

Restoring wild salmon

Power system costs and benefits
of lower Snake River dam removal

A NW Energy Coalition issue paper

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NW Energy Coalition
for a clean and affordable energy future

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The report's findings and recommendations are those of the NW Energy Coalition alone and do not necessarily represent the views of all reviewers.

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Executive summary

Nearly 35 years after the Northwest Power Act mandated equal treatment for fish and power generation in the Columbia-Snake system, 13 of the basin's wild salmon and steelhead stocks are still listed under the Endangered Species Act. Several remain at high risk of extinction. The past summer's battered returns from high water temperatures and altered river flows show that climate change will continue to exacerbate these species' plight.

Hydropower dams can pose a significant challenge to salmon recovery. This is especially true for endangered Snake River stocks whose pristine, high-altitude spawning habitats need little improvement.

More than anything, all of these wild fish need the power system to share enough of the river to let them survive and flourish. That remedy – be it through diversion of water from hydropower turbines or removal of four relatively low-production dams in southeast Washington – would ultimately require the Bonneville Power Administration to secure replacement resources. Clearly, the cost of such replacement is of concern to Northwest power customers.

This study finds that the costs of replacing the power from the lower Snake River dams, net of avoided expenses for maintaining those dams, would be nearly imperceptible to the average public power customer, on the order of *\$1 per month*.

In addition to their contribution to the Northwest power system, the lower Snake River dams provide or enable other services such as transport. This study is limited to the Northwest power system economics if removal of the four Snake River dams proceeds. This paper does not investigate the navigation, flood control, irrigation, fisheries or outdoor industry economics. Nor does it factor in the costs of physical dam removal. While all these concerns must be part of the overall conversation, they lie outside the scope and expertise of the NW Energy Coalition. Our aim is to inform current discussions on the future of the power system rather than to provide a comprehensive examination of all the costs and benefits of dam removal.

This analysis of replacing the power from the lower Snake River dams (which collectively generate about 1,040 average megawatts¹ of electricity a year) may apply to any measure or set of measures that change hydropower operations or river flow requirements to restore threatened and endangered wild salmon populations to sustainable and harvestable levels. We compare the costs of maintaining the four dams with those of replacing their power with a mix of utility-scale solar (currently one of the cheapest new clean renewable energy options) and electricity purchases from the market, incorporating an added carbon price for the fossil-fueled content of those market purchases.

We conclude:

- The costs to maintain the four lower Snake River dams and associated infrastructure are far greater than the U.S. Army Corps of Engineers' 2002 estimate of \$56 million per year. A more realistic estimate is nearly **five times** as great -- *\$269 million annually*.
- Utility-scale solar power costs have dropped significantly in the past five years. Replacing the dams' firm (always counted upon) winter output of 463 aMW with solar and the remainder, about 579 aMW, with market purchases would cost \$609 million per year.
- Doing the math results in a net cost of **\$340 million** per year,² which would increase average residential bills about \$1 per month for customers of utilities that get power from Bonneville.

We recommend:

- More sophisticated, data-enriched analysis by the Northwest Power and Conservation Council of lower Snake River dam removal costs and benefits to the power system.

¹ An average megawatt (aMW) is equivalent to 8,760 megawatt-hours, or the amount a 1-megawatt generator would produce if it operated for an entire year.

² In its 6th regional power plan, the Northwest Power and Conservation Council estimated the net cost to be \$550 million/year based on power costs in 2010.

I. Introduction

Most Columbia-Snake basin wild salmon and steelhead are threatened, endangered or at risk. Climate change is further stressing their spawning, rearing and migratory patterns. Preventing their extinction and restoring their abundance will require more access to prime habitat, easier passage through the hydrosystem, and more cold and free-flowing water.

The lower Snake River stocks hold special ecological value. Because their spawning areas in eastern Oregon and central Idaho are by far the highest, coldest, healthiest, best-connected and best-protected habitats in the West, they have a better chance than other stocks of surviving climate change. Thus, protecting their migratory passage is like building a Noah's Ark for salmon survival.

Many scientists consider removing the four lower Snake River dams and their warm, slack-water reservoirs the surest restoration strategy. Many scientists also advocate further study of the efficacy of greatly expanded spill over the dams.

Either approach would likely reduce hydropower generation by at least 1,000 aMW per year and thus bring costs to the power system. This report details the costs and benefits of replacing the 1,040 aMW (about 4% of regional load) of power generated by the lower Snake River dams. What would lower Snake River dam removal cost the power system compared to what it will cost to keep the four dams in place?

This analysis focuses on power system costs – it is not a comprehensive study of dam removal costs and benefits. Our calculations do not include the one-time costs of physical dam removal/decommissioning (\$400 million - \$800 million³). They do not incorporate the costs of adapting and operating irrigation hookups (estimated at \$421 million⁴). Nor do they include the cost of updating or operating transportation systems, especially rail, to carry the cargo now barged on the Snake River waterway (most recently estimated at about \$230 million⁵).

³ The Cost of Keeping the Lower Snake River Dams: A Reevaluation of the Lower Snake River Feasibility Report (2015) and U.S. Army Corps of Engineers Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (2002), respectively.

⁴ Lower Snake River Juvenile Salmon Migration Feasibility Report/EIS, Appendix I, and cited in Revenue Stream: An Economic Analysis of the Costs and Benefits of Removing the Four Dams on the Lower Snake River (Feb. 2009), <http://www.wildsalmon.org/facts-and-information/the-solutions/revenue-stream.html>

⁵ Revenue Stream, p. 9.

On the other side of the ledger, this study does not assess the considerable long-term economic benefits of a free-flowing lower Snake River to commercial and recreational fishing and other outdoor recreation interests and local communities (estimates in the billions⁶). It also assigns no dollar value to the cultural importance to Tribes and other Northwest residents of recovering our iconic wild salmon.

But the power system costs themselves comprise a critical piece of the larger puzzle. Necessary to that calculation are the large and often-overlooked cost *savings* associated with dam removal. Ongoing operations and maintenance outlays, river channel dredging, fish transportation and bypass facilities, many parts of the Lower Snake River Compensation Plan⁷ and, most significantly, expensive turbine rehabilitation and system improvement costs would be avoided if the lower Snake River dams were removed.

This report gathers information from respected sources to answer the following questions:

- What will it cost to maintain and operate the four dams and related fish facilities — in other words, what costs would be *avoided* if the dams were removed?
- What will it cost to replace the four lower Snake River dams' energy production?

⁶ See: Revenue Stream; Quantifying Recreation Use Values from Removing Dams and Restoring Free-flowing Rivers: A Contingent Behavior Travel Cost Demand Model for the Lower Snake River, Dr. John Loomis, (Nov. 2000) p. 22; and Potential Economic impacts of Restored Salmon and Steelhead Fishing in Idaho, Ben Johnson Asso. Inc., (Feb. 2005).

⁷ Congress authorized the Lower Snake River Compensation Plan (LSRCP) as part of the Water Resources Development Act of 1976 (90 Stat. 2917). A major element of the authorized plan was a program to design and construct fish hatcheries to compensate for some of the losses of salmon and steelhead adult returns.

II. Ongoing costs of keeping the dams

In 2002, the U.S. Army Corps of Engineers' Walla Walla (Wash.) district released its *Lower Snake River Juvenile Salmon Migration Feasibility Report*, (<http://www.nwww.usace.army.mil/Library/2002LSRStudy.aspx>) analyzing such dam-related costs as dredging, scheduled rehabs of generators and other equipment, and fish facilities' maintenance and operation.

The report sets the estimated cost of maintaining the four lower Snake River dams at \$56 million per year. Retired Walla Walla Corps deputy engineer Jim Waddell⁸ recently took a fresh look at the 2002 report. His 2015 paper, *The Cost of Keeping the Lower Snake River Dams: A Reevaluation of the Lower Snake River Feasibility Report*,⁹ specifically addresses:

1. Fish passage facilities, including rehabilitation of aging equipment
2. Operations and maintenance (O&M) for the dams and fish facilities
3. Turbine rehabilitation over the remaining lives of the projects
4. Lower Snake River Compensation Plans
5. Operations and management (O&M) and minor repairs related to generation ("power service")
6. Navigation and dredging

Waddell finds that his office "understated the true cost of keeping the dams in place by a staggering" amount. He puts the "true cost" at *\$269 million a year*.

How does he reach this startling conclusion? He does so by addressing omissions, miscalculations and faulty assumptions in the Corps' work and incorporating and updating the actual costs of recent projects, and by adding cost-escalation rates.

For example, the Corps estimated that rehabilitating the four dams' total of 24 turbines would cost \$380 million. But now, with the work about to start, Bonneville estimates a cost of \$97 million for the first three turbines alone. That works out to \$776 million for all 24, more than double the Corps' estimate. In addition, the Corps study includes the costs of fish hatchery O&M, but not major rehabs or replacements within hatcheries, and it doesn't escalate costs for inflation.

⁸ Waddell retired in 2013 after 35 years with Corps. He was there when the *Lower Snake River Juvenile Salmon Migration Feasibility Report* was finalized in 2002.

⁹ <http://www.nwenergy.org/data/Cost-LSR-Dams-1-1-2015F1.pdf>

Identifying and tracking dam-retention costs is a challenge. BPA directly pays some, including the turbine rehabilitation costs that comprise the bulk of future expenditures. The U.S. Army Corps of Engineers covers other expenses with U.S. Treasury funds and is reimbursed by BPA for most of these costs. Waddell assumes that the relative allocations mirror current construction cost allocations described in the 2002 Corps report¹⁰; thus the hydrosystem reimburses the Corps for at least 91% of these costs (four-dam average).

Waddell uses cost-of-living inflation estimates and the “discount rate” (time value of money used) to compare expenditures at different points in time. This Coalition paper simplifies Waddell’s analysis by comparing the year-by-year “real” costs of keeping versus removing the dams, which means ignoring inflation by keeping all costs in 2015 dollars.

While Waddell presents a 100-year perspective, we use a 20-year timeframe. Estimating the costs of replacement power and dam rehabilitation, operations and maintenance, etc., beyond 20 years can be quite speculative; plus, this report is meant to align with the timeframe of the Northwest Power and Conservation Council’s 7th regional power plan.

Unlike physical dam removal,¹¹ dam retention costs will likely escalate faster than inflation. As equipment ages, it becomes more and more expensive to maintain, rehab or replace. Waddell escalates most costs at a conservative 3% annually, except for the Lower Snake River Compensation Plan, for which he justifies a 5% escalation rate, and for dredging, which he escalates at 2.5% per year. (Refer to his study for a detailed discussion of this issue.) We use Waddell’s generally conservative cost-escalation rates – often taken directly from Bonneville’s analyses -- for our comparison.¹²

¹⁰ Corps of Engineers, *2002 Feasibility Report*, Appendix I, pp. I11-2.

¹¹ Physical dam removal primarily involves labor and use of heavy equipment whose costs generally increase with inflation. Calculated in real dollars, the cost of dam removal is the same now as it will be far in the future. The Corps’ 2002 study estimates an \$800 million cost for dam removal. Because the four dams are mainly earthen bunkers, Waddell believes the Corps’ estimate is vastly inflated and should be about half that amount. In any case, when spread over the timeframes under discussion, that cost is in the range of \$20 million to \$40 million per year.

¹² These are real escalation rates that include the effects of inflation.

III. Power output of the four lower Snake River dams

The four lower Snake River dams have a combined nameplate capacity of about 3,300 megawatts. But the Northwest's highly variable precipitation pattern results in considerable variation in streamflows and power generation potential through the year. Demand for power, and, consequently price, also varies both seasonally and hourly. So we must consider both the *energy* supplied by the lower Snake River dams at different times of the year and the dams' *capacity* to help meet seasonal, system-wide peak power demand.

As run-of-the-river facilities, the lower Snake River dams have very limited ability to store water.¹³ Their output can be adjusted from hour to hour, but not month to month. Their potential output peaks in the spring when the river is high and energy prices are low, reflecting low power demand during mild weather. In the summer and winter, when energy demand is high and power most valuable, river flows are at their lowest. The four dams' combined output during those months meets only about 2% of the region's energy needs.

In addition, because the dams impede fish passage, various biological opinions and court orders have established spill and flow requirements limiting their operations during certain times of the year. Together, the lower Snake River dams now generate only about 1,042 average megawatts in an average water year.

The dams' annual total *firm* power — the amount that can be counted on in a drought — is 567 aMW.¹⁴ However, for November-February, when the region needs it most, the four dams produce only a combined 463 aMW of firm power (or about 14% of their total nameplate capacity).¹⁵ In late summer, the dams produce even less energy on average.

Quantifying the dams' capacity value is harder than quantifying their energy value.

Today, the four lower Snake River dams primarily provide contingency reserves — power banked for withdrawal in emergencies such as an unexpected outage of another resource. Contingency reserves are used rarely, but must be always available.

¹³ The dams do have 72 hours of pondage; when minimum flow requirements are not an obstacle, the dams can generate power at whatever hour is desirable within that window.

¹⁴ Bonneville Power Administration's 2014 *Whitebook*.

¹⁵ *Ibid.*

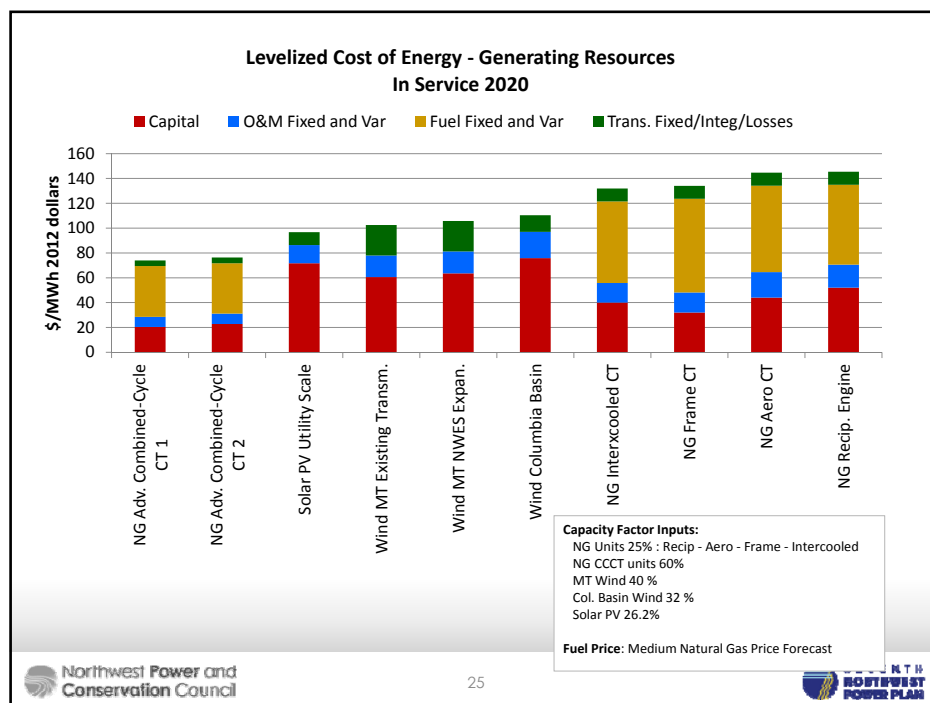
The dams have enough short-term storage in the winter to provide *load-following* capability – they can hold back some water during low-demand hours and then use it to generate power in peaking hours (periods of high need). The lower Snake River dams also can help integrate variable resources into the system by holding back water while resources such as wind or solar are generating power and then releasing the water to generate power when those resources stop.

Currently, the lower Snake River dams generate more power during daytime hours, when loads are higher, and ramp down at night when less power is needed. According to the Council, the four lower Snake River dams' combined capacity value is about 2,100 MW in fall and winter and tapers to zero in spring and summer.

IV. Replacement power scenario

This study compares Waddell’s costs of keeping the four lower Snake River dams to the costs of replacing their average firm (November–February critical water) winter output (463 aMW) with carbon-free, utility-scale solar built in eastern Oregon and southwest Idaho, one of the cheapest new clean power resources according to Council data (see **Figure 1**, below). The remaining 579 aMW would be met with market purchases. We assume a breaching date of 2020 to align with the dam removal scenarios the Northwest Power and Conservation Council’s 6th Plan analysis.¹⁶

FIGURE 1:
Utility-scale solar cheapest new clean resource



We use Bonneville Power Administration’s monthly power price forecasts to model market purchase costs and the Council’s cost estimates of the levelized cost of solar power.¹⁷ We assume the solar would be sited to take advantage of the transmission lines no longer needed by the dams. The Council’s cost figures include transmission and integration costs.

¹⁶ We recognize that dam breaching in 2020 is not highly likely given the short timeframe, however, we use this date to maintain consistency with 6th Plan’s rate impact analysis.

¹⁷ See Figure 1

We add a carbon price to the market purchase power cost because grid power comprises multiple generation resources, some of which would be subject to future carbon emissions pricing or other regulatory constraints on carbon emissions. We apply the social cost of carbon¹⁸ as a proxy carbon price to that fraction of replacement power that comes from fossil fuels.

To compute the carbon emissions associated with market purchases, this analysis starts with the emissions factor BPA applies to unspecified market purchases: the Energy Information Administration's Northwest Power Pool eGrid value from 2014.¹⁹ However, in spring, when much of the dams' output occurs, market purchases are greener due to greater hydro generation. In addition, the carbon intensity of purchased power should decrease as the proportion of renewables in the market (especially rooftop solar in California) increases over time. Finally, as the carbon price used here is implemented, market forces will depress fossil fuel use and encourage more efficiency and renewables to be developed. To reflect these assumptions, we reduce the amount of CO₂ included in the purchased power by 25% compared to eGrid's emission value in 2015 and by an additional 1% per year after that.

Utility-scale solar in this scenario stands for the lowest-cost clean energy resource, whatever that may be at the time replacement power is needed. Modeling a combination of renewables (including both wind and solar) plus conservation would not significantly change the solar-only cost modeled in this scenario. Ideally, conservation up to the cost of the replacement resources would be selected first, followed by the next least-cost renewable resource.

Unfortunately, modeling for conservation resource selection is beyond the scope of this study. The utility-scale solar modeled here would likely be the next least-cost available resource selection, especially when a carbon price is added to any thermal generating resource.

For comparison purposes, we modeled a scenario replacing the dams' winter output (463 aMW) with natural gas-fired combined cycle combustion turbines instead of solar. Perhaps surprisingly, the annual cost was about the same as the cost of solar: \$601 million compared to \$609 million. The Council's 7th Plan costs for utility scale solar are very close to those of natural gas-fired combined cycle combustion turbines; once

¹⁸ We use the 3% average-case social cost of carbon consistent with the social cost of carbon values being used by the Council in developing scenario analyses for the upcoming 7th Plan. See <https://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>

¹⁹ Emissions factor of 847 pounds (about .4 tons) of CO_{2-e} per MWh. EIA, eGrid (2014).

carbon costs are added to the resource costs, natural gas-fired CCCT's become a more expensive option.

It was harder to quantify the lower Snake River dams' capacity value. We are aware of no studies that determine an economic value for their capacity contributions. We note, however, that lower Snake River dam power production now ramps up slightly in the daytime, thus closely matching actual solar generation. That means no additional capacity replacement resources will be needed to balance solar output for this capability. Additionally, the four dams primarily perform as contingency reserves, and we substitute demand response²⁰ to fulfill this function.

Based on Council data, the four lower Snake River dams provide 2,100 MW²¹ of winter capacity. Using 7th Power Plan rankings of demand response measures and their cost effectiveness, replacing 2,100 MW of winter capacity with demand response resources will cost an estimated \$70 million a year.²² Deeper analysis would provide a more accurate cost projection for replacing the specific capacity value of the four lower Snake River dams.

This study also assigns a \$15 million a year credit for reduced oversupply costs. This is based on the value of reduced hydro generation during springtime oversupply events.

Base case power cost calculations

Power cost	Average annual cost (million \$)
Solar replacement power	283.6
Market purchases	188.4
Carbon cost	81.4
Capacity cost	70.0
Avoided oversupply cost	minus 15.0
Total power cost	608.5

²⁰ Demand response refers to programs that compensate end use consumers for reducing their electrical use during periods of high prices or when the reliability of the grid is threatened.

²¹ Northwest Power and Conservation Council memorandum *Re: Value of Four Lower Snake River Dams to the Power System*, 2008 Update.

²² We use the Council's 7th Power Plan supply curves for demand response to obtain costs for replacing 2,100 MW of capacity.

V. Results and effect on bills

Detailed results are presented in the accompanying spreadsheets, including more explanation of the assumptions used in the calculations. The listed amounts are average yearly costs for 2020-2039 in 2015 dollars.

An added sensitivity addresses concerns about the Council's solar cost projections. Several reviewers and some actual recent contract bids suggest those costs are too high. Solar costs have dropped dramatically and should continue to do so as this relatively new technology continues to mature.

Summary of results (costs in thousands)

Retain dams	Remove dams (power replacement costs only)		
Total annual cost to keep dams	Replace power with solar and market purchases – annual cost	Annual replacement cost minus cost of keeping dams	Replacement cost minus cost to keep dams, with 10% lower solar cost
\$269,246	\$608,542	\$339,296	\$232,713
	Increase in residential bills	\$1.03 per month	72 cents per month

Estimating electricity bill effects requires several assumptions about how costs are passed on to consumers. A good starting point is the Council's regional analysis in Appendix O-4 of the 6th Plan.

According to the Council study from 2010, a dam removal cost of \$550 million per year would increase residential bills across the region by about 2%, or \$1.71 per month. Why is this so small? Two reasons. First, while \$550 million is a large amount of money, it's quite small compared to the regional utility system's enormous annual expense budget. Second, the Council's analysis notes that population growth in the next 10-20 years will significantly boost the number of households the cost would be spread among. Our

finding of a roughly \$340 million difference in power system costs between removing and keeping the dams translates to a residential bill increase of about **\$1 per month**.²³

Some argue against using an *average* regional residential monthly bill, saying consumers of utilities that purchase BPA power would absorb all the dam removal costs. Were that true, public utility customers – comprising about half the region’s residential load – would seemingly face double the bill increase the Council calculated.

A deeper look into the Council’s methodology exposes the flaws in that argument. The Council’s dam-removal scenario features a hefty carbon cost ramping up to \$47 per ton 10 years after the assumed date of the dams’ removal. This cost raises utilities’ costs by about the same amount as the cost of dam removal, but it is not paid for by all utilities. Those carbon costs are paid almost exclusively by customers of fossil fuel-reliant utilities that don’t purchase BPA’s hydro-heavy power. In essence, end-use customers supplied by BPA power would pay about half extra due to dam removal, while customers in utility service areas not directly served by BPA would pay about half extra to cover carbon costs. Thus the Council’s estimate for the bill effect on the average residential customer is reasonable.

²³ Interestingly, the Council’s study shows that even with the high carbon penalty and dam removal, average residential bills would still go *down* by 0.6% per year due to reduced per-household use due to energy efficiency measures coupled with population growth.

VII. Conclusions and recommendations

The costs to maintain the four lower Snake River dams have been underestimated for years, and are continuing to rise. Meanwhile, the quantity and value of their output has decreased, and the cost of replacing their power has fallen significantly. The cost difference between keeping them and removing them has narrowed – to about a dollar per month to the average Northwest billpayer.

Lower Snake River dam removal is the scientifically surest path to restoring Snake River salmon, and our analysis suggests that the four dams' power can be affordably replaced. Another potential salmon restoration measure, expanded spill, would likely reduce hydro generation by the same amount as dam removal. Our analysis indicates this approach would be more expensive, because we would not save the costs associated with dam retention. Either way, Columbia Basin wild salmon survival depends on hydrosystem operation changes, which means diverting more water from power generation.

We have provided an initial estimate of power system costs for removal of the lower Snake River dams. Updated and more detailed investigation of dam-retention costs and the dams' capacity value will sharpen the economic projections. With its sophisticated data sets, advanced modeling capability and a second-to-none technical/analytical staff, the Northwest Power and Conservation Council is uniquely equipped to pursue these investigations on behalf of the region it serves.

Consequently, we recommend that the Northwest Power and Conservation Council undertake a new analysis of power system costs associated with lower Snake River dam removal. Prior to and in preparation for its analysis and modeling, the Council should:

1. Incorporate updated stream flow data based on IPPC-5 into its regional portfolio model's hydroelectric generation data as soon as it is available (estimated 2016).
2. Have the Bonneville Power Administration, in the first quarter of 2016, provide a complete estimate of all power system costs needed to maintain and retain the lower Snake River dams over the next 20 years. These updated dam retention costs should be included in the analysis.