February 8, 2006

MEMORANDUM

TO: Council Members

FROM: John Fazio, Senior System Analyst

SUBJECT: Cover Memo for the Multiple Use of the River Paper

Whenever alternative fish-and-wildlife hydroelectric operations are considered, estimates of impacts to energy production and power system cost are always done. This has been true since the early 1980s when the Council developed its first Fish and Wildlife Program. Throughout this period many have also asked how other uses of the river system affect energy and cost. A lot of these questions were addressed in the System Operation Review, an EIS published by federal agencies in late 1995. This report examined many different hydroelectric operations and their impacts to all river users, including power. Although this report is quite comprehensive (over a dozen appendices were written), several gaps remain, in particular the effects of irrigation on the power supply.

The attached memorandum provides a brief summary of the many uses for the Columbia River system. Each summary includes an estimate, whenever available, of the energy impacts and power system costs for that particular river use. All of the information in this document was taken from existing studies, some of which may be somewhat out of date. However, the focus of the memorandum is to simply identify each river use and to illustrate its relative effect on the power supply. It does not make, nor does it intend to imply, any recommendations to change any of the operations discussed therein.

Operating the system to provide all these benefits requires cooperation among federal and non-federal agencies and the Canadian government. Unfortunately, not all desired operations can be provided at all times because of conflicts that arise. By far, fish and wildlife operations and irrigation withdrawals impart the largest impact to the power supply. Fish operations under the NOAA Fisheries' 2004 biological opinion reduce average hydroelectric generation by about 9 percent and irrigation withdrawals reduce generation by about 5 percent.

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Northwest Power and Conservation Council

February 7, 2006

MEMORANDUM

TO: Council Members

FROM: John Fazio, Senior System Analyst

SUBJECT: Multiple Purposes of the Columbia River Hydroelectric System

Summary

The many storage and hydroelectric facilities built in the Columbia River Basin provide a number of benefits to the citizens of the Pacific Northwest and Canada. On average, the US portion of the hydroelectric system provides nearly 75 percent of the electricity needs for the northwest.[1] The hydroelectric system also influences:

- Protection from flooding
- Opportunities for recreation
- Water for irrigation
- Water for municipal and industrial uses
- Routes for navigation
- Protection for Native American cultural resources
- Passage for anadromous fish
- Protection for resident fish
- Habitat for wildlife
- Control of water quality and temperature

Operating the system to provide these benefits requires cooperation among federal and non-federal agencies and the Canadian government. Unfortunately, not all desired operations can be provided at all times because of conflicts that arise. For example, water releases in the spring

[1] Hydroelectric generation in the Pacific Northwest averages about 16,000 average megawatts and annual demand is about 21,000 average megawatts.

and summer for fish migration would be more valuable to the power system during winter. Fish operations under the NOAA Fisheries' 2004 biological opinion reduce the average hydroelectric generation by about 9 percent[2] and water withdrawals identified for irrigation by state and federal law reduce the opportunity for downstream power generation by about 5 percent.[3]

Background

Over 250 dams have been constructed[4] in the Columbia River Basin. Federal agencies have built 33 of those projects in the United States[5] and 12 projects[6] are in Canada. The total useable storage capability of the system is about 42 million acre-feet, split almost equally between US and Canadian reservoirs. That volume represents about 40 percent of the average annual runoff volume that passes The Dalles Dam.

Power Supply

On average, the Columbia River hydroelectric system accounts for about 75 percent of the northwest's electricity supply. In the driest year, regional hydroelectric generation yields about 11,700 average megawatts compared to about 16,000 average megawatts in an average year. Because the combined storage capability of the reservoir system only holds 42 percent of the average runoff volume[7], the region calculates its firm (guaranteed) energy based on the critical (driest) year. In most years this leaves the region with surplus hydroelectric generation, which is sold in the electricity market.

The northwest hydroelectric system is optimized to provide the maximum amount of generation (shaped to match northwest loads) while adhering to all non-power constraints[8]. This operation is possible because of the Columbia River Treaty (between the US and Canada) and because of the Pacific Northwest Coordination Agreement (among US owners and operators). These agreements allow all participants to share the benefits of an optimized operation. Two non-power uses that most affect available water for power production are spill and bypass operations for fish mitigation, and irrigation.[9] If these two operations were not required the firm energy generating capability of the hydroelectric system would be about 14 percent greater.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of

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[2] Average generation loss due to fish operations is about 1,035 average megawatts relative to about 11,700 average megawatts of firm hydroelectric capability.

[3] Irrigation withdrawals reduce the potential for hydroelectric generation by an average of about 625 average megawatts.

[4] Source: Columbia River System Operation Review, Main Report, BPA, COE, BOR, November 1995, page 3-1.

[5] Source: Northwest Regional Forecast of Power Loads and Resources, PNUCC, www.pnucc.org.

[6] Source: Project Operating Procedures and Constraints Manual, BPA.

[7] For planning purposes, the January through August runoff volume at The Dalles is most commonly used. That average volume is about 136 million acre-feet.

[8] This includes operations to improve fish and wildlife survival.

[9] Irrigation is recognized as a separate use of the hydrosystem, distinct from hydropower generation with unique authorizations institutionalized through state and/or federal law. Similar situations are true for many of the other uses of the river.

Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-23 to 3-26, November 1995.

"2003 Pacific Northwest Loads and Resources Study," Bonneville Power Administration, December 2003.

Flood Control

Columbia River reservoirs provide both local and downstream flood protection by filling during periods of excessive runoff, thus keeping downstream river flows from reaching dangerously high levels. The Army Corps of Engineers has flood control jurisdiction over all US and Canadian reservoirs. The primary flood control season is May through July during the snowmelt period. Using forecasted runoff volumes, flood control elevations for each reservoir are adjusted throughout the season. If necessary, reservoirs are drafted prior to an anticipated increase in runoff to allow sufficient space to capture excessive water. Flood control elevations are inversely proportional to the runoff volume forecast, that is, the higher the forecasted runoff volume, the lower the flood control elevation. Currently, 37 million acre-feet of storage is available for flood control space in the Columbia River Basin, with US projects providing 16.5 million acre-feet and Canadian Treaty projects providing 20.5 million acre-feet. For perspective, the total useable storage in both US and Canadian reservoirs is about 42 million acre-feet. Levees, floodwalls and other types of bank protection supplement flood control protection.

No known analysis to date has been done to assess the cost of providing flood control protection. Performing such an analysis is not as simple as just removing flood control constraints. The hydroelectric operation must also be re-optimized to adjust operating rule curves. Such a study would require assistance from Bonneville, since Council staff does not have the analytical tools to re-optimize the hydroelectric system operation. However, some insight can be obtained by looking at a simple example.

If we assume that reservoirs could hold water above flood control elevations in June and if we assume that this water would then be released in July, we could estimate the increase in revenue by comparing the difference in electricity prices between June and July. The additional volume of water that could be stored in US reservoirs[10] by the end of June is about 900 million acre-feet, on average. The average June price for electricity[11] is about $ 43/megawatt-hour and the price in July is about $ 49/megawatt-hour. Doing the math shows that, on average, the region's revenues could increase by $ 5.6 million per year under the assumptions stated above. This dollar amount is insignificant relative to Bonneville's net revenue requirement. This operation would also decrease flows in June by about 14,500 cubic feet per second and increase July flows by a similar amount.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of

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[10] This estimate comes from a recent GENESYS study of the 2004 biological opinion.
[11] These estimates for electricity prices are for the 2007 operating year and incorporate long-term assumptions regarding natural gas prices and do not include the recently observed increases those prices.

Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-8 to 3-11, November 1995.

Wildlife

Wildlife in the northwest has also been affected by the construction of the hydroelectric system. Much land that was prime habitat for wildlife is now submerged behind storage reservoirs. However, no estimate could be found regarding the total acreage of lost or damaged habitat. Through the Council's fish and wildlife program, the region is considering a variety of actions to acquire, restore, enhance and/or protect wildlife habitat.

The operation of the hydroelectric system is minimally affected by constraints to protect existing habitat. The power system cost is insignificant relative to overall system operation.

Sources:
"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-21 to 3-23 and Appendix N, November 1995.

Recreation

Recreational use of the river system includes activities such as boating, fishing, waterskiing, rafting, windsurfing, swimming and sightseeing. Recreational facilities are available at most larger projects. At federal sites, facilities are authorized under the Federal Water Project Recreation Act of 1964 and include boat ramps, beaches and swimming areas, marinas, campgrounds and picnic areas. To provide access to these facilities during the peak recreational season, reservoirs must be maintained at near full elevations through the end of summer. This synchronizes well with power operations, which would also have reservoirs full by summer's end. However, since about 1980, water behind Libby, Hungry Horse, Dworshak and Coulee dams has been used to augment summer river flows to enhance smolt survival. This operation leaves these projects less than full by August 31st but generally does not affect recreational use, except perhaps at Dworshak, which is projected to be 65 feet from full by the end of August and 80 feet from full by the end of September.

Operating constraints for recreation are considered minor and do not affect the overall operation of the hydroelectric system. The power system cost is insignificant relative to the overall operation.

Sources:
"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-26 to 3-31 and Appendix J, November 1995.

Irrigation

About 7.3 million acres of northwest land is irrigated with water from the Columbia River and its tributaries. Water withdrawals for irrigation are authorized by state and/or federal law on a state-by-state basis. Irrigation withdrawals are estimated to result in an average net annual reduction in streamflow volume of about 14.4 million acre-feet (maf) at McNary, of which about 8.4 maf is estimated to come from withdrawals in the Snake River Basin. For perspective, the annual average volume of water passing The Dalles Dam is about 173 maf. On average, about 45 percent of withdrawn water returns to the river at some point downstream from the withdrawal site. Irrigation withdrawals vary from year to year and from month to month, with the primary irrigation period being from April through September.

The power system impact of providing this level of irrigation results in an average energy loss of about 625 average-megawatts (aMW). Firm regional hydroelectric generation (based on the driest year on record) amounts to about 11,700 aMW. Thus, irrigation represents a little over 5 percent of the firm hydroelectric capability. The equivalent cost ~~of this operation~~ averages about $250 million per year based on an average bulk electricity price of $51/megawatt-hour.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-31 to 3-32 and Appendix F, November 1995.

Fazio, John, "Value of Diverted Water in the Columbia River Basin," memorandum to the Regional Technical Forum, May 24, 2000, also see www.nwcouncil.org.

Fazio, John, "Preliminary Assessment of Irrigation Diversion Impacts to the Power System," memorandum to Council Members, September 3, 2003, also see www.nwcouncil.org.

Flightner, Gary and Evans, Art, contractors for the Bonneville Power Administration, 1929-1978 Revised Historical Modified Streamflow Record (irrigation withdrawals and return flows removed), 2003.

"2003 Pacific Northwest Loads and Resources Study," Bonneville Power Administration, December 2003.

Municipal and Industrial Uses

Most of the municipal and industrial water withdrawals are concentrated near the Lower Granite and McNary dams. The cities of Richland, Kennewick and Pasco along with nearby industrial users draw from the McNary pool, while the City of Lewiston and Potlatch Corporation draw from the Clearwater River above the Lower Granite pool.

Water diversions for municipal and industrial use are small and have little measurable impact on overall system operation. Total depletion is estimated to be less than 2 percent of the annual flow. The power system cost of providing water for municipal and industrial uses is insignificant relative to the overall operation.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-32, November 1995.

Navigation

The four lower Columbia River dams and the four lower Snake River dams are equipped with locks that allow passage for both recreational and commercial shipping. The Columbia/Snake River Inland Waterway is a 465-mile navigation corridor from the Pacific Ocean to Lewiston, Idaho. The channel accommodates shallow-draft tugs, barges, log rafts, and recreational boats. The presence of the inland waterway has led to the development of a sizable river transportation industry, primarily for agricultural and timber products. Other navigational uses of the river system include mail boats and ferries, commercial vessels for tours and transportation services and, of course, private boats.

The four lower Columbia River and the four lower Snake River reservoirs must be no lower than minimum operating pool (MOP) elevations for the locks to be operable. The operation of the locks requires a small volume of water, which obviously cannot be run through the turbines to generate electricity. In addition, water releases from upstream reservoirs might occasionally be needed in order to provide minimum flow requirements for navigation. These volumes are small and have no consequence to the overall operation of the hydroelectric system. The power system cost of providing navigation is insignificant relative to the average revenues gained from hydroelectric generation.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-11 to 3-14, November 1995.

Native American Cultural Resources

Cultural resources include historic camps, structures, rock art, cemeteries and other remnants of historic human occupation. Hundreds of sites exist at or near Libby, Hungry Horse, Albeni Falls, Grand Coulee and Dworshak dams. Additional sites lie in the middle and lower parts of both the Columbia and Snake rivers. Federal agencies work closely with Indian tribes to manage and protect these historic sites.

The hydroelectric system is operated to avoid damaging these historic sites. In some cases that means restricting reservoir elevations or limiting outflow levels. Hydroelectric operations to protect cultural resources are small and have no consequence to the overall operation of the hydroelectric system. The power system cost is insignificant relative to the overall operation.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-34 to 3-36 and Appendix D, November 1995.

Anadromous Fish

Anadromous fish (salmon and steelhead) spawn in freshwater, migrate to the ocean and then return after a number of years to repeat the cycle. Juvenile fish must travel great lengths and avoid many pitfalls to reach salt water. Besides passage through the hydroelectric facilities, these fish face predation from terns, seals and squawfish. Water conditions also play an important part of passage survival. Water temperature, level of dissolved gas and nutrient availability can vary year-to-year and month-to-month. Scientific evidence implies that the shorter the travel time to the ocean, the greater the passage survival.

Operations to improve anadromous fish survival fall into two general categories, flow augmentation and bypass spill. During winter months water is stored in reservoirs for later release during the migration period, usually between April and August. Storing additional water during winter months means less hydroelectric generation during that time. In many cases the region must replace that energy with generation from other, more costly resources. The release of the stored water in spring and summer generates more energy but a portion of that water is diverted around turbines (bypass spill) to improve dam passage survival. In extremely dry years some fish may be captured and transported to the ocean via barges or trucks.

The combined flow augmentation and bypass spill operations reduce firm hydroelectric generation capability by about 1,035 aMW. This loss represents about 9 percent of the 11,700 aMW total firm hydroelectric energy generating capability. The average annual regional cost of this operation is about $460 million assuming an average annual electricity price of $51/megawatt-hour.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-14 to 3-20 and Appendix C, November 1995.

Fazio, John, "2000 Biop Impacts.xls," Microsoft Excel Spreadsheet, February 1, 2006.

Resident Fish

Rivers and lakes behind reservoirs in the Columbia River are also home to fish that do not migrate. These fish include various species of trout, bass and sturgeon. Operations to protect these species include maintaining high water quality, providing ample flow for spawning, minimizing fluctuations in river flows and maximizing reservoir nutrient retention time.

NOAA Fisheries' biological opinion contains an operation to provide higher flows for sturgeon spawning by releasing water from the Libby reservoir during May and June. It also implements a new set of flood control rule curves (VARQ) at Libby and Hungry Horse dams, which keep those reservoirs higher during the winter and early spring. The sturgeon flow operation shifts some hydroelectric generation into May and June when prices are somewhat lower than in earlier months. The revised flood control operation also shifts energy production from winter to spring months. These operations, however, are minor relative to the overall hydroelectric system operation. The power system cost of these operations is generally a few million dollars per year.

The Council's Fish and Wildlife Program (Program) contains additional operations for resident fish. The Program calls for flows out of Libby and Hungry Horse dams to be evened out, to the extent possible, over the months of July through September. In addition, it calls for the implementation of nutrient retention time targets for the Grand Coulee reservoir. These operations are not currently being implemented. There impact to energy production is minor and the power system cost is generally on the order of a few million dollars per year.

Sources:
"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-20 to 3-21 and Appendix K, November 1995.

Fazio, John, "Impacts of the VARQ Flood Control," Memorandum to Council members, June 6, 2000.

Fazio, John, "Analysis of Recommendations to Amend the Fish and Wildlife Program Relating to Mainstem Hydroelectric Operations," Memorandum to Council members, April 3, 2002.

Water Quality

Water quality, in reference to the hydroelectric system operation, generally refers to temperature and levels of dissolved gases, such as nitrogen. Dam operators affect downstream water temperature by regulating outflows and by using multilevel outlets installed at some projects. Dissolved gas can be controlled by regulating outflows, by limiting spill and by installing flip lips wherever appropriate. Conflicts sometimes occur between desired levels of bypass spill for smolt passage survival and dissolved gas. As a consequence, efforts to keep dissolved gas levels below state standards have not always been completely effective.

Operations to control water temperature could involve the release of additional water from behind participating reservoirs. If the additional draft is an excursion from normal power operations, then the corresponding additional energy produced may be sold in a month when electricity prices are different than when that water would normally be released. This translates into either a cost or into additional revenue depending on conditions. However, this type of draft does not often occur but even if it did, would not represent a significant deviation from normal operations. Operations to control dissolved gas levels include cutting back bypass spill, which would result in additional revenue for the region. For the most part, bypass spill levels are set so as not to violate dissolved gas limits. No known analysis to date has been done to assess the cost of maintaining water quality. Operations for water quality are considered minor and do not affect the overall operation of the hydroelectric system. The power system cost is insignificant relative to the overall operation.

Sources:

"Columbia River System Operation Review, Final Environmental Impact Statement, Main Report," Document DOE/EIS-0170, Bonneville Power Administration, US Army Corps of Engineers - North Pacific Division, US Department of the Interior - Bureau of Reclamation, p. 3-32 to 3-34 and Appendix M, November 1995.

Power System Impacts of Non-power Uses of the Columbia River
Presentation to the Council

John Fazio
February 22, 2006

Since the Council was created and tasked with developing river operation strategies to aid fish and wildlife, estimates of those strategies' impacts to energy production and power system cost have always been done. Throughout this period, starting in 1981, many also have asked how other uses of the river system affect energy and cost. This analysis responds to a recent Council request.

A lot of these questions were addressed in the System Operation Review, an Environmental Impact Statement (EIS) published by federal agencies in late 1995. This report examined many different hydroelectric operations and their impacts to all river users, including power. Although this report is quite comprehensive (over a dozen appendices were written), several gaps remain, in particular the effects of irrigation on the power supply.

The presentation today provides a brief summary of the many uses for the Columbia River system and an estimate, whenever available, of the energy impacts and power system costs for each particular river use.

All of the information in this presentation was taken from existing studies, some of which may be somewhat out of date. However, the focus of the presentation is to identify each river use and to ***illustrate*** its relative effect on the power supply. ***It does not make, nor does it intend to imply, any recommendations to change any of the operations discussed.***

Operating the system to provide these benefits requires cooperation among federal and non-federal agencies and also the Canadian government. Unfortunately, not all desired operations can be provided at all times because of conflicts that arise.

The many storage and hydroelectric facilities built in the Columbia River Basin provide a number of benefits to the citizens of the Pacific Northwest and Canada. On average, the U.S. portion of the hydroelectric system provides nearly 75 percent of the electricity needs for the Northwest.[1] The hydroelectric system also provides:

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[1] Hydroelectric generation in the Pacific Northwest averages about 16,000 average megawatts and annual demand is about 21,000 average megawatts.

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- Protection from flooding
- Opportunities for recreation
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- Protection for Native American cultural resources
- Passage for anadromous fish
- Protection for resident fish
- Habitat for wildlife
- Control of water quality and temperature

The Northwest hydroelectric system is optimized to provide the maximum amount of generation (shaped to match Northwest loads) while adhering to all non-power constraints. This operation is possible because of the Columbia River Treaty (between the U.S. and Canada) and because of the Pacific Northwest Coordination Agreement (among U.S. owners and operators). These agreements allow all participants to share the benefits of an optimized operation.

Hydroelectric project operating data along with non-power requirements are forwarded to the Northwest Power Pool in February of each year. The Power Pool then uses this information to compute the Firm Energy Load Carrying Capability (FELCC) of the hydroelectric system. The power pool also computes each party's drafting rights, obligations and headwater benefits. The drafting rights elevation represents a lower bound for a reservoir's operation.

The Corps of Engineers has flood control jurisdiction over all reservoirs in the Columbia River Basin, including those in Canada. With minor exceptions, flood control elevation represents the upper bound for a reservoir's operation. Operating guidelines such as flood control and drafting rights elevations commonly are referred to as "rule curves." All non-power operations are incorporated into the development of rule curves.

Because the Northwest is a winter-peaking region, reservoirs are targeted to be as full as possible by September first. They are then drafted for power through the fall and winter periods. In spring, prior to the anticipated peak river flows from snowmelt, flood control limitations generally dictate the operation of reservoirs. During summer months, some stored water is used to augment flows for anadromous fish migration.

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Most of the river uses identified in this presentation (and in the associated memo to the Council) have relatively insignificant impacts to power generation and cost. Fish and wildlife operations and irrigation withdrawals, however, impart more measurable effects to the power supply. Fish operations under the NOAA Fisheries' 2004 Biological Opinion reduce average hydroelectric generation by about 9 percent, and irrigation withdrawals reduce generation by about 5 percent.

The firm generating capability of the hydroelectric system, calculated using all non-power operations, is about 11,700 average megawatts. Removing all fish and wildlife operations would raise the annual average generation by about 1,035 average megawatts (thus the 9 percent figure from above), which is roughly enough energy to power the city of Seattle. Removing all irrigation withdrawals (and return flows) would raise the annual average generation by about 625 average megawatts.

Estimating the power system cost of these operations requires assumptions regarding the price of electricity. Using current electricity market prices (which average about $51 per megawatt-hour), the cost of fish and wildlife operations is approximately $460 million per year and the cost of irrigation is about $250 million per year. For perspective, the Bonneville Power Administration's annual net revenue requirement is on the order of $4 billion.

I must emphasize that estimating the power system cost for various river uses provides an incomplete analysis. The provided memo does not include any estimates for system benefits (both economic, social and cultural) of these operations.

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