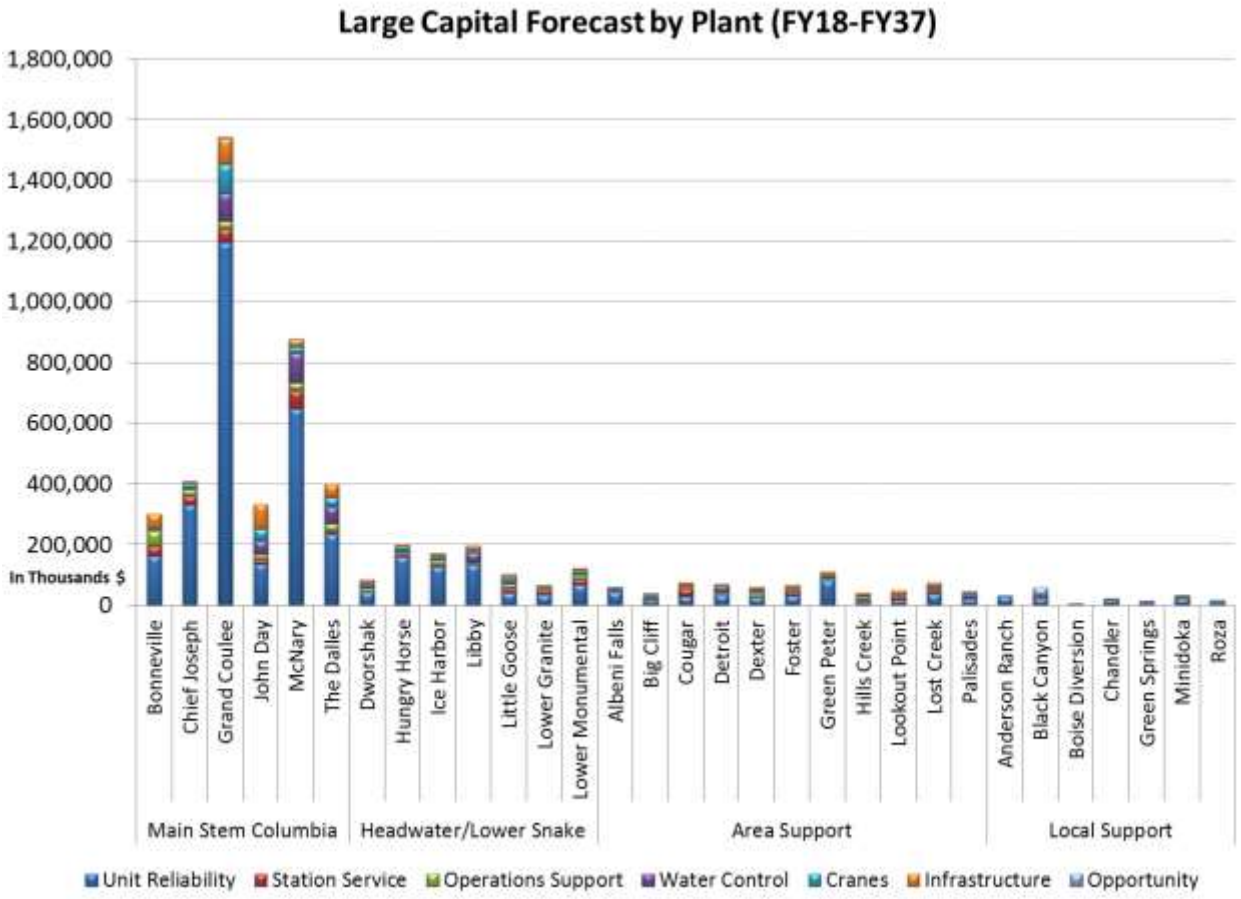
Table 11.1.1.1, Spend Levels ($ Millions)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Capital	206	217	239	261	281	300	306	313	319	326	333	340	347	354	362	369	377	385	393	401
Routine Expense	345	349	359	368	373	381	388	396	404	412	420	429	437	446	455	464	473	483	492	502
Non-Routine Expense	74	61	59	52	53	54	56	57	58	59	60	61	63	64	65	66	68	69	70	72

Strategy Alternative #1 Capital Program Forecast



40 percent of the capital investment over the next 20 years is focused at Grand Coulee and McNary which together represent over half of the of the current lost generation risk in the FCRPS. At McNary, Turbine Runner replacements make up the majority of the investment over the next decade while the modernization of units 19-21 and the electrical modernization of units 1-18 are the primary investments at Grand Coulee. John Day Turbines and Generators are currently under evaluation and are optimized to begin in the mid-2030s based on current information. Results of the study, currently scheduled to complete at the end of 2018, may shift the start date earlier into the 2030s or late 2020s. This would result in a rebalancing of the portfolio in the 2030s but not change future total capital forecasts.

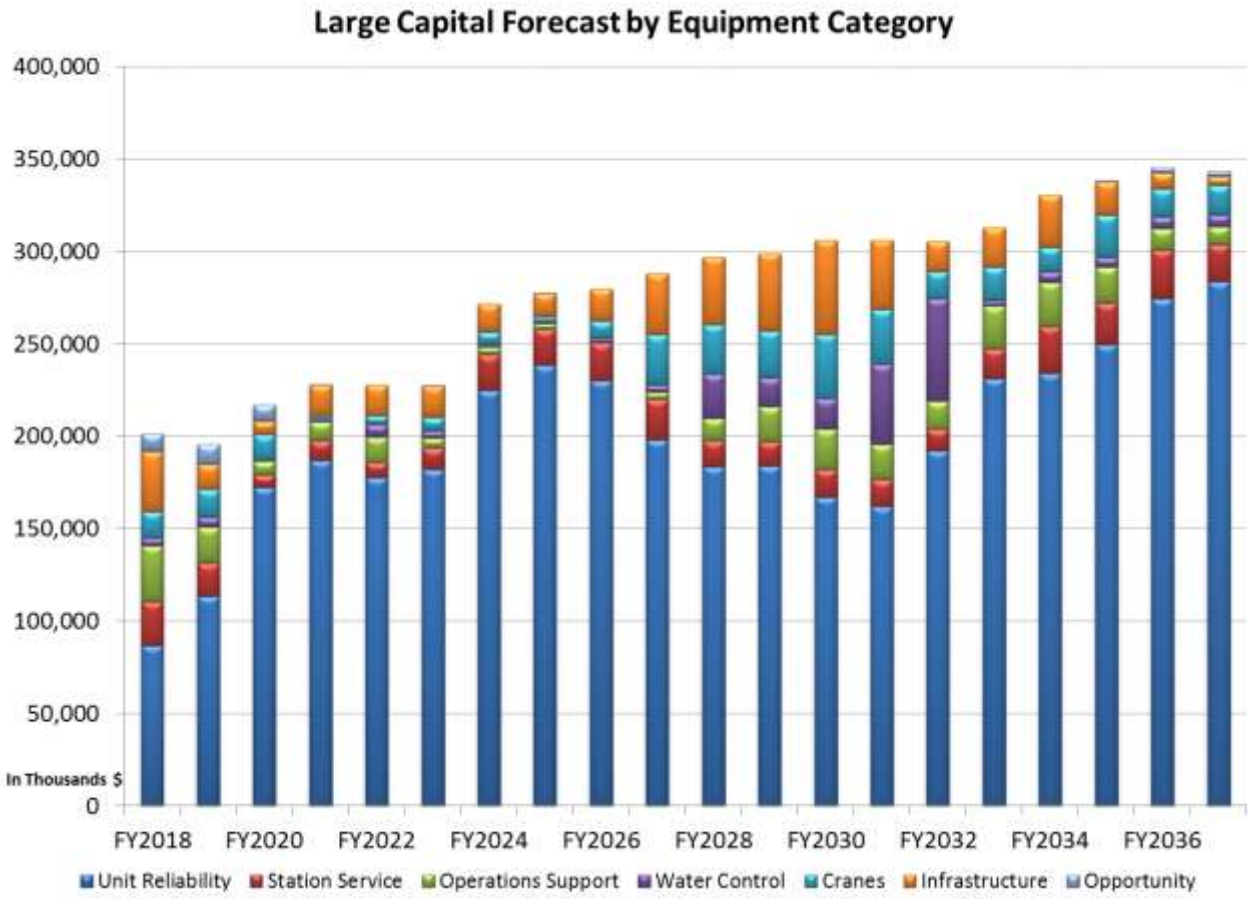


Unit Reliability represents 67% of the investment in the system of the next 20 years, with the majority of the investment in the Main Stem and Headwater facilities.

Percentage of 20 Year Capital Investment Program

Unit Reliability	Station Service	Operations Support	Water Control	Cranes	Infrastructure	Opportunity
67%	6%	5%	8%	6%	8%	1%

Recent years have more heavily focused on Station Service, Operations Support, Cranes and Infrastructure investments in anticipation of the major investments in Unit Reliability. Bridge and Gantry Crane replacement or rehabilitation, Station Service modernizations, switchyard modernizations and SCADA/GDACs replacements have been a major focus. Investments in oil water separators, fire protection and arc flash hazard reduction have also been a focus to reduce safety and environmental risk.



The level of investment by Asset Class correlates with the percentage of total FCRPS represented by each Asset Class. Investment in Area Support assets is high relative generation. A quarter of the investment in Area Support plants represents investment in joint assets. These assets support the other authorized purposes of the facilities such as Flood Control, Navigation, Recreation and Fish and Wildlife Mitigation. Reinvestment costs are shared between BPA and Federal Appropriations according to the cost allocation authorized by Congress for each facility.

Annual Generation versus Capital Investment by Asset Class

Asset Class	% of Average Annual Generation	% of 20 year Capital Forecast
Main Stem Columbia	77%	68%
Headwater/Lower Snake	18%	17%
Area Support	4%	12%
Local Support	1%	3%

1.1.2 Operation and Maintenance Methods

The Corps and Reclamation have a mature and robust preventative maintenance program at each of their hydro projects, consisting of routine inspection and maintenance of both power and non-power assets. Both agencies utilize computerized maintenance management systems to plan, schedule, resource, and track the completion of all routine work orders, as well as any corrective maintenance that arises. Additionally, some plants with critical generating units have begun to utilize online condition monitoring systems to better predict potential issues so that they can intervene with maintenance activities and avoid failures.

Maintenance procedures and recurrence intervals are informed by internal agency standards such as Reclamation's Facilities, Instructions, Standards, and Techniques (FIST) manual, as well as many from outside entities such as OSHA, NERC CIP, EPA, and Oregon DEQ. O&M practices at each facility are reviewed and compared to best practices on a periodic basis through the agencies' Power Operations and Maintenance Review programs. In 2017, the three agencies kicked off an O&M Excellence initiative to identify potential cost savings and to align maintenance strategies with the long term operational needs and investment plans for each project.

1.1.3 Performance and Risk Impact

Under this Strategy Alternative, progress is made towards reducing the number of assets forecasted to be in the high risk categories of their respective risk maps. The following subsections show the future state risk maps as well as a comparison of the high risks assets between now and the future state.

1.1.3.1 Safety Impacts

The number of high risks assets is expected to decrease from 103 to 26.

Figure 11.1.1.5-1, Alternative Strategy #1, 20-Year Risk Assessment Safety

Safety Consequence Risk Map

Likelihood	No or minor injury, first aid	Treatment by medical professional	Lost time Accident - temporary disability	Lost Time Accident - permanent disability/fatality	Multiple fatalities
Almost Certain	254 Unit Reliability 24 Station Service 5 Operations Support 8 Infrastructure 3 Water Control 9 0 9 0	28 Unit Reliability 2 Cranes 44 Station Service 25 Operations Support 16 Infrastructure 4 Water Control	18 Operations Support	1 Operations Support	
Likely	93 Unit Reliability 27 Station Service 3 Operations Support 6 Infrastructure	38 Unit Reliability 35 Cranes 55 Station Service 33 Operations Support 15 Infrastructure 7 Water Control	8 Cranes 15 Station Service 7 Operations Support	7 Operations Support	
Possible	522 Unit Reliability 42 Station Service 13 Operations Support 43 Infrastructure	58 Unit Reliability 16 Cranes 33 Station Service 24 Operations Support 12 Infrastructure 15 Water Control 1 0 1 0	10 Unit Reliability 9 Cranes 2 Station Service 1 Operations Support	9 Operations Support	16 Unit Reliability 58 Water Control
Unlikely	275 Unit Reliability 16 Station Service 6 Operations Support 6 Infrastructure 2 Water Control	6 Unit Reliability 4 Cranes 1 Station Service 1 Operations Support 2 Infrastructure 1 Water Control	11 Unit Reliability 6 Cranes 18 Station Service 3 Operations Support	13 Operations Support	19 Unit Reliability 5 Water Control
Rare	1439 Unit Reliability 268 Station Service 66 Operations Support 33 Infrastructure	391 Unit Reliability 57 Cranes 42 Station Service 49 Operations Support 15 Infrastructure 7 Water Control	232 Unit Reliability 80 Cranes 58 Station Service 100 Operations Support	23 Operations Support	240 Unit Reliability 121 Water Control

Consequence

Condition: 0 (top) – 10 (bottom)

Risk Level	Low	Medium	High

Number of High Risk Assets - Safety

High Risk Asset Type	Current	Future State (20 years)
Unit Reliability	20	0
Cranes	0	0
Station Service	0	0
Operations Support	56	26
Infrastructure	0	0

This information was made publicly available on July 13, 2018, and contains information sourced not directly from BPA financial statements.

Water Control	27	0

1.1.3.2 Financial Impacts

The number of high risks assets is expected to decrease from 369 to 223.

Figure 11.1.5.3-1, Alternative Strategy # 1, 20-Year Risk Assessment Financial

Financial Consequence Risk Map

Likelihood	Insignificant < $ 10K	Minor $ 10K to $ 100K	Moderate $ 100K to $ 1 M	Major $ 1 M to $ 10 M	Extreme > $ 10 M
Almost Certain	9 Station Service 13 Operations Support	183 Unit Reliability 1 Cranes 35 Station Service 18 Operations Support 1 Infrastructure 1 Water Control	97 Unit Reliability 1 Cranes 24 Station Service 14 Operations Support 22 Infrastructure 6 Water Control	2 Unit Reliability 4 Operations Support 1 Infrastructure	
Likely	4 Station Service 14 Operations Support 2 Infrastructure	1 Cranes 55 Station Service 26 Operations Support 1 Water Control	84 Unit Reliability 38 Cranes 38 Station Service 9 Operations Support 19 Infrastructure 6 Water Control	46 Unit Reliability 4 Cranes 1 Operations Support	1 Unit Reliability
Possible	2 Station Service 16 Operations Support 3 Infrastructure	41 Unit Reliability 1 Cranes 49 Station Service 19 Operations Support 20 Infrastructure 10 Water Control	383 Unit Reliability 22 Cranes 26 Station Service 11 Operations Support 28 Infrastructure 52 Water Control	179 Unit Reliability 2 Cranes 1 Operations Support 4 Infrastructure 10 Water Control	3 Unit Reliability 1 Water Control
Unlikely	7 Operations Support	61 Unit Reliability 5 Station Service 3 Operations Support 1 Infrastructure 1 Water Control	148 Unit Reliability 7 Cranes 30 Station Service 13 Operations Support 6 Infrastructure 7 Water Control	99 Unit Reliability 3 Cranes 1 Infrastructure	3 Unit Reliability
Rare	84 Operations Support 1 Infrastructure	213 Unit Reliability 2 Cranes 7 Station Service 59 Operations Support 4 Infrastructure 9 Water Control	986 Unit Reliability 77 Cranes 205 Station Service 90 Operations Support 37 Infrastructure 87 Water Control	1021 Unit Reliability 57 Cranes 156 Station Service 5 Operations Support 6 Infrastructure 27 Water Control	82 Unit Reliability 1 Cranes 5 Water Control

Condition: 0 (Almost Certain) – 10 (Rare)

Consequence

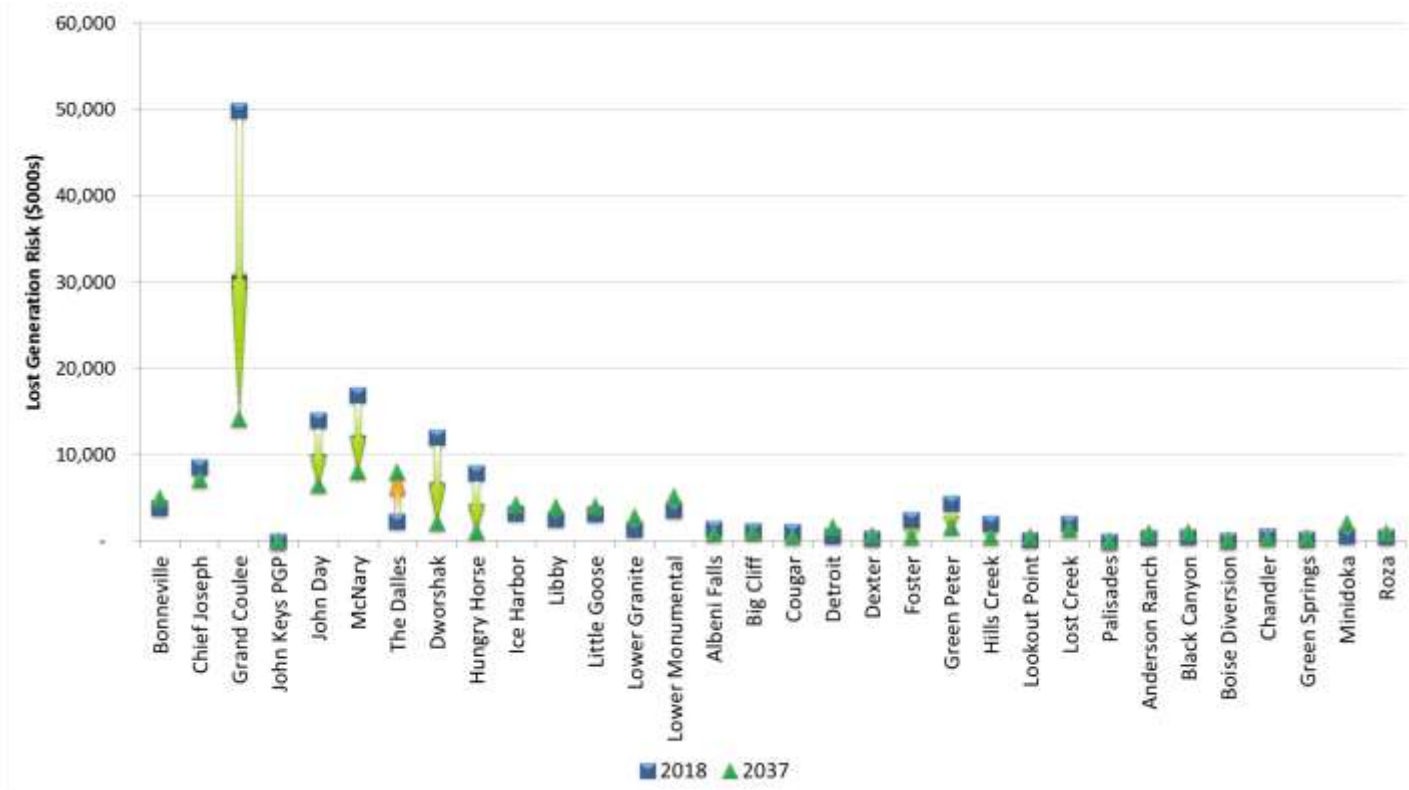
Risk Level	Low	Medium	High

Number of High Risk Assets - Financial

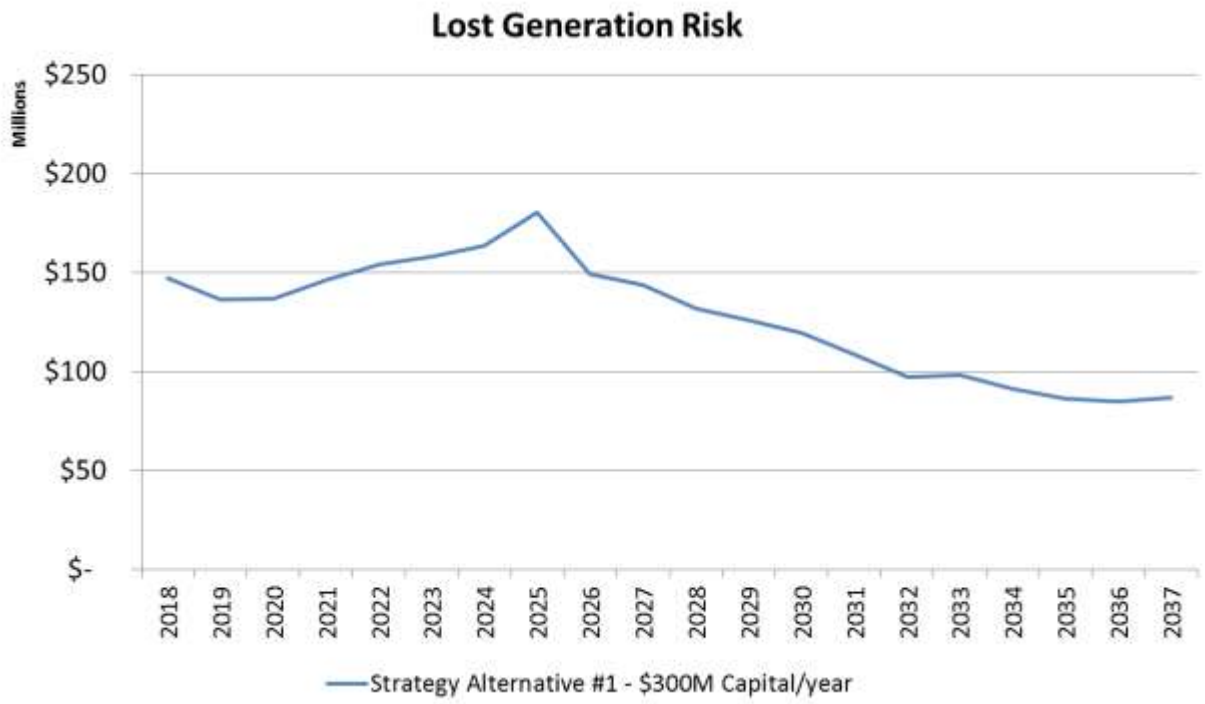
High Risk Asset Type	Current	Future State (20 Years)
Unit Reliability	196	146
Cranes	25	5
Station Service	83	24
Operations Support	37	19
Infrastructure	18	23
Water Control	10	6

In 20 years, the number of assets in the high Financial Risk category is reduced by 42% relative to today. This translates into large reductions in lost generation risk at Grand Coulee, McNary, Dworshak, Hungry Horse and Green Peter.

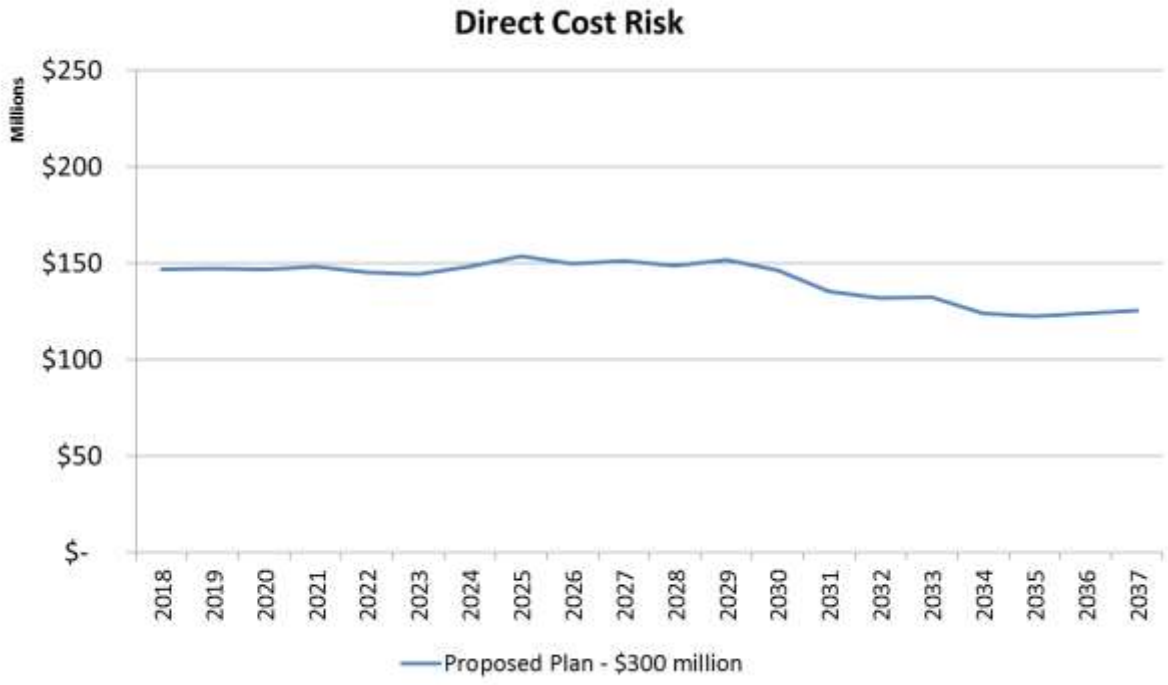
Change in Lost Generation Risk by Plant – 2017 to 2037



At a system level, Lost Generation Risk is expected to continue to increase until the mid-2020s. Lost Generation Risk then begins to decline as progress is made on replacements at Grand Coulee (Electrical Modernization of Units 1-18 and Modernization of 19-21) and McNary (Runner Replacements on Units 1-14).



Direct Costs risk associated with the inefficiency of reactive replacement and repair activities is expected to remain relatively flat. Direct Costs themselves could manifest themselves in a number of ways, but primarily in unplanned maintenance activities and higher cost for repair or replacement due to the need to expedite the process to return a unit to service.



This information was made publicly available on July 13, 2018, and contains information sourced not directly from BPA financial statements.

1.1.3.3 Environmental Impacts

The number of high risks assets is expected to decrease from 95 to 53.

Figure 11.1.5.4-1, Alternative Strategy # 1, 20-Year Risk Assessment Environment/Trustworthy/Stewardship

Environmental Consequence Risk Map

Likelihood						
Almost Certain	254 Unit Reliability 2 Cranes 24 Station Service 5 Operations Support 24 Infrastructure 9 0 9 0	28 Unit Reliability 44 Station Service 10 Operations Support	34 Operations Support 7 Water Control			0
Likely	84 Unit Reliability 35 Cranes 27 Station Service 3 Operations Support 21 Infrastructure	47 Unit Reliability 55 Station Service 1 Operations Support	8 Cranes 15 Station Service 34 Operations Support 7 Water Control	12 Operations Support		Condition
Possible	423 Unit Reliability 16 Cranes 42 Station Service 13 Operations Support 55 Infrastructure 1 0 1 0	157 Unit Reliability 33 Station Service 1 Operations Support	26 Unit Reliability 9 Cranes 2 Station Service 27 Operations Support 15 Water Control	6 Operations Support	58 Water Control	
Unlikely	236 Unit Reliability 4 Cranes 16 Station Service 6 Operations Support 8 Infrastructure	45 Unit Reliability 1 Station Service	30 Unit Reliability 6 Cranes 18 Station Service 16 Operations Support 3 Water Control	1 Operations Support	5 Water Control	
Rare	1230 Unit Reliability 57 Cranes 268 Station Service 66 Operations Support 48 Infrastructure	600 Unit Reliability 42 Station Service 14 Operations Support	472 Unit Reliability 80 Cranes 58 Station Service 129 Operations Support 7 Water Control	29 Operations Support	121 Water Control	10
	No impact	Impact to on-site environment (simple remediation)	Limited impact off-site (localized remediation required)	Detrimental impact on- or off-site (long-term remediation required)	Detrimental or catastrophic impact off-site (mitigation impossible)	

Consequence

Risk Level	Low	Medium	High

Number of High Risk Assets - Environmental

High Risk Asset Type	Current	Future State (20 Years)
Unit Reliability	16	0
Cranes	0	0
Station Service	0	0
Operations Support	52	46
Infrastructure	0	0
Water Control	27	7

1.2 Strategy Alternative #2

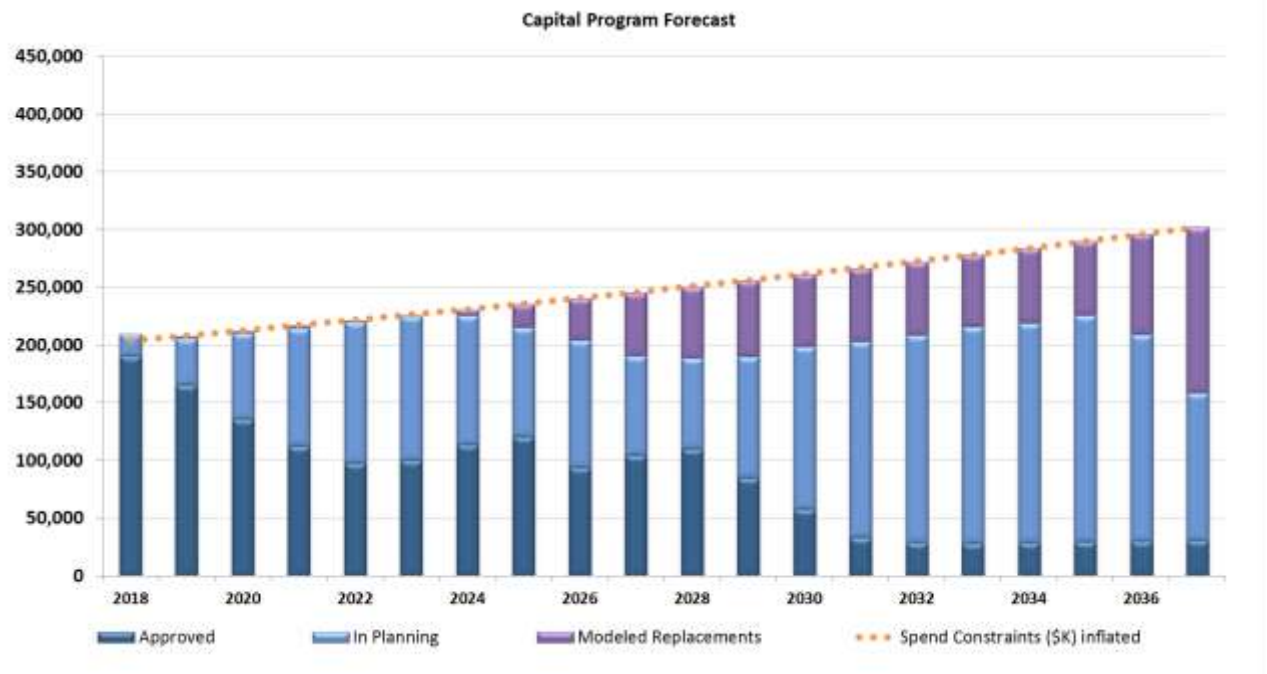
Strategy Alternative #2 holds the Capital investment program flat in real terms at $200 million per year terms, with nominal increases reflecting inflation. At this investment level, planned work at McNary and Grand Coulee cannot proceed as scheduled in Strategy Alternative #1. Optimizing the portfolio within this constraint leads to deferring replacement of Turbines on Grand Coulee Units 19 through 21 in order to leave investment dollars available for the other plants in the system.

1.2.1 Planning Levels

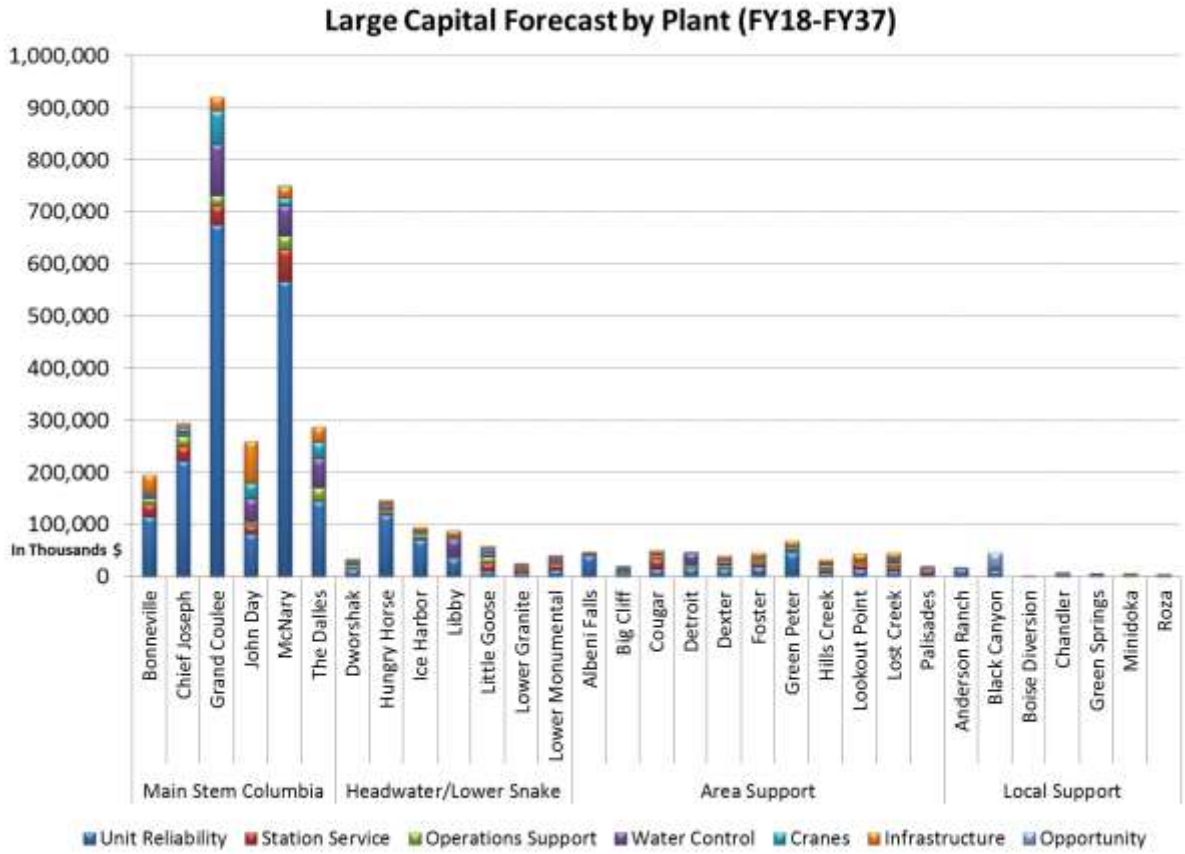
Routine Expense and Non-Routine Expense forecasts are not modified for this scenario. If this were the chosen strategy alternative there would likely be increases in the Non-Routine expense forecasts in future years. BPA, the Corps and Reclamation would need to more thoroughly consider the impacts.

Table 11.2.1.1, Spend Levels ($ Millions)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Capital	210	200	200	200	200	200	200	200	200	200	204	208	213	217	222	226	231	236	241	246
Routine Expense	345	349	359	368	373	381	388	396	404	412	420	429	437	446	455	464	473	483	492	502
Non-Routine Expense	74	61	59	52	53	54	56	57	58	59	60	61	63	64	65	66	68	69	70	72



Under this strategy, investment alternatives are unchanged with the exception of the investments in Grand Coulee Units 19-21, however many investments are deferred to stay within budget constraints. Specific investment deferrals are shown in section **Error! Reference source not found.**.

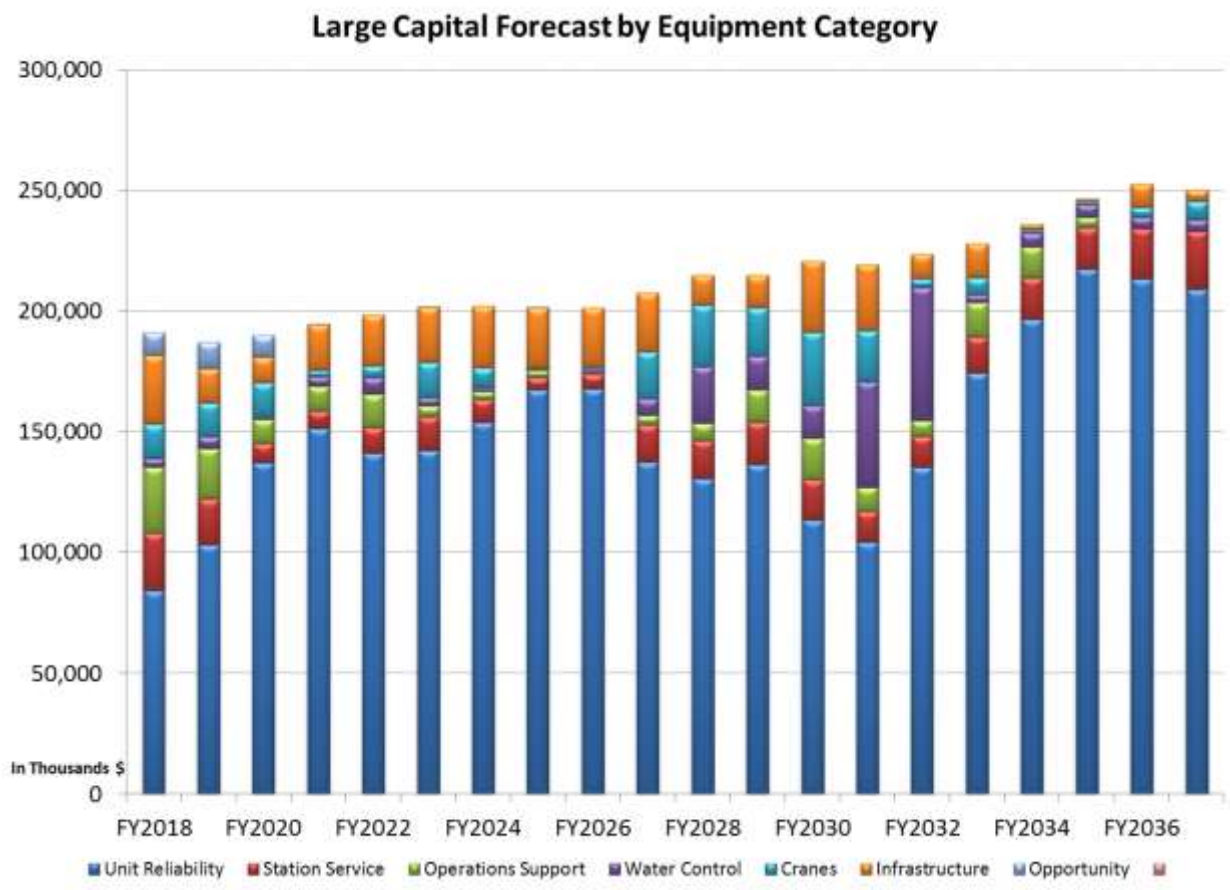


On a percentage basis, the largest reductions relative to Strategy Alternative #1 come from the Headwater/Lower Snake and Local Support Asset Classes which would nearly have their level of investment over the next 20 years reduced by half.

Change Relative to Strategy Alternative #1

Asset Class	Strategy 2 Reduction ($)	Strategy 2 Reduction (%)
Main Stem Columbia	($1,162,434,000)	-30%
Headwater/Lower Snake	($457,692,000)	-48%
Area Support	($242,324,000)	-34%
Local Support	($89,653,000)	-49%

Proportionately, investment across equipment categories is mostly unchanged between the alternatives with Unit Reliability still being a major focus.



Unit Reliability	Station Service	Operations Support	Water Control	Cranes	Infrastructure	Opportunity
67%	6%	5%	9%	5%	7%	1%

1.2.2 Operation and Maintenance Methods

If Capital investment was held flat for a prolonged period of time, more serious consideration for the impacts to the expense program would need to be considered. This would include the maintenance practices that would need to be taken to mitigate for the forecasted decline in unit reliability between the scenarios.

1.2.3 Performance and Risk Impact

Strategy Alternative #2 is not sufficient to stem the increase in risk in the first twenty years. The number of assets in the high risk category increases from today's levels for Safety, Environmental and Financial risk maps. Lost Generation and Direct Costs are also expected to increase overtime, especially while the focus is on Grand Coulee and McNary.

1.2.3.1 Safety Impacts

The number of high risk assets is expected to increase from 103 to 126. Most of the Operations Support equipment posing a high safety risk are communications equipment within the facilities. Poor communication abilities within the dam can lead to longer response times in the event of an incident or the need to change operations or protocols to safely execute work.

Figure 11.2.5.1-1, Alternative Strategy #2, 20-Year Risk Assessment Safety

Safety Consequence Risk Map

Likelihood	No or minor injury, first aid	Treatment by medical professional	Lost time Accident - temporary disability	Lost Time Accident - permanent disability/fatality	Multiple fatalities
Almost Certain	362 Unit Reliability 36 Station Service 6 Operations Support 27 Infrastructure 3 Water Control	26 Unit Reliability 28 Cranes 45 Station Service 40 Operations Support 28 Infrastructure 4 Water Control	114 Operations Support	2 Operations Support	4 Unit Reliability
Likely	202 Unit Reliability 32 Station Service 3 Operations Support 5 Infrastructure	75 Unit Reliability 35 Cranes 44 Station Service 36 Operations Support 15 Infrastructure 7 Water Control	13 Unit Reliability 37 Cranes 9 Station Service 6 Operations Support	5 Operations Support	1 Unit Reliability
Possible	591 Unit Reliability 48 Station Service 7 Operations Support 45 Infrastructure	173 Unit Reliability 17 Cranes 49 Station Service 21 Operations Support 12 Infrastructure 15 Water Control	18 Unit Reliability 17 Cranes 9 Station Service 2 Operations Support	11 Operations Support	37 Unit Reliability 58 Water Control
Unlikely	307 Unit Reliability 16 Station Service 10 Operations Support 4 Infrastructure 1 Water Control	11 Unit Reliability 2 Cranes 8 Station Service 4 Operations Support 1 Water Control 1 0 1 0	18 Unit Reliability 8 Cranes 18 Station Service 3 Operations Support	12 Operations Support	4 Unit Reliability 2 Water Control
Rare	1121 Unit Reliability 245 Station Service 68 Operations Support 15 Infrastructure 1 Water Control	236 Unit Reliability 32 Cranes 29 Station Service 31 Operations Support 5 Infrastructure 7 Water Control	204 Unit Reliability 41 Cranes 57 Station Service 4 Operations Support	23 Operations Support	229 Unit Reliability 124 Water Control

Consequence

Condition: 0 (top) – 10 (bottom)

Risk Level	Low	Medium	High

Number of High Risk Assets - Safety

High Risk Asset Type	Current	Future State (20 years)
Unit Reliability	20	5
Cranes	0	0

Station Service	0	0
Operations Support	56	121
Infrastructure	0	0
Water Control	27	0

1.2.3.2 Financial Impacts

The number of high risk assets is expected to increase from 355 to 525. Governors, exciters and station service equipment in the Main Stem Columbia and Headwater and Lower Snake make up the majority the equipment.

Figure 11.2.5.2-1, Alternative Strategy #2, 20-Year Risk Assessment Financial

Financial Consequence Risk Map

Likelihood	Insignificant < $ 10K	Minor $ 10K to $ 100K	Moderate $ 100K to $ 1 M	Major $ 1 M to $ 10 M	Extreme > $ 10 M
Almost Certain	9 Station Service 31 Operations Support 1 Infrastructure	183 Unit Reliability 3 Cranes 35 Station Service 66 Operations Support 5 Infrastructure 1 Water Control	207 Unit Reliability 24 Cranes 34 Station Service 57 Operations Support 44 Infrastructure 6 Water Control	2 Unit Reliability 1 Cranes 3 Station Service 8 Operations Support 5 Infrastructure	
Likely	14 Operations Support 1 Infrastructure	1 Cranes 48 Station Service 26 Operations Support 1 Water Control	178 Unit Reliability 51 Cranes 37 Station Service 9 Operations Support 19 Infrastructure 6 Water Control	108 Unit Reliability 20 Cranes 1 Operations Support	5 Unit Reliability
Possible	6 Station Service 10 Operations Support 4 Infrastructure	39 Unit Reliability 1 Cranes 49 Station Service 22 Operations Support 20 Infrastructure 10 Water Control	438 Unit Reliability 27 Cranes 40 Station Service 8 Operations Support 29 Infrastructure 52 Water Control	334 Unit Reliability 6 Cranes 11 Station Service 1 Operations Support 4 Infrastructure 10 Water Control	8 Unit Reliability 1 Water Control
Unlikely	11 Operations Support	49 Unit Reliability 10 Station Service 3 Operations Support 1 Infrastructure 1 Water Control	157 Unit Reliability 4 Cranes 32 Station Service 15 Operations Support 3 Infrastructure 3 Water Control	123 Unit Reliability 6 Cranes 1 0 1 0	11 Unit Reliability
Rare	69 Operations Support	195 Unit Reliability 9 Station Service 8 Operations Support 9 Water Control	726 Unit Reliability 37 Cranes 156 Station Service 48 Operations Support 17 Infrastructure 91 Water Control	792 Unit Reliability 35 Cranes 166 Station Service 1 Operations Support 3 Infrastructure 27 Water Control	77 Unit Reliability 1 Cranes 5 Water Control

Condition: 0 (top) – 10 (bottom)

Consequence

Risk Level	Low	Medium	High

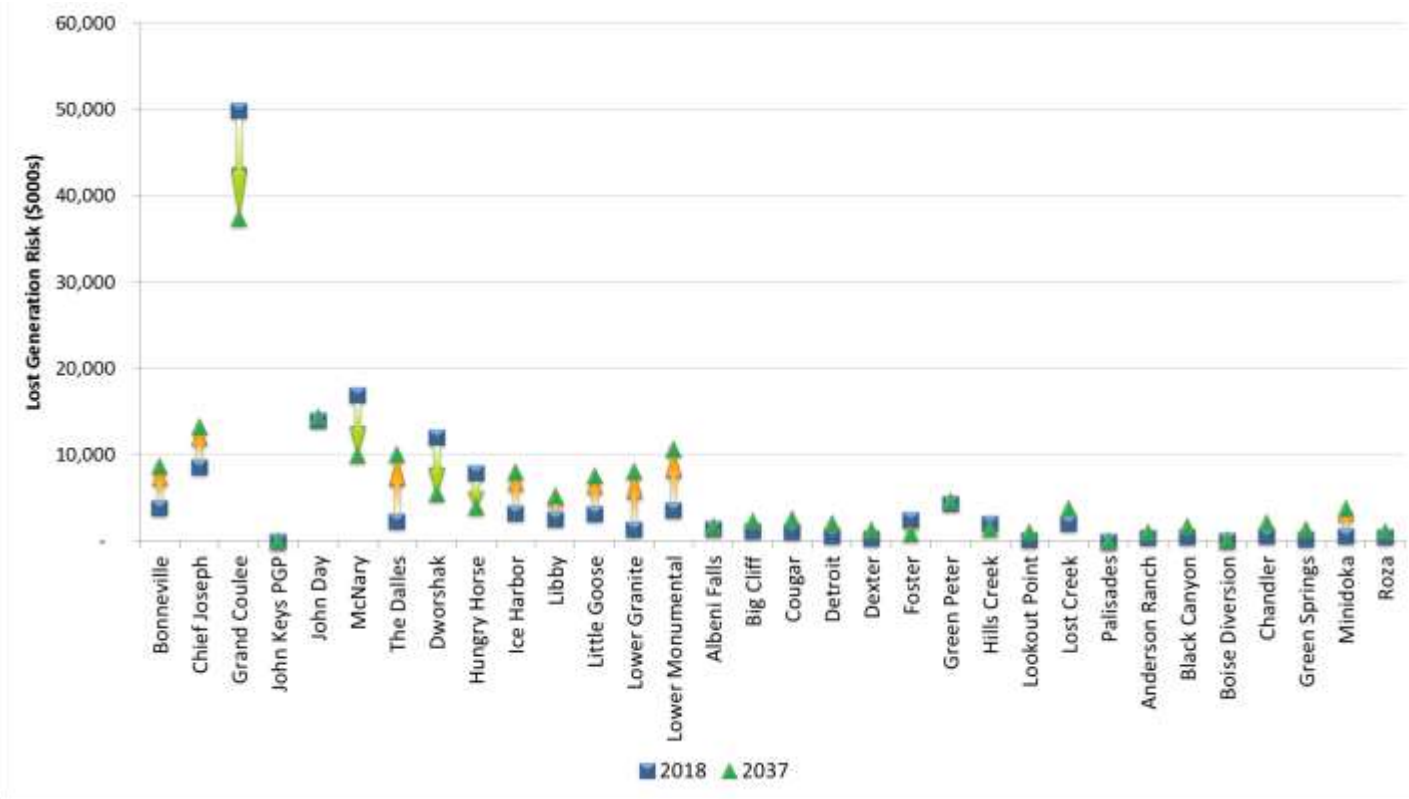
This information was made publicly available on July 13, 2018, and contains information sourced not directly from BPA financial statements.

Number of High Risk Assets - Financial

High Risk Asset Type	Current	Future State (20 Years)
Unit Reliability	196	322
Cranes	25	45
Station Service	83	37
Operations Support	37	66
Infrastructure	18	49
Water Control	10	6

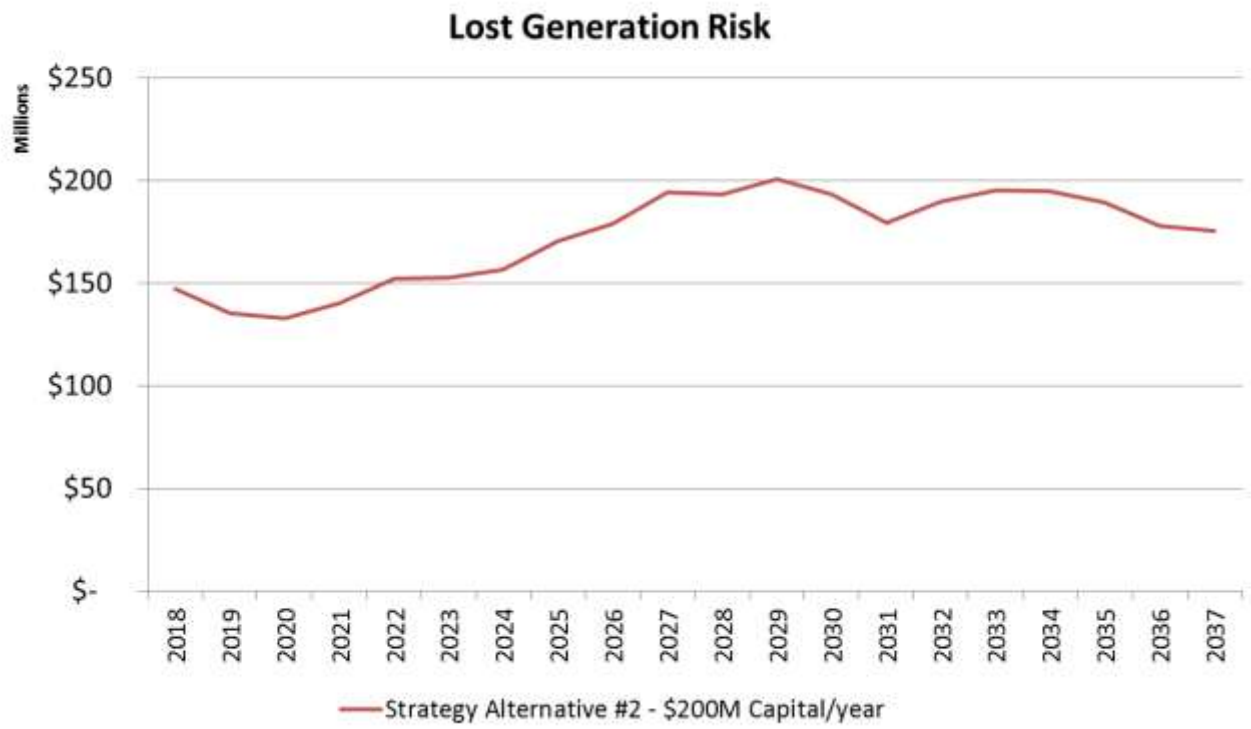
Unlike Strategy Alternative #1, Lost Generation Risk is expected increases across the system before declining back to today's levels by the late 2030s. With the exception of Dworshak and Hungry Horse, all Main Stem Columbia and Headwater/Lower Snake plants show significant increases in Lost Generation Risk. The reduced capital investment levels results in significant delays for some powertrain equipment, shown in 11.2.3. In particular, Transformers at Grand Coulee and the Headwater/Lower Snake Projects are deferred until the 2040s in this alternative. Electrical components of governor systems, which have a design life of 20 years, also end up being deferred well past their design lives at Chief Joseph, Grand Coulee, McNary and Libby.

Change in Lost Generation Risk – 2017 to 2037

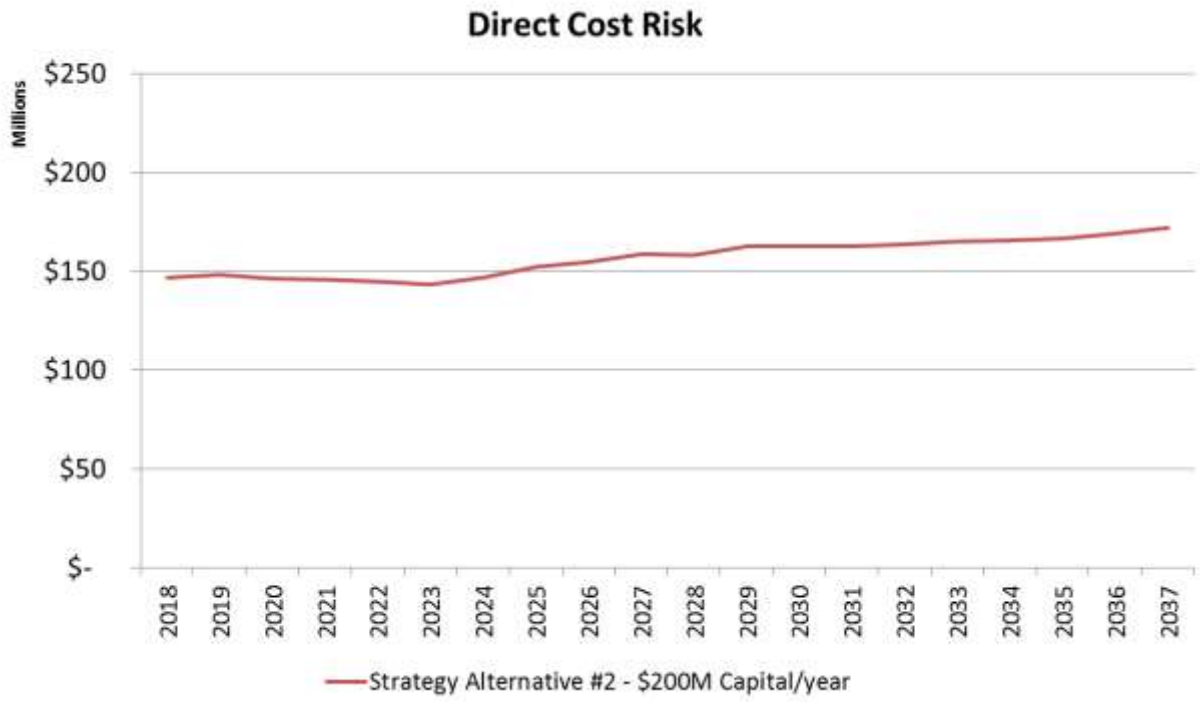


The sharp decline in risk in the late 2030s is a result of the modeling aggressively selecting assets for replacement which currently have no associated investments in the Asset Plan. In reality, replacements

could not be made as quickly as suggested by the modeling in those years due to resource, outage or physical constraints within the powerhouses. A closer analysis of the Asset Plan investments optimized into the 2030s and the asset replacements suggested by Asset Analytics making up the sharp decline may result in a more flattened out Lost Generation Risk profile for this Strategy Alternative.



Direct Cost Risk is also expected to increase, however, a reduction similar in magnitude to the one seen in the Lost Generation Risk is not observed. This is because much of the Balance of Plant items that do not impact generation are allowed to degrade in condition in favor of making replacements powertrain equipment to reduce Lost Generation risk. Direct Cost Risk on these assets is relatively small individually, but add up to a significant amount in total if not addressed. Since the modeling created an overly aggressive set of replacements in the late 2030s, a more realistic plan would likely include a more investment in Balance of Plant assets in those years.



1.2.3.3 Reliability and Compliance Impacts

Reliability and Compliance impacts will be evaluated in FY18 and FY19 for inclusion in the next revision of the SAMP.

1.2.3.4 Environmental Impacts

The number of high risk assets increases from 95 to 159. As with safety, the condition of the communications systems also pose a risk to the environment if they do not operate as intended. Poor quality or a lack of communication can lead to slow response times in the event of an incident.

Figure 11.2.1.4-1, Alternative Strategy #2, 20-Year Risk Assessment Environment/Trustworthy/Stewardship

Environmental Consequence Risk Map

Likelihood	No impact	Impact to on-site environment (simple remediation)	Limited impact off-site (localized remediation required)	Detrimental impact on- or off-site (long-term remediation required)	Detrimental or catastrophic impact off-site (mitigation impossible)
Almost Certain	362 Unit Reliability 28 Cranes 36 Station Service 6 Operations Support 55 Infrastructure	26 Unit Reliability 45 Station Service 21 Operations Support	4 Unit Reliability 135 Operations Support 7 Water Control		
Likely	180 Unit Reliability 35 Cranes 32 Station Service 3 Operations Support 20 Infrastructure	97 Unit Reliability 44 Station Service 2 Operations Support	14 Unit Reliability 37 Cranes 9 Station Service 32 Operations Support 7 Water Control	13 Operations Support	
Possible	443 Unit Reliability 17 Cranes 48 Station Service 7 Operations Support 57 Infrastructure	321 Unit Reliability 49 Station Service 1 Operations Support	55 Unit Reliability 17 Cranes 9 Station Service 30 Operations Support 15 Water Control	3 Operations Support	58 Water Control
Unlikely	246 Unit Reliability 2 Cranes 16 Station Service 10 Operations Support 4 Infrastructure 1 0 1 0	72 Unit Reliability 8 Station Service	22 Unit Reliability 8 Cranes 18 Station Service 15 Operations Support 2 Water Control	4 Operations Support	2 Water Control
Rare	996 Unit Reliability 32 Cranes 245 Station Service 68 Operations Support 20 Infrastructure	361 Unit Reliability 29 Station Service 2 Operations Support	433 Unit Reliability 41 Cranes 57 Station Service 28 Operations Support 8 Water Control	28 Operations Support	124 Water Control

Consequence

Condition: 0 (top) – 10 (bottom)

Risk Level	Low	Medium	High

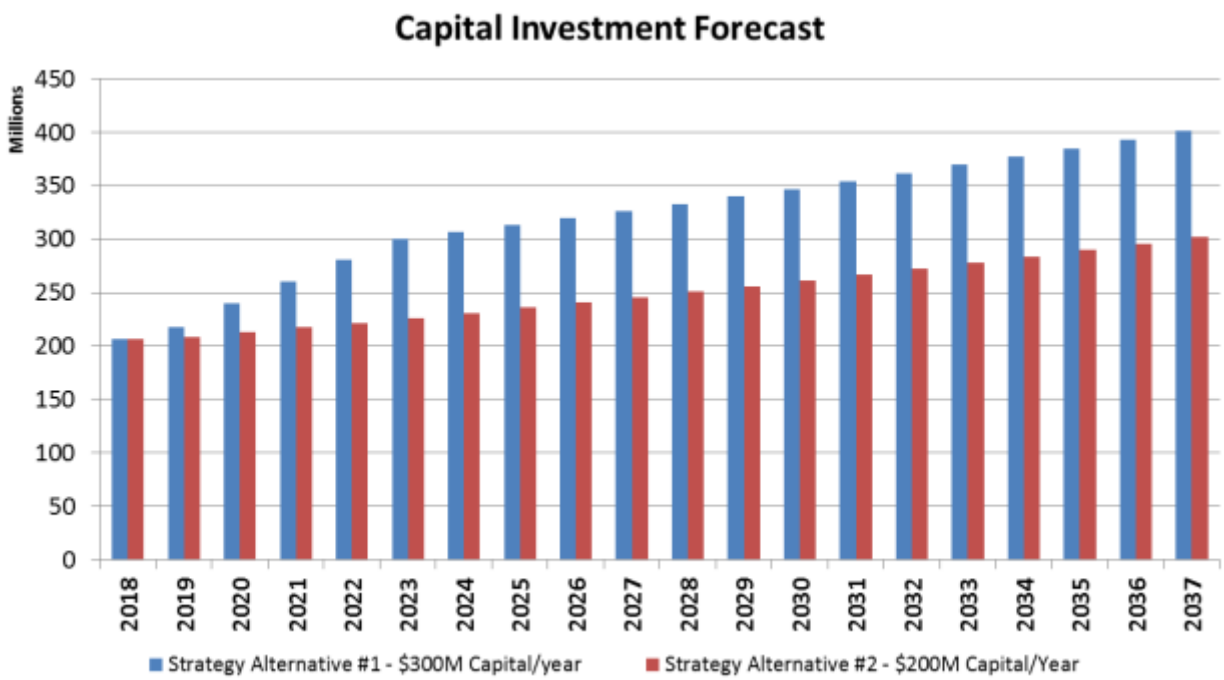
Number of High Risk Assets - Environmental

High Risk Asset Type	Current	Future State (20 Years)
Unit Reliability	16	4
Cranes	0	0
Station Service	0	0
Operations Support	52	148
Infrastructure	0	0
Water Control	27	7

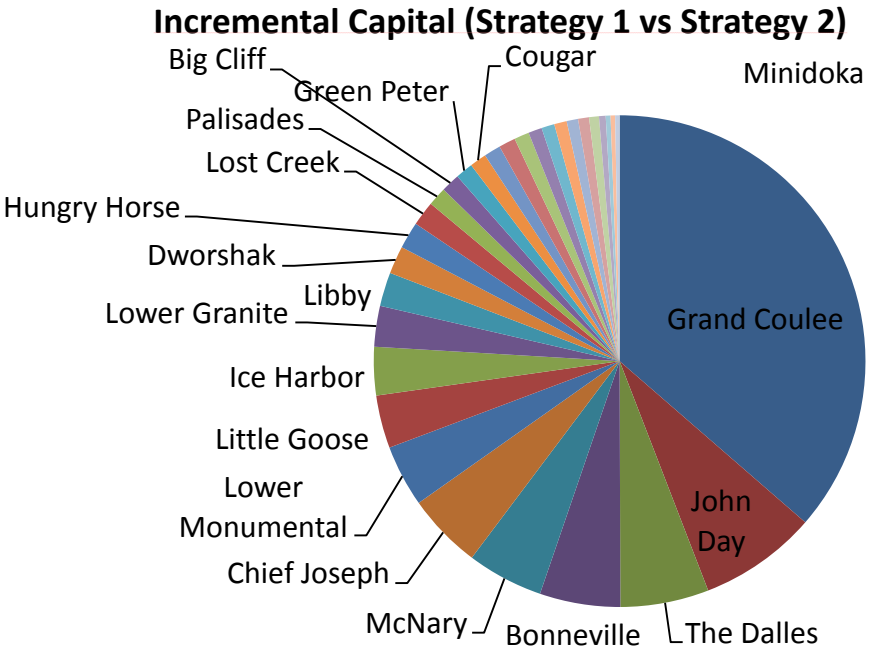
1.3 Alternative Strategy Comparisons

1.3.1 Capital Investment Costs

Strategy Alternative #1 calls for the Capital Program to ramp up to a $300 million per year by 2023 and then increase with inflation. Generally, it takes three to five years from the start of an investment before a replacement or refurbishment activity is complete and the benefits of the project can begin to be realized. Since the two investment strategies are quite similar until the 2020s, benefits of the increased investment are not expected to start until the mid to late 2020s. In both Strategy Alternatives, the modeling indicates that it is optimal to expend the full inflation adjusted budget.



Compared to Strategy Alternative 2, the optimized portfolio distributes capital dollars proportionate to each strategic class with Grand Coulee receiving more than a third of the incremental funds. In Strategy Alternative #2, there is not enough available capital to support replacement of the turbines on units 19 through 21 while also making critical replacements in the remainder of the system. This results in a deferral of turbine replacements and an increase in risk.



1.3.2 Equipment Age

Understanding the age of the asset population at replacement can be a useful measure in determining the adequacy of a replacement program. Generally speaking, high risk assets should be replaced near their design lives while it may be tolerable for less risky assets to operate well beyond their design lives. Overall, a vast majority of the powertrain assets are forecast to be replaced well beyond their design lives.

Average Equipment Age at Replacement by Strategy Alternative

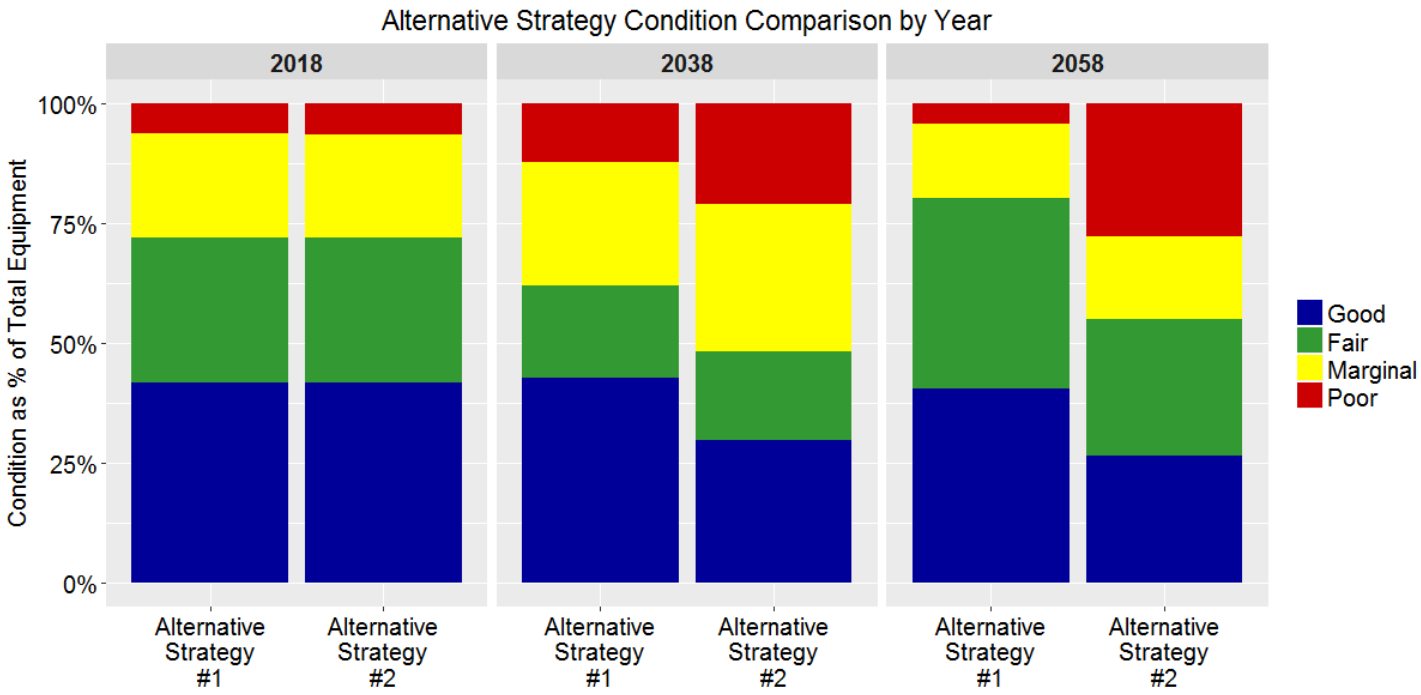
Strategy	Breakers	Exciters	Generator Rotors	Generator Windings	Governor Electrical	Governor Mechanical	Transformer	Turbine Adjustable	Turbine Fixed
Strategy Alternative #1	43	38	72	50	40	57	58	74	53
Strategy Alternative #2	50	54	80	63	72	74	70	87	76
Design Life	**40**	**35**	**60**	**30**	**25**	**50**	**50**	**50**	**50**

Under Strategy Alternative #1, the average age at replacement is reduced closer to equipment design life. The biggest differences are for the electrical components of Governor Systems, Fixed Blade (Francis) Turbines, Exciters and Generator Windings.

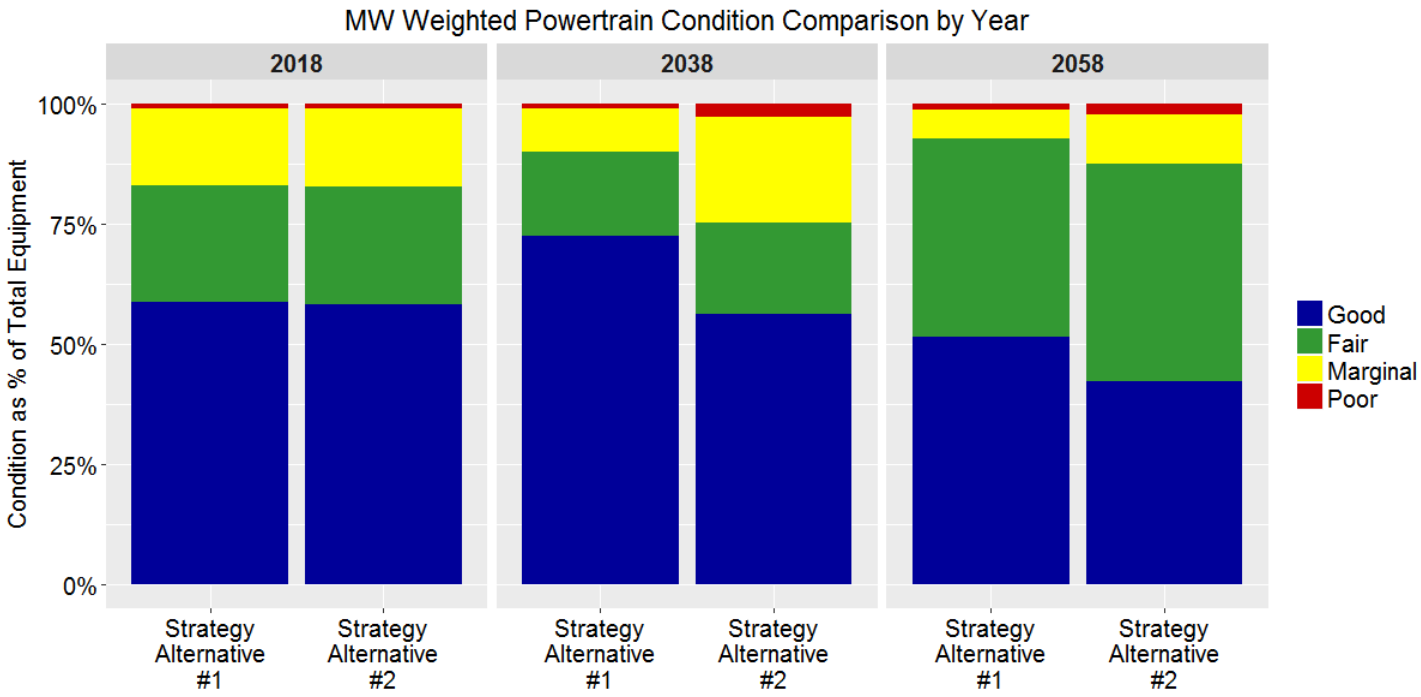
1.3.3 Equipment Condition

A comparison of equipment condition over time is shown below. Condition is presented as a percentage of total equipment in each condition category (Good, Fair, Marginal and Poor). Currently, just over 25% of FCRPS equipment is in Marginal and Poor condition. In 20 years, this percentage is expected to grow to 38% and 51% for Alternative Strategy #1 and Alternative Strategy #2 respectively. Over the long term, Alternative Strategy #1 is able to reduce the percentage of equipment in Marginal and Poor condition

below even todays levels, while Alternative Strategy #2 remains at a steady-state of about 50% of FCRPS equipment in Marginal and Poor condition.

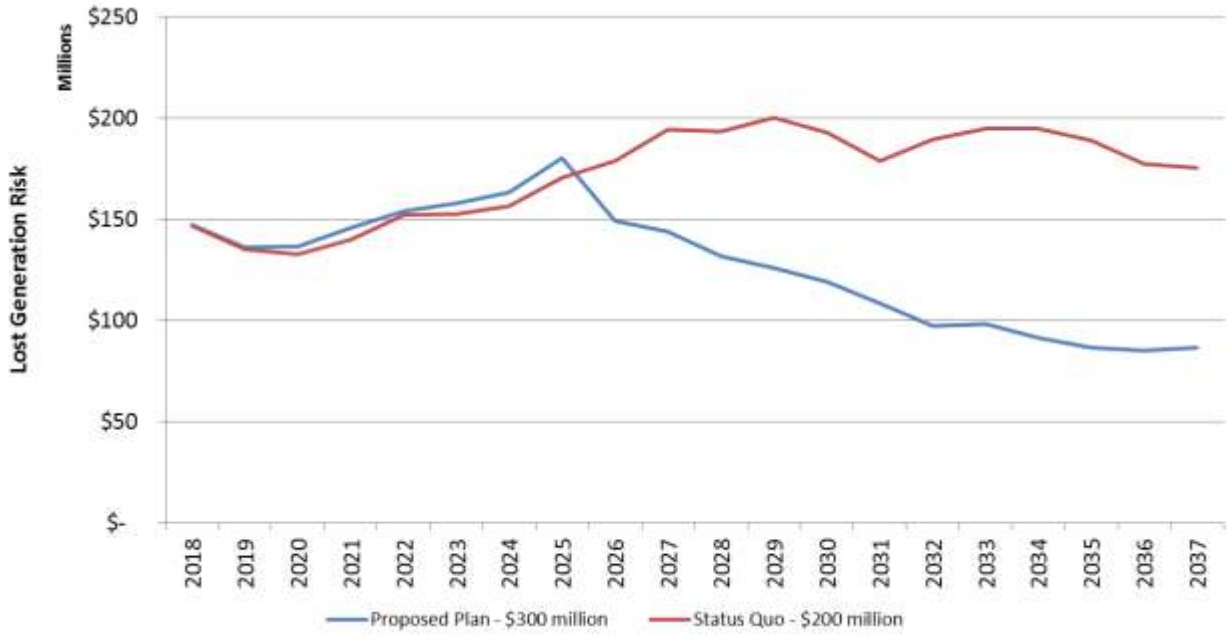


Although more equipment is projected to be in marginal and poor condition in 2038 than today, Powertrain equipment in Strategy Alternative #1 shows improvement when weighted by unit capacity. Powertrain condition still declines over the same time period with Strategy Alternative #2.



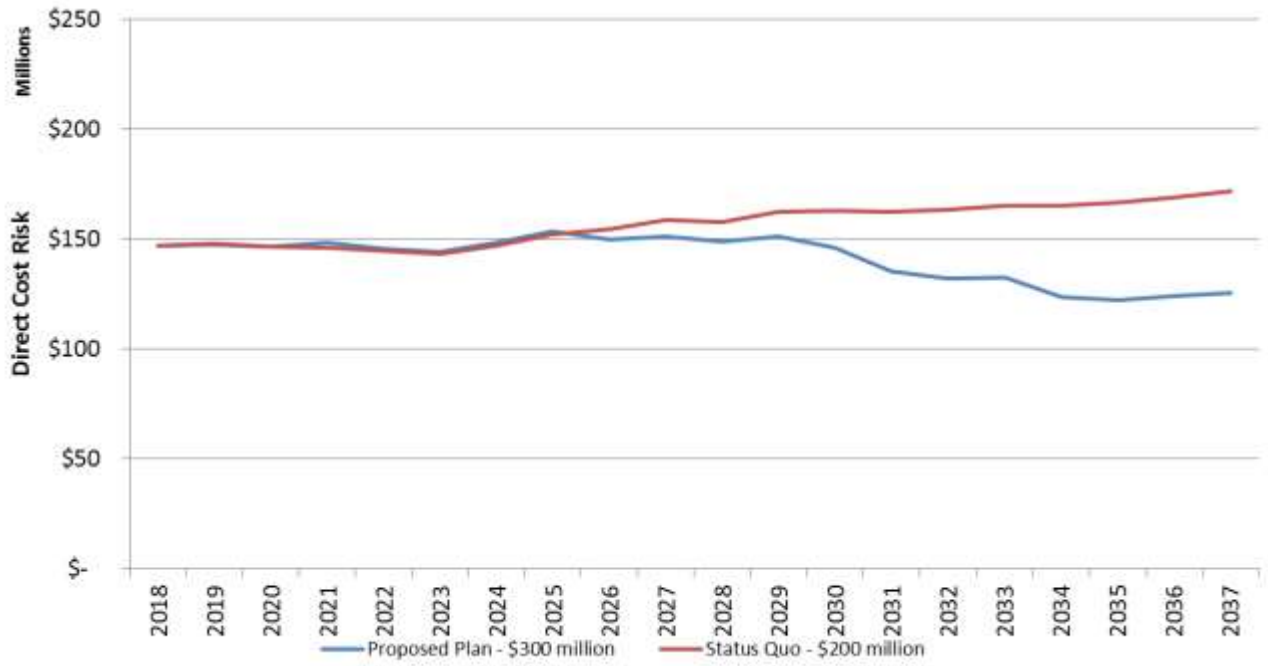
1.3.4 Lost Generation Risk

Mentioned earlier in this section, the difference in spending between the two scenarios does not begin until 2020 and increases until 2024. After 2024, both scenarios increase with inflation and are held flat in real terms. Due to this, the benefits of Strategy Alternative #1 do not begin until the mid-2020s. Comparing the two alternatives, the difference in lost generation grows to about $100 million per year by the 2030s.



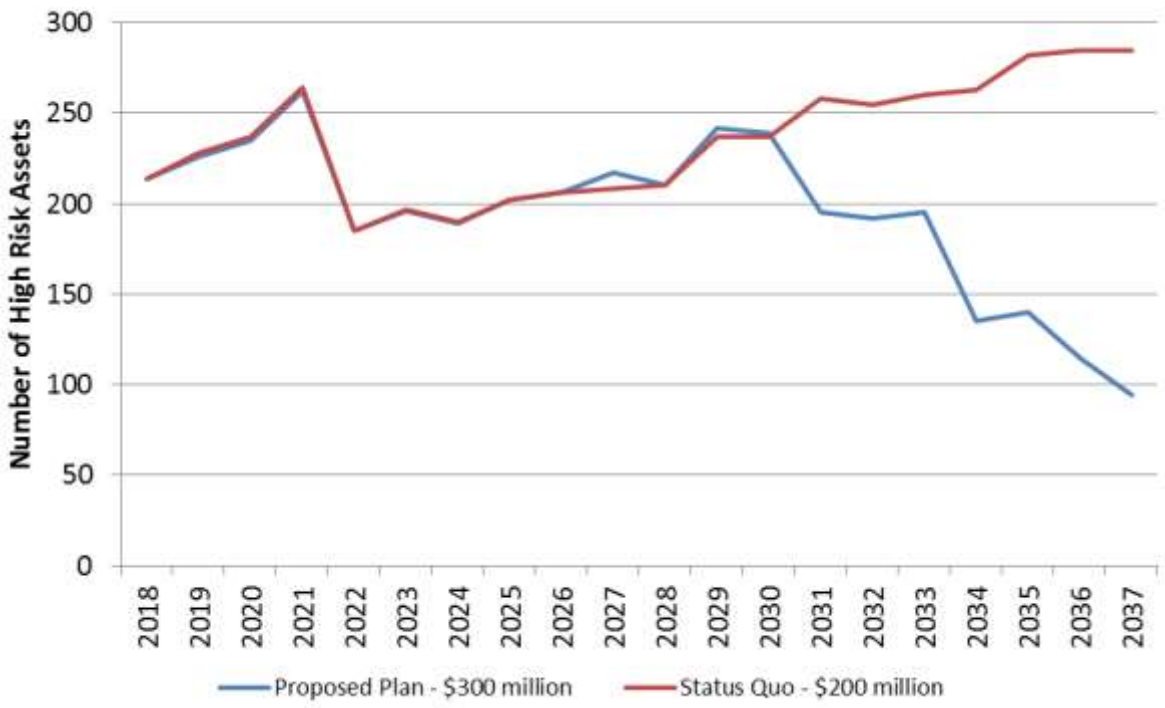
1.3.5 Direct Cost Risk

With less investment deferral in Strategy Alternative #1 relative to Strategy Alternative #2, the difference in direct cost risk between the alternatives begins to grow in 2025. A steady-state of about a $50 million annual difference is reached in the 2030s.



1.3.6 Safety and Environmental Risk

The number of assets in the High Risk categories of the Safety and Environmental Risk Maps is reduced in the near term but increases in subsequent years to levels higher than today under Strategy Alternative #2. Strategy Alternative #1 has the ability to reduce the number starting in the 2030s.



1.4 Chosen Strategy

Strategy Alternative #1 is the chosen strategy for the FCRPS. The Net Present Value of increased investment in the system is expected to be $500 million dollars relative to Strategy Alternative #2. Alternative #1 greatly reduces lost generation risk beginning in the late-2020s with significant benefits continuing into the future. Direct Cost Risk is reduced by a similar magnitude relative to Strategy Alternative #2 and the number of high risk Safety and Environmental is reduced by more than half.

2018 Net Present Value ($ Millions) – Strategy Alternative #1 versus Strategy Alternative #2

Alternative	PV Lost Generation Risk	PV Direct Cost Risk	PV Lost Efficiency Opportunity	PV Capital Investment Spend	Total Cost
Strategy Alternative #2 - 200 Million	$ 2,550	$ 2,686	$ 462	$ 3,407	$ 9,105
Strategy Alternative #1 - 300 Million	$ 1,898	$ 2,260	$ 162	$ 4,285	$ 8,605
Incremental Value of Strategy Alternative #1	**$ 653**	**$ 426**	**$ 300**	**$ (878)**	**$ 501**

Strategy Alternative #2 keeps Capital expenditures flat in real terms at the cost of increasing safety, environmental and financial risks as well as increasing Lost Generation and Direct Cost Risks. This level of funding appears to be inadequate to sustain even the current level of service of the FCRPS.