Appendix B

SUMMARY OF HYDROPOWER COSTS AND IMPACTS OF THE MAINSTEM PASSAGE ACTIONS

This document summarizes regional hydropower costs and impacts of the mainstem passage actions in the Northwest Power Planning Council's 1994 Columbia River Basin Fish and Wildlife Program. This appendix presents a summary of the staff's hydropower and economic analysis, which provides an indication of the magnitude of the costs and impacts of these actions, as compared to the Council's 1992 Strategy for Salmon measures. In addition, a staff analysis of the biological benefits of these actions is presented in a separate appendix.

Summary

Implementation of a four-pool lower Snake River drawdown to near spillway crest would increase spring flow equivalents in the Snake River by nearly 135 percent in the lowest eight water years and by almost 110 percent in the next lowest 12 years. Summer flow equivalents under a four-pool drawdown operation increase by more than 30 percent. Equivalent spring flows with the four-pool lower Snake River drawdown are above the 140,000 cubic feet per second operational objective about 95 percent of the time. Implementation of only Lower Granite and Little Goose reservoir drawdowns to near spillway crest would increase spring flow equivalents in the Snake River by roughly 50 percent and summer flow equivalents between 10 and 20 percent in the 20 lowest water years. Equivalent spring flows under a two-pool drawdown would exceed the 140,000 objective about two-thirds of the time compared to 14 percent under the Strategy for Salmon operation.

In the lower Columbia River, operation of John Day pool at near spillway crest would increase both spring and summer flow equivalents between 55 and 65 percent in the 20 lowest water years. Equivalent spring flows with John Day drawn down to near spillway crest are above the 300,000 cubic feet per second operational objective about 95 percent of the time. Operation of John Day reservoir at minimum operating pool level would increase spring and summer flow equivalents by 10 to 15 percent in the 20 lowest water years. Equivalent spring flows under this operation would exceed the 300,000 cubic feet per second operational objective about 60 percent of the time, compared to 42 percent under the Strategy for Salmon operation.

Refill probabilities increase at Libby and Hungry Horse dams due to operation of both projects under their respective integrated rule curves. Average end-of-July refill probability at Libby increases from 90 to 92 percent and at Hungry Horse from 86 to 96 percent. At Grand Coulee, the refill probability drops from 100 percent in the Strategy for Salmon to between 40-50 percent in the 1994 measures. This is because in low water years, Grand Coulee is often drafted to an elevation of 1,280 feet in July and August to attempt to achieve the late summer flow objectives. At Dworshak, refill probability depends on whether a drawdown of the four lower Snake River dams is implemented. Without a drawdown operation, Dworshak's refill probability falls from 42 percent under the Strategy for Salmon to 10 percent. With a four-pool Snake River drawdown operation, its refill probability increases to 72 percent. In a two-pool Snake River drawdown operation, Dworshak's refill probability is 34 percent. Brownlee's July elevations are generally higher under the Council's mainstem actions, but its August refill probability falls from 100 percent in the Strategy for Salmon to about 66 percent.

In general, monthly average nutrient retention times at Grand Coulee Dam remain above or close to the suggested 30-day minimum level except in May. May retention times in the mainstem passage actions are similar to, or improved by about one day from the retention times in the Strategy for Salmon. In the months of April and June, the average retention times hover close to the 30-day value. In July and August, retention times decrease by about 6 to 16 percent, but remain above the 30-day limit. In July, average retention time ranges from about 38 days to 41 days, and in August it is about 44-45 days.

Average annual costs to the Bonneville Power Administration range from about $90 to $225 million.[1] The corresponding average rate impacts range from about 4 percent in the near term to 11 percent in the long term. Power system costs, which include the cost of replacement resources, energy purchases and lost revenues, amount to about one-third to one-half of the total cost. Non-power costs include the capital costs of modifying dams for drawdown,[2] costs of improving bypass or transportation and other related costs. Firm hydropower losses range from 400 to 850 average megawatts, depending on the package of measures implemented.

Background and Study Description

The mainstem passage actions adopted by the Council provide flow and velocity improvements in both the Snake and Columbia rivers to improve salmon survival over the next 20 years.

These actions include an evaluation strategy for smolt transportation, coupled with immediate and long-term flow improvement and/or reservoir drawdown measures. The actions are analyzed in sequence as depicted in Figure 1. They include:

1995 Actions

- A 28-foot drawdown from full pool of Lower Granite reservoir to elevation 710 for two months from mid-April to mid-June. This action will disable the existing juvenile bypass system, but adult passage can still be provided. Since navigation and juvenile fish bypass facilities are not functional during the drawdown period, smolt transportation of spring migrants cannot occur from this project, and spill provides juvenile fish bypass.

- Spill at all mainstem projects for 80 percent fish passage efficiency as constrained by state water quality guidelines, except at Little Goose Dam, which becomes the only smolt collecting and transport project.

[1] Costs to Bonneville Power Administration include 71 percent of the regional power system costs, capital costs of modifying dams and other related costs. They reflect the levelized cost of implementing various measures at various future dates. Section 1 of the fish and wildlife program discusses these costs in estimated expenditures for specific years and are, therefore, different from those levelized costs reported here.

[2] Capital costs of drawdown-related dam modifications are based on Corps of Engineers cost estimates from its System Configuration Study, including contingency costs.

- An additional 100,000 acre-feet of water (over the 427,000 called for in the Strategy for Salmon) from the upper Snake Basin, and up to 1 million acre-feet of water (over the 3 million called for in the Strategy for Salmon) stored operationally in the upper Columbia Basin reservoirs of Grand Coulee, Libby and Arrow.

- Additional drafts from Brownlee reservoir are also provided, with Brownlee passing inflow from the upper Snake Basin and not refilling until the fall.

- Implementation of integrated rule curves to protect resident fish and aquatic life at Libby and Hungry Horse reservoirs in Montana. In addition, the minimum lake elevation at Albeni Falls is raised to 2,056 feet for salmon flows and resident fish.

1999 Actions - Alternative A
(same as 1995 plus)

- Maintain John Day Pool near its minimum operating pool level (elevation 257 feet) year-round, which is an 11-foot drawdown from its normal full pool level.

- Provide an additional 1,000,000 acre-feet of water from the upper Snake Basin for flow augmentation and refill of drawn down reservoirs, for a total of 1.427 million acre-feet from the upper Snake.

- Lower Granite and Little Goose reservoirs are lowered for two months to near spillway crest elevations, which are drawdowns of about 45 feet from full pool. Bypass is enhanced at Lower Granite through the addition of a surface juvenile fish bypass system with an effective fish guidance efficiency of 70 percent.

- Due to the drawdown of the two upper Snake River projects, smolt transportation is confined to Lower Monumental Dam.

- Spill at all mainstem projects for 80 percent fish passage efficiency, as constrained by state water quality standards, except at Lower Monumental Dam, which becomes the smolt collecting and transport project.

2002 Actions - Alternative B
(same as 1999 plus)

- Lower Monumental and Ice Harbor pools are drawn down to near spillway crest elevations for two months, during the spring, which represent 45 and 40-foot drawdowns from normal full pool levels, respectively.

- John Day pool is drawn down to near spillway crest elevation (elevation 220 feet) year-round, which is a drawdown of about 48 feet from full pool.

- No transportation, spill at all mainstem projects for 80 percent fish passage efficiency as constrained by state water quality standards.

2002 Actions - Alternative C
(same as 1999 plus)

- Lower Monumental and Ice Harbor are drawn down to near spillway crest elevations for two months in the spring.

- No transportation, spill at all mainstem projects for 80 percent fish passage efficiency as constrained by state water quality guidelines.

2002 Actions - Alternative D
(same as 1999 plus)

- Lower Monumental and Ice Harbor pools are held at normal minimum operating pool elevations.

- John Day is drawn down to near spillway crest elevation (elevation 220 feet) year-round.

- Spill at all mainstem projects for 80 percent fish passage efficiency as constrained by state water quality standards, except at Lower Monumental Dam, which becomes the smolt collector and transport project.

A decision to implement either Alternative B, C or D, or to continue implementation of Alternative A measures will be made before the year 2002.

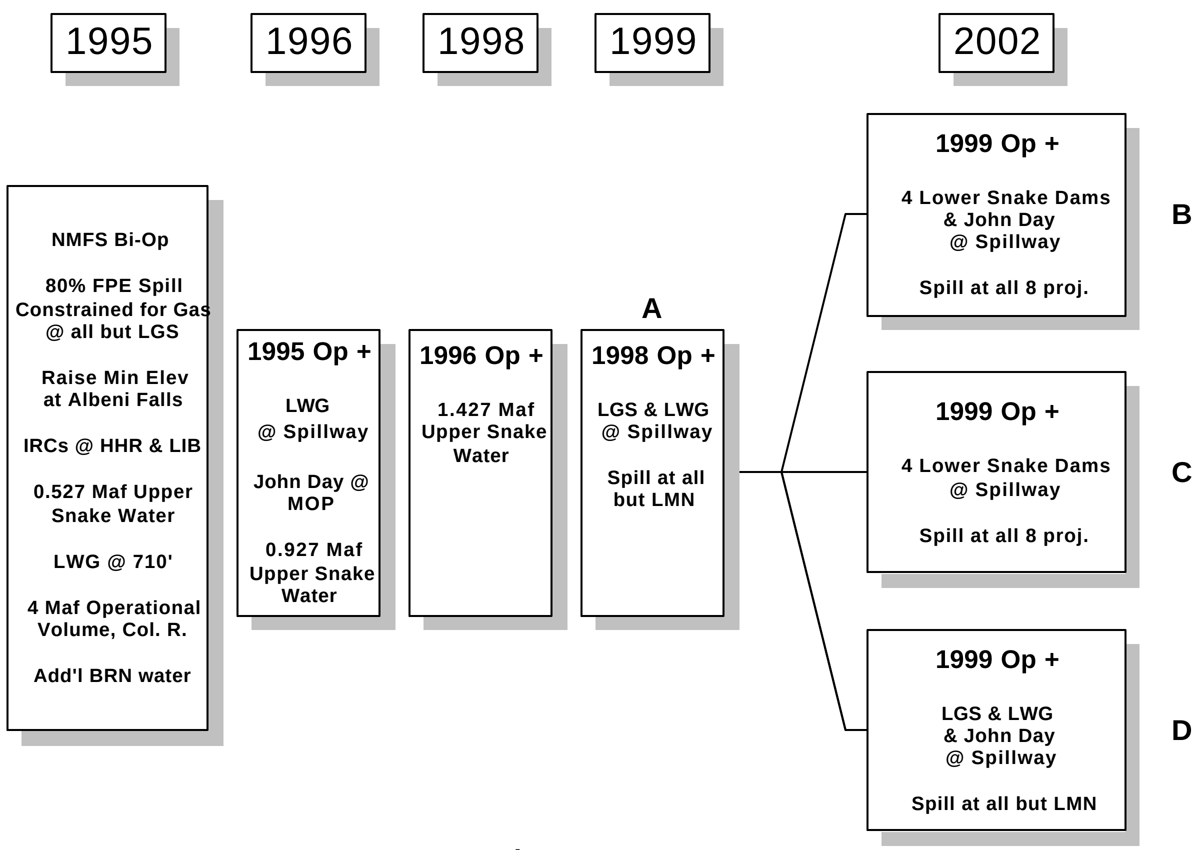


Figure 1

Assumptions

Assumptions for this analysis generally reflect information found in the Northwest Power Planning Council's 1991 Northwest Conservation and Electric Power Plan. Specific hydropower data and project operating rule curves are taken from Bonneville's System Operation Review studies. Gas price information was updated to reflect more current estimates, as were assumptions about combined-cycle combustion turbines. In addition, Southwest market assumptions were also updated based on new information from California and new gas prices.

Water for Flow Augmentation

In the Snake River, water for flow augmentation comes from the Dworshak or Brownlee reservoirs or from the upper Snake River Basin above Brownlee. Upper Snake River water is assumed to be used first, as needed, to meet the flow or water temperature objectives. It is also assumed that this water will be passed, or, in some cases, shaped through the Brownlee reservoir. Because it is presently unclear where and when upper Snake River water would be available within each year, it is assumed that certain volumes would be available for each month, on call as needed to help meet the flow objectives. For the 1995 analysis, 50,000 acre-feet are assumed to be available in the second half of April, 150,000 acre-feet in May and 90,000 acre-feet in June. In August, 137,000 acre-feet could be provided, and in September 100,000 acre-feet for temperature control operations are available. The total amount of upper Snake River water assumed to be available in 1995 is 527,000 acre-feet.

In later years, the Council's Strategy for Salmon calls for an additional 1 million acre-feet from the upper Snake River Basin. For that operation, it is assumed that 250,000 would be available in the second half of April, 550,000 in May, 390,000 in June, 137,000 in August and 100,000 in September. Upper Snake River dams are assumed to refill beginning in October and throughout the winter months, thus reducing the inflows to Brownlee reservoir.

Dworshak will provide up to 1 million acre-feet of water for spring flow augmentation, as needed, to meet the flow objective. In addition, any water stored in shifted flood control space will also be used for flow augmentation. In July, Dworshak is allowed to draft to an elevation no lower than 1,520 feet, if needed to achieve the desired summer flows.

Brownlee reservoir is drafted for flow augmentation only if volumes from the upper Snake and Dworshak are depleted. In spring (second half of April and May) Brownlee would be drafted no lower than elevation 2,069 for flow augmentation. This provides as much as 110,000 acre-feet, if drafted from full. In June, Brownlee would not refill, but simply pass water through from the upper Snake. In July, Brownlee could be drafted up to 137,000 acre-feet if needed to meet the flow objective. It would not be drafted below elevation of 2,067 feet in July. In August, normally the Brownlee reservoir would refill. Under the new measures, in the near term, Brownlee would allow 50,000 acre-feet of upper Snake River water to pass through. In the long term, it would allow a pass-through of all 137,000 acre-feet of upper Snake water.

In the Columbia River, the original 3.45 million acre-feet of water budget volume is assumed to be available for flow augmentation. The additional 3 million acre-feet of operational volume called for in the Strategy for Salmon is increased to 4 million acre-feet. The amount of additional volume to be stored is based on runoff conditions, with the full 4 million acre-feet to be stored in poor water years. It is to be stored above normal power draft elevations subject to: a) space available up to flood control elevations; and b) maintaining Vernita Bar and at-site minimum flow constraints. It is assumed that this water would be stored, as much as possible, in equal volumes beginning in January through the middle of April, and prior to the spring salmon migration season. This 4 million acre-foot operational fish volume is stored first in Grand Coulee, then Libby, and finally in the Arrow project in Canada, if necessary.

Any remaining flow augmentation volume can be held and released in the summer to achieve the summer flow objective. In addition to this water, Grand Coulee can be drafted to an elevation of 1,280 feet in July or August, if necessary to meet summer flow objectives. This represents about 800,000 acre-feet, if drafted from full pool elevation of 1,290 feet.

Flow Objectives for the Snake River

It is understood that in low runoff years there is insufficient water to achieve the mainstem passage flow objectives unless a drawdown of the four lower Snake River dams is implemented (see discussion of flow results below). Thus, for those packages of measures that include a two-pool drawdown or no drawdown operation below minimum operating pool levels, a sliding scale flow target was used in the model to distribute the release of flow augmentation water. In these low years, simply applying a 140,000 cubic feet per second objective would use up all or most of the volume in the first month, leaving little or no water for salmon flows during the latter part of the migration season. By applying a sliding scale target, starting at 85,000 cubic feet per second and ramping up to 140,000 cubic feet per second, a more even distribution of flow augmentation is achieved in these low water years. In the shoulder months, second half of April and June, the sliding scale started at 70,000 cubic feet per second to better simulate a typical spring hydrograph shape. No sliding scale flow targets are used for July, but Dworshak is allowed to draft to an elevation of 1,520 feet, if needed to achieve the summer flow objective.

Flow Objectives for the Columbia River

Various fishery agencies and lower river Indian tribes recommended specific Columbia River flow objectives, ranging from 300,000 cubic feet per second from April 15 to June 15, to 200,000 cubic feet per second in last half of June and all of July, and ramping down to 160,000 cubic feet per second in August. The spring flow objectives are decreased by 40,000 cubic feet per second in each of the second- and third-year critical periods, so that the spring flow objective under third-year critical rule curves is 220,000 cubic feet per second. These flow objectives are treated as operational flow objectives, which the system will try to achieve.

To cover the early migration, a target of 170,000 cubic feet per second is used in the modeling analysis in the second half of April. In May and June, a sliding scale target ranging from 180,000 to 300,000 cubic feet per second is used at The Dalles. As in the Snake, the flow objectives cannot be achieved in low water years without a drawdown of the John Day pool. Again, a sliding scale flow target is used to even out the distribution of flow augmentation for these low runoff conditions and more accurately simulate the natural hydrograph. In summer months, the targets remained fixed for all conditions at 200,000 cubic feet per second in July and 160,000 cubic feet per second in August.

Other Hydro-Related Assumptions

Non-treaty storage water is allowed to be used for power purposes, but is not modeled for flow augmentation. Too many complexities prevented a simulation of the use of non-Treaty water for flow augmentation.

The analysis takes into consideration the existing agreement between the United States and Canada over the lake elevations at Corra Linn Dam. This agreement affects the operation of the Libby project in Montana.

The Vernita Bar minimum flow of 70,000 cubic feet per second, as well as flood control requirements, are maintained from January through April. These requirements can sometimes limit the quantity of operational storage for salmon. This year, for example, the Vernita Bar required minimum flow was 60,000 cubic feet per second.

Estimating Firm Energy Losses

Firm energy losses were estimated using the Council's System Analysis Model. A critical period operation was simulated (operation of the hydro system over the 1929 through 1932 water conditions) in order to calculate the maximum amount of firm hydro energy, given a particular set of constraints. For a normal critical period operation (prior to water budget operations), the hydro system starts full at the beginning of the critical period and is empty by February of the 1932 water year. During the critical period no electricity service is curtailed, except interruptible contracts. All available and declared non-hydro firm resources are in operation and no imports or exports are allowed. This defines the maximum amount of firm hydro energy available in the region.

Because of the water budget and other non-power constraints, this operation must be modified somewhat. Because of efforts to store water in winter for later release for flow augmentation, out-of-region energy purchases are allowed up to 2,000 megawatts per month from January to April. Firm energy loss estimates assume the availability of up to 2,000 megawatts of energy per month from out-of-region utilities.

Southwest Market

A better and more current estimate of the Southwest market was made, taking into account current estimates of Southwest resources and demand. This produces a smaller market in the near term. Also, more current information on interregional contracts was used.

Gas Prices

Current estimates for gas prices, which are lower than those in the 1991 Power Plan, result in lower revenues from Southwest sales, but also result in lower Northwest operating costs.

Replacement Resources

Combined-cycle combustion turbines were used to replace lost firm hydro energy. This choice of replacement resource is not optimal, but it provides a good estimate of what likely costs would be. (See the section on cost uncertainty, below, for more information.) Combustion turbines are a reasonable choice for replacement resource in lieu of performing a full power plan to develop a mix of resources that would minimize the cost. Capital costs for combustion turbines are about one-third lower than the assumptions used in the 1991 Power Plan.

Spill Levels

Spill levels were increased from the Strategy for Salmon to try to achieve 80-percent fish passage efficiency. However, the spill levels at each mainstem federal dam are constrained to limit dissolved gas supersaturation below 120 percent, as determined from the actual 1994 spill levels and 1994 dissolved gas monitoring information.

Integrated Rule Curves at Libby and Hungry Horse Dams

Integrated rule curves obtained from the Montana Department of Fish, Wildlife and Parks in June of 1994 are incorporated in the analysis. These rule curves provide a set of minimum elevations for each of the

50 historic water conditions simulated. It was assumed that the State of Montana fully integrated these curves with flood control protection. Thus, these curves took precedence over the older flood control elevations at these projects.

Albeni Falls Minimum Elevation

By raising the minimum elevation at Albeni Falls to 2,056 feet, some additional water would be available for flow augmentation in the spring. Normally, this project is drafted to an elevation of 2,051 feet during the winter. Keeping the reservoir 5 feet higher in the winter represents about 440,000 acre-feet of spring water that does not have to come from natural streamflows to fill the project. In other words, water that would have filled Lake Pend Oreille from 2,051 to 2,056 feet in early spring can instead be passed through the dam. In order for this “passive” flow augmentation to work most effectively for flow augmentation, however, replacement energy (in November when it otherwise would have been drafted) must come from a non-hydro resource. Thus, this volume should be treated just as the operational volume stored in Grand Coulee, Libby and Arrow. To hold water in Albeni Falls, either: a) nonfirm hydropower sales to out-of-region utilities must be curtailed; b) non-hydropower resources must be used in the region; or c) out-of-region energy can be purchased. In this analysis, however, the minimum elevation is raised, but no active replacement strategy is used. The entire Northwest resource system is used to replace the water held at Albeni Falls. Therefore, since some of the replacement energy may have come from the hydro system, spring outflows from Albeni Falls may not be quite as high as they could be under a more desired replacement energy operation.

Methodology

System simulation models can be used to evaluate the costs and benefits of the actions called for in the Council’s program. For this analysis, as noted above, the System Analysis Model (SAM) was used. SAM is a Monte Carlo program that simulates the monthly operation of the region's hydroelectric dams and thermal resources to meet demand (load) for electricity, including regional interruptible loads and extra-regional secondary loads. Short-term demand uncertainty, hydropower uncertainty (in terms of variable runoff conditions) and thermal performance uncertainty are modeled explicitly. Exchanges with B.C. Hydro and the Pacific Southwest are also modeled. SAM will simulate the dispatch of generating resources to achieve the most economical operation for the Pacific Northwest region.

SAM provides detailed information for reservoir elevations and outflows. It can be used to estimate the magnitude of lost firm energy generating capability for a proposed change in system operations. It will also calculate the magnitude of changes in secondary energy production and the corresponding change in revenue. Costs of out-of-region energy purchases are also included.

Since SAM is a monthly model, it cannot analyze capacity losses. Capacity issues, such as the hydrosystem’s ability to meet daily peaking requirements, must be analyzed using a smaller time increment. Models exist that can simulate the hydrosystem operation on an hourly basis, but these programs are cumbersome to use and require extensive computer time. Efforts are under way to develop tools to analyze capacity issues in a more timely fashion.

The spring smolt migration period is assumed to be April 16 to June 15 in the Snake and May 1 through June 30 in the lower Columbia. During the migration periods, desired fish flows are modeled as sliding-scale target flows, which are proportional to basin runoff conditions. That is, the higher the runoff, the higher the target flow, and vice versa. Target flows can be set at Lower Granite Dam on the Snake River, Priest

Rapids Dam in the mid-Columbia River and The Dalles Dam in the lower Columbia River. Target flows are set so that all of the water stored for fish flow augmentation is released by the end of the migration period.

The intent of these flow targets is to evenly distribute, as much as possible, discharge throughout the migration period. For example, if in a particular year, natural runoff is early and flows are high in May, then most of the water reserved for flow augmentation would be saved for later release in June. In general, the sliding scale target flows are achieved provided enough water is in storage and no project limitations are violated. In some low runoff conditions, however, the target flows could not be achieved.

Two cases are usually analyzed to identify costs and impacts from a previous operation. For this analysis the base case reflects the operation of the hydrosystem under the Council's Strategy for Salmon measures. Alternate cases reflect changes adopted in the Council's amendments to its fish and wildlife program (see Figure 1).

Impacts to the power system are defined as differences in reservoir elevations, river flows and costs between the two cases. Energy costs are comprised of lost revenue from changes to secondary energy sales, replacement resource capital and operating costs, additional operating costs for existing resources and out-of-region purchase costs.

Results

The following tables summarize the impacts and costs to the hydropower system of the mainstem passage actions called for in the 1994 Fish and Wildlife Program. Tables 1 through 4 show the expected change in river flows at Lower Granite and The Dalles dams for spring and summer periods. Table 5 highlights the change in end-of-July average reservoir elevations and refill probabilities for Libby, Hungry Horse, Grand Coulee and Dworshak dams. Tables 6 and 7 summarize changes to the average nutrient retention times at Grand Coulee Dam. Table 8 identifies the range of lost firm hydro energy, the cost to Bonneville and its estimated rate increases.

River Flows

Implementation of the four-pool lower Snake River drawdown to near spillway crest (Alternatives B and C) would increase spring flow equivalents in the Snake River in the eight lowest water years by nearly 135 percent, and by almost 110 percent in the next 12 lowest water years. Summer flow equivalents would also increase by more than one-third in the 20 lowest water years. In some years, both for the Snake and Columbia rivers, normal flows would generate flow equivalent values over the flow objectives. In some of those years, some of the flow augmentation volume could be held in storage for later release in the summer, or for reservoir refill, or to minimize system cost.

Implementation of only Lower Granite and Little Goose reservoir drawdowns to near spillway crest (Alternatives A and D) would increase spring flow equivalents in the Snake River in the eight lowest water years by 57 percent, and by 50 percent in the next 12 lowest water years. Summer flow equivalents would also increase between 10 and 20 percent in the 20 lowest water years.

Table 1
Average Spring Flow Equivalents[3]
in the Snake River at Lower Granite Dam
(thousands of cubic feet per second)

	Strategy for Salmon	1995	A	B	C	D
Lowest eight water years	64.1	73.3	100.5	150.3	150.3	100.6
Next lowest 12 water yrs.	88.3	99.8	132.5	184.4	184.7	132.5
Highest 30 water years	126.4	143.4	187.7	239.8	239.8	187.7
50-Year Avg.	107.3	121.8	157.3	212.6	212.6	157.3

Table 2
Average Summer Flow Equivalents
in the Snake River at Lower Granite Dam
(thousands of cubic feet per second)

	Strategy for Salmon	1995	A	B	C	D
Lowest eight water years	24.1	25.9	26.7	32.1	32.1	26.7
Next lowest 12 water yrs.	28.6	31.3	34.4	39.1	39.0	34.0
Highest 30 water years	40.7	40.8	42.1	44.4	44.6	42.1
50-Year Avg.	35.1	36.1	37.9	41.1	41.2	37.8

Under a four-pool drawdown (Alternative C), the spring flow objectives can be achieved with lower absolute flows. For that alternative, flow targets at Lower Granite Dam are reduced to about 64,000 cubic feet per second (which is the 140,000 cubic feet per second equivalent flow with a four-pool drawdown operation) for the April 16 through June 15 period. The equivalent flow, averaged over the eight driest years, is about 150,000 cubic feet per second compared to about 64,000 cubic feet per second for the Strategy for Salmon. Under a two-pool drawdown (Alternative A), absolute spring flows, in the driest years, are higher than they are under a four-pool drawdown, but the equivalent flow is about 100,000 cubic feet per second.

In the lower Columbia River, operation of John Day pool at near spillway crest would increase both spring and summer flow equivalents between 55 and 65 percent in the 20 lowest water years. Operation of

[3] An equivalent flow produces the same water particle travel time at full pool as the regulated flow under a reservoir drawdown condition.

John Day reservoir at minimum operating pool level would increase spring and summer flow equivalents between 10 and 15 percent in the 20 lowest water years.

Table 3
Average Spring Flow Equivalents
in the Columbia River at The Dalles Dam
(thousands of cubic feet per second)

	Strategy for Salmon	1995	A	B	C	D
Lowest eight water years	191.0	201.4	215.3	302.7	210.7	308.6
Next lowest 12 water yrs.	242.7	250.4	266.7	376.0	262.1	382.7
Highest 30 water years	334.9	345.0	366.3	515.3	360.4	524.9
50-Year Avg.	289.8	299.4	318.2	447.9	312.9	456.0

Table 4
Average Summer Flow Equivalents
in the Columbia River at The Dalles Dam
(thousands of cubic feet per second)

	Strategy for Salmon	1995	A	B	C	D
Lowest eight water years	125.3	130.8	142.9	203.4	141.6	205.5
Next lowest 12 water yrs.	160.7	167.6	185.3	265.4	184.9	264.2
Highest 30 water years	188.7	194.5	214.4	307.1	214.6	307.5
50-Year Avg.	171.8	177.9	196.0	280.6	195.7	280.7

Note that reservoir drawdowns play an important role in meeting the velocity equivalent flow objectives. Without drawdowns, the Strategy for Salmon flow measures fall short of achieving either the National marine Fisheries Service 1994-98 Biological Opinion flow targets or the 140,000 cubic feet per second operational flow objective. For example, in the eight lowest water years in the Snake River, the Strategy's spring flow measures fall 3 million acre-feet short of achieving the 85,000 cubic feet per second National Marine Fisheries Service spring flow target for the Snake, and 10.8 million acre-feet short of providing the 140,000 cubic feet per second operational flow objective. In the next 12 lowest water years, the Strategy is almost 7.4 million acre-feet short of the operational flow objective. Over all 50 water years, the Strategy would need more than 4.6 million acre-feet to fully achieve the 140,000 cubic feet per second operational flow objective.

Similarly, in the eight lowest water years in the Snake River, the Strategy for Salmon's summer flow measures are more than 2.1 million acre-feet short of achieving the 50,000 cubic feet per second National Marine Fisheries Service summer flow target for the Snake. In the next 12 lowest water years, the shortfall to achieve 50,000 cubic feet per second is 1.7 million acre-feet. Over all 50 water years, the summer shortfall is 1.2 million acre-feet.

For the lower Columbia River, in the eight lowest water years in the Snake River, the Strategy for Salmon's spring flow measures fall more than 700,000 acre-feet short of achieving the 200,000 cubic feet per second National Marine Fisheries Service spring flow target for the Columbia, and almost 8.9 million acre-feet short of providing a 300,000 cubic feet per second operational flow objective. In the next 12 lowest water years, the Strategy is almost 4.7 million acre-feet short of the operational flow objective. Over all 50 water years, the Strategy would need more than 800,000 acre-feet to fully achieve a 300,000 cubic feet per second operational flow objective.

In the eight lowest water years in the Columbia River, the Strategy for Salmon's summer flow measures are about 2.1 million acre-feet short of achieving the 160,000 cubic feet per second National Marine Fisheries Service summer flow target for the Columbia, and nearly 4.6 million acre-feet shy of providing a 200,000 cubic feet per second operational flow objective in July. In the next lowest 12 water years, the shortfall to achieve the 200,000 cubic feet per second flow objective is 2.4 million acre-feet. Over all 50 water years, the shortfall is more than 1.7 million acre-feet to fully meet the summer operational flow objective.

The equivalent flow levels in Tables 1-4 indicate that the 1995 salmon flow measures also fall short of providing the operational flow objectives recommended by the fishery agencies and lower river Indian tribes, except in the 30 highest water years. Implementation of a four-pool drawdown in the Snake River, and a drawdown of John Day reservoir to near spillway crest elevations would achieve the operational flow objectives, even in the lowest water years. In addition, implementation of a two-pool drawdown in the Snake River and drawdown of John Day pool to minimum operating pool level come closer to achieving the operational flow objectives than the Strategy for Salmon flow measures.

Figure 2

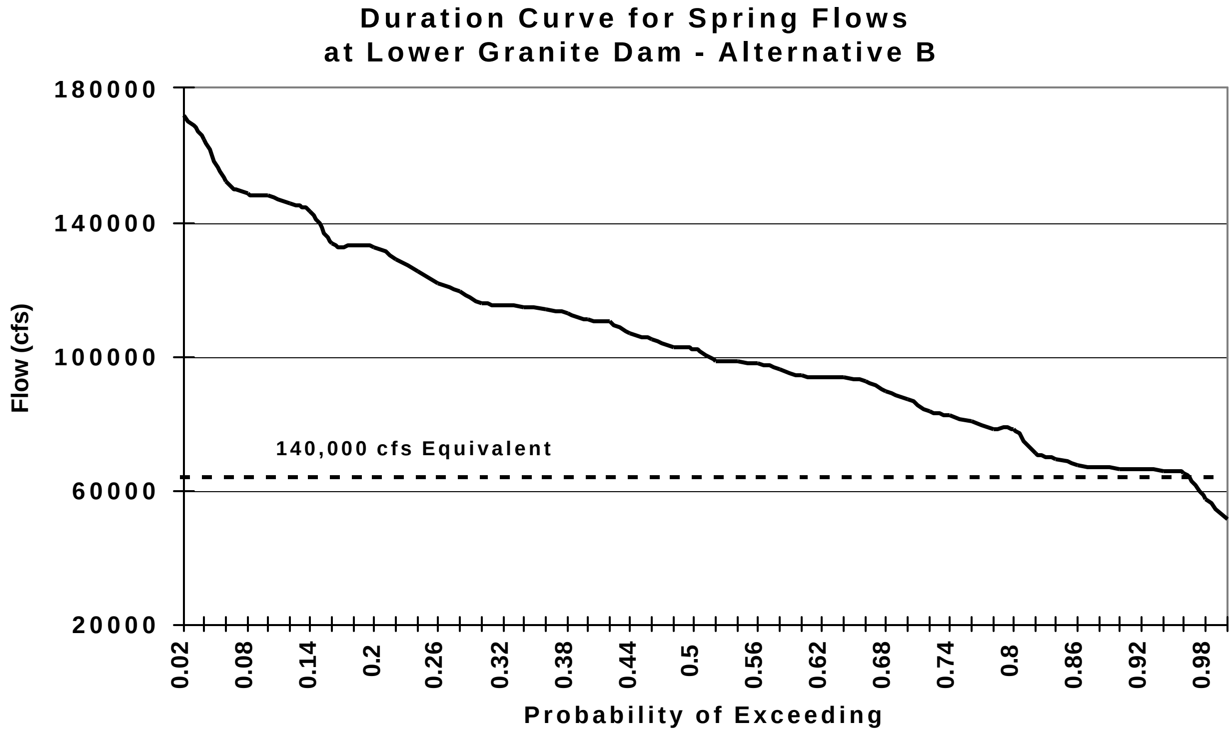


Figure 3

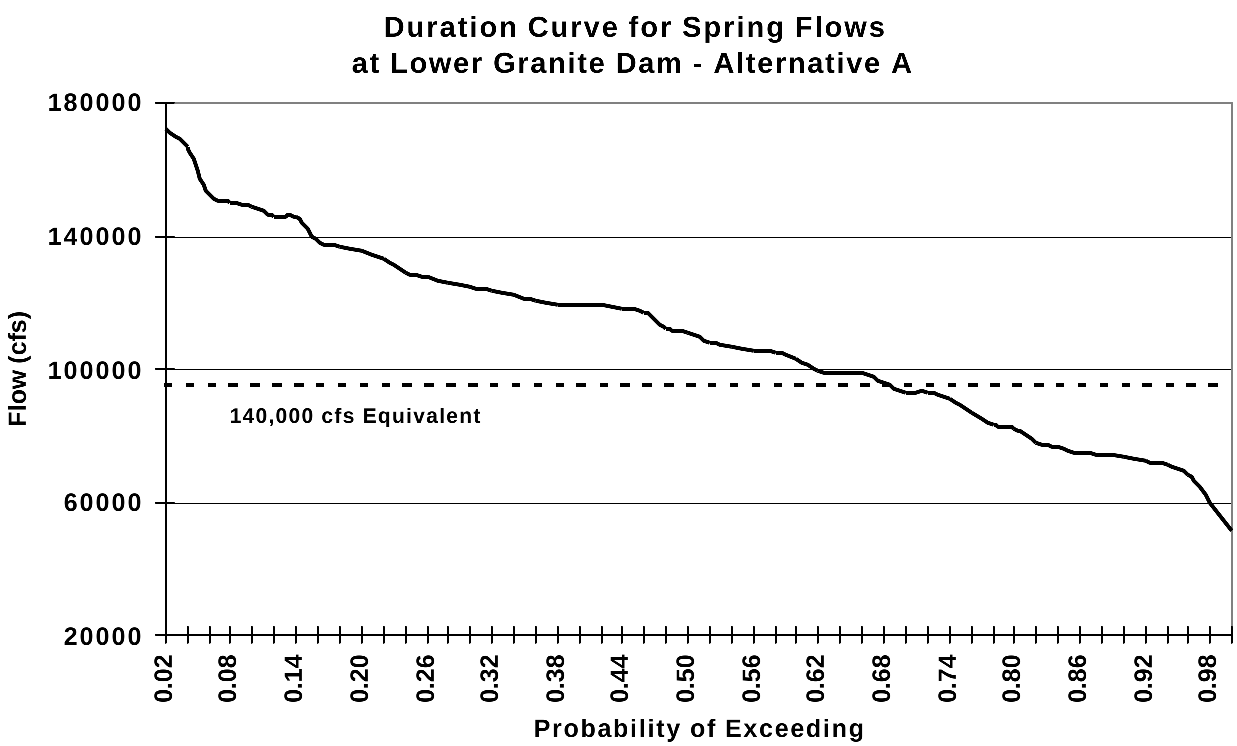


Figure 4

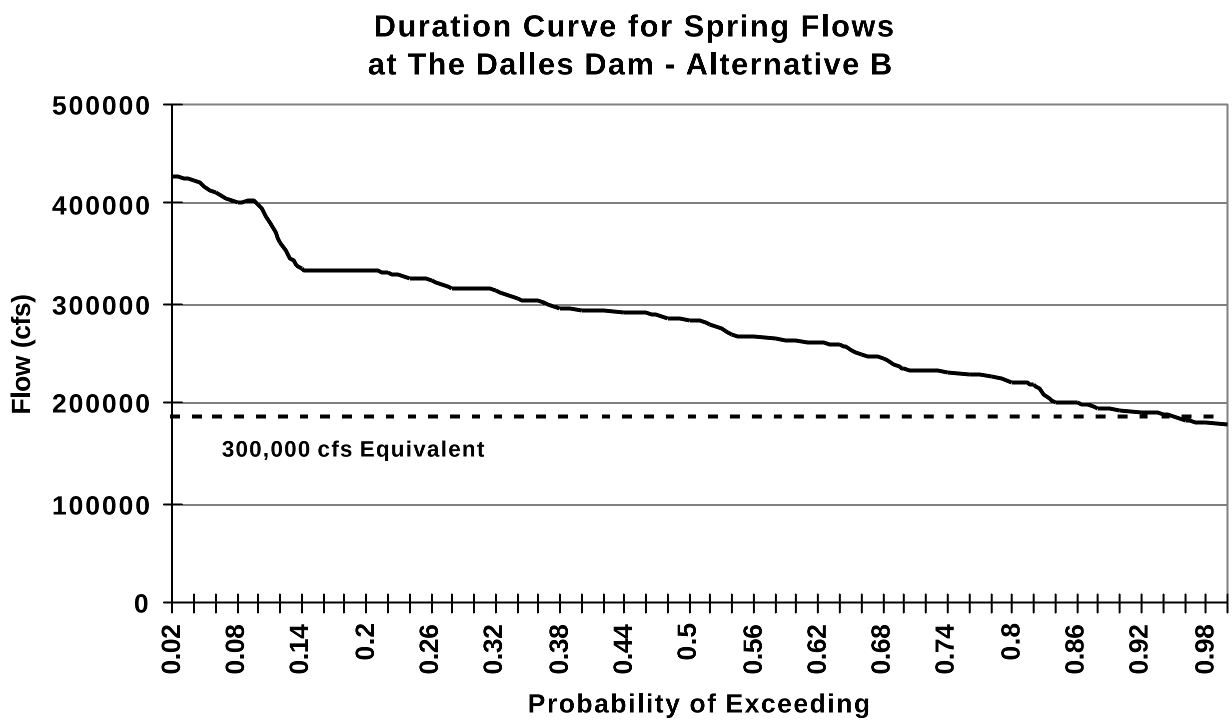
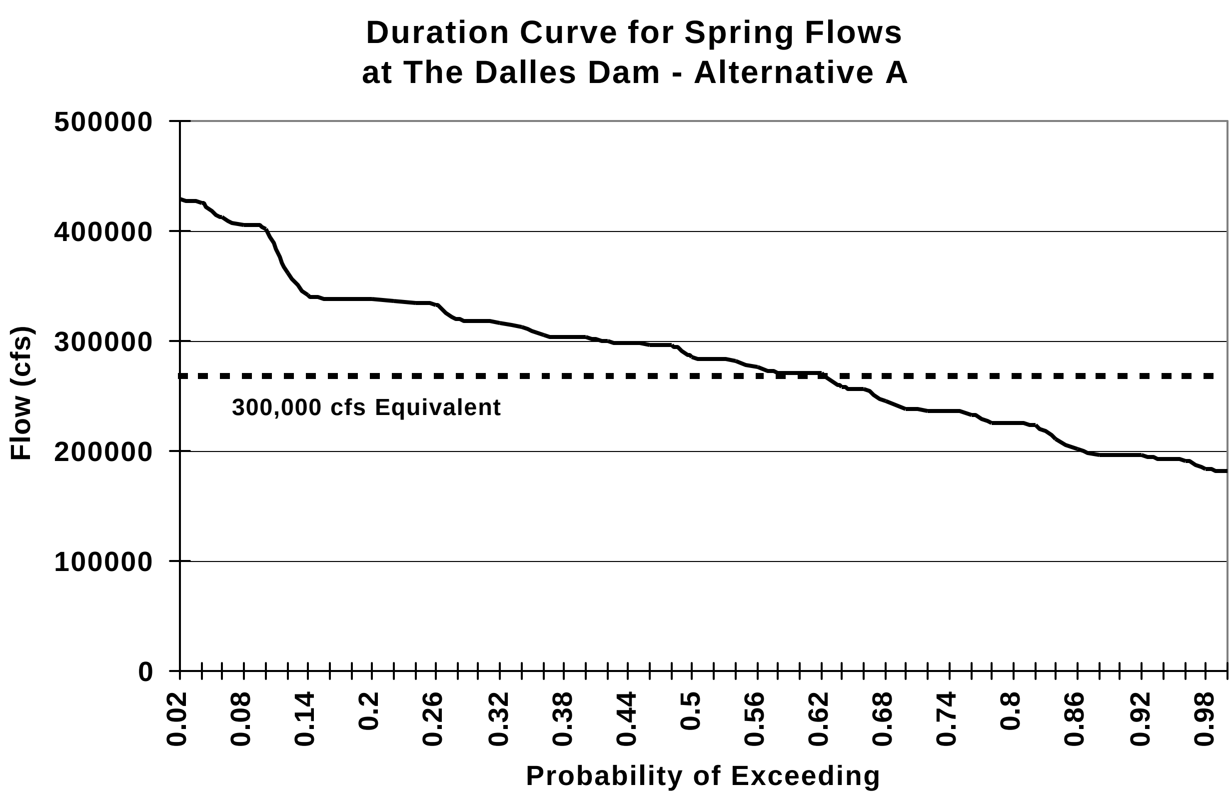


Figure 5



Figures 2 and 3 illustrate how often the 140,000 cubic feet per second flow equivalent is achieved under a two- and four-pool drawdown operation on the Snake River. The curve in Figure 3 (a two-pool drawdown) indicates how often a specific flow level will be achieved or exceeded. The horizontal line, at about 95,000 cubic feet per second, in that figure shows where the 140,000 cubic feet per second flow equivalent is based on a two-pool drawdown. For this operation, the flow objective is achieved about two-thirds of the time. In Figure 2 (a four-pool drawdown), it is achieved about 95 percent of the time. Under the Strategy for Salmon operation, the flow equivalent in the Snake River is achieved about 14 percent of the time.

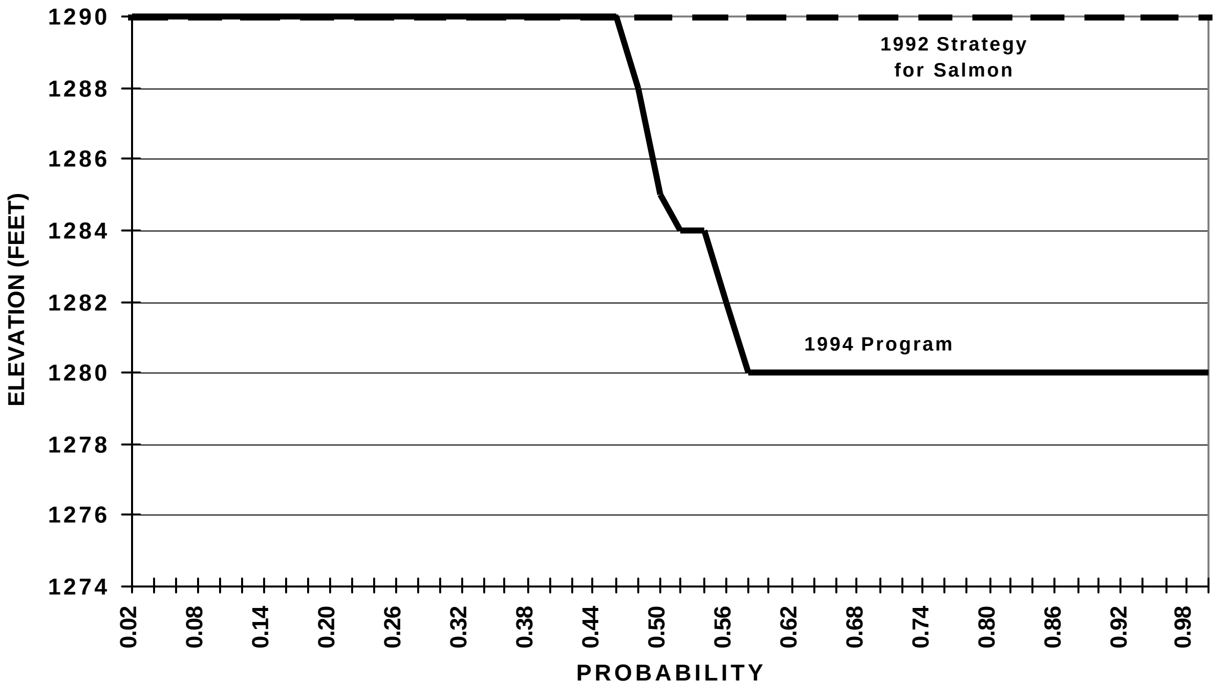
Figures 4 and 5 illustrate the probabilities of achieving the spring flow objective of 300,000 cubic feet per second in the Columbia River. When John Day is operated at near spillway crest elevation, the flow equivalent objective is achieved about 95 percent of the time (Figure 4). Under a John Day operation to minimum operating pool, the flow equivalent objective is achieved about 60 percent of the time (Figure 5). Under the Strategy for Salmon operation, the flow equivalent in the Columbia River is achieved 42 percent of the time.

Reservoir Elevations and Refill Probabilities

Refill probabilities increase significantly at Libby and Hungry Horse dams due to implementation of the recommended integrated rule curves at both projects. Refill probability at Libby increases from 90 to 92 percent and at Hungry Horse from 86 to 96 percent. At Grand Coulee, the end-of-July refill probability drops from 100 percent in the Strategy for Salmon to under 50 percent. However, when Coulee does not refill it is generally 10 feet down from full, due to the 1,280-foot draft limit. By having August flow objectives at The Dalles, Grand Coulee cannot refill in August in dry years, and the project remains at its lower elevation of 1,280 feet. The refill probability curve for Grand Coulee is shown in Figure 6.

Figure 6

End-of-July Refill Probability at Grand Coulee Dam - Alternative A



At Dworshak, refill probability depends on whether a drawdown of the four lower Snake River dams is implemented. Without a drawdown, Dworshak's refill probability falls from 42 percent under the Strategy for Salmon to 34 percent. This is due to its draft to elevation 1,520 feet, if necessary, to assist in meeting a summer flow objective of 50,000 cubic feet per second. With a four-pool Snake River drawdown operation, its refill probability increases to more than 70 percent. Figure 7 illustrates Dworshak's refill curve for the end of July. As evident in that figure, Dworshak will be drafted to an elevation of 1,520 feet in July, about one-third of the time, in the lowest water years.

The end-of-July refill probability for Brownlee Dam (Table 5) under the Strategy for Salmon operation is zero. This is because the Strategy measures call for a release of 137,000 acre-feet of water from the Brownlee Reservoir in July of every year, which is to be replaced by upper Snake River water in August. Under that operation, Brownlee refills by the end of August for all water conditions. Under the actions called for in the 1994 program, however, release of the 137,000 acre-feet of water in July is conditioned on the need for that water. Because of that, Brownlee's July elevation is higher, on average, than under the Strategy, and quite often it refills in that month. In August, the 1994 program calls for the upper Snake water, that would have refilled Brownlee, to be passed through instead. Because Brownlee is generally higher by the end of July under the 1994 program, the simulation shows that it is still able to refill by the end of August in every year. During winter months, Brownlee is used both for power and to maintain minimum flow requirements through April for salmon egg incubation.

Figure 7

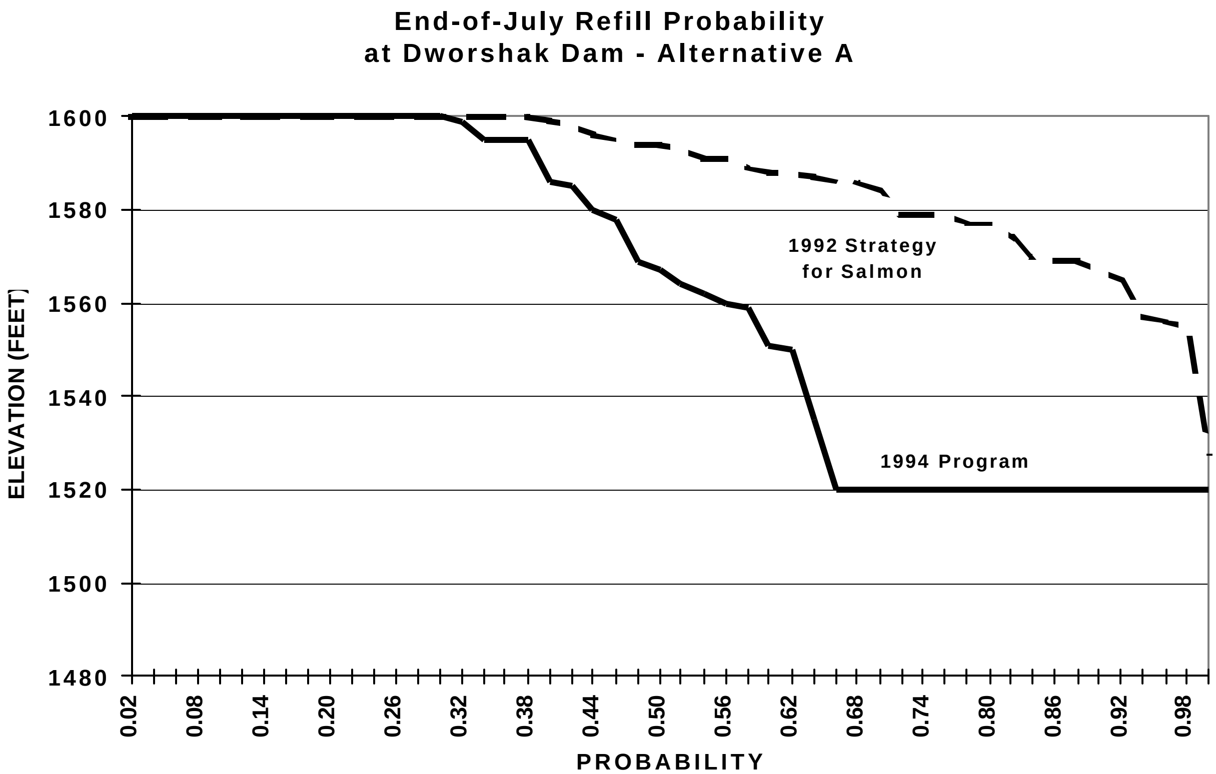


Table 5
Average End-of-July Elevations (feet)
and Refill Probabilities for Major
Columbia Basin Storage Projects

	Strategy for Salmon	1995	A	B	C	D
Libby (full=2459 ft.)	2457.1 90%	2458.3 92%	2458.2 92%	2458.2 92%	2458.2 92%	2458.3 92%
Hungry Horse (full=3560 ft.)	3556.9 86%	3559.1 96%	3559.1 96%	3559.0 96%	3559.0 96%	3559.1 96%
Grand Coulee (full=1280 ft.)	1290.0 100%	1285.2 50%	1285.1 46%	1284.6 40%	1284.7 40%	1285.0 46%
Brownlee (full=2077 ft.)	2067.0 0%	2073.2 62%	2073.6 64%	2075.8 88%	2075.8 88%	2073.6 64%
Dworshak (full=1600 ft.)	1586.9 42%	1548.9 10%	1560.1 34%	1583.4 72%	1583.3 72%	1560.1 34%

Nutrient Retention Time at Grand Coulee Dam

In general, monthly average nutrient retention times at Grand Coulee Dam remain close to or above the suggested 30-day minimum level except during May. In April and June, average retention times are close to the 30-day value. In July and August, retention times decrease by about 6 to 16 percent from current operations, but remain above the 30-day level. In July, average retention time is between 38 and 41 days; in August it ranges from about 43 to 45 days.

Table 6
Average Nutrient Retention Time
at Grand Coulee Dam[4]
(Days)

	Current Oper.	1995	A	B	C	D
April 16-30	30.0	29.0	29.8	28.7	28.6	29.9
May	22.4	23.1	23.5	22.0	22.0	23.5
June	31.2	29.9	29.8	29.0	28.9	29.8
July	43.5	37.7	38.1	41.1	40.7	38.0
Aug 1-15	49.8	43.1	43.7	44.9	45.0	43.7
Aug 16-31	52.6	45.2	44.5	44.4	44.7	44.7

Table 7
Difference in Average Nutrient Retention Time
from Current Operations[5]
(Percent)

	1995	A	B	C	D
April 16-30	- 3	- 1	- 1	- 1	0
May	+ 3	+ 5	- 2	- 2	+ 5
June	- 4	- 5	- 7	- 5	- 5
July	-13	-12	- 6	- 6	-13
Aug 1-15	-14	-12	-10	-10	-12
Aug 16-31	-14	-15	-16	-15	-15

[4] For nutrient retention times at Grand Coulee Dam, the current river operation was used as the base case.

[5] For nutrient retention times at Grand Coulee Dam, the current river operation was used as the base case.

Cost and Rate Impact to Bonneville Power

Average annual costs to Bonneville Power[6] range from about $90 million to $225 million. The corresponding average rate impacts range from 4 to 11 percent. The 4 percent increase would be realized if only the 1995 measures were implemented over the next 20 years. In the long-term, depending on which additional measures are implemented, the average rate increase over the next 20-year period ranges from 7 to 11 percent. Energy costs, which include the cost of replacement resources, energy purchases and lost revenues, amount to about one-third to one-half of the total cost. Non-power costs include the capital costs of modifying mainstem dams for drawdown operations,[7] costs of improving fish bypass or transportation and other related fish and wildlife project costs. Firm hydro energy losses range from 400 to 850 average megawatts, depending on the final package of measures implemented.

Table 8
Cost and Rate Impacts
to Bonneville Power[8]

	Firm Energy Loss (MWa)	Capital Costs (millions)	Other Annual Costs (millions)	Energy Costs (millions)	Annual BPA Costs (millions)	Average Rate Increase (%)
1995	400	$ 17	$21	$53	$ 89	3.7
A	525	$ 61	$21	$69	$151	7.2
B	750	$108	$21	$95	$225	11.1
C	525	$ 81	$21	$67	$170	8.1
D	850	$ 89	$21	$99	$209	10.3

Uncertainties in Cost

A number of factors can affect regional cost estimates. Generally, cost estimates are made by comparing net revenue requirements between two different power system operations. The base case defines the operations from which changes are made. For this analysis, the base case represents the hydro operation under the Council's Strategy for Salmon measures.[9] Even though those measures differ from current river

6 Costs to Bonneville Power include 71 percent of the regional power system costs, capital costs of modifying dams and other related costs. They reflect the levelized cost of implementing various measures at various future dates.

7 Capital costs of drawdown-related dam modifications are based on Corps of Engineers' cost estimates from its System Configuration Study, including contingency costs. Edward L. McLean, a consultant, estimates the total cost of a four-pool Snake River drawdown to near spillway crest at $610 million. This estimate is 50-percent lower than the Corps' estimate of $1.3 billion.

8 The costs shown in Table 8 are levelized over the period from 1994 to 2015. In the introduction, some of these costs are discussed for specific years and thus will differ from those in this table.

9 For nutrient retention times at Grand Coulee Dam (Tables 6 and 7), the current river operation was used as the base case.

operations,[10] the Strategy for Salmon is the correct base case to use because amendments being considered by the Council reflect changes to the Strategy measures.

Cost estimates can also differ depending on the computer programs used to simulate river operations. Some programs provide very detailed simulations, while others use simplifying assumptions that yield more approximate estimates of operations. The System Analysis Model provides a very detailed simulation of river operations. It models the operation of individual dams in the Columbia River Basin and includes specific non-power constraints at those projects.

Besides variations in estimates caused by factors mentioned above, cost can also vary due to fluctuations in other assumptions. For example, the cost of a particular set of measures can vary dramatically based on the amount of precipitation in a given year. The *average* cost of current river operations compared to the Strategy measures, for example, is about $40 million, yet in dry years the cost could be as high as $125 million.

What follows is a description of the variance in cost estimates due to uncertainty in four variables: gas price, capital cost of combustion turbines, water conditions and resource replacement type. Figure 8 illustrates the range in energy cost[11] (in percent) due to the uncertainty in these four variables.

A swing in gas price of 25-percent changes cost estimates by about 5 percent. A 25-percent reduction in the capital cost of a combustion turbine reduces the energy cost by about 8 percent, and correspondingly, a 50-percent increase in capital cost results in a 16-percent raise in energy cost.

Water conditions swing the cost more dramatically. Cost in years of poor water conditions would be nearly double the average value or more, and cost in good water conditions would be about half the average or less.

Each of the packages of measures being proposed will have some effect on the hydropower system's ability to produce firm energy. Losses to firm energy generation must be replaced if the same level of service is to be provided to Northwest customers. The choice of replacement resource makes the largest difference in the cost. In Figure 8, the change in cost due to resource type ranges almost 90 percent in either direction.

The choice of replacement resource for the average values was a combined-cycle combustion turbine. This resource has low capital costs and reasonable operating costs. When nonfirm hydro energy is available, the combustion turbines can be turned off to save operating costs. In the simulations, the replacement turbines operated about half the time. While this choice is probably not the optimum, it does represent a low cost option that continues to provide a high level of service to Northwest customers. Ideally, an optimal package of replacement resources[12] would be designed that would minimize the costs, while not harming level of service.

[10] Current river operations represent the National Marine Fisheries Service 1994-98 biological opinion measures. Those measures decrease firm hydro energy generation by about 150 average megawatts and cost the region about $40 million per year, on average, more than the Strategy.

[11] These fluctuations in cost reflect only energy costs, which represent about a third to one half of the total cost of the measures being proposed.

[12]This optimal package of resources would be developed through the Council's power planning activities in conjunction with efforts of other Northwest utilities and agencies.

This package would undoubtedly include conservation and renewable resources, as well as additional purchases or energy exchanges with out-of-region utilities.

On the high cost side, a "flat," non-displaceable and non-dispatchable, 35-mill per kilowatt-hour resource was chosen to replace lost firm hydro energy. This type of resource yields the greatest cost because the region must pay for it every hour of the year. It can not be turned off when surplus nonfirm hydro energy is available.

On the other end of the spectrum, only out-of-region energy purchases were used to replace lost hydro energy. Whenever there was a shortage, energy would be purchased from out-of-region utilities. If the interties (major power transmission lines) were full or if the supply was depleted, the model would simply curtail service to Northwest customers at a lost revenue rate of about 45 mills per kilowatt-hour.

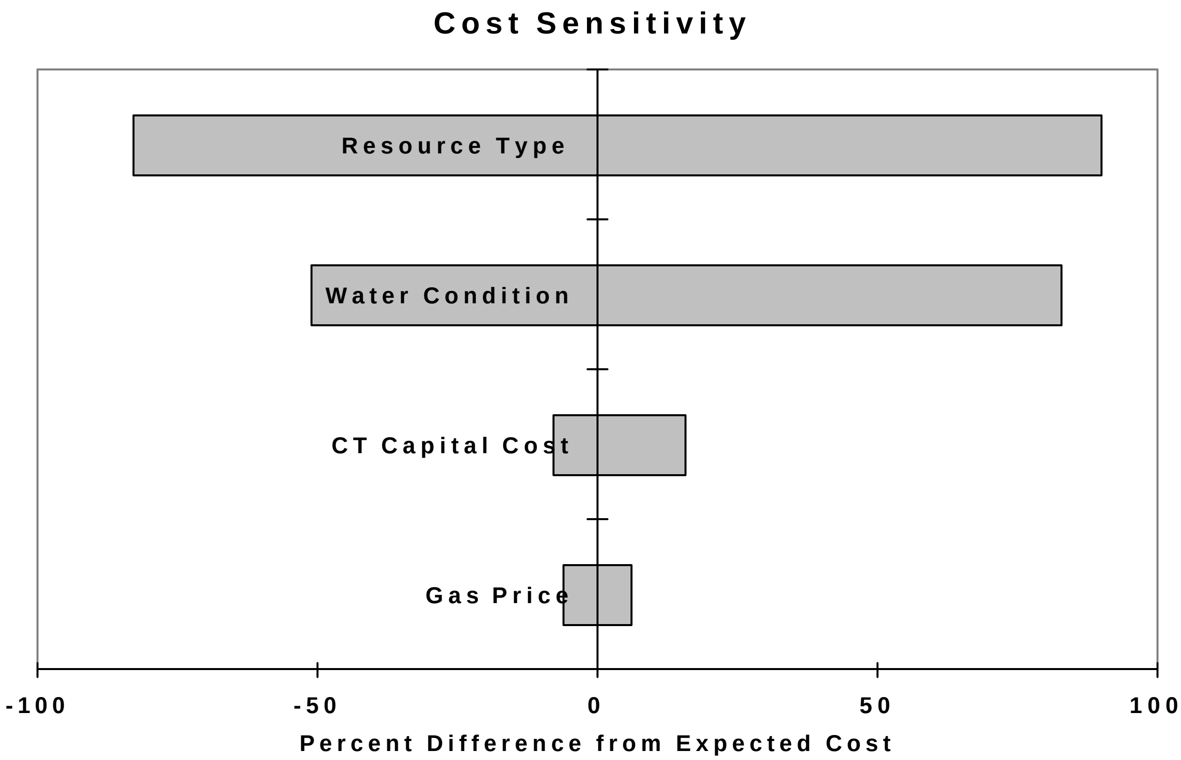


Figure 8

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