System Operating Strategies

4.0 SYSTEM OPERATING STRATEGIES

Chapter 4.0 presents a complete discussion of alternatives and potential impacts for one of the four SOR actions, selection of a long-term SOS. The chapter is divided into three sections. Section 4.1 describes the SOS alternatives that were evaluated in detail and explains how they were derived. It also addresses the alternatives and operating approaches that were considered at some point in the SOR process but, for various reasons, were not studied in detail for the EIS. Section 4.2 displays the effects of the alternative SOSs on each river use or resource area and documents the results of the SOR full-scale analysis for the SOS decision. Section 4.3 summarizes and compares the projected impacts of the SOSs, and discusses cumulative effects, trade-off relationships, mitigation, and other key factors.

4.1 SOS ALTERNATIVES

The operating procedures for the Columbia River system today reflect a combination of the project-specific requirements established when the Federal dams were built and subsequent individual project and systemwide requirements brought about through various programs or legal agreements. Historically, the two dominant functions of the reservoir system have been power generation and flood control. Issues have since emerged, such as diminishing salmon and steelhead runs and the growing use of reservoirs for recreation, that were not considered when the dams were authorized 30 to 60 years ago. While the Federal agencies have adjusted for these additional and sometimes competing interests, an overall system operating strategy specifically geared to accommodating the multiple uses has not been developed. The alternatives presented in this section propose some possible strategies.

An SOS alternative is a plan for operating the 14 Federal projects in the Columbia River system in a way that considers competing uses of the river. The alternatives prescribe water management actions to operate the system to achieve a desired objective. Alternative strategies range from continuing current practices to adopting major changes. These actions were evaluated for their effect on the overall system.

4.1.1 SOS Development

Technical work groups representing the 10 key river uses and several other critical issues provided the cornerstone of the analysis for the SOR. They played a key role in developing and screening alternatives in the early stages of the SOR, and in conducting the full-scale analysis reported in Sections 4.2 and 4.3. The work groups were guided through screening by the AMG described in Chapter 1. What follows is a synopsis of the alternative development and screening process; a detailed discussion can be found in *Screening Analysis, Volumes 1 and 2* (BPA, Corps, and Reclamation, 1992a).

Identifying Candidate Alternatives

The work groups' mission in developing alternatives was twofold. First, they were asked to develop an alternative that would represent the near-optimum operation for their river use. In other words, they were to describe the system operating scenario that would provide the greatest benefit to, for example, anadromous fish, recreation, or irrigation. The groups were also asked to describe one or more alternatives that, while not ideal would provide an acceptable environment for their river use. The purpose of examining the extreme conditions needed to optimize conditions for a single river use was to learn more about operating relationships, define which uses are compatible and which conflict, and identify under what conditions and to what extent the conflicts occur.

The AMG also offered alternatives for analysis during screening. Some of the AMG alternatives came from the SOR scoping meetings (see Scoping Document, 1991) held in August 1990. Many were suggested by

OPTIMUM CONDITIONS FOR EACH RIVER USE

The work groups identified the optimum operating conditions for their river use in very specific terms, indicating the flows and elevations required at various Federal hydroelectric projects. In general, the types of operation that appear to provide optimum benefits for each river use can be characterized as follows:

- Anadromous Fish—Streamflows as close to "natural" river conditions as possible, with mainstem reservoirs well below spillway levels
- Cultural Resources—Stable reservoir elevations year-round
- Flood Control—Reservoirs drafted in early spring to capture snowmelt inflows
- Irrigation—Full reservoirs April through October (growing season)
- Navigation—No reservoir drawdowns below minimum operating pool
- Power—Eliminate or reduce nonpower operating constraints on the system
- Recreation—Full reservoirs for long summer season (May-October) and stable downstream flows
- Resident Fish—Stable reservoirs year-round, with natural river flows
- Water Quality—Natural river flows with minimum spill
- Wildlife—Draw down and stabilize reservoirs year-round to expose maximum acreage for long-term habitat recovery

activities and events taking place in the region that affect river operations. For example, several alternatives came about as a result of the Salmon Summit and later from the Corps of Engineers' *1992 Columbia River Salmon Flow Measures Options Analysis/Environmental Impact Statement* (OA/EIS) and a drawdown test the Corps conducted at Lower Granite and Little Goose Dams on the Snake River in March 1992. The NPPC's Fish and Wildlife Program amendments were the source of other alternatives for the SOR, as was a 1991 proposal by the CBFWA to increase flows in the Columbia River. Altogether, 90 different ways to operate the river were proposed, many in groups or series because there was little difference between them.

Screening the Alternatives

The second part of each work group's task was to develop a screening model and screen the

90 alternatives, based on impacts to key value measures associated with their river use. In other words, the Anadromous Fish Work Group not only attempted to define the ideal operating conditions for salmon and steelhead in the Columbia River system, it evaluated the impact of the operations proposed by others on anadromous fish populations.

Establishing Value Measures—In order to make such evaluations, the work groups had to establish ways to measure the impacts of the various river operating scenarios on their river use. They defined what were called "value measures" as the yardsticks by which to quantify change. The objective was to define a few measures that could serve as suitable indicators for key resources; it was not to identify all measures that would fully or perfectly capture all effects for each river use. Likewise, the numerical results were used only to compare

alternatives; they were not intended to represent precise predictions or absolute values of impact.

Some work groups had many value measures; others had few. For example, the Wildlife Work Group identified 11 value measures ranging from evidence of indicator species, such as the number of Canada goose nests and otter den sites, to habitat quality and acreage figures. The Water Quality Work Group screened for two measures: water temperature and dissolved gas saturation.

The work groups looked for changes in the value measure results that would take place given differing operating scenarios on the Columbia River system. The quantitative measures were aided by computer programs that churned out hundreds of pieces of data—both numbers and diagrams—for each alternative.

Some work groups also limited the geographic area for their screening analysis. Rather than consider all 14 Federal hydro projects included in the scope of the SOR, most groups chose fewer representative projects or river reaches over which to establish identifiable patterns. For example, the Irrigation Work Group focused its screening analysis on those reservoirs and pools where major pumping activity currently exists and where the impact on irrigation costs could be most significant.

Where Hydroregulation Models Fit Into Screening—Planning and regulation of the
system are aided by sophisticated computer programs called hydroregulation models. These models can rapidly calculate the river system's response to a variety of streamflow and operating conditions. From the data the models provide, analysts can estimate the systemwide impacts of projected operations. A more detailed discussion of the hydroregulation models can be found in *Modeling the System: How Computers are Used in Columbia River Planning* (BPA, Corps, and Reclamation, 1992b).

Each of the 90 alternatives was reviewed by the SOR support group, ROSE. ROSE determined whether the alternative had been described

precisely enough to be run on a hydroregulation model. If not, the work group was asked to provide more detail about the operating condition it was proposing. When the alternative was sufficiently detailed, the operation was simulated using the computer model.

ROSE ran simulations for all 90 alternatives to determine how the physical river system would respond to each one. Once the hydroregulation model run was completed for an alternative, the work groups were given printouts and graphs that showed the average flows and end-of-month elevations that would result from the proposed operating scenario in each of five representative water years. The water years ranged from very dry to very wet. The next task for the work groups was to analyze how those flows and elevations translated into impacts on their river use. Each group decided independently how to do this part of the analysis. They generally used spreadsheets and other computer programs to determine the environmental effects.

ROSE designated an operating "base case" that each of the work groups would use. The base case for screening was the 1990-91 annual operating plan. This plan represents how the system operated prior to the changes implemented for the 1992 operating year to help the recovery of salmon stocks listed under the ESA. (This base case was used to provide a clear, common benchmark for analysis. It does not represent the No Action Alternative in NEPA terminology. See Section 4.1.3 for further discussion.) The work groups compared the impacts of a particular alternative on their river use to this baseline operation. When the analysis was complete, the work groups ranked each alternative according to its impact on their river use (see *Screening Analysis: A Summary* for a complete listing of the preference or rankings).

Identifying the Alternatives for Full-Scale Analysis

The SOR Interagency Team assigned the alternatives to five groups based on their general operating characteristics:

* Base Case—Alternatives that represent 1991 operations
* Flow Augmentation—Alternatives that modify water storage and flow requirements for the benefit of anadromous fish
* Drawdown—Alternatives that involve lower Snake River and/or John Day reservoir drawdown
* Stable Pools—Alternatives that stabilize storage reservoir elevations
* Power—Alternatives that change power system planning and operation

The team used the numerical results of screening to further sort the alternatives into distinct categories according to their effects on river uses. For example, several of the lower Snake River drawdown alternatives showed similar benefits to anadromous fish, with minimal effects on recreation and resident fish. Wildlife was slightly affected, but there were serious adverse impacts to navigation and irrigation. These alternatives formed a subset within the drawdown group.

Some of the categories reflected a single operating strategy. Others, however, did not alone suggest a strategy, but instead contained an element that could be added to another more distinct operating strategy. Based on these categories and the qualitative and quantitative screening results, the SOR team initially developed 10 candidate system operating strategies. These 10 strategies were presented for public and agency review in September 1992.

Following this review, the team narrowed the 10 strategies down to six strategies for evaluation in full-scale analysis, based on similarities or overlaps among the original 10 candidates. Another strategy was subsequently added to reflect the recommendations of the

USFWS and NMFS. This resulted in seven final strategies, all with multiple options, that were evaluated in the Draft EIS. The seven strategies represented a total of 21 different courses of action.

The strategies analyzed in the Draft EIS reflected results of the numerical screening data, the categories of effects described above, and qualitative factors not captured in the numerical results. In addition, other regional activities—Corps' System Configuration Study and the NMFS's ESA and Recovery Plan deliberations—influenced the list of alternatives identified for full-scale analysis.

This Final EIS also evaluates 7 operating strategies, with a total of 13 alternatives now under consideration when accounting for options. The 13 final alternatives represent the results of the third analysis and review phase completed since SOR began. As was done after screening, broad public review and comment was sought on the full-scale analysis results published in the Draft EIS. A series of nine public meetings was held in September and October 1994, and a formal comment period on the Draft EIS was held open for over 4.5 months. Following this last process, the SOR agencies have again reviewed the list of alternatives and have selected 13 alternatives for consideration and presentation in the Final EIS.

Six options for the alternatives remain unchanged from the specific options considered in the Draft EIS. One option (SOS 4c) is a revision to a previously considered alternative, and the rest represent replacement or new alternatives. The basic categories of SOSs and the numbering convention remains the same as was used in the Draft EIS. However, because some of the alternatives have been dropped, the final SOSs are not numbered consecutively. There is one new SOS category, Settlement Discussion Alternatives, which is labeled SOS 9 (see Section 4.1.6 for discussion).

The eventual set of SOS alternatives for the Final EIS are summarized in the following narratives. Table 4-1 presents the basic features

on the alternatives with respect to operations of projects located in the United States. Many of the SOSs evaluated in the Final EIS incorporate one adjustment to the operation of Canadian projects, which is operation of Arrow to allow storage of up to 1 MAF (1.2 billion m³) of water for spring and summer flow augmentation. The table outlines specific operating requirements the alternative prescribes for individual projects. Hydroregulation model results for the alternatives, which reflect the simulated hydrological outcomes, are included in Appendix A.

The following Sections 4.1.2 through 4.1.8 describe the final alternatives, while Section 4.1.9 reviews the rationale for their inclusion in the Final EIS.

4.1.2 SOS 1–Pre-ESA Operation

This alternative represents one end of the range of the SOR strategies in terms of their similarity to historical system operations. This strategy reflects Columbia River system operations before changes were made as a result of the ESA listing of three Snake River salmon stocks. This SOS has two options:

- **SOS 1a (Pre-Salmon Summit Operation)** represents operations as they existed from 1983 through the 1990 to 1991 operating year, including Northwest Power Act provisions to restore and protect fish populations in the basin. Specific volumes for the Water Budget would be provided from Dworshak and Brownlee reservoirs to attempt to meet a target flow of 85 kcfs (2,380 cms) at Lower Granite Dam in May. Sufficient flows would be provided on the Columbia River to meet a target flow of 134 kcfs (3,752 cms) at Priest Rapids Dam in May. Lower Snake River projects would operate within 3 to 5 feet (0.9 to 1.5 m) of full pool. Other projects would operate as they did in 1990 to 1991, with no additional water provided from the Snake River above Brownlee Dam.

- **SOS 1b (Optimum Load-Following Operation)** represents operations as they existed prior to changes resulting from the Northwest Power Act. It is designed to demonstrate how much power could be produced if most flow-related operations to benefit anadromous fish were eliminated including the Water Budget; fish spill requirements; restrictions on operation of Bonneville's second powerhouse; and refill targets for Libby, Hungry Horse, Grand Coulee, Dworshak, and Albeni Falls. It assumes that transportation would be used to the maximum to aid juvenile fish migration.

4.1.3 SOS 2–Current Operations

This alternative reflects operation of the Columbia River system with interim flow improvement measures made in response to ESA listings of Snake River salmon. It is very similar to the way the system operated in 1992 and reflects the results of ESA Section 7 consultation with NMFS then. The strategy is consistent with the 1992 to 1993 operations described in the Corps' *1993 Interim Columbia and Snake Rivers Flow Improvement Measures Supplemental EIS* (SEIS). SOS 2 also most closely represents the recommendations issued by the NMFS Snake River Salmon Recovery Team in May 1994. Compared to SOS 1, the primary changes are additional flow augmentation in the Columbia and Snake Rivers and modified pool levels at lower Snake and John Day reservoirs during juvenile salmon migration. This strategy has two options:

- **SOS 2c (Final SEIS Operation—No Action Alternative)** matches exactly the decision made as a result of the 1993 SEIS. Flow augmentation water of up to 3.0 MAF (3.7 billion m³) on the Columbia River (in addition to the existing Water Budget) would be stored during the winter and released in the spring in low-runoff years. Dworshak would provide at least an additional 300 KAF (370 million m³) in the spring and 470 KAF (580 million m³) in the summer for flow augmentation. System flood control shifts from Dworshak and Brownlee to Grand

Table 4-1. SOS Alternatives–1

Summary of SOS

SOS 1 Pre-ESA Operation	SOS 2 Current Operations	SOS 4 Stable Storage Project Operation
SOS 1 represents system operations before changes were made as a result of the ESA listing of three Snake River salmon stocks. SOS 1a represents operations from 1983 through the 1990–91 operating year, influenced by Northwest Power Act; SOS 1b represents how the system would operate without the Water Budget and related operations to benefit anadromous fish. Short-term operations would be conducted to meet power demands while satisfying nonpower requirements.	SOS 2 reflects operation of the system with interim flow improvement measures in response to the ESA salmon listings. It is consistent with the 1992–93 operations described in the Corps' 1993 Interim Columbia and Snake River Flow Improvement Measures Supplemental EIS. SOS 2c represents the operating decision made as a result of the 1993 Supplemental EIS and is the no action alternative for the SOS. Relative to SOS 1a, primary changes are additional flow augmentation in the Columbia and Snake Rivers and modified pool levels at lower Snake and John Day reservoirs during juvenile salmon migration. SOS 2d represents operations of the 1994–98 Biological Opinion issued by NMFS, with additional flow aumentation measures compared to SOS 2c.	SOS 4 would coordinate operation of storage reservoirs to benefit recreation, resident fish, wildlife, and anadromous fish, while minimizing impacts to power and flood control. Reservoirs would be managed to specific elevations on a monthly basis; they would be kept full longer, while still providing spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. SOS 4c attempts to accommodate anadromous fish needs by shaping mainstem flows to benefit migrations and would modify the flood control operations at Grand Coulee.

Actions by Project

	SOS 1	SOS 2	SOS 4
LIBBY	**SOS 1a** Normal 1983–1991 storage project operations	**SOS 2c** Operate on system proportional draft as in SOS 1a	**SOS 4c** • Meet specific elevation targets as indicated by Integrated Rule Curves (IRCs); IRCs are based on storage content at the end of the previous year, determination of the appropriate year within the critical period, and runoff forecasts beginning in January
	SOS 1b • Minimum project flow 3 kcfs • No refill targets • Summer draft limit of 5–10 feet	**SOS 2d** • Provide flow augmentation for salmon and sturgeon when Jan. to July forecast is greater than 6.5 MAF • Meet sturgeon flows of 15, 20, and 12.5 kcfs in May, June, and July, respectively, in at least 3 out of 10 years	• IRCs seek to keep reservoir full (2,459 feet) June-Sept; minimum annual elevation ranges from 2,399 to 2,327 feet, depending on critical year determination • Meet variable sturgeon flow targets at Bonners Ferry during May 25-August 16 period; flow targets peak as high as 35 kcfs in the wettest years

KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives–1

SOS 5 Natural River Operation	SOS 6 Fixed Drawdown	SOS 9 Settlement Discussion Alternatives	SOS PA
SOS 5 would aid juvenile salmon by increasing river velocity. The four lower Snake River projects would have new outlets installed, allowing the reservoirs to be drawn down to near the original river elevation. The "natural river" operation would be done for 4 1/2 months in SOS 5b and year-round in SOS 5c. John Day would also be operated at MOP for 4 months, and flow augmentation measures on the Columbia River portion of the basin would continue as in SOS 2c.	SOS 6 involves drawing down lower Snake River projects to fixed elevations below MOP to aid anadromous fish. SOS 6b provides for fixed drawdowns for all four lower Snake projects for 4 1/2 months; SOS 6d draws down Lower Granite only for 4 1/2 months. John Day would also be operated at MOP for 4 months, and flow augmentation measures on the Columbia River portion of the basin would continue as in SOS 2c.	SOS 9 represents operations suggested by the USFWS, NMFS, the state fisheries agencies, Native American tribes, and the Federal operating agencies during the settlement discussions in response to the *IDFG v. NMFS* court proceedings. This alternative has three options, SOSs 9a, 9b, and 9c, that represent different scenarios to provide increased river velocities for anadromous fish by establishing flow targets during migration and to carry out other actions to benefit ESA-listed species. The three options are termed the Detailed Fishery Operating Plan (9a), Adoptive Management (9b), and the Balanced Impacts Operation (9c).	SOS PA represents the operation recommended by NMFS and the USFWS Biological Opinions issued March 1, 1995. This SOS supports recovery of ESA-listed species by storing water during the fall and winter to meet spring and summer flow targets, and protects other resources by setting summer draft limits to manage negative effects, by providing flood protection, and by providing for reasonable power generation.

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b Operate on system proportional draft as in SOS 1a **SOS 5c** Operate on system proportional draft as in SOS 1a	**SOS 6b** Operate on system proportional draft as in SOS 1a **SOS 6d** Operate on system proportional draft as in SOS 1a	**SOS 9a** • Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period • Provide sturgeon flow releases April-Aug. to achieve up to 35 kcfs at Bonner's Ferry with appropriate ramp up and ramp down rates **SOS 9b** • Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation • Provide sturgeon flow releases similar to SOS 2d • Can draft to elevation 2,435 by end of July to meet flow targets **SOS 9c** • Operate to the Integrated Rule Curves and provide sturgeon flow releases as in SOS 4c	**SOS PA** • Operate on minimum flow up to flood control rule curves beginning in Jan., except during flow augmentation period • Strive to achieve flood control elevations in Dec. in all years and by April 15 in 75 percent of years • Provide sturgeon flows of 25 kcfs 42 days in June and July • Provide sufficient flows to achieve 11 kcfs flow at Bonner's Ferry for 21 days after maximum flow period • Draft to meet flow targets, to a minimum end of Aug. elevation of 2,439 feet, unless deeper drafts needed to meet sturgeon flows

1 kcfs = 28 cms   1 ft = 0.3048 meter

Table 4-1. SOS Alternatives–2

Actions by Project

HUNGRY HORSE

SOS 1	SOS 2	SOS 4
SOS 1a	**SOS 2c**	**SOS 4c**
Normal 1983–1991 storage project operations	Operate on system proportional draft as in SOS 1a	• Meet specific elevation targets as indicated by Integrated Rule Curves (IRCs), similar to operation for Libby
SOS 1b	**SOS 2d**	• IRCs seek to keep reservoir full (3,560 feet) June–Sept.; minimum annual elevation ranges from 3,520 to 3,450 feet, depending on critical year
• No maximum flow restriction from mid-Oct. to mid-Nov. • No draft limit; no refill target	Operate on system proportional draft as in SOS 1a	

ALBENI FALLS

SOS 1	SOS 2	SOS 4
SOS 1a	**SOS 2c**	**SOS 4c**
Normal 1983–1991 storage project operations	Operate on system proportional draft as in SOS 1a	Elevation targets established for each month, generally 2,056 feet Oct.–March, 2,058 to 2,062.5 feet April–May, 2,062.5 feet (full) June, 2,060 feet July–Sept. (but higher if runoff high); Oct.–March drawdown to 2,051 feet every 6th year
SOS 1b	**SOS 2d**	
No refill target	Operate on system proportional draft as in SOS 1a	

KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives–2

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Operate on system proportional draft as in SOS 1a	Operate on system proportional draft as in SOS 1a	• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period	• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period
SOS 5c	**SOS 6d**	**SOS 9b**	• Strive to achieve flood control elevations by April 15 in 75 percent of the years
Operate on system proportional draft as in SOS 1a	Operate on system proportional draft as in SOS 1a	• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation	• Draft to meet flow targets, to a minimum end-of-August elevation of 3,540 feet
		• Can draft to meet flow targets, to a minimum end-of-July elevation of 3,535 feet	
		SOS 9c	
		• Operate to the Integrated Rule Curves as in SOS 4c	

	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Operate on system proportional draft as in SOS 1a	Operate on system proportional draft as in SOS 1a	Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period	• Operate to flood control elevations by April 15 in 90 percent of the years
SOS 5c	**SOS 6d**	**SOS 9b**	• Operate to help meet flow targets, but do not draft below full pool through Aug.
Operate on system proportional draft as in SOS 1a	Operate on system proportional draft as in SOS 1a	• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period	
		• Can draft to meet target flows, to a minimum end-of-July elevation of 2,060 feet	
		SOS 9c	
		• Elevation targets established for each month, generally no lower than 2,056 feet Dec.—April, no lower than 2,057 feet end of May, full (2,062.5 feet) June—Aug., 2,056 feet Sept.—Nov.	

1 kcfs = 28 cms   1 ft = 0.3048 meter

Table 4-1. SOS Alternatives–3

Actions by Project

	SOS 1	SOS 2	SOS 4
GRAND COULEE	**SOS 1a** • Operate to meet Water Budget target flows of 134 kcfs at Priest Rapids in May [1] • Meet minimum elevation of 1,240 feet in May **SOS 1b** • No refill target of 1,240 feet in May • Maintain 1,285 feet June–Sept.; minimum 1,220 feet rest of year • No May–June flow target	**SOS 2c** • Storage of water for flow augmentation from January through April • Supplemental releases (in conjunction with upstream projects) to provide up to 3 MAF additional (above Water Budget) flow augmentation in May and June, based on sliding scale for runoff forecasts • System flood control space shifted from Brownlee, Dworshak **SOS 2d** • Contribute, in conjunction with upstream storage projects, up to 4 MAF for additional flow augmentation • Operate in summer to provide flow augmentation water and meet downstream flow targets, but draft no lower than 1,280 feet	**SOS 4c** • Operate to end-of-month elevation targets, as follows: 1,288 Sept.-Nov 1,287 Dec. 1,270 Jan. 1,260 Feb. 1,270 Mar. 1,272 Apr. 15 1,275 Apr. 30 1,280 May 1,288 Jun.-Aug. • Meet flood control rule curves only when Jan.-June runoff forecast exceeds 68 MAF

	SOS 1	SOS 2	SOS 4
PRIEST RAPIDS	**SOS 1a** • Meet May-June flow targets [1] • Maintain minimum flows to meet Vernita Bar Agreement [2] **SOS 1b** • No May flow target • Meet Vernita Bar Agreement	**SOS 2c** Operate as in SOS 1a **SOS 2d** Operate as in SOS 1a	**SOS 4c** Operate as in SOS 1a

1/ Flow targets are weekly averages with weekend and holiday flows no less than 80 percent of flows over previous 5 days.
2/ 55 kcfs during heavy load hours October 15 to November 30; minimum instantaneous flow 70 kcfs December to April
   KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives–3

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Operate on system proportional draft and provide flow augmentation as in SOS 2c	Operate on system proportional draft and provide flow augmentation as in SOS 2c	• Operate to meet flood control requirements and Vernita Bar agreement	• Operate to achieve flood control elevations by April 15 in 85% of years
SOS 5c	**SOS 6d**	• Provide flow augmentation releases to help meet targets at The Dalles of 220-300 kcfs April 16-June 15, 200 kcfs June 16-July 31, and 160 kcfs Aug. 1-Aug.31, based on appropriate critical year determination	• Draft to meet flow targets, down to minimum end-of-Aug. elevation of 1,280 feet
Operate on system proportional draft and provide flow augmentation as in SOS 2c	Operate on system proportional draft and provide flow augmentation as in SOS 2c	• In above average runoff years, provide 40% of the additional runoff volume as flow augmentation	• Provide flow augmentation releases to meet Columbia River flow targets at McNary of 220-260 kcfs April 20-June 30, based on runoff forecast, and 200 kcfs July-Aug.
		SOS 9b	
		• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period	
		• Can draft to meet flow targets, bounded by SOS 9a and 9c targets, to a minimum end-of-July elevation of 1,265 feet	
		SOS 9c	
		• Operate to meet McNary flow targets of 200 kcfs April 16-June 30 and 160 kcfs in July	
		• Can draft to meet flow targets, to a minimum end-of-July elevation of 1,280 feet	
		• Contribute up to 4 MAF for additional flow augmentation, based on sliding scale for runoff forecasts, in conjunction with other upstream projects	
		• System flood control shifted to this project	

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Operate as in SOS 1a	Operate as in SOS 1a	Operate as in SOS 1a	Operate as in SOS 1a
SOS 5c	**SOS 6d**	**SOS 9b**	
Operate as in SOS 1a	Operate as in SOS 1a	Operate as in SOS 1a	
		SOS 9c	
		Operate as in SOS 1a	

1 kcfs = 28 cms   1 ft = 0.3048 meter

Table 4-1. SOS Alternatives—4

Actions by Project

	SOS 1	SOS 2	SOS 4
SNAKE RIVER ABOVE BROWNLEE	**SOS 1a** Normal 1990—91 operations; no Water Budget flows	**SOS 2c** Release up to 427 KAF (190 KAF April 16—June 15; 137 KAF Aug.; 100 KAF Sept.) for flow augmentation	**SOS 4c** Same as SOS 1a
	SOS 1b Same as SOS 1a	**SOS 2d** • Release up to 427 KAF, as in SOS 2c • Release additional water obtained by purchase or other means and shaped per Reclamation releases and Brownlee draft requirements; simulation assumed 927 KAF available	

	SOS 1	SOS 2	SOS 4
BROWNLEE	**SOS 1a** • Draft as needed (up to 110 KAF in May) for Water Budget, based on target flows of 85 kcfs at Lower Granite • Operate per FERC license • Provide system flood control storage space	**SOS 2c** Same as SOS 1a except for additional flow augmentation as follows: • Draft up to 137 KAF in July, but not drafting below 2,067 feet; refill from the Snake River above Brownlee in August • Draft up to 100 KAF in Sept. • Shift system flood control to Grand Coulee • Provide 9 kcfs or less in November; fill project by end of month • Maintain November monthly average flow December through April	**SOS 4c** Same as SOS 1a except slightly different flood control rule curves
	SOS 1b • No maximum flow restriction from mid-Oct. to mid-Nov. • No draft limit; no refill target	**SOS 2d** Same as SOS 2c, plus pass additional flow augmentation releases from upstream projects	

KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives-4

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Same as SOS 1a	Same as SOS 1a	Provide up to 1.927 MAF through Brownlee for flow augmentation, as determined by Reclamation	Provide 427 KAF through Brownlee for flow augmentation, as determined by Reclamation
SOS 5c	**SOS 6d**	**SOS 9b**	
Same as SOS 1a	Same as SOS 1a	Provide up to 927 KAF through Brownlee as determined by Reclamation	
		SOS 9c	
		Provide up to 927 KAF through Brownlee as determined by Reclamation	

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Same as SOS 4c	Same as SOS 4c	• Draft up to 110 KAF in May, 137 KAF in July, 140 KAF in Aug., 100 KAF in Sept. for flow augmentation • Shift system flood control to Grand Coulee	Draft to elevation 2,069 feet in May, 2,067 feet in July, and 2,059 feet in Sept., passing inflow after May and July drafts
SOS 5c	**SOS 6d**	**SOS 9b**	
Same as SOS 4c	Same as SOS 4c	• Draft up to 190 KAF April-May, 137 KAF in July, 100 KAF in Sept. for flow augmentation • Shift system flood control to Grand Coulee • Provide an additional 110 KAF in May if elevation is above 2,068 feet and 110 KAF in Sept. if elevation is above 2,043.3 feet	
		SOS 9c	
		Same as SOS 9b	

1 kcfs = 28 cms   1 ft = 0.3048 meter

Table 4-1. SOS Alternatives–5

Actions by Project

SOS 1	SOS 2	SOS 4
DWORSHAK		

SOS 1a	**SOS 2c**	**SOS 4c**
• Draft up to 600 KAF in May to meet Water Budget target flows of 85 kcfs at Lower Granite • Provide system flood control storage space	Same as SOS 1a, plus the following supplemental releases: • 900 KAF or more from April 16 to June 15, depending on runoff forecast at Lower Granite • Up to 470 KAF above 1.2 kcfs minimum release from June 16 to Aug. 31 • Maintain 1.2 kcfs discharge from Oct. through April, unless higher required • Shift system flood control to Grand Coulee April–July if runoff forecasts at Dworshak are 3.0 MAF or less	Elevation targets established for each month: 1,599 feet Sept.-Oct.; flood control rule curves Nov.-April; 1,595 feet May; 1,599 feet June-Aug.;

SOS 1b

• Meet minimum project flows (2 kcfs, except for 1 kcfs in August); summer draft limits; maximum discharge requirement Oct. to Nov. (1.3 kcfs plus inflow)

• No Water Budget releases

SOS 2d

• Operate on 1.2 kcfs minimum discharge up to flood control rule curve, except when providing flow augmentation (April 10 to July 31)

• Provide flow augmentation of 1.0 MAF plus 1.2 kcfs minimum discharge, or 927 KAF and 1.2 kcfs, from April 10-June 20, based on runoff forecasts, to meet Lower Granite flow target of 85 kcfs

• Provide 470 KAF from June 21 to July 31 to meet Lower Granite flow target of 50 kcfs

• Draft to 1,520 feet after volume is expended, if Lower Granite flow target is not met; if volume is not expended, draft below 1,520 feet until volume is expended

KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives—5

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
• Operate to local flood control rule curve	Same as SOS 5b	• Remove from proportional draft for power	• Operate on minimum flow-up to flood control rule curve year-round, except during flow augmentation period
• No proportional draft for power	**SOS 6d**	• Operate to local flood control rule curves, with system flood control shifted to Grand Coulee	• Draft to meet flow targets, down to min. end-of-Aug. elevation of 1,520 feet
• Shift system flood control to lower Snake projects	Same as SOS 5b	• Maintain flow at 1.2 kcfs minimum discharge, except for flood control or flow augmentation discharges	• Sliding-scale Snake River flow targets at Lower Granite of 85 to 100 kcfs April 10-June 20 and 50 to 55 kcfs June 21-Aug. 31, based on runoff forecasts
• Provide Water Budget flow augmentation as in SOS 1a		• Operate to meet Lower Granite flow targets (at spillway crest) of 74 kcfs April 16-June 30, 45 kcfs July, 32 kcfs August	
• Draft to refill lower Snake projects if natural inflow is inadequate			
SOS 5c		**SOS 9b**	
• Operate to flood control during spring		• Similar to SOS 9a, except operate to meet flow targets at Lower Granite ranging from 85 to 140 kcfs April 16-June 30 and 50-55 kcfs in July	
• Refill in June or July and maintain through August		• Can draft to meet flow targets to a min. end-of-July elevation of 1,490 feet	
• Draft for power production during fall			
		SOS 9c	
		• Similar to SOS 9a, except operate to meet Lower Granite flow target (at spillway crest) of 63 kcfs April-June	
		• Can draft to meet flow targets to a min. end-of-July elevation of 1,520 feet	

1 kcfs = 28 cms   1 ft = 0.3048 meter

Table 4-1. SOS Alternatives–6

Actions by Project

SOS 1	SOS 2	SOS 4

LOWER SNAKE

SOS 1a	**SOS 2c**	**SOS 4c**
• Normal operations at 4 lower Snake River projects (within 3 to 5 feet of full pool, daily and weekly fluctuations)	• Operate reservoirs within 1 foot above MOP from April 16 to July 31	Same as SOS 2c
• Provide maximum peaking capacity of 20 kcfs over daily average flow in May	• Same as SOS 1a for rest of year	

SOS 1b	**SOS 2d**
Same as 1a, except:	Same as SOS 2c
• No minimum flow limit (11,500 cfs) during fall and winter	
• No fish-related rate of change in flows in May	

SOS 1	SOS 2	SOS 4

LOWER COLUMBIA

SOS 1a	**SOS 2a**	**SOS 4c**
• Normal operations at 4 lower Columbia projects (generally within 3 to 5 feet of full pool, daily and weekly fluctuations)	Same as SOS 1a except: lower John Day to minimum irrigation pool (approx. 262.5 feet) from April 15 to Aug. 31; operate within 1.5 feet of forebay range, unless need to raise to avoid irrigation impacts	Same as SOS 2c, except operate John Day within 2 feet of elevation 263.5 feet Nov. 1 through June 30
• Restricted operation of Bonneville second powerhouse		

SOS 1b	**SOS 2d**
Same as 1a, except no restrictions on Bonneville second powerhouse	Same as SOS 2c

KAF = 1.234 million cubic meters   MAF = 1.234 billion cubic meters

Table 4-1. SOS Alternatives—6

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
• Draft 2 feet per day starting Feb. 18 • Operate at natural river level, approx. 95 to 115 ft below full pool, April 16-Aug. 31; drawdown levels by project as follows, in feet: Lower Granite 623 Little Goose 524 L. Monumental 432 Ice Harbor 343 • Operate within 3 to 5 ft of full pool rest of year • Refill from natural flows and storage releases	• Draft 2 feet per day starting April 1 • Operate 33 feet below full pool April 16-Aug. 31; drawdown levels by project as follows, in feet: Lower Granite 705 Little Goose 605 L. Monumental 507 Ice Harbor 407 • Operate over 5-foot forebay range once drawdown elevation reached • Refill from natural flows and storage releases • Same as SOS 1a rest of year	• Operate 33 feet below full pool (see SOS 6b) April 1-Aug. 31 to meet L. Granite flow targets (see Dworshak); same as SOS 1a rest of year • Spill to achieve 80/80 FPE up to total dissolved gas cap of 120% daily average; spill cap 60 kcfs at all projects	• Operate at MOP with 1 foot flexibility between April 10 - Aug. 31 • Refill three lower Snake River pools after Aug. 31, Lower Granite after Nov. 15 • Spill to achieve 80% FPE up to total dissolved gas cap of 115% 12-hour average; spill caps range from 7.5 kcfs at L. Monumental to 25 kcfs at Ice Harbor
SOS 5c		**SOS 9b**	
Same as SOS 5b, except drawdowns are permanent once natural river levels reached; no refill	**SOS 6d** • Draft Lower Granite 2 feet per day starting April 1 • Operate Lower Granite near 705 ft for 4 1/2 months, April 16-Aug. 31	• Operate at MOP, with 1 foot flexibility April 1-Aug. 31; same as SOS 1a rest of year • Spill to achieve 80/80 FPE up to total dissolved gas cap of 120% daily average; spill caps range from 18 kcfs at L. Monumental to 30 kcfs at L. Granite	
		SOS 9c	
		• Operate 35 to 45 feet below full pool April 1-June 15 to meet L. Granite flow targets (see Dworshak), refill by June 30; same as SOS 1a rest of year • Spill to achieve 80/80 FPE, as in SOS 9b	

SOS 5	SOS 6	SOS 9	SOS PA
SOS 5b	**SOS 6b**	**SOS 9a**	**SOS PA**
Same as SOS 2, except operate John Day within 1.5 feet above elevation 257 feet (MOP) from May 1 through Aug. 31; same as SOS 2c rest of year	Same as SOS 5	• Same as SOS 5, except operate John Day within 1 foot above elevation 257 feet April 15-Aug. 31 • McNary flow targets as described for Grand Coulee • Spill to achieve 80/80 FPE, up to total dissolved gas cap of 120% daily average, as derived by state agencies	• Pool operations same as SOS 2c, except operate John Day at 257 feet (MOP) year-round, with 3 feet of flexibility March-Oct. and 5 feet of flexibility Nov.-Feb. • Spill to achieve 80% FPE up to total dissolved gas cap of 115% 12-hour average; spill caps range from 9 kcfs at John Day to 90 kcfs at The Dalles
SOS 5c	**SOS d** Same as SOS 5	**SOS 9b**	
Same as SOS 5b		• Same as SOS 2, except operate John Day at minimum irrigation pool or 262.5 feet with 1 foot of flexibility from April 16-Aug. 31 • McNary flow targets as described for Grand Coulee • Spill to achieve 80/80 FPE, up to total dissolved gas cap of 120% daily average, as derived by Corps	
		SOS 9b	
		Same as SOS 9b, except operate John Day at minimum operating pool	

1 kcfs = 28 cms   1 ft = 0.3048 meter

Coulee would occur through April as needed. It also provides up to 427 KAF (527 million m³) of additional water from the Snake River above Brownlee Dam.

- **SOS 2d (1994-98 Biological Opinion)** matches the hydro operations contained in the 1994-98 Biological Opinion issued by NMFS in mid-1994. This alternative provides water for the existing Water Budget as well as additional water, up to 4 MAF, for flow augmentation to benefit the anadromous fish migration. The additional water of up to 4 MAF would be stored in Grand Coulee, Libby, and Arrow, and provided on a sliding scale tied to runoff forecasts. Flow targets are established at Lower Granite and McNary.

In cases such as the SOR, where the proposed action is a new management plan, the No Action Alternative means continuing with the present course of action until that action is changed (46 FR 13027). Among all of the strategies and options, SOS 2c best meets this definition for the No Action Alternative.

4.1.4 SOS 4-Stable Storage Project Operation

This alternative is intended to operate the storage reservoirs to benefit recreation, resident fish, wildlife, and anadromous fish while minimizing impacts of such operation to power and flood control. Reservoirs would be kept full longer, but still provide spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. For the Final EIS, this alternative has one option:

- **SOS 4c (Stable Storage Operation with Modified Grand Coulee Flood Control)** applies year-round Integrated Rule Curves (IRCs) developed by the State of Montana for Libby and Hungry Horse. Other reservoirs would be managed to specific elevations on a monthly basis; they would be

kept full longer, while still providing spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. Grand Coulee would meet elevation targets year-round to provide acceptable water retention times; however, upper rule curves would apply at Grand Coulee if the January to July runoff forecast at the project is greater than 68 MAF (84 billion m³).

4.1.5 SOS 5-Natural River Operation

This alternative is designed to aid juvenile salmon migration by drawing down reservoirs (to increase the velocity of water) at four lower Snake River projects. SOS 5 reflects operations after the installation of new outlets in the lower Snake River dams, permitting the lowering of reservoirs approximately 100 feet (30 m) to near original riverbed levels. This operation could not be implemented for a number of years, because it requires major structural modifications to the dams. Elevations would be: Lower Granite—623 feet (190 m); Little Goose—524 feet (160 m); Lower Monumental—432 feet (132 m); and Ice Harbor—343 feet (105 m). Drafting would be at the rate of 2 feet (0.6 m) per day beginning February 18. The reservoirs would refill again with natural inflows and storage releases from upriver projects, if needed. John Day would be lowered as much as 11 feet (3.3 m) to minimum pool, elevation 257 feet (78.3 m), from May through August. All other projects would operate essentially the same as in SOS 1a, except that up to 3 MAF (3.7 billion m³) of water (in addition to the Water Budget) would be provided to augment flows on the Columbia River in May and June. System flood control would shift from Brownlee and Dworshak to the lower Snake River projects. Also, Dworshak would operate for local flood control. This alternative has two options:

- **SOS 5b (Four and One-half Month Natural River Operation)** provides for a lower Snake River drawdown lasting 4.5 months, beginning April 16 and ending August 31. Dworshak would be drafted to

refill the lower Snake River projects if natural inflow were inadequate for timely refill.

- **SOS 5c (Permanent Natural River Operation)** provides for a year-round drawdown, and projects would not be refilled after each migration season.

4.1.6 SOS 6–Fixed Drawdown

This alternative is designed to aid juvenile anadromous fish by drawing down one or all four lower Snake River projects to fixed elevations approximately 30 to 35 feet (9 to 10 m) below minimum operating pool. As with SOS 5, fixed drawdowns depend on prior structural modifications and could not be instituted for a number of years. Draft would be at the rate of 2 feet (0.6 m) per day beginning April 1. John Day would be lowered to elevation 257 feet (78.3 m) from May through August. All other projects would operate essentially the same as under SOS 1a, except that up to 3 MAF (3.7 billion m^3) of water would be provided to augment flows on the Columbia River in May and June. System flood control would shift from Brownlee and Dworshak to the lower Snake projects. Also, Dworshak would operate for local flood control. This alternative has two options:

- **SOS 6b (Four and One-half Month Fixed Drawdown)** provides for a 4.5-month drawdown at all four lower Snake River projects beginning April 16 and ending August 31. Elevations would be: Lower Granite—705 feet (215 m); Little Goose—605 feet (184 m); Lower Monumental—507 feet (155 m); and Ice Harbor—407 feet (124 m).

- **SOS 6d (Four and One-half Month Lower Granite Fixed Drawdown)** provides for a 4.5-month drawdown to elevation 705 feet at Lower Granite beginning April 16 and ending August 31.

4.1.7 SOS 9–Settlement Discussion Alternatives

This SOS represents operations suggested by USFWS and NMFS (as SOR cooperating agencies), the state fisheries agencies, Native American tribes, and the Federal operating agencies during the settlement discussions in response to a court ruling in the *IDFG v. NMFS* lawsuit. The objective of SOS 9 is to provide increased velocities for anadromous fish by establishing flow targets during the migration period and by carrying out other actions that benefit ESA-listed species. The specific options were developed by a group of technical staff representing the parties in the lawsuit. The group was known as the Reasonable and Prudent Alternatives Workgroup. They developed three possible operations in addition to the 1994-98 Biological Opinion. This strategy has three options:

- **SOS 9a (Detailed Fishery Operating Plan [DFOP])** establishes flow targets at The Dalles based on the previous year's end-of-year storage content, similar to how PNCA selects operating rule curves. Grand Coulee and other storage projects are used to meet The Dalles flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to near spillway crest level for 4.5 months. Specific spill percentages are established at run-of-river projects to achieve no higher than 120 percent daily average total dissolved gas. Fish transportation is assumed to be eliminated.

- **SOS 9b (Adaptive Management)** establishes flow targets at McNary and Lower Granite based on runoff forecasts. Grand Coulee and other storage projects are used to meet the McNary flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and the upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to minimum operating pool levels and John Day

is at minimum irrigation pool level. Specific spill percentages are established at run-of-river projects to achieve no higher than 120 percent daily average for total dissolved gas.

- **SOS 9c (Balanced Impacts Operation)** draws down the four lower Snake River projects to near spillway crest levels for 2.5 months during the spring salmon migration period. Full drawdown level is achieved on April 1. Refill begins after June 15. This alternative also provides 1994-98 Biological Opinion flow augmentation (as in SOS 2d), IRC operation at Libby and Hungry Horse, a reduced flow target at Lower Granite due to drawdown, limits on winter drafting at Albeni Falls, and spill to achieve no higher than 120 percent daily average for total dissolved gas.

4.1.8 SOS PA–Preferred Alternative

This SOS represents the operation recommended by NMFS and USFWS in their respective Biological Opinions issued on March 1, 1995. SOS PA is intended to support recovery of ESA-listed species by storing water during the fall and winter to meet spring and summer flow targets, and to protect other resources by managing detrimental effects through maximum summer draft limits, by providing public safety through flood protection, and by providing for reasonable power generation. This SOS would operate the system during the fall and winter to achieve a high confidence of refill to flood control elevations by April 15 of each year, and use this stored water for fish flow augmentation. It establishes spring flow targets at McNary and Lower Granite based on runoff forecasts, and a similar sliding scale flow target at Lower Granite and a fixed flow target at McNary for the summer. It establishes summer draft limits at Hungry Horse, Libby, Grand Coulee, and Dworshak. Libby is also operated to provide flows for Kootenai River white sturgeon. Lower Snake River projects are drawn down to minimum operating pool levels during the spring and summer. John Day is operated at minimum operating pool level year-round. It should be noted that the NMFS

Biological Opinion recommends this operation, on the condition that appropriate mitigation measures are assured. Specific spill percentages are established at run-of-river projects to achieve 80-percent FPE, with no higher than 115-percent 12-hour daily average for total dissolved gas measured at the forebay of the next downstream project.

4.1.9 Rationale for Selection of the Final SOSs

Table 4-2 summarizes the changes in the set of SOS alternatives from the Draft EIS to the Final EIS. SOSs 1a and 1b are unchanged from the Draft EIS. SOS 1a represents a base case condition and reflects system operation during the period from passage of the Northwest Power Planning and Conservation Act until ESA listings. It provides a baseline alternative that allows for comparison of the more recent alternatives and shows the recent historical operation. SOS 1b represents a limit for system operation directed at maximizing benefits from development-oriented uses, such as power generation, flood control, irrigation, and navigation and away from natural resources protection. It serves as one end of the range of alternatives and provides a basis for comparison of the impacts to power generation from all other alternatives. Public comment did not recommend elimination of this alternative because it serves as a useful milepost. However, the SOR agencies recognize it is unlikely that decisions would be made to move operations toward this alternative.

In the Draft EIS, SOS 2 represented current operation. Three options were considered. Two of these options have been eliminated for the Final EIS and one new option has been added. SOS 2c continues as the No Action Alternative. Maintaining this option as the No Action Alternative allows for consistent comparisons in the Final EIS to those made in the Draft EIS. However, within the current practice category, new operations have been developed since the original identification of SOS 2c. In 1994, the SOR agencies, in consultation with the NMFS and USFWS, agreed to an operation that was

Table 4-2. Summary of alternatives in the Draft and Final EIS.

Draft EIS Alternatives	Final EIS Alternatives
SOS 1 Pre-ESA Operation SOS 1a Pre-Salmon Summit Operation SOS 1b Optimum Load Following Operation	SOS 1 Pre-ESA Operation SOS 1a Pre-Salmon Summit Operation SOS 1b Optimum Load Following Operation
SOS 2 Current Practice SOS 2a Final Supplemental EIS Operation SOS 2b Final Supplemental EIS with Sturgeon Operations at Libby. SOS 2c Final Supplemental EIS Operation - No-Action Alternative	SOS 2 Current Practice SOS 2c Final Supplemental EIS Operation—No-Action Alternative **SOS 2d 1994-98 Biological Opinion Operation**
SOS 3 Flow Augmentation SOS 3a Monthly Flow Targets SOS 3b Monthly Flow Targets with additional Snake River Water	[Deleted for Final EIS]
SOS 4 Stable Storage Project Operation SOS 4a1 Enhanced Storage Level Operation SOS 4a3 Enhanced Storage Level Operation SOS 4b1 Compromise Storage Level Operation SOS 4b3 Compromise Storage Level Operation SOS 4c Enhanced Operation with Modified Grand Coulee Flood Control	SOS 4 Stable Storage Project Operation **SOS 4c Enhanced Operation with Modified Grand Coulee Flood Control**
SOS 5 Natural River Operation SOS 5a Two-Month Natural River Operation SOS 5b Four and One-Half Month Natural River Operation	SOS 5 Natural River Operation SOS 5b Four and One-Half Month Natural River Operation **SOS 5c Permanent Natural River Operation**
SOS 6 Fixed Drawdown SOS 6a Two-Month Fixed Drawdown Operation SOS 6b Four and One-Half Month Fixed Drawdown Operation SOS 6c Two-Month Lower Granite Drawdown Operation SOS 6d Four and One-Half Month Lower Granite Drawdown Operation	SOS 6 Fixed Drawdown SOS 6b Four and One-Half Month Fixed Drawdown Operation SOS 6d Four and One-Half Month Lower Granite Drawdown Operation
SOS 7 Federal Resource Agency Operations SOS 7a Coordination Act Report Operation SOS 7b Incidental Take Statement Flow Targets SOS 7c NMFS Conservation Recommendations	**SOS 9 Settlement Discussion Alternatives** **SOS 9a Detailed Fishery Operating Plan** **SOS 9b Adaptive Management** **SOS 9c Balanced Impacts Operation** **SOS PA Preferred Alternative**

Note: Bold indicates a new or revised SOS alternative; Draft EIS SOS 7 options replaced with SOS 9 options for Final EIS.

reflected in the 1994-98 Biological Opinion. This operation (SOS 2d) has been modeled for the Final EIS and represents the most "current" practice. SOS 2d also provides a good baseline comparison for the other, more unique alternatives. SOSs 2a and 2b from the Draft EIS were eliminated because they are so similar to SOS 2c. SOS 2a is identical to SOS 2c except for the lack of an assumed additional 427 KAF of water from the upper Snake River Basin. This additional water did not cause significant changes to the effects between SOSs 2a and 2c. There is no reason to continue to consider an alternative that has impacts essentially equal to another alternative. SOS 2b is also similar to SOS 2c, except it modified operation at Libby for Kootenai River white sturgeon. Such modifications are included in several other alternatives, namely SOSs 2d, 9a, 9c, and PA.

SOSs 3a and 3b, included in the Draft EIS, have been dropped from consideration in the Final EIS. Both of these alternatives involved anadromous fish flow augmentation by establishing flow targets based on runoff forecast on the Columbia and Snake Rivers. SOS 3b included additional water from the upper Snake River Basin over what was assumed for SOS 3a. This operation is now incorporated in several new alternatives, including SOSs 9a and 9b. Public comment also did not support continued consideration of the SOS 3 alternatives.

SOS 4 originally included five options in the Draft EIS. They were similar in operation and impact. In SOSs 4a and 4b, the primary feature was the use of Biological Rule Curves for Libby and Hungry Horse reservoirs. SOS 4c also included these rule curves but went further by optimizing the operation of the other storage projects, particularly Grand Coulee and Dworshak. For the Final EIS, the SOR agencies have decided to update the alternative by substituting the IRCs for the Biological Rule Curves and by eliminating SOSs 4a and 4b. The IRCs are a more recent, acceptable version of minimum elevations for Libby and Hungry Horse. Significant public comment in support of this alternative with IRCs was received. Similar

to SOS 2 above, SOSs 4a and 4b were not different enough in operation or impacts to warrant continued consideration.

The Natural River (SOS 5) and the Spillway Crest Drawdown (SOS 6) alternatives in the Draft EIS originally included options for 2 months of drawdown to the appropriate pool level and 4.5 months of drawdown. The practicality of 2-month drawdowns was questioned during public review, particularly for the natural river. It did not appear that the time involved in drawing down the reservoirs and later refilling them provided the needed consideration for other uses. Flows are restricted to refill the reservoirs at a time when juvenile fall chinook are migrating downstream and various adult species are returning upstream. The 2.5-month drawdown strategies (SOSs 5a, 6a, and 6c) have been dropped from the Final EIS. However, 2.5-month spillway crest drawdown at all four lower Snake projects is still an element in SOS 9c, so the impacts associated with this type of operation are assessed in the Final EIS.

A new option was added to SOS 5, namely SOS 5c. This option includes natural river drawdown of the lower Snake River projects on a permanent, year-round basis. The Corps received comment on this type of alternative during the review of Phase I of the SCS, a reconnaissance assessment of potential physical modifications for the system to enhance fish passage. Many believe the cost for such modification would be less than that required for periodic, temporary drawdowns, which would require specialized facilities to enable the projects to refill and operate at two different pool elevations.

SOS 7 Federal Resource Agencies Operations, which included three options in the Draft EIS, has been dropped from the Final EIS and replaced with an alternative now labeled as SOS 9 that also has three options. SOS 7a was suggested by the USFWS and represented the state fishery agencies and tribes' recommended operation. Since the issuance of the Draft EIS, this particular operation has been revised and

replaced by the DFOP (SOS 9a). The SOR agencies received comment that the DFOP was not evaluated, but should be. Therefore, we have included this alternative exactly as proposed by these agencies; it is SOS 9a. SOSs 7b and 7c were suggested by NMFS through the 1993 Biological Opinion. This opinion suggested two sets of flow targets as a way of increasing flow augmentation levels for anadromous fish. The flow targets came from the Incidental Take Statement and the Conservation Recommendation sections of that Biological Opinion. The opinion was judged as arbitrary and capricious as a result of legal action, and these operational alternatives have been replaced with other alternatives that were developed through settlement discussions among the parties to this lawsuit. SOSs 7b and 7c have been dropped, but SOSs 9b and 9c have been added to represent operations stemming from NMFS or other fishery agencies. In particular, SOS 9b is like DFOP but has reduced flow levels and forgoes drawdowns. It is a modification to DFOP. SOS 9c incorporates elements of operation supported by the State of Idaho in its "Idaho Plan." It includes a 2.5-month spillway crest drawdown on the lower Snake River projects and several other elements that attempt to strike a balance among the needs of anadromous fish, resident fish, wildlife, and recreation.

Shortly after the alternatives for the Draft EIS were identified, the Nez Perce Tribe suggested an operation that involved drawdown of Lower Granite, significant additional amounts of upper Snake River water, and full pool operation at Dworshak (i.e., Dworshak remains full year round). It was labeled as SOS 8a. Hydroregulation of that operation was completed and provided to the Nez Perce Tribe. No technical response has been received from the Nez Perce Tribe regarding the features or results of this alternative. However, the elements of this operation are generally incorporated in one or more of the other alternatives, or impose requirements on the system that could not be met without changes in state water laws. Therefore, this alternative has not been carried forward into the Final EIS.

The Preferred Alternative (SOS PA) represents operating requirements contained in the 1995 Biological Opinions issued by NMFS and USFWS on operation of the FCRPS. These opinions resulted from ESA consultation conducted during late 1994 and early 1995, which were a direct consequence of the lawsuit and subsequent judgement in *IDFG v. NMFS*. The SOR agencies are now implementing this operating strategy and have concluded that it represents an appropriate balance among the multiple uses of the river. This strategy recognizes the importance of anadromous fish and the need to adjust river flows to benefit the migration of all salmon stocks, as well as the needs of resident fish and wildlife species at storage projects.

4.1.10 SOS Alternatives Not Studied in Detail

The SOR Interagency Team considered a number of alternative ways to address the project purposes in the SOS. Alternatives that the Interagency Team decided not to study in detail for this EIS are briefly described below.

A broad range of changes in system operations was considered for the SOR, including some fairly radical proposals. During scoping, many actions were suggested that were outside the scope of the study, which was limited to the operation of the Columbia River system. Additional alternatives of this type were suggested in review comments on the Draft EIS. Alternatives beyond the scope of the SOR included structural modifications at the projects to improve specific resource areas, and actions independent of project operations that go beyond the jurisdiction of the Federal agencies involved in the SOR. While such alternatives were not studied in detail in this EIS, many are being or have been considered in other studies undertaken by one of the SOR agencies or other parties within the region (see Chapter 10 of this EIS, and *Scoping Document, Appendix 1: Related Activities*). The SOR work groups suggested alternatives in the early stages of their work, but many of these alternatives were not carried

forward for further study after screening, for a variety of reasons.

Structural Modifications at the Projects

The Corps' System Configuration Study (SCS) is evaluating major structural modifications to some of the 14 Federal projects in response to the NPPC's Phase 2 and Phase 3 amendments to its regional Fish and Wildlife Program. Structural measures were suggested for study during the SOR, but were not pursued because they are part of the SCS or are otherwise beyond the SOR scope. These measures include:

- Modifying adult fish ladder entrances and exits to improve adult passage survival

- Installing juvenile bypasses at all major dams with high fish mortality rates

- Installing fish screens at dams and over irrigation diversion outlets

- Developing fish byways to divert and rejoin the rivers

- Constructing a smolt canal paralleling the Snake and Columbia Rivers from just below the mouth of the Clearwater to just below Bonneville Dam

- Developing new facilities and equipment to improve the juvenile fish transportation program

- Installing locks at additional dams to expand the navigation system

- Modifying recreational facilities to allow their use over a wider range of operating conditions.

While structural measures themselves are not a part of the SOR, system operations that would be possible only with significant project modifications are represented in some of the system operating strategies.

Nonproject Alternatives

Early in the SOR, some alternatives were suggested that pertained to river uses but did not directly involve operations at the 14 Federal projects within the SOR scope. Most of these alternatives emphasized fish and wildlife concerns, topics that drew a lot of attention during SOR scoping. Fisheries managers and other interests have had most of these concepts under consideration for a decade or more. Many have been or will be implemented through the NPPC's Fish and Wildlife Program amendments, or through agency responses to ESA requirements. In other cases, it is possible that the measures will not be implemented due to a lack of incentives or political consensus. Such measures include the following:

- Improving streams and watersheds to restore salmonid spawning and rearing habitat

- Preserving and enlarging wildlife habitat by protecting watersheds, re-establishing native vegetation, discouraging grazing and cropping in erosion-prone areas, and planting cottonwoods and poplars for riparian wildlife

- Expanding research on hatchery programs and preservation of native fish stocks, and improving hatchery operations to both increase survival of hatchery fish and reduce competition with wild fish

- Encouraging propagation of fish species that are more adaptable to current operations

- Banning or lifting commercial fishing on the Columbia River

- Prohibiting fishing with gill nets

- Further limiting catches and the length of fishing seasons and instituting larger minimum sizes for fish that can be kept by anglers

- Undertaking a comprehensive review of logging and mining practices, agricultural runoff, and municipal and industrial pollution to determine their effects on anadromous fish

- Modifying irrigation delivery systems and methods to conserve water for instream use

- Examining the possible use of increased cogeneration, improved irrigation efficiency; and energy conservation to save water and thereby improve flows for anadromous fish

- Implementing controls for nonpoint sources of water pollution to improve the quality of runoff entering streams

- Energy and capacity marketing that would shift or adjust load shape.

SOS Alternatives Not Carried Forward from Screening

As noted above, in screening the SOR agencies grouped many alternatives by their operating similarities. In formulating the strategies to be carried forward to full-scale analysis, only one alternative representative of each type was put on the list, in most cases. Some alternatives were dropped from further consideration when screening information indicated they were not viable. Still others were eliminated because they were already under study in other related regional activities, such as the Corps' SCS.

The SOR publication, *Screening Analysis, Volumes 1 and 2* contains a full description of the results of the screening analysis, ranking of alternatives, and the initial development of candidate strategies.

While some of the screening alternatives included selected drawdown measures for lower Columbia River projects, the SOS alternatives evaluated in the Draft and Final EIS (see Section 4.1) do not incorporate any specific operational changes at McNary, The Dalles, or Bonneville on the lower Columbia. This was because the Corps' 1992 OA/EIS (Corps et al., 1992)

indicated that without major structural modifications, operation of the four lower Columbia River reservoirs at or near minimum operating pool levels would cause significant adverse impacts to water users. The NPPC and the Corps are continuing to investigate drawdown actions at John Day because it is the largest lower Columbia reservoir and might yield measurable water velocity increases. Based on the 1992 analysis, lead agencies believe that the costs and resource impacts of operational changes at McNary, The Dalles, and Bonneville outweigh the potential flow improvement benefits. Consequently, these types of actions are not included in the SOS alternatives.

Non-Treaty Storage

The Columbia River Treaty required Canada to provide 15.5 MAF (19.1 billion m^3) of usable storage at Mica, Keenleyside, and Duncan Dams. The Canadians also built storage on the Columbia River system in excess of that required by the Treaty (termed non-Treaty storage). This additional storage capacity includes about 2 MAF behind Revelstoke Dam, an additional 5 MAF (6.2 billion m^3) of usable storage at Mica, and 2 feet (0.6 m) of storage behind Keenleyside above the normal full elevation. Agreements in addition to the Treaty are required to operate non-Treaty storage space.

Prior to the current NTSA, an older agreement covered the operation of 2 MAF (2.5 billion m^3) of non-Treaty space in Mica. In the operation of the old NTSA from 1983 to 1990, there was a distinct pattern of storing when flows were high and releasing when flows were low. This pattern is apparent among water years as well as among seasons. In high water years, non-Treaty space may be filled and then the stored water released in later low flow years. There is also a pattern of filling in the late winter and spring, and releasing water in the late summer, fall, and winter.

The current NTSA, signed in 1990, is an agreement between British Columbia Hydro and Power Authority (B.C. Hydro) and BPA establishing a means of using 4.5 MAF (5.6

billion m^3) of storage space in Mica. The other 0.5 MAF (0.6 billion m^3) of Mica space B.C. Hydro retained for its own use. There are also small amounts of space behind Keenleyside and Revelstoke that B.C. Hydro may occasionally make available at its discretion. Each party gets the use of 2.25 MAF (2.8 billion m^3) of the space and receives all of the energy produced by its water releases from non-Treaty space, and suffers all of the energy losses when water is stored in that space. For example, if B.C. Hydro released 5 kcfs (140 cms) of water from non-Treaty storage, it would keep the energy produced at its Mica and Revelstoke plants and would also receive all of the energy produced at the U.S. plants (Grand Coulee to Bonneville) by this release. Conversely, if B.C. Hydro stored some water, it would have to send to the United States the energy that would have been produced in the United States by the water that they stored, as well as foregoing some energy production at their own plants. The intent is that the party storing or releasing would be affected by that action, while the other party would be unaffected in terms of energy. All inflow into Mica is by definition Treaty inflow, so the only way to put water into non-Treaty space is to reduce Mica outflows by foregoing generation and delivering energy to replace the other party's losses.

The NTSA is secondary to, and is not allowed to conflict with, the Columbia River Treaty. The new NTSA, like the old one, does not stipulate the purposes for which NTSA must be used, nor does it preclude its use for any purpose. A companion agreement between BPA and the CBFWA does state that NTSA shall not be operated in a manner in which fish are worse off than if the NTSA had not existed. A companion agreement between BPA and mid-Columbia utilities allows them to share benefits and costs of the NTSA.

The NTSA adds system flexibility for many uses. It has been used to serve firm loads, to enhance fish flows, to store surplus energy, and to produce nonfirm energy when markets are good. Water in non-Treaty space is also valuable because the water-to-energy conversion

factor is as high as any sources on the Federal system. This is because when water is released, the energy produced at both the United States and Canadian projects is returned to the releasing party. An amount of water in non-Treaty space will produce nearly twice as much energy as a similar amount of water from Grand Coulee or Keenleyside. In the spring, if BPA is attempting to store energy, water stored in non-Treaty space will provide almost twice as much energy for the same reduction in flow compared to putting the water in Keenleyside or Grand Coulee. From an energy perspective, this high energy content makes non-Treaty storage a great place to store water, but a very poor choice to provide higher streamflows during energy surpluses.

The use of NTS water for flow enhancement has some limits. The NTSA provides that B.C. Hydro can at any time claim unacceptable impacts on their system and prevent all storing or releasing by either party, so the ability to release water when needed for fish cannot be ensured. Further, water released during fish migration periods (which are usually the most opportune time to store) must be replaced at another time of year. This would quite possibly be at higher energy prices, which can get very expensive since each unit of water has such a high energy content. In addition, the rate of release may be restricted at Mica, Revelstoke, or Keenleyside due to operational constraints in Canada.

Because the NTSA was designed to be used by both BPA and B.C. Hydro as a way to absorb short-term energy availability variations of the hydro system (gluts and shortages), the contract rights of the parties to store or release water are not firm. They can only be exercised with the concurrence of the other party at the time of the action. Thus, while BPA cannot promise an operation to help fish, the NTSA is likewise not obligated to any operation that harms fish. As a result, although the NTSA may actually be used to meet a commitment of the hydro system at times, it cannot be viewed as a separate source of water for consideration in the SOR.

Confederated Tribes of the Umatilla Indian Reservation Alternative

Subsequent to the close of comment on the Draft EIS, the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) proposed an operating alternative for consideration in the Final EIS. Briefly, this alternative is a variation on or modification of the DFOP evaluated as SOS 9a. Key features of the CTUIR alternative include operation of all four lower Snake River projects and John Day at natural river levels year-round; spill at McNary, The Dalles, and Bonneville to achieve 80 percent FPE in the spring and 90 percent FPE in the summer; and a 50 percent reduction in the October-through-March flood control space currently required at the storage projects, so as to be able to meet spring and summer fish flow targets.

The SOR agencies determined that it would not be practicable or necessary to conduct a full-scale analysis of the CTUIR alternative to the same level as the 13 final SOSs. Nevertheless, the agencies agreed that this proposed operation should be investigated and addressed in the Final EIS. Working through the CTUIR contract for SOR participation, the Tribe, the Tribe's contractor, and the CRITFC developed operational specifications as input to hydroregulation modeling. ROSE performed a series of hydroregulation iterations for the CTUIR alternative, which at this point was termed SOS 9d.

The SOR agencies then asked the work groups to consider SOS 9d and address its expected effects. The Power and Anadromas Fish Work Groups were requested to provide quantitative impact results. The other work groups were requested to prepare, at a minimum, a qualitative assessment of the implications of SOS 9d for their respective resource area. The work group contributions are reported below, following the same order of resource areas as is used in Section 4.2. Impact issues for these areas are also discussed in depth in Section 4.2. Impact issues for these areas are also discussed in depth in Section 4.2.

Earth Resources

Earth resources impacts from SOS 9d would be comparable to those of SOS 5c, but somewhat greater in extent because of the drawdown of John Day to natural river level in SOS 9d (compared to operation at MOP in SOS 5c). Initially, erosion and mass wasting from the drawdown to natural river levels would contribute large volumes of sediment from the lower Snake River reservoirs and John Day. These volumes have not been specifically calculated for SOS 9d, but they would be similar to the figures presented in Section 4.2.1 for SOS 5c. Because there would be no annual drawdown-refill cycle, however, within about 5 to 15 years erosion rates at these projects would diminish to background levels. Relatively large water level fluctuations at the storage reservoirs, combined with greater duration of shoreline exposure as a result of refill failures, would lead to significant increases in erosion and mass wasting at the storage projects.

The material eroded from the lower Snake River projects and John Day after implementation of SOS 9d would be deposited in McNary pool (which would receive the bulk of the sediment) and The Dalles pool. The useful lifespans of these two projects would be reduced, although the increased deposition would decrease markedly after several years. Sedimentation generated by shoreline erosion at the storage projects would increase significantly. SOS 9d would permanently lower the water table near the lower Snake River and John Day by approximately 100 feet (30 m). This would cause some wells to go dry, and others to have decreased yields. Effects on wells would be most concentrated or significant around John Day, and would affect M&I water supplies as well as domestic users.

Water Quality

At Lower Granite, May and June flows would be the highest under SOS 9d; flows would be about the same under all SOSs from July to October. At Priest Rapids and The Dalles, SOS 9d flows would be highest from April through

October. Lower Granite would have the lowest pool from April to October, and Dworshak would have one of the lowest (in the 1,510 to 1,550-foot range). HYDROSIM's output shows some spill at Lower Granite from April to August even during a low-flow year, such as 1929. It is believed, however, that this may be a misnomer because a natural river system should not have caused any spill. SOS 9d would cause the highest spill of all alternatives at Priest Rapids (113,200 cfs spill in June) and at The Dalles, which would spill nearly 250,000 cfs on average in June.

Water temperature model runs, using 1929, 1959, 1962, 1973, and 1974 HYDROSIM-regulated flows, indicated water temperatures under SOS 9d would be warmer in the lower Snake River reservoirs and cooler in the lower Columbia River at and below John Day compared to SOS PA.

SOS 9d would have the most extreme effects of all alternatives, especially compared to the other SOS 9 options and SOS PA. It would keep reservoirs very low in the summer and would affect summer water temperatures.

Operation of the lower Snake River reservoirs at natural river pool throughout the year is likely to create heavy sediment transport in the first few (5 to 10) years. Exposed reservoir banks would quickly erode until they reached a stable profile. Reservoir banks that are now exposed year-round would be more severely affected by wind and precipitation.

Under a drawdown scenario, water would be moving faster through the reservoirs and the water surface exposed to solar radiation would be reduced compared to normal operation. However, less water body would be available to absorb this radiation, so water temperatures would increase. Dworshak and Brownlee would be operated at relatively lower pool elevations and would have a smaller volume of cool water to contribute to the lower river. These factors combined would increase peak summer temperatures in the lower Snake River reservoirs, and increase the duration of warmer

temperatures. These warm temperatures would last longer. And, because water depth would be much more shallow, pockets of cool water that can now be found at several spots in the reservoirs would also be more scarce. On the other hand, in the lower Columbia River, water temperature model runs predict that the operation proposed for John Day Reservoir would decrease the number of days water temperatures would exceed 20°C at John Day and below.

Maintaining a high level of streamflows during the spring and summer would mean annual flow recession; therefore, greater bank erosion would occur over a longer period. This condition would also increase incidences of involuntary spill because of limited powerhouse hydraulic capacities and unit outages due to routine preventive maintenance and service.

Spill might not affect reservoirs that would be drawn down to natural river levels (lower Snake River and John Day Reservoirs), but would be a major factor at the mid-Columbia PUD dams and Bonneville Dam. Bonneville's powerhouse hydraulic capacity is about 220 kcfs, and its pool is not big enough to store excess inflows. Under SOS 9d, a monthly flow of 426 kcfs in May and 483 kcfs in June at The Dalles would cause a spill of 206 and 263 kcfs, respectively, during normal Bonneville powerhouse operation, and even more during unit outages. Tailwater total dissolved gas levels could be significantly higher than 125 percent. Despite the goal of achieving 80/90 percent FPE, this goal would not be achievable because of the spill caps imposed.

Of all the projected water quality impacts, dissolved gas would be most seriously effect under SOS 9d. In general, all flow alternatives that are required to comply with water quality standards cannot achieve the desired FPE levels. Therefore, SOSs that do not rely this heavily on flows and that entail other forms of fish passage improvements would have a higher chance of improving salmon recovery.

Air Quality

The air quality concerns for SOS 9d are the same as for the other SOSs: the potential for windblown emissions, high ambient PM_{10}, TSP, and hazardous air pollutant concentrations, and the indirect impacts resulting from generating replacement electricity.

Under SOS 9d, Lower Granite Reservoir (one of three reference projects for illustrating potential direct air quality impacts) would return to its natural river elevation, about 23 feet (7.0 m) lower than any of the other alternatives. This would expose a greater area of sediments to wind erosion for all months of the year. PM_{10} emissions for this alternative would be greater than for SOSs 5c and 5b, which, for the other alternatives, had the largest estimated emissions for Lower Granite. The exposed sediments would be subject to wind erosion until the sediments were vegetated or washed away.

Libby would be operated at elevations of 2,348 to 2,362 feet (715.7 to 719.9 m) for the entire year under SOS 9d. Although the other alternatives call for drafting to lower elevations, this would only occur during March and April when weather conditions are still cold and damp. SOS 9d would leave the reservoir at lower elevations during the summer, when the hot and windy conditions would increase the potential for wind erosion. Some of the highest wind speeds at Kalispell were measured during the summer.

The natural river elevation is lower than all other reservoir elevations evaluated for John Day. Large areas of exposed sediments would be susceptible to wind erosion, especially during the summer. Particulate matter emissions would be greatest at John Day for SOS 9d.

In general, SOS 9d would result in lower reservoir elevations than all other alternatives. These lower elevations would expose larger areas of sediment to wind erosion, especially during the dry summers. SOS 9d would result in higher PM_{10} and total suspended particulate (TSP) emissions and concentrations than all other alternatives. For this alternative, PM_{10}

concentrations greater than the 150 $\mu g/m^3$ AAQS would extend to greater distances away from the source of the emissions. PM_{10} concentrations greater than 5 $\mu g/m^3$, and thus noticeable above background concentrations, would extend to greater distances away from the shoreline than under the other alternatives.

The potential for windblown emissions would be a concern, especially the blowing dust in areas that are located near project reservoirs. These areas include the Wallula Junction area near Ice Harbor and McNary, Clarkston and Lewiston located on the Lower Granite Reservoir, and Sandpoint located on Lake Pend Oreille.

Some of the Lake Roosevelt and Lower Granite sediments contain contaminants. Exposing these contaminants to wind erosion would increase the probability that air concentrations would be higher than concentrations considered safe for human health. The potential for increased contaminant concentrations would increase for SOS 9d, compared to other alternatives.

Of all the SOSs, SOS 9d represents the greatest amount of lost electricity generation. Replacement electricity would have to be generated by new or existing fossil-fueled plants, or purchased from other areas. Replacing lost electricity would result in additional emissions of criteria air pollutants and CO_2, a greenhouse gas. These indirect air quality impacts would be greatest for SOS 9d.

If John Day and the lower Snake River were drawn down to their natural levels, materials and goods normally barged on the river system would instead be hauled by truck or rail. Because the other drawdown alternatives would only disrupt navigation on the lower Snake River, while SOS 9d would essentially shut down navigation above Bonneville Dam, SOS 9d would have significantly greater effects through transportation mode switching. Increased use of truck or rail transport would increase air emissions, which would represent another indirect air quality impact.

Anadromous Fish

SOS 9d was proposed by the CTUIR as a primary method to enhance anadromous salmon and steelhead stocks within the Columbia River System. SOS 9d in-river survival would exceed that of SOS 2c (the base case) for all Columbia River Basin stocks (Table 4-3). However, CRISP1.5 predicts that SOS 2c survival of Snake River spring, summer, and fall chinook; Dworshak Steelhead; Methow summer chinook; and Hanford fall chinook, with transport would be higher. There are two factors that influence these results: 1) under SOS 2c, with transport, Methow spring chinook and Wenatchee steelhead are transported from McNary Dam only and, thus, do not benefit from the additional transport sites available to the Snake River stocks; and 2) survival of these two stocks, with transport, assumes the 1986 transport/in-river ratio (TIR) (76 percent transport survival for Methow spring chinook and 90 percent transport survival for Wenatchee steelhead). In contrast, in-river survival under SOS 9d is noticeably less than survival with transport under the base case for Methow summer chinook and Hanford fall chinook because the base case assumes 98 percent fixed barge survival for these two stocks. Most of the in-river survival improvement under SOS 9d, compared to the base case without transport, would likely be attributable to drawdown of the lower Snake and John Day reservoirs and higher mainstem flows. Similar comparisons would hold for SOS 2d compared to SOS PA.

Estimates of adult returns under SOS 9d fall between the two alternatives that have similar operation characteristics, SOS 9a (four-pool drawdown of Snake River projects without transport) and SOS 5 (natural river operation of Snake River projects with transport from McNary only), in total escapement in 30 to 40 years. The Stochastic Life Cycle Model (SLCM) predicts adult returns for SOS 9d to be higher than returns for SOS 9a for the four Snake River stocks and mid-Columbia Methow summer chinook, but about the same for Hanford Reach fall chinook. Both SOSs 9a and 9d draw down the lower Snake projects and

neither assumes the use of transport; therefore, the difference in adult returns of Snake River stocks may be due to the fact that turbine mortality is assumed under SOS 9a but no turbine mortality is assumed under SOS 9d. The higher returns of Methow summer chinook for SOS 9d compared to SOS 9a are primarily due to the drawdown of John Day Reservoir, because neither alternative assumes any transport from McNary Dam. SLCM-predicted adult returns under SOS 9d for Methow summer chinook and Hanford fall chinook are lower than any other alternative except SOS 9a. Again, these lower returns are due to the lack of transport at McNary Dam. When SOS 9d is compared to SOS 5 (natural river), SOS 5 had higher escapement for all 6 stocks evaluated, which is attributable to fish transport at McNary Dam with SOS 5.

For four of the six stocks analyzed, SLCM results show a marked decline in adult abundance, compared to the base case (SOS 2c) with transport, when forecast 30 to 40 years into the future. Median spawning escapement for Snake River spring chinook decreases from about 6,000 to about 2,000 fish; Snake River fall chinook decreases from about 5,000 to about 470; Dworshak hatchery steelhead decline from about 15,000 to 8,500; and the Methow summer chinook stock decreases from about 570 to about 140. For Snake River summer chinook, there is a modest decrease in spawning escapement from about 850 under SOS 2c to about 760 under SOS 9d. Hanford fall chinook spawning escapement remains at about 32,000 for both alternatives, although its total harvest declines by about 15 percent. The transport survival hypotheses used here were those used in the *Anadromous Fish* portion of Section 4.2. As with juvenile survival, similar comparisons in adult return trends occur between SOSs 9d and PA as between SOSs 9d and 2c.

The lowering of lower Snake River reservoirs to river bed would increase available spawning habitat, primarily for fall chinook, by returning the reach to a flowing river having suitable spawning substrate similar to SOS 5c. SOS 9d would also create an increase in the

Table 4-3. Estimated Columbia River Basin juvenile salmonid survival to below Bonneville Dam using CRiSP1.5, SOS 2c vs SOS 9d

Stock	SOS 2c (No Action) In-River Survival (%)	SOS 2c (No Action) Survival with Transport[1] (%)	SOS 9d In-River Survival (No Transport) (%)
Snake River Spring Chinook	26	51	43
Snake River Summer Chinook	28	47	46
Snake River Fall Chinook	5	46	19
Dworshak Hatchery Steelhead	17	63	35
Methow Spring Chinook	24	25	29
Methow Summer Chinook	3	7	5
Hanford Fall Chinook	19	34	29
Wenatachee Steelhead	18	22	25
Deschutes River Spring Chinook[2]	48	N/A	51
Rock Creek Steelhead[2]	36	N/A	42

1/ Assumes 1986 TIR transport hypothesis except for Snake River fall chinook, Methow summer chinook, and Hanford fall chinook, which use the 98 percent fixed barge survival transport hypothesis.

2/ This stock is not transported.

spawning area for fall chinook in the John Day pool reach, which was considered to have a substantial naturally spawning stock of fall chinook prior to construction of that dam (Fulton, 1968).

SOS 9d would likely have effects on shad, lamprey and sturgeon similar to those anticipated under SOS 5c. However, the effects would probably be more pronounced with the drawdown of John Day pool to natural river bed.

Resident Fish

The following constitutes a qualitative assessment of resident fish impacts by project or river reach under SOS 9d (note that all results assume no load following, which would cause impacts to resident fish spawning, rearing, and food production in rivers if it should occur):

Bonners Ferry Flows (Kootenai River)—This operation mimics natural river flows and in general should benefit resident fish. Sturgeon and some resident species should be assisted to the extent that spring flows are limiting these stocks. However, this alternative would cause major spring flooding in many years, and this is not the desired outcome of resident fish managers.

Lake Koocanusa Elevation—In the hydroregulation results, SOS 9d causes major

reservoir fluctuations and includes many years of deep drafts. Refill failures also occur, though in some years refill occurs or is approached. All of this large and inconsistent fluctuation would cause major problems with benthic food organism production. Food organisms would be frozen and desiccated in many years. Vegetation cannot establish permanently in the fluctuation zone when refill does not occur, because later inundation would kill much of it. Hence, terrestrial insects would not be reliably provided as a food source either. The result is that resident trout growth, and ultimately reproduction, would be reduced. Heavy outflows in spring might wash out large numbers of kokanee and zooplankton, reducing the plankton forage base for remaining kokanee, which provide prey for kamloops rainbow trout.

Hungry Horse/Columbia Falls Flows (Flathead River)—Simulated flows

approximate natural runoff patterns as in the Kootenai River. These flows should benefit fish using the Flathead River, assuming temperature control of Hungry Horse releases is achieved.

Hungry Horse Elevation—As with Lake

Koocanusa, major drafts, fluctuations, and refill failures would affect benthos, which would reduce growth and reproduction of trout. Other impacts are the same as for Lake Koocanusa, with the exception that kokanee and kamloops are not present in Hungry Horse.

Albeni Falls Outflow (Pend Oreille River)—The SOS 9d operation mimics natural

river flows. However, smallmouth bass spawning might be diminished by higher-than-optimal spring flows.

Lake Pend Oreille—Operations under SOS 9d

are varied and problematic for resident fish. In some years, the lake level would remain very low, causing problems for kokanee spawning and warm-water fish habitat requirements. Refill occurs in some years, but not in others. This would also cause problems for warm-water fish as would the occasional spring draft. The winter "draw-up" in SOS 9d should benefit kokanee and warmwater species, but there is

little benefit and possibly a detriment to raising the pool in the winter only to lower it again.

Lake Roosevelt—SOS 9d causes some severe

simulated elevation fluctuations, and filling seldom occurs at Lake Roosevelt. Riverine conditions with low pool and high flow are created in many years but are not maintained consistently enough from year to year to allow for sound management of either a lake-type fish community or a riverine fish community. Probable short-water retention times would reduce plankton production and fish growth.

Brownlee—Simulated operations at Brownlee

reflect inconsistent filling and drafting, including some spring drafting that, sometimes severely, would dewater redds of warm-water fish and reduce spawning. Spring filling after early May would inundate warm-water fish redds with cold water, impairing egg survival.

Dworshak Reservoir—Large simulated

variations in pool elevation occur here, with filling rare. Spring drafts in some years would harm warm-water fish spawning by dewatering redds, as would spring filling after early May, by inundating redds with cold water.

Lower Snake and Columbia River Mainstem Projects—Year-round stability at

these projects should benefit resident fish in general.

Wildlife

Generally, SOS 9d would be similar to other SOS 9 alternatives with regards to wildlife impacts (see Section 4.2.6). River flows would be high in the spring and summer and drop to very low levels in the late summer and fall. The effect on reservoir levels would vary by individual site. At storage reservoirs, the impacts would be similar to the other alternatives that involve significant drafting. The impacts at run-of-river reservoirs would generally be similar to other SOS 9 options or SOS PA, except at John Day, where an extremely low elevation would be established.

The pattern of river flows in SOS 9d attempts to duplicate the natural flows that existed in the system. This would support natural wildlife patterns of distribution and species diversity in those areas where the river channel is not significantly modified (e.g., the Flathead River below Kerr Dam). However, where the river channel is modified—as by levees on the Kootenai River below Bonner's Ferry—the amount of unvegetated habitat (cobble, etc.) should increase without a commensurate increase in other habitats (wetlands or riparian). The resultant impacts to wildlife resources systemwide would likely be somewhat negative, as large portions of the existing river channels are modified and would limit the development of new habitat in response to the new, more natural flow pattern.

While SOS 9d would increase drawdowns at the major storage reservoirs (Grand Coulee, Dworshak, etc.), the impacts would be similar to other alternatives (mostly SOS 9) that increase drawdown. At reservoirs with existing large drawdowns (Dworshak is the classic example), the additional increment of drawdown is not expected to cause any significant additional impacts. Reservoirs where the existing drawdowns are not too severe would suffer greater impacts to wildlife.

Run-of-river reservoirs such as Bonneville, the mid-Columbia dams, and Chief Joseph would not be affected. The lower Snake reservoirs would be operated as in SOS 5c, which would have some significant negative impacts to wildlife. John day is a special case and would suffer severe impacts from the large, year-round drawdown proposed in SOS 9d. However, some recovery of habitat values would be likely over time.

SOS 9d would generally have negative impacts to wildlife throughout the system. While some areas would experience little impact, others would sustain significant negative impacts.

Cultural Resources

The overall effect of SOS 9d on cultural resources would be to reduce substantially the level of ongoing impact. There are 354 known archeological sites in the lower Snake River and John Day pools, and it is likely that there are many additional sites that archaeologists have not yet discovered. Drawdown to natural river level under this alternative would immediately halt the deterioration of these sites that is caused by shoreline wave action and inundation. The drawdown would at first subject these sites to a variety of adverse impacts because of exposure in the devegetated reservoir pools. These impacts would include vandalism and artifact theft, and surface erosion from wind and water. As the former pools revegetated, however, the vegetation would afford some protection from both vandalism and erosion. Deterioration of the sites would be slowed and permanent access to them for scientific study and traditional cultural practice would be restored. Included are several sites listed on the National Register of Historic Places and many that are eligible for listing on the National Register.

SOS 9d would also change system operations in a way that would increase the rates of exposure of archeological sites within a drawdown zone at all of the storage projects. This effect would be most pronounced at Hungry Horse, where the known sites would be exposed 93 percent of the time, according to the Cultural Resources Work Group's computer simulation model of system operation. This high rate is partly due, however, to the fact that archaeological survey has only recently begun at Hungry Horse, and most of the known sites (24 in number) are high in the reservoir pool, above the minimum water level at the time of survey. There would be a corresponding decrease in the rate of shoreline erosion at the known storage reservoir sites, but this would not entirely offset the increase in site exposure. Despite some increase in the rate of site exposure at the storage projects, the net effect of SOS 9d would be beneficial because of the restoration of a large number of archeological sites at the lower Snake River projects and John Day.

Native Americans

The projected impacts of SOS 9d on Native American resources and concerns are uncertain, and appear to be variable among resources, tribes and geographic areas. SOS 9d was proposed by the CTUIR as the alternative that would best protect and restore their treaty rights (and the rights of the other lower-river tribes) to anadromous fish. As discussed previously in Section 4.1.10, the SOR anadromous fish modeling indicates that SOS 9d would increase in-river survival compared to SOS 2c, but that survival under SOS 2c with transport would still exceed survival estimates for SOS 9d. Consequently, the SOR modeling generally shows decreases in adult returns for SOS 9d compared to SOS 2c. These results must be interpreted carefully, however, because the SOR modeling is based on fish transportation assumptions that have long been at issue between the tribes and the SOR agencies. From the tribal perspective, SOS 9d is probably the most advantageous alternative for treaty fishing rights. Based on the model results, the SOR agencies question whether SOS 9d would ultimately benefit treaty rights and the Indian trust assets that anadromous fish represent for the lower-river tribes.

SOS 9d would have negative consequences for some other resources that are important to Native Americans, particularly resident fish and wildlife. The SOR Wildlife Work Group concluded that SOS 9d would generally have negative wildlife impacts throughout the system, with significant negative impacts (at least in the short and medium term) at the lower Snake River projects, John Day, and possibly some of the storage reservoirs. SOS 9d would result in major drafts, fluctuations, and/or refill failures at all five of the Federal storage projects that would have severe adverse consequences for resident fish. Consequently, SOS 9d would generally harm the treaty rights and trust assets of the upriver tribes.

The effects of SOS 9d on cultural resources would vary somewhat among projects, but were considered to be positive overall. The storage projects would generally experience an increase in the rate of archeological site exposure, which would be partially offset by a decrease in the rate of shoreline erosion. The greatest projected effects would be at the lower Snake River projects and John Day, where the long-term restoration of a large number of archeological sites and access for traditional cultural practice was considered to be a significant benefit.

In addition to these impacts on specific resources, SOS 9d would have a significant long-term effect on the total river environment along the lower Snake River and the John Day reach of the Columbia. With revegetation and recovery of the river corridor over the years, most Native Americans would probably believe that SOS 9d would provide significant benefits to the overall integrity and naturalness of the river environment.

Aesthetics

Aesthetically, SOS 9d would have significant adverse effects throughout much of the river system. SOS 9d would result in much lower pool elevations, and therefore greater duration and extent of reservoir shoreline exposure at all five of the storage projects. This effect would be most pronounced during the summer, when the greatest numbers of viewers are present. While the average annual shoreline exposure by project was not determined for SOS 9d (see Section 4.2.9 for such information on the other SOSs), comparison of the hydroregulation results suggests that SOS 9d would rate significantly higher (worse) than the other SOSs by this measure.

SOS 9d would also permanently expose the entire inundated pool area at the lower Snake River projects and John Day. This would result in a major reduction in aesthetic quality at these five projects that would last for many years. The exposed areas would eventually revegetate and recover the appearance of a more natural riverine landscape, but this would be a lengthy process.

Recreation

Of the alternative operating strategies evaluated under the SOR, SOS 9d would have the most severe impacts on recreation across the system. Despite modified flood control rule curves, meeting high minimum monthly flow requirements would result in extremely low pool elevations during the summer recreation season at all of the storage projects in the system, including Hungry Horse, Grand Coulee, Libby, Albeni Falls, and Dworshak. Over the 50-year average, summer monthly pool elevations at all of these projects would be lower than any other alternative, with corresponding impacts on recreation facilities and activities. Extremely high minimum flows would impair recreational use of some rivers, such as the Kootenai, while benefiting others such as the Clearwater. Permanent drawdown of John Day and the four lower Snake River projects to natural river levels would make virtually all existing water-related recreation facilities at those projects unusable and would severely restrict accessibility, at least until such time as replacement facilities could be developed.

The SOR Recreation Impact Assessment Model was used to estimate changes in recreation visitation and consumer surplus values under SOS 9d. The model results are based primarily on the 50-year average pool elevations and flows derived from the SOS 9d hydroregulation. The exceptions were for the run-of-river projects covered by the model, including John Day and Lower Granite. (The model uses Lower Granite demand curves to estimate visitation and consumer surplus for the other lower Snake River projects). SOS 9d would permanently draw down these projects to natural river levels, with resulting forebay elevations of 210 and 600 feet (64 and 182.9 m), respectively. Pool elevations at those levels fall below the recreation demand curves estimated by the models and result in zero estimated trips. The Recreation Work Group does not believe that this would be an accurate representation of recreation demand; while the impact of natural river drawdown at these projects would be severe, some recreational use would continue.

Consequently, it was necessary to modify the hydroregulation results for those projects. At natural river, the surface profile of the rivers would vary with flow but would be much higher at the upper ends of the reservoir areas. For example, with a forebay elevation of 210 feet (64 m) and a flow of 150 kcfs (4,200 cms), the river surface at the upper end of the John Day Reservoir would be near elevation 240 feet (73.2 m). Since most of the major recreation sites on the project are located in the upper one-third of the project, it was assumed that this pool elevation accurately represents potential conditions at John Day under SOS 9d and was used in the model. Similarly, elevation 651 feet (198.4 m) was chosen as an appropriate river elevation for Lower Granite.

Visitation (in recreation days) and consumer surplus values for SOS 9d were compared against several baseline strategies, including SOS 1, SOS 2c, SOS PA, and actual 1992-1993 visitation. The projected impacts for each project and river reach are summarized below.

Lake Koocanusa—SOS 9d is by far the worst alternative for recreation at Lake Koocanusa. During the average summer, lake elevations would never rise within 100 feet (30.5 m) of full, severely limiting use of most recreation facilities on the lake and rendering much of the upper half of the lake in Canada unusable. Estimated annual visitation is 817,804 recreation days, a decrease of approximately 18 percent from either SOS 1a, 2c, or PA. For comparison, the next-worst alternative for recreation at Lake Koocanusa is SOS 9a, with estimated annual visitation at about 950,000 days of use.

Kootenai River—SOS 9d is also by far the worst alternative for recreation on the Kootenai River below Libby Dam. Average monthly releases from Libby result in extremely high downstream flows (30 to 40 kcfs [850 to 1,130 cms]) in May and June, followed by very low flows (4 kcfs [113 cms]) in August. Estimated annual visitation is 8,425 recreation days, a decrease of approximately 75 percent from either SOS 1a, 2c, or PA. For comparison, the next-

worse alternative for recreation on the Kootenai River is SOS 9a, with estimated annual visitation at about 14,000 days of use.

Hungry Horse—SOS 9d is by far the worst alternative for recreation at Hungry Horse. Summer reservoir elevations would be extremely low, barely rising within 100 feet (30.5 m) of full for the entire season. Reservoir conditions would prohibit boat access, result in huge unsightly mudflats, and create additional safety problems in the large drawdown area. Use of land-based facilities would drop off as the lake recedes. Estimated annual visitation is 51,797 recreation days, a decrease of approximately 60 percent from either SOS 1a, 2c, or PA. For comparison, the next-worse alternative for recreation at Hungry Horse is SOS 9a, with estimated annual visitation at about 91,000 days of use.

Lake Pend Oreille—SOS 9d is also by far the worst alternative for recreation at Lake Pend Oreille. Average lake elevations would range from 3 to 8 feet (0.9 to 2.4 m) below full throughout the summer, impairing use of most recreation facilities on the lake. Estimated annual visitation is 817,804 recreation days, a decrease of approximately 33 percent from either SOS 1a, 2c, or PA. For comparison, the next-worse alternative for recreation at Pend Oreille is SOS 9a, with estimated annual visitation at about 1 million days of use.

Columbia River, Canada—Recreational impacts for the upper Columbia River in Canada were not modeled. However, SOS 9d produces huge average monthly flows from combined releases in Brilliant and Keenleyside Dams during May, June, and July. These flows would be expected to have severe negative impacts on recreational use during those months.

Grand Coulee—SOS 9d is by far the worst alternative for recreation at Lake Roosevelt. During the average summer, lake elevations would never rise within 30 feet (9.1 m) of full, severely impairing use of most recreation facilities on the lake. Estimated annual visitation is 859,100 recreation days, a decrease of

approximately 48 percent from either SOS 1a, 2c, or PA. For comparison, the next-worse alternative for recreation at Grand Coulee is SOS 9a, with estimated annual visitation at about 1.25 million days of use.

Chief Joseph—Recreational impacts for the Chief Joseph Project (Lake Rufus Wood) were not modeled. No significant impacts are expected.

Mid-Columbia PUD Projects—Recreational impacts for the Mid-Columbia PUD Projects (Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids) were not modeled. However, SOS 9d produces huge average monthly flows during May, June, and July. These flows would be expected to have severe negative impacts on recreational use of the Mid-Columbia projects during those months. Under existing conditions, high spring flows flood out some recreation facilities and high velocities create unsafe swimming and boating conditions. The extremely high flows under SOS 9d would be expected to exacerbate those conditions.

Hanford Reach—Recreational impacts for the Hanford Reach of the Columbia River were not modeled. However, SOS 9d produces huge average monthly flows during May, June, and July (260, 305, and 195 kcfs [7,360, 8,638, and 5,522 cms], respectively). Under current high flow conditions (greater than 120 kcfs [3,398 cms]) boating use of the river markedly decreases. SOS 9d flows would be expected to have severe negative impacts on recreational use of the Hanford Reach during those months.

Snake River, Hells Canyon—Recreational impacts for the Hells Canyon Reach of the Snake River were not modeled. Flow conditions for SOS 9d are very similar to those of SOS 9a. Both of these alternatives result in very high summer releases from Brownlee Dam that are the highest of any of the alternatives in August. The high flows are at the upper end of or exceed the optimum boating conditions through much of the season and would create boating hazards.

Dworshak Lake—Along with SOS 9b, which is very similar, SOS 9d is the worst alternative for recreation at Dworshak Lake. During the average summer, lake elevations would never rise within 80 feet (24.4 m) of full, severely limiting use of most recreation facilities on the lake. Estimated annual visitation is about 133,000 recreation days, a decrease of approximately 34 percent from SOS 2c and about 11 percent from SOS PA.

Clearwater River—SOS 9d would be one of the better alternatives for recreation on the Clearwater River.

Lower Snake River—Under SOS 9d, all four lower Snake River projects would be permanently drawn down to natural river level. Along with SOS 5c, which calls for the same operation, this alternative would have the most severe impacts on recreational use of these projects. Virtually none of the existing water-based recreation facilities, including boat ramps, marinas, boat docks and swimming beaches, on all four of these lakes would be usable at any time of the year. Access to and from the lake for anything other than small hand carry craft would be virtually impossible, at least until such time as replacement access facilities were developed.

McNary Project—Recreational impacts for the McNary Project (Lake Wallula) were not modeled. No significant impacts are expected.

John Day Project—Under SOS 9d, Lake Umatilla would be permanently drawn down to natural river level. This alternative would have by far the most severe impacts on recreational use of any of the alternatives under consideration. Virtually none of the existing water-based recreation facilities, including boat ramps, marinas, boat docks, and swimming beaches, would be usable at any time of the year. Access to and from the lake for anything other than small hand carry craft would be very difficult, at least until such time as replacement access facilities were developed. Estimated annual visitation is about 196,000 recreation days, a decrease of over 90 percent from either

SOS 1a, 2c, or PA. For comparison, the next-worst alternative for recreation at John Day is SOS PA, which calls for a permanent drawdown to MOP and has estimated annual visitation of about 1.5 million days of use.

The Dalles/Bonneville Projects and Columbia River Below Bonneville—Recreational impacts for the lowest two projects and for the Columbia River below Bonneville Dam were not modeled. However, SOS 9d produces huge average monthly flows during May (383 kcfs [10,847 cms]), June (432 kcfs [12,234 cms]), and July 252 kcfs [7,137 cms]). These flows drastically exceed those experienced under any other alternative. The average monthly flow for June is 130 kcfs (3,682 cms) greater than the next highest alternative (SOS 9b). May and June flows would far exceed the maximum optimum flow for recreation through the reach of about 250 kcfs (7,080 cms). Consequently, SOS 9d would be expected to have severe negative impacts on recreational use of the lower Columbia reach during those months. Under existing conditions, high spring flows flood out some recreation facilities and high velocities create unsafe swimming and boating conditions. The extremely high flows under SOS 9d would be expected to exacerbate those conditions.

System Summary—As indicated by the project- and reach-specific summaries above, SOS 9d would have severe negative impacts on recreation systemwide. Estimated annual system-wide visitation under SOS 9d is approximately 12.6 million recreation days. This is far lower than the estimated visitation of any of the 13 alternative SOSs evaluated in detail.

Flood Control

The impacts to flood control under SOS 9d would be as follows:

- At all locations, floods would occur in many years in which the hydrology is known to be near or below normal.

- Reservoir elevations would be kept artificially high during the drawdown period and, in many cases, refill would occur before the flood peak has passed.

- The 50 percent exceedence frequency stage at Bonners Ferry for SOS 9d is 11 feet over that of SOS 2c, which translates to a major flood every other year on the average.

- At The Dalles (the system control point) three regulated floods in 50 simulation years exceeded 800 kcfs (22,660 cms), each representing a catastrophic flood. For SOS 2c, no simulated floods exceeded this level.

Navigation

Snake and Columbia River Navigation—Without significant structural modifications, navigation above Bonneville Dam would be essentially shut down under SOS 9d. The elevations of water at the four Snake River dams would be well below the minimum operating depth for the navigation locks. The McNary pool elevation would be high enough for barge transportation, but because John Day pool would be below MOP, only intra-pool transportation would be possible. Because the outflow from Bonneville Dam would violate current operating restrictions in the late fall in some years, it is assumed that navigation on the Bonneville pool might likewise be impaired. The physical impacts of this type of permanent drawdown would be dramatic. Ports and facilities along the mainstem pools would be inoperable.

Dworshak Dam Log Rafting Operations—Log rafting operations would be suspended in most years for most of the summer season under SOS 9d.

Lake Roosevelt Ferries—For SOS 9d, there are significantly more simulation years in which the elevation of Lake Roosevelt is lowered enough to disrupt ferry service for two or more months each year.

High Flows Below Ice Harbor and Lower Monumental Dams—High flow problems below Lower Monumental and Ice Harbor Dams would be significantly more likely with SOS 9d than for any other SOS analyzed. However, if barge transportation through the locks would not be possible, the problem is a moot point in the analysis.

Deep Draft Navigation on the Lower Columbia River—It is not possible to analyze SOS 9d impacts without daily flow generations. Based on the average monthly flows shown for Bonneville Dam, it is likely that the impacts would be similar to or slightly worse than those reported for the drawdown alternatives.

In summary, it is likely that SOS 9d would be the worst alternative for navigation.

Power

SOS 9d would substantially reduce the 50-year average annual hydro energy generation. In the power system analysis, average annual hydro energy generation was reduced by 4,262 aMW as compared to SOS 2c, the No Action Alternative. This is almost four times the loss in energy generation for SOS 9a, the SOS with the most severe reduction in energy generation among the final 13 SOSs. Although not quantified, it is estimated that capacity impacts would also be severe, likely at least double those shown for SOS 9a in the winter. In simulated low-water periods, Libby, Hungry Horse, and Grand Coulee are all empty in the winter, leading to severe capacity impacts from head loss and inability to release water needed for downstream power generation.

The same spreadsheet model used to calculate power system impacts in Appendix I, Power, was used to evaluate the effects of SOS 9d. Only changes in total regional energy costs were quantified. These changes were estimated as compared to SOS 2c. The numbers reported here are consistent with the numbers shown in Appendix I, Power, Table 5-2.

can increase erosion within the reservoir and stream channels downstream. As with rapid drawdown, this condition can cause slope failures and affect archeological sites.

Natural River Operations—Operating reservoirs at near natural river levels is a special case of operation at new reservoir levels. This feature leaves the largest possible area open to erosion and slope failure that could affect cultural resources. It combines the effects of flow augmentation, rapid drawdown, and new reservoir levels. Natural river operation is a feature of SOS 5 and the lower Snake River reservoirs only. With SOS 5b, the lower Snake reservoirs would draw down to natural river level and refill annually, exposing large areas to erosive forces. With SOS 5c, the drawdowns would take place at one time, and would be permanent, however, so that the former reservoir sideslopes would no longer be subject to erosive forces due to pool operation.

Geomorphic Comparison of the Alternatives—The most significant increases in sedimentation and erosion would occur with SOS 5, natural river operation, and SOSs 6 and 9, deep drawdown strategies (except 9b). Certain alternatives, such as SOSs 2d, 4c, and 9b, could cause significant slope failures that may affect cultural resources at Dworshak and Grand Coulee. These strategies feature hydropower flows combined with flow augmentation with target spill levels that may lead to short-term cyclic drawdown and refill over a range of a few feet. This can cause bank slumping in loose, unconsolidated soils such as the glacial tills in the storage reservoirs at the upper reaches of the basin.

SOSs 1 and 2c should cause the lowest rates of ongoing adverse effect on landforms and the cultural resources located on them. These strategies have been in effect for some time, and shorelines have to some extent reached an equilibrium condition due to armoring effects. These alternatives represent the least amount of change from the current situation. In contrast, SOSs 2d, 6, and 9 would create new minimum levels for some reservoirs. For example, under

SOS 6, the lower Snake River projects (Lower Granite only under 6d) would begin drawdowns to new minimum pools located below the existing minima. This would lead to the creation of new wave-cut benches at these levels, which would dramatically increase erosion at any archeological sites located at these levels.

The SOS 5 options would draw the lower Snake reservoirs down to natural river level. This would lead to the maximum possible exposure of unvegetated sediments in the drawdown zone and would consequently lead to potential erosion of landforms containing archeological sites over a large area. SOS 5b would annually draw down these four projects to natural river level for 4.5 months. Under SOS 5c, however, the drawdown would be permanent. The drawdown zone would thus have the opportunity to revegetate, affording some protection for cultural resources from erosion and sedimentation.

Summary of Effects

Because the simulation study and geomorphic analysis are complementary approaches to comparing the effects of the alternatives, combining their results provides a comprehensive view of the system's effects. This combined analysis shows that SOSs 5c, 2c, 1a, 1b, and PA would be the most beneficial in terms of impacts to cultural resources. These alternatives would either maintain the current ongoing rate of impact, or would improve it in some way. SOSs 9a, 5b, 4c, 9c, 9b, 6b, 6d, and 2d would be the least beneficial. These alternatives would increase the ongoing rate of impact to cultural resources.

SOS 1—The SOS 1 options would probably cause a slight decrease in the rate of ongoing impacts to cultural resources of system operation. The simulation model predicts slightly reduced shoreline erosion and site exposure for SOS 1a, compared with the baseline. The geomorphic analysis shows that returning to operation under SOS 1a would involve returning the shoreline zone to areas likely to have reached erosional equilibrium

during the time period when the system operated according to SOS 1a.

SOS 2—SOS 2 would also not cause very much change from current operations and so would not accelerate the rates of ongoing impact to cultural resources. The simulation model uses SOS 2c as the baseline condition and so predicts no change in ongoing impact rates for SOS 2c, and only insignificant changes for SOS 2d. The geomorphic analysis predicts that SOS 2d would change reservoir levels at John Day and the lower Snake River projects, leading to accelerated erosion of landforms.

SOS 4—The simulation study results show some change in ongoing effects for SOS 4c as compared to current conditions. It would accelerate shoreline erosion at known cultural resources sites, while simultaneously slowing down the rate of drawdown zone exposure at these sites. According to the geomorphic analysis, rapid drawdowns at John Day and Dworshak in the fall months could accelerate slope failures on steeper slopes at these reservoirs. Otherwise, SOS 4c would cause less exposure of landforms to erosive processes than other alternatives because it would maintain high pool levels at the storage reservoirs for a longer period of time in the summer. The known archeological sites, however, are disproportionately located in the high pool shoreline areas at the storage reservoirs. These sites, particularly at Albeni Falls, would experience accelerated erosion.

SOS 5—SOS 5 represents a large departure from current operations. SOS 5b would draw down the lower Snake River projects to natural river level for part of the year and would thus involve repeatedly inundating and exposing all of the archeological sites in these reservoirs. SOS 5c would involve permanent drawdown to natural river level. According to the simulation model, both would dramatically increase average site exposure rates while decreasing the rate of shoreline erosion. According to the geomorphic model, both would expose large areas to erosion. SOS 5c, however, should be considered the most beneficial for cultural

resources because the drawdown to natural river level would be permanent. Therefore, access to archeological sites in the reservoirs would be restored. The drawdown zones would revegetate, affording some additional protection from erosion.

SOS 6—SOS 6, with its new reservoir minima at the lower Snake River projects, would increase erosion and sedimentation. According to the simulation model, it would increase the rate of site exposure and decrease the rate of shoreline erosion, though by small amounts in either case.

SOS 9—SOS 9a is unique among the alternatives in that it would increase the rates of both shoreline exposure and site erosion at the known sites, according to the simulation model. SOS 9b and 9c, by contrast, are similar to SOS 4c in that they would increase the rate of shoreline erosion, but also decrease the rate of site exposure. The geomorphic analysis also predicts that SOS 9a would cause an acceleration of erosion and sedimentation because it would involve drawdowns to new minima at the lower Snake River projects and John Day as well as increased flow velocities and pool fluctuations.

SOS PA—SOS PA would not cause major changes in the rates of ongoing impact to cultural resources. There would be some increases in shoreline erosion at the lower Snake River reservoirs and at John Day because of flow augmentation and new minimum water levels. Throughout the study, the Cultural Resources Work Group has attempted to consider and evaluate additional factors relating to cultural resources impacts. A key question has involved the significance of the affected resources. Within the legal and regulatory framework of cultural resource management, answers to the significance question come from determinations of eligibility and nominations for the National Register of Historic Places. Unfortunately, not all of the cultural resources in the Columbia River system have been inventoried and evaluated. Consequently, analysis based on the limited existing information must be interpreted very carefully

SOS 9d increased total regional energy costs by $941 million in operating year (OY) 1996 and $1.1 billion in OY 2004 in 1996 dollars. Again, this is nearly four times the costs of SOS 9a. The simulated loss of hydropower generation required the acquisition of 3,000 aMW of combined-cycle combustion turbines in OY 1996 and 5,500 aMW of combustion turbines in OY 2004. Costs would likely be even higher than estimated for OY 1996, since acquisition of CTs would not be possible in that short of time. Regional deficits would be so great in some months in low-water conditions that curtailments would be required, because not enough power could be brought into the region. For example, in January under 1932 water conditions, nearly 10,000 aMW would be required to meet regional loads in OY 1996. Interties are not capable of importing that much power.

Again, although not quantified, capacity costs could run several hundreds of millions of dollars, leading to a total regional cost for SOS 9d well in excess of $1 billion per year.

Irrigation/M&I Water Supply

Implementation of SOS 9d would affect irrigation and M&I users of six projects: Grand Coulee, John Day, Ice Harbor, Little Goose, Lower Monumental, and Lower Granite.

Overall, these impacts under SOS 9d would be greater than for any of the 13 SOSs, evaluated in detail for the Final EIS. The impact on John Day users would be especially severe, compared to the effects of the other operations that have been evaluated for John Day. The following discussion summarizes a qualitative assessment of the effects of SOS 9d for Grand Coulee, John Day, and the lower Snake River projects.

Grand Coulee—Prior to formulation SOS 9d, SOS 9a had the greatest impact (increase) on irrigation pumping cost. The hydroregulations showed SOS 9a drafting Lake Roosevelt to very low levels during the spring and summer. The hydroregulation for SOS 9d shows an even greater number of months over the period of record with Lake Roosevelt at the minimum elevation of 1,208 feet ([368 m] top of inactive storage). The cost of pumping irrigation water for the Columbia Basin Project would increase from $911,300 for SOS 2c (the No Action Alternative) to $946,200 for SOS 9a and $989,500 under SOS 9d, which is an increase of 8.6 percent.

There is concern by Grand Coulee Project management about the operability of the pumping system from Lake Roosevelt to Banks Lake under such conditions. With the lower Lake Roosevelt levels, the head differential between reservoirs would increase, thus reducing the efficiency or even precluding the use some of the 12 pumping units. The question becomes one of being able to meet irrigation demand from Banks Lake during critical peak irrigation demand periods. The physical impact would be that Banks Lake elevation would decline as the pumping units would not be able to keep up with irrigation demand. During critical water periods, the pumping units would be operated for extended periods, and at head differential greater than historical levels. The impacts of increased wear on the pumping units, the increased risk of non-delivery, and the inability to meet irrigation demand were not evaluated in detail.

John Day—The 113.5-foot (34.6-m) drawdown of John Day from the normal operating pool level elevation of 263.5 feet (80.3 m) to the natural river elevation of 150 feet (45.7 m) would have a significant impact on irrigation and M&I pumpers. The existing pumping plant modification cost curve developed for the relatively small drawdown of 6.5 feet (2 m) for the Final EIS analysis would not be adequate for evaluating the SOS 9d drawdown. In many cases, a new river pumping plant system would need to be designed, rather than modifying the existing plant by extending the intake pipe or lowering the intake units into the reservoir pool.

To continue service to the 139,5000 acres (56,456 ha) irrigated from the John Day Pool, other alternatives to pumping plant modification

should be reviewed, such as drilling wells. It is anticipated that alternatives would be considerably more costly than the $14.3 million to modify irrigation pumps required for the 6.5-foot (2 m) drawdown previously analyzed. A buyout of the irrigated farms could be considered if pumping alternatives were not feasible. However, under a buyout scenario, using a capitalized land value of $600 to $900 per acre ($1,480 to $2,220 per ha) the buyout cost could range from $83.7 million to $125.5 million.

In addition to the irrigation plants, modification or replacement of M&I pumping systems would be required. Once again, it is anticipated that modification or replacement cost for M&I systems under SOS 9d would be considerably greater than the $39.5 million in capital costs identified for drawdown to MOP under several SOSs.

Annual operation, maintenance, and power costs for both irrigation and M&I pumpers would be higher under SOS 9d than for other SOSs evaluated in detail.

Lower Snake River Projects—M&I pumping occurs at all four lower Snake River projects. Irrigation (36,389 acres [14,727 ha]) only occurs from the Ice Harbor pool. SOS 9d would require additional modification or replacement for irrigation and M&I pumping systems. As for John Day, existing cost curves for plant modification under other drawdown scenarios might not be adequate for plants that need to be located directly at river level.

Pumping plant modification cost and annual operating and maintenance costs under SOS 9d would be greater than for SOS 5b or 5c, because there would be an additional drawdown ranging from 11 to 24 feet (3.4 to 7.3 m). An estimate of the increased pumping cost for irrigation and M&I pumpers was not made for SOS 9d. Under SOSs 5c and 5b, the capital cost of plant modification was estimated at $28.3 million for irrigation systems and $6.6 million for M&I systems.

Annual operation, maintenance, and power costs for both irrigation and M&I pumpers would be higher under SOS 9d than for other SOSs evaluated in detail.

Economics

An assessment of potential economic impacts of implementing SOS 9d was conducted by the EAG, based on physical impact data developed by the other SOR work groups. Because the analysis was very preliminary in nature, actual impacts could be much higher or lower than those shown in Table 4-4. Despite the preliminary nature of the analysis, the economic impacts presented in the table are considered to be reasonably representative of the general magnitude of direct economic impacts that would result from implementation of SOS 9d. The cost of modifying John Day Dam to operate at the level of the natural river, however, was not estimated and is not shown. The results of the analyses which were conducted are presented by river use in absolute terms and relative to SOS 2c, the no action alternative. As indicated by the impacts shown in the table, costs related to flood damages in the upper Columbia River, shallow draft navigation, power generation, and irrigation from the John Day pool would be significantly increased. Recreation and anadromous fish benefits would decrease with implementation of this SOS. Annual costs and benefits were developed using a discount rate of 3.0 percent.

Pacific Northwest Coordination Agreement

Like all SOSs produced during the course of the SOR, SOS 9d could be accommodated by any of the five PNCA alternatives without significant impacts to the objectives of SOS 9d.

However, this strategy could have some impacts on the need for any of the PNCA alternatives. Because this SOS appears to fully dedicate all system storage for anadromous fish operation, very little storage would be left for power coordination. Unlike the other SOSs in the Final EIS, this SOS takes the remaining

Table 4-4. Summary of direct annual economic impacts associated with SOS 9d.   **Page 1 of 2**

River Use	Economic Impact ($1,000)	Change from SOS 2c		Comments
		$1,000	Percent	
Anadromous Fish	42,860.0	(890.0)	(2.0)	The amount shown is the estimated commercial and recreational value based on "high" recreation and commercial values. Since the value shown is a "benefit" this negative benefit represents a system cost (loss of output).
Flood Control				Values shown are average annual expected damages.
Upper Columbia	10,247.5	3,275.0	212.9	
Clearwater	8.9	(1.4)	(13.6)	
Tri-Cities	0	0	0	No impact.
Lower Columbia	0	0	0	Analysis was limited to mainline levee protected areas, primarily in the Portland metropolitan area.
Total	n/a	n/a	n/a	
Irrigation and M&I Water				Values shown are the increase in capital and O&M costs over current conditions with SOS 2c. Costs associated with SOS 2c were not estimated.
Lower Snake	n/a	n/a	n/a	Impacts on the lower Snake River would be the same as SOS 5c. Costs specific to the lower Snake projects, however, are not readily separable from the total costs developed for SOS 5c. Therefore, they are not shown.
Grand Coulee	989.0	77.7	8.5	Additional impacts would occur, but they have not been evaluated.
John Day	n/a	n/a	n/a	The likely alternative is canals from the McNary pool on the Oregon and Washington sides of the river. Costs were not estimated, but the Corps' System Configuration Study found that canals in Oregon and Washington would cost 5 and 40 times, respectively, more than pump modifications required for drawdown to MOP.
Total	n/a	n/a	n/a	

Table 4-4. Summary of direct annual economic impacts associated with SOS 9d.   Page 2 of 2

		Change from SOS 2c		
River Use	Economic Impact ($1,000)	$1,000	Percent	Comments
Navigation				
Dworshak Reservoir	n/a	n/a	n/a	The elevation of the pool would be consistently and significantly below what it would be with SOS 2c. However, because the reservoir is only marginally usable for transport of logs with the SOS 2c operation, the marginal economic impact of this alternative would not be very large. Based on average monthly pool elevations, economic impacts could be expected to be about the same as those for SOS PA.
Shallow Draft	473,925.0	59,498.0	14.4	Values shown are the total estimated transportation costs for all commodities now shipped on the Columbia/Snake waterway and the difference (increase) in costs compared with the current operation of the system which allows year-round navigation.
Total	n/a	n/a	n/a	
Power	1,897,000.0	941,000.0	98.4	System costs shown are for operating year 1996, assuming the system was operated as specified in SOS 9d. Average annual costs were not computed for this alternative. Costs do not include potential changes in capacity costs.
Recreation	71,260	(243,529)	(77)	The values shown represent system benefits or outputs. Therefore, the decrease in these benefits, compared with SOS 2c, is a cost to the system (decrease in benefits).

Note: n/a = not available

flexibility offered by the Treaty storage in
Canada and operates it for fish flows. This
would conceivably give the non-Federal power
producers a legitimate argument for relief from
CEAA obligations, which in turn could eliminate
their need for a power coordination agreement.

4.2 IMPACTS OF THE SOS ALTERNATIVES

Section 4.2 is designed to provide the reader
with a basic understanding of the effects of the
SOS alternatives evaluated in detail in the EIS.
This section displays the effects of the
alternative SOSs for each river use or resource
area. More complete detail on the analysis of
the SOS alternatives and their implications can
be found in Appendices A through O. Section
4.3 presents a comparison of the alternatives.

How Effects Are Discussed
Impact Issues
• Key Issues
• How, Why, and Where System Operations Affect Resources
Effects of SOS Alternatives
• Changes Resulting from SOSs
• Magnitude and Extent of Changes

The effects of the SOSs are discussed by the
resource or subject areas within the Columbia
River system that are affected by system
operations. These are: earth resources, water
quality, air quality, anadromous fish, resident
fish, wildlife, cultural resources, Native
Americans, aesthetics, recreation, flood control
navigation, power, irrigation, municipal and
industrial water supply, economics, and social
effects. For each subject, the stage is first set
by explaining how operations affect the resource
and river use. Under the subheading "Impact
Issues," the discussion identifies specific issues
examined in the effects analysis. These issues
derive from scoping, information and comments,
prior controversy, concern within specific
communities, and other factors that render them
key to the analysis. The discussion also explains

the impacts, or how, why, and where system
operations affect the resource or river use (e.g.,
reservoir elevation influences on recreational
use).

The next section describes the "Effects of
Alternatives" for each resource and use. The
discussion identifies the sources and directions of
change that result from each alternative;
characterizes the magnitude, extent, and duration
of change; and illustrates these changes with
simple graphics and tables. The agencies have
tried to use the same format (issue-by-issue
discussion) for each resource to facilitate
comparison. For some resource areas, however,
(e.g., wildlife) the effects were better described
by deviating from the standard format. To
present a more understandable discussion of a
highly complex system, this EIS attempts to
avoid the extensive quantification of effects that
traditionally appears in EISs, leaving such detail
to the appendices.

The impact analyses generally present the
effects of the SOS alternatives both in absolute
terms and in comparison to existing conditions.
SOS 2c, the No Action Alternative, provides the
benchmark for comparative analysis because it
best represents existing conditions and the point
of departure for analysis of potential future
operations. Chapter 1 of the EIS explains the
need for and scope of the SOR, which relate to
the operation of the Columbia River System
given its current configuration. The basis for
comparison must be existing conditions, which
reflect the current system configuration. During
the SOR process, some commentors suggested
that pre-dam conditions should be the basis for
comparison. The SOR agencies did not adopt
this suggestion because comparison of existing
and pre-dam conditions would only be necessary
if a return to pre-dam conditions were within the
range of reasonable alternatives, which is not the
case.

The discussions in Section 4.2 refer
frequently to the hydroregulation model results
for each SOS. These river flow and reservoir
elevation patterns provide the basis for virtually
all of the impact analyses. The reader is

encouraged to consult Appendix A, River Operation Simulation, for detailed information on hydrologic conditions.

4.2.1 Earth Resources

This section examines the impacts of system operations on geology and groundwater. These impacts are manifested in three ways—shoreline modification by erosion and mass wasting, sedimentation in the reservoirs, and changes in groundwater levels. Appendix L, Soils, Geology, and Groundwater, provides background information on the geologic setting and more detailed descriptions of the impacts.

Earth Resources Impact Issues

Rivers have altered the landscape for thousands or millions of years. Their form and position are a result of a delicate balance between sediment-carrying capacity and sediment supply. Changes in sediment capacity and supply depend on the nature of the change and the setting of each river. Many of the rivers in the Columbia River Basin have been altered in some way. Most notable among these is the Columbia River itself, which has few remaining reaches of free-flowing water.

Damming a river represents a fundamental change, at least in the short term, in the river's regime. Filling the reservoirs behind the dams creates changes that alter two geomorphic systems: rivers and hillslopes.

All river activity is controlled by a base level, the level below which rivers cannot downcut. In a natural system, sea level is the base. Reservoirs act as local base levels, interrupting the dynamic equilibrium of rivers and tributary streams flowing through the area. As expected, tributaries and mainstem rivers slow at their contact with a reservoir; this contact also reduces flow upstream. Sediment that would otherwise be carried downstream drops out of the water within the reservoir so that water exiting the reservoir contains relatively little sediment. All reservoirs have this effect, and the amount of sediment coming

from the upstream basin primarily determines the useful life span of the reservoir. Basins producing large quantities of sediment tend to fill reservoirs faster than those producing relatively little sediment.

Prior to reservoir filling, the hillslopes are exposed only to the forces of gravity which can cause rock falls, soil to creep, and small-scale landslides. After a reservoir is filled, water becomes superpositioned on hillslopes and new forces begin to operate on the hillslopes. Four main variables control response of the hillslope system to reservoir filling and operation: pool level fluctuation, shoreline orientation, shoreline geology, and reservoir climate. Within the scope and projected period of the proposed system operations, only pool level fluctuation is truly variable at a reservoir. Pool level fluctuations affect both the river system and the hillslope/soil system.

Pool level fluctuations (drafting and refilling) occur whenever the inflow into a reservoir does not equal the outflow. The changes that influence pool level fluctuations are: (1) increasing outflow, such as power peaking operations, flow augmentation, or flood control space management; (2) decreasing outflow, such as holding back spring floods; and (3) changing the timing of outflow releases. For storage reservoirs, drafting and filling curves are generally smooth, but are occasionally interrupted. These curves vary with changes in runoff and the demand for electricity. Pool levels change seasonally and, where peaking occurs, daily. At run-of-river projects, relatively static pool levels concentrate wave erosion in a narrow range of elevation along shoreline slopes.

Erosion and Mass Wasting

The two types of projects, storage and run-of-river, have very different erosion processes due to the differences in their operation. Pool level fluctuation is the primary difference between the two types of projects. Run-of-river projects typically have a 3-foot (0.91-m) to 5-foot (1.5-m) pool elevation range (P_R) annually,

which is a small enough P_R so that mass wasting is relatively minor. For example, a study at Priest Rapids on the mid-Columbia River indicated there had been no significant shoreline erosion after 14 years of operation (CH2M Hill, 1975). Additionally, waves concentrate on a narrow zone of shoreline. Therefore, relatively stable shorelines can develop, and the surface that waves (and precipitation) can affect is relatively small. In addition, run-of-river reservoirs are relatively narrow, and the fetch (distance across the reservoir, that affects wave energy) can be short. Conversely, the fetch can sometimes be several miles of the reservoir's length, resulting in large waves.

Significant pool level fluctuations occur seasonally, and in some cases, daily, at storage reservoirs. The P_R of storage reservoirs affects all the processes acting on the shorelines, such as wave erosion, freeze-thaw weathering, incision, mass wasting, surface erosion, and groundwater movement. Figure 4-1 shows examples of some of these processes. Both the magnitude and rate of pool level fluctuation affect these processes.

Pool level fluctuation increases the area exposed to shoreline wave erosion and surface erosion. The greater the seasonal pool level variation, the more total wave and surface erosion occurs, because the surface area that waves can attack increases as pool elevation range increases. When a storage reservoir is drafted during the colder parts of the year, shoreline soils and sediments are subject to freeze-thaw cycles. During spring thaw, melting of one zone in a sediment column above a still-frozen layer may result in mass movement of the upper thawed unit. In addition, reservoir embayments that have ice may erode as the pool level drops, and the weight of the ice contributes to mass wasting of the shoreline.

The rate of drafting may affect mass wasting and groundwater movement in the shoreline materials. When the reservoir level is stable, unconsolidated shoreline materials become saturated. If the level drops quickly, the increased weight of the saturated materials,

along with removal of lateral support from the water, can cause slumping. Draining of the saturated materials may increase mass wasting through sapping (see Figure 4-1). Sapping occurs when water moves downward through porous materials and encounters a layer of decreased permeability. The water then flows horizontally until it reaches the intersection of the less permeable layer with the surface. At this point, the water can remove tiny particles from the sediment, creating a cavity, which undermines the more permeable sediments and leads to collapse.

Existing site-specific data on location or rates of shoreline erosion or recession within the Columbia River system are scarce to non-existent. While landslide areas on some reservoirs have been studied, the information as a whole is spotty. The SOR studies addressed geologic conditions of the shoreline around the affected reservoirs from the available literature. This minimal information indicates that significant shoreline erosion and mass wasting are occurring, particularly at storage reservoirs.

Sedimentation

Pool level fluctuations affect the river system by redistributing sediments within a reservoir and affecting the behavior of tributary streams entering the reservoir. Since dam construction, deltas have been deposited at the mouths of these tributaries. Seasonal pool level fluctuations tend to flush out some or most of the sediment accumulated in these deltas. The sediments typically get deposited lower in the reservoir, although the finest particles may remain in suspension and be carried out of the reservoir as turbid water. Over the long term, reservoirs fill with the accumulated sediment that they trap. The rate of accumulation, and thus the useful life of a reservoir, depend on the sediment inflow and velocity through the reservoir.

Groundwater Processes

Although groundwater is affected by pool level fluctuations, few studies have examined the behavior of groundwater during pool level
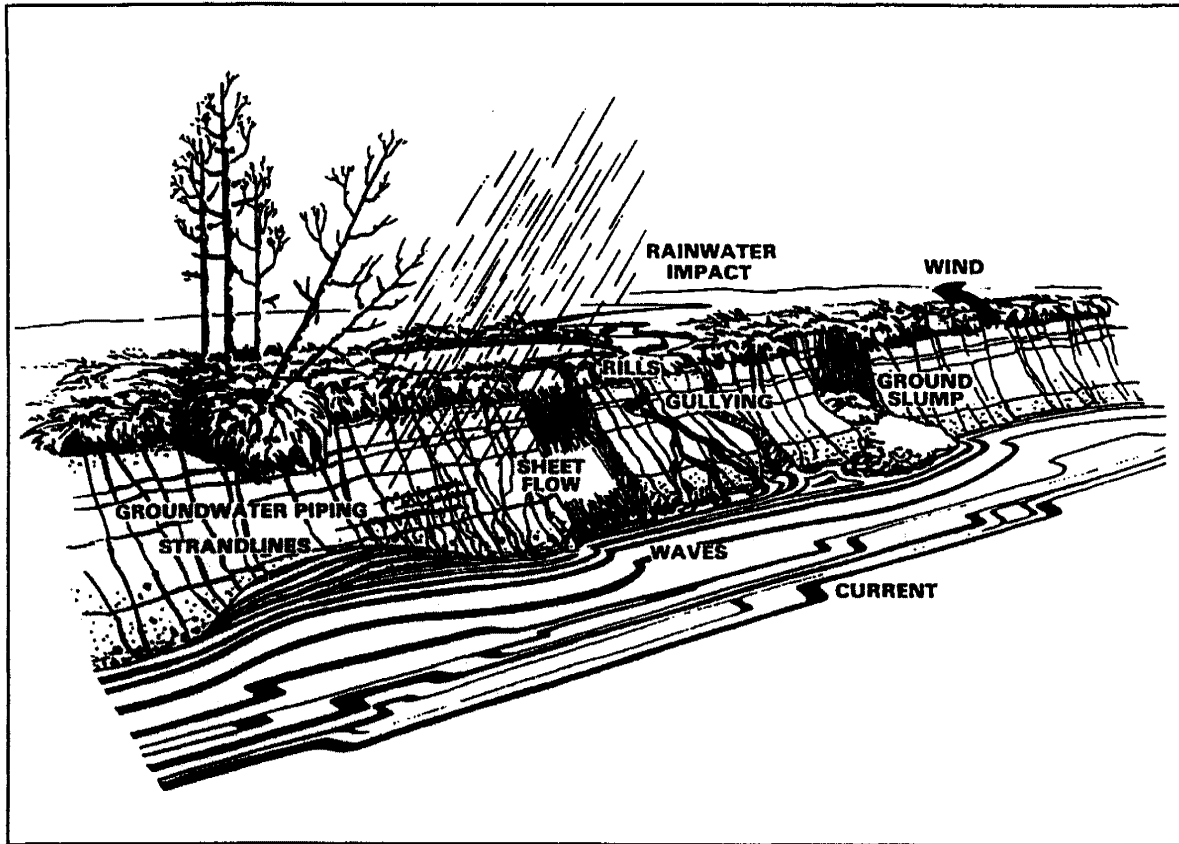
Figure 4-1. Shoreline erosion processes and characteristics that contribute to erosion. Sheet flow, rills, gullying, and rainwater impact are all surface erosion processes, while slumping is a mass-wasting process. Strandlines are a result of wave erosion. (Source: Gatto and Doe, 1983)

fluctuations. As a result, determining site-specific impacts of changes in reservoir operation would require detailed three-dimensional groundwater modeling. In addition, there are few wells near reservoirs in the Columbia River Basin, because water needs in most areas are met with surface water. Because of these limitations, a qualitative assessment of the effects of changes in pool level fluctuations was performed.

Near reservoirs, the gradient of groundwater movement is toward the reservoir. The groundwater most free to fluctuate with pool level is in the unconfined aquifers. These aquifers have a water table which changes with

the amount of infiltrating water. Therefore, the effects of pool level on these aquifers occur in the immediate vicinity of reservoirs. A drop in pool level has an effect on the water table that varies with the nature of the aquifer material. In highly permeable aquifers, the ratio of pool level drop to water table drop may be 1:1. In low-permeability aquifers, the water table may only drop a fraction of the amount of pool level drop.

Because water supply wells are frequently located in the upper unconfined aquifer, it is likely that wells near the reservoirs already experience some fluctuation. They now must be installed to allow continued production when pool levels are low. If a well is very close to a

reservoir, however, and the depth interval from which water is withdrawn (in unconsolidated deposits) is narrow, abnormally low pool levels could make the well go dry. Raising the pool level above the normal elevation would raise the water table, but this increase would not diminish water supply for the wells.

Effects of SOS Alternatives

Qualitative and quantitative analyses were used to assess the SOS impacts on geology and groundwater. In general, the selection of a qualitative or quantitative analysis was based on the availability of applicable data and the degree of change in expected impacts. While all of the SOS alternatives would continue erosion, sedimentation, and groundwater impacts from operations, some would introduce major changes in these physical processes. The quantitative effort was focused on these alternatives. Chapter 3.0 of Appendix L gives a detailed outline of the methods used and the data limitations in the quantitative analysis.

To provide a context for assessing SOS impacts, operational impacts of each alternative were compared to baseline conditions. In terms of geologic processes, baseline conditions are those that evolved under historical system operations, as best represented by SOS 1b. The rate of change in these conditions has been modified slightly at some projects (primarily Dworshak and Grand Coulee) since 1983, through operating patterns represented by SOS 1a, and subsequently by SOS 2c. While the actions included in SOS 2c have generally been in effect since the 1992 operating year, these operations are not drastically different from SOS 1a, and as yet have not likely caused any identifiable change in baseline conditions.

Erosion and Mass Wasting

A useful indicator of erosion intensity is the total P_R. While local geology and reservoir geometry greatly influence the relationship of P_R to total erosion, P_R helps to indicate trends in erosion that can be expected at a given reservoir. As indicated above, pool-level fluctuations

influence most of the processes acting on the shoreline. In addition, changes in P_R tend to outlast effects of other changes related to pool levels. For instance, if the P_R is reduced by 30 percent and the average annual pool elevation is decreased, the surface area above the average annual maximum level reached would increase, and would be exposed to more surface erosion (overland flow, rilling, gullying). The resulting erosion would, however, be limited by prior removal of detachable particles (when waves could attack the shore at these elevations) and by revegetation. In addition, wave erosion tends to produce greater volumes of sediment than surface erosion. Thus, the net effect would be an overall decrease in shoreline erosion.

Figure 4-2 shows the simulated P_R at each affected reservoir for each SOS. This figure was compiled from the hydroregulation model results for each SOS. Projects for which the P_R would be unchanged from current conditions, regardless of SOS, are not included in Figure 4-2 and are not addressed in the following discussion. These projects include Canadian projects (except Keenleyside); Chief Joseph and the mid-Columbia PUD; and McNary, The Dalles, and Bonneville Dams on the lower Columbia River.

SOS 1, Pre-ESA Operation—This alternative would continue historical patterns of shoreline erosion and mass wasting. The impacts of SOSs 1a and 1b would be nearly identical.

At Grand Coulee, both SOSs 1a and 1b would cause continued significant erosion and mass wasting. P_R would average about 60 feet (18.28 m) for either SOS 1a or SOS 1b. There are at least 82 active landslides (slides that have moved within the last 10 years) around Lake Roosevelt (Reclamation, 1992). In the initial period of reservoir operation, about 500 landslides occurred along Lake Roosevelt between 1941 and 1954 (Jones et al., 1961). Jones et al. (1961) demonstrated a clear relationship between P_R and landslides. Because there is little evidence of Lake Roosevelt shorelines stabilizing (approaching equilibrium

form), this level of landslide activity could be expected to continue for decades with operation under SOS 1.

The initial period of operations at Dworshak resulted in documented slides along approximately 13 miles (21 km) of shoreline (Gatto and Doe, 1983), which is about 10 percent of the total shoreline length. The authors believed that daily fluctuations in pool level of up to 5 feet (1.5 m) during drafting and refilling periods contributed significantly to landslides. Similar patterns of mass wasting would continue under SOS 1a and SOS 1b.

There is some evidence that comparable erosion and mass wasting conditions have developed at the other storage reservoirs. Hungry Horse Reservoir exhibits significant shoreline erosion in its upstream reaches, as well

as several large, active landslides. Libby has had rockslides, but these were unrelated to pool fluctuation (Voight, 1979). Brownlee has experienced significant mass wasting, with numerous active landslides along its shoreline (BPA, 1985). Lake Pend Oreille, behind Albeni Falls Dam, has experienced as much as 5 feet (1.5 m) of shoreline retreat at one location during a 12-year period (Gatto and Doe, 1983). Although 5 feet (1.5 m) of retreat is not normally significant, this amount occurred on a reservoir with a P_R of only 11 feet (3.4 m).

Future operation under SOS 1a or 1b would continue the historical pattern of erosion and mass wasting. Some shoreline retreat, attributable to wave erosion, would continue at Lake Pend Oreille. Based on the erosion rate reported in the one applicable prior study, the average rate of shoreline retreat would likely be
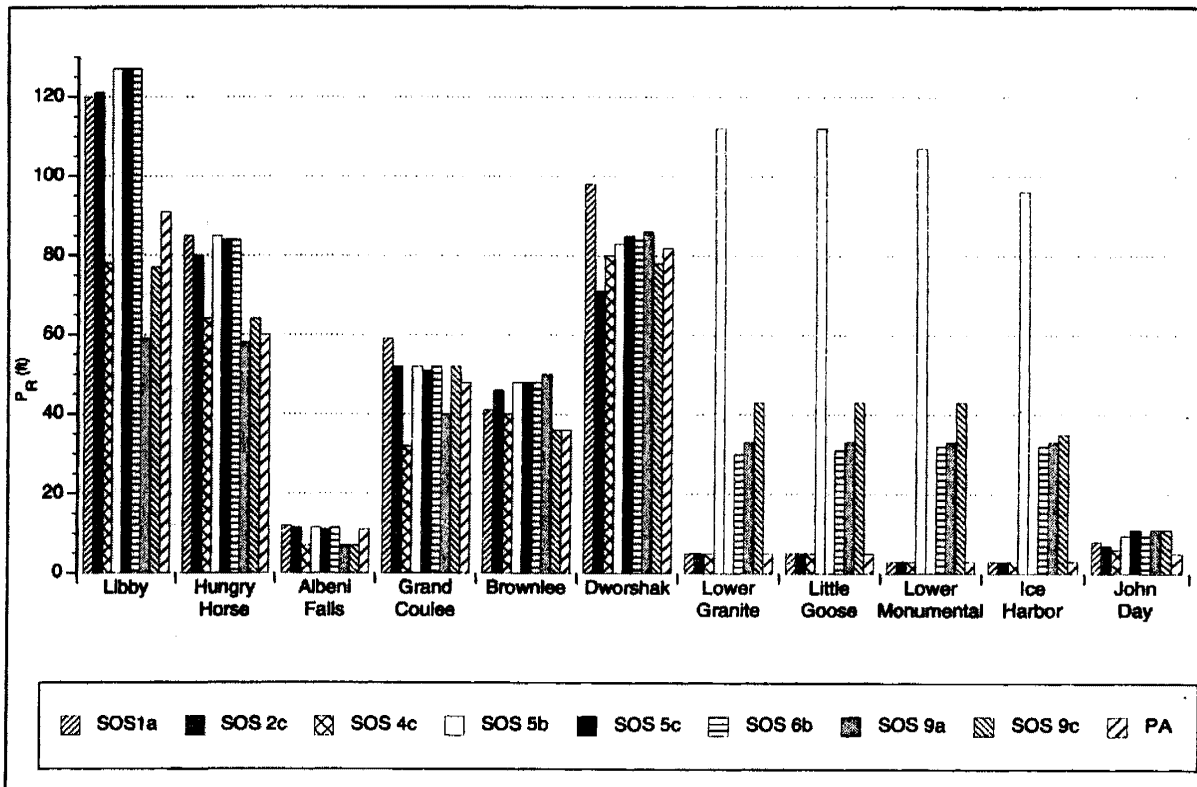
Figure 4-2. Total average pool elevation range (P_R) at affected projects for representative SOSs, by alternative

about 0.4 feet (0.1 m) per year. Localized conditions such as bedrock ledges could limit or prevent further shoreline retreat in some areas. Comparable information on erosion rates is not available for the other storage reservoirs. Most of the erosion in these reservoirs occurs in the drawdown zone below the full-pool elevation and is not readily evident or easily studied. Mass wasting, which is more evident, would likely continue at the same or slightly decreasing rate.

Available information indicates that the run-of-river projects have generally experienced only minor amounts of shoreline erosion and mass wasting. This result is primarily due to relatively stable pool levels and riprap shoreline armoring that has prevented erosion or mass wasting in many locations. Among the run-of-river projects, several low-angle slides have been documented at John Day (Gustafson, 1992), but shoreline erosion does not appear to be significant. Current erosion and mass wasting patterns, such as the minor landslides at John Day, would continue at the run-of-river projects under SOS 1a or 1b.

SOS 2, Current Operations—For most
reservoirs, current operations are the same as or a minor departure from historical operations. Therefore, erosion and sedimentation would remain within historical ranges for most reservoirs. For the other reservoirs, continuing current operations would cause differences from historical conditions as summarized below.

Current operations (SOS 2c) continued over the long term would accelerate erosion slightly at Brownlee compared to historical conditions due to a minor increase (less than 10 feet [3 m]) in P_R. The slight increase in the rate of drafting might also lead to a minor increase in mass wasting. Overall, however, shoreline erosion at the storage projects would remain within historical ranges. Shoreline erosion at Hungry Horse and Grand Coulee would decrease slightly, while erosion at Dworshak could decrease significantly.

Operating John Day near elevation 262.5 feet (80 m) and the lower Snake River projects near

minimum pool would expose the shoreline within the normal operating range for a longer duration. This scenario would lead to a short-lived increase in erosion, and possibly mass wasting, at these run-of-river projects.

SOS 2d would have essentially the same impacts as current operations, with two minor exceptions. Grand Coulee would experience slightly less erosion due to a 5-foot (1.5-m) reduction in P_R. At Brownlee, an additional but small cycle of draft/refill would occur each year, increasing the amount of time for erosion and mass wasting processes to affect the shoreline.

SOS 4, Stable Storage Project
Operation—SOS 4c would generally reduce shoreline erosion and mass wasting.

P_R at Libby under SOS 4c would be reduced by nearly half, compared to historical conditions. Erosion would also be less at Hungry Horse, for which SOS 4c would reduce the P_R by about 25 percent.

Albeni Falls would experience a slight decrease in erosion under SOS 4c, with P_R reduced from about 11 feet (3.4 m) to 7 feet (2.1 m). SOS 4 would result in about the same P_R at Brownlee as with historical conditions. The annual draft in these cases would be about 10 feet (3 m) less than reported previously for SOS 2.

SOS 4c would decrease erosion at Dworshak slightly, due to an 18 percent decrease in the total draft. SOS 4c would also generally reduce erosion at Grand Coulee, where annual drafting would be nearly halved. A major reduction in erosion and mass wasting would result.

Under SOS 4c, the run-of-river projects would generally operate the same as in SOS 2. Therefore, there could be a very slight increase in erosion and mass wasting at the lower Snake River projects. John Day would operate within 2 feet (0.6 m) of elevation 263.5 feet (80.3 m) during the late spring and summer, which is essentially midway between the average elevation for SOSs 1a and 2c.

SOS 5, Natural River Operation—This alternative would be fundamentally different from SOSs 1 through 4 in both the magnitude and location of impacts. Drawing the four lower Snake River projects down to natural river level for 4.5 months each year or permanently would expose large areas of reservoir shoreline to erosion.

A simple shoreline erosion model was developed as part of the quantitative analysis conducted for water quality (see Appendix L for details). This model estimated the volume of reservoir sediments eroded by four processes: surface erosion, slumping/sapping (mass wasting), tributary incision, and wave erosion. There are no detailed studies of shoreline behavior during drawdown, and the model relied heavily on the 1992 drawdown test for empirical information. The model focused on Lower Granite because more information is available for that reservoir than others. Surface erosion was estimated using the universal soil loss equation (a standard method for estimating soil erosion from a variety of surfaces, developed by the U.S. Soil Conservation Service). The surface area was estimated using the pre-dam river terrace topography. Armored areas, such as riprap and coarse-grained alluvial fans, were subtracted from the total estimated area exposed. Slumping/sapping was estimated using data from the 1992 drawdown test. Geometry of slumps was estimated using photos and knowledge of the behavior of slumped materials. Total slumped material was estimated for the 1992 drawdown test and adjusted for drawdown level and shoreline geometry. Tributary erosion was similarly estimated, using aerial photos and ground-based photos. Volumes of eroded materials were estimated for each major tributary using channel geometry. These estimates were adjusted for pool levels in SOS 5 and SOS 6, since both are lower than the maximum drawdown in the 1992 test. Wave erosion was estimated using the geometries of wave-cut terraces along the reservoir shoreline. Several classes of exposed areas were developed based on slope and geomorphic conditions. The volumes were multiplied by the number of terraces at various sites of uniform slope, and

adjusted for the slope as well. The estimates were extrapolated for areas that would be exposed under SOS 5 and SOS 6.

Estimates for each process were calculated for three different scenarios: low, moderate, and extreme. Because the 1992 test occurred during unusually calm conditions, the estimated wave erosion, for example, was assumed to represent a low erosion scenario. Surface erosion, mass wasting, and incision were also considered to represent the low end of the possible spectrum of erosion. For the moderate scenario, weather conditions during the test were compared to average conditions for that period and correspondingly adjusted. Adjustments were also made for the timing and duration of the proposed drawdowns.

Erosion estimates for the other three lower Snake reservoirs were made using the average erosion per mile under the moderate erosion scenario on Lower Granite, and multiplying by the mileage along those reservoirs. This estimate was adjusted for the amount of available sediment, noting that the dam construction sequence went progressively upstream in a relatively short period. This means that the other dams did not have very much time to accumulate thick sediments; most sediments have been trapped by Lower Granite. Some reservoirs, though, have major tributaries draining highly erosive land (the Palouse region), so further adjustments were made to account for these major sources of sediment.

Estimates of the erosion in the following years were based on best professional judgement, in lieu of sediment routing. Most erosion is likely to occur in the first few years, with the amount of erosion rapidly tapering off, as the easily erodible sediments are removed and the coarser, pre-dam sediments exposed. Surfaces would become somewhat armored with time. However, because an average of 3 million cubic yards (2.3 million m^3) of sediment flow down the Snake into Lower Granite, most of these sediments would remain within the reservoir, assuming at least half reach the reservoir at times other than the drawdown.

The erosion model results indicate that about 900,000 cubic yards (688,000 m³) of sediment would erode from Lower Granite alone during the first year of operation under SOS 5b. Figure 4-3 shows estimated erosion at Lower Granite for the drawdown alternatives (SOSs 5, 6, 9a, and 9c). Another 2.5 million cubic yards (1.9 million m³) of sediment would erode from the other three lower Snake River reservoirs during the first year, for a total of 3.4 million cubic yards (2.6 million m³) from the four projects. Erosion would decrease rapidly during the first 6 years of operation, then reach a relatively constant level as lag deposits developed along the exposed shorelines and reduced the volume of available sediment. The constant rate for all four lower Snake projects would be between 700,000 and 1.3 million cubic yards (535,220 and 993,980 m³) per year, which is considerably less than the total estimated annual sediment influx to the lower Snake of 3 million cubic yards (2.29 million m³). The rate has a large margin of error because of high degrees of uncertainty in sediment wedge geometry, contribution of pre-existing sediments, and variability in weather patterns. The rates for SOS 5b fall within this range. Under SOS 5c, erosion would be significantly less due to the elimination of the drawdown-refill cycle. Within

5 to 15 years, the amount eroded would decrease to background levels, and sediment leaving the Snake River would be approximately equal to the sediment influx in the river.

The stability of fill material along the reservoir margins would be reduced as water drained out of the fill during the annual drafting period. This would cause slumping and piping, and result in damage to embankments and port facilities along the lower Snake River reservoirs.

SOS 5 also provides for operation of John Day at minimum pool (elevation 257 feet [78.3 m]) for much of the spring and summer, when the reservoir elevation is normally between 265 and 268 feet (80.8 and 81.7 m). This scenario would effectively double the total annual draft, but would not significantly affect erosion along Lake Umatilla's shoreline over the long term. The lower pool could contribute activity along a landslide west of Alderdale on the north shore of the lake (Gustafson, 1992).

Conditions at the storage reservoirs under SOS 5 would generally be similar to those reported for SOS 1. Compared to historical conditions, differences among the storage projects would generally be in the range of 5 to 10 feet (1.5 to 3 m). P_R at Dworshak would be 20 feet (6.1 m) lower, and would decrease erosion and mass wasting.

SOS 6, Fixed Drawdown—This alternative is similar to SOS 5, involving drawdown of all four lower Snake River projects (SOS 6b), or of Lower Granite only (SOS 6d), to fixed elevations. However, the degree of impact would not be as great because the depth of drawdown would be approximately 33 feet (10 m) per dam, as opposed
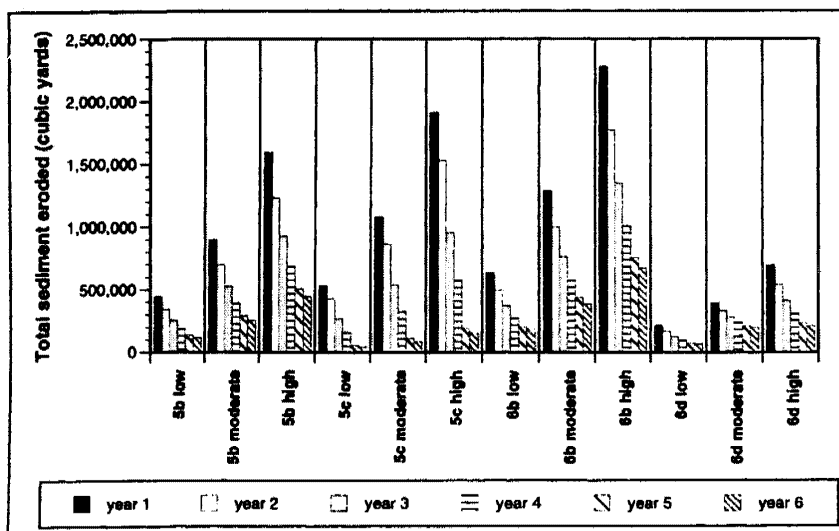

Figure 4-3. Total sediment eroded from lower Snake River reservoirs under average conditions, SOS 5 and 6 (Source: Appendix L; 1 cubic yard = 0.765 cubic meter)

to about 100 feet (30.5 m) with the natural river operation.

Nonetheless, SOS 6 would still cause major increases in erosion and mass wasting. SOS 6b would mobilize about 1.5 million cubic yards (1.14 m^3) of sediment during the first year, which is half as much sediment as produced under SOS 5b. The yearly rate of erosion after 6 years under SOS 6b would be less than half of that under SOS 5b, being roughly 500,000 cubic yards (76,460 and 382,300 m^3). The rate is significantly less because most sediment would be retained within each reservoir. Under SOS 6d, the erosion rate would be roughly 300,000 cubic yards (38,230 and 229,380 m^3).

Again, SOS 6 would cause some damage to embankments and port facilities. Unlike SOS 5, which has river bank erosion, shoreline wave erosion would become the dominant erosion process.

The impacts of SOS 6d on erosion would essentially mirror those of SOS 6b, but would be limited to Lower Granite and its vicinity. The estimated volumes of sediment mobilized in Lower Granite 390,000 cubic yards (298,194 m^3) for SOS 6d. Little Goose would trap most of the sediment passed through Lower Granite.

SOS 9, Settlement Discussion Alternatives—The three options under SOS 9 present very different potentials for impacts. The two that involve drawdown, 9a and 9c, would generally have significantly more effects than 9b.

Erosion and mass wasting would be significantly reduced under 9a at both Libby and Hungry Horse, due to the decrease in P_R. Areas currently seasonally inundated and then exposed would become vegetated and not subject to wave or surface erosion.

Erosion would increase at several reservoirs. At Brownlee, an additional draft/refill cycle would cause a significant increase in the amount of shoreline exposed to wave attack. At Dworshak, the P_R would increase slightly,

resulting in a moderate increase in erosion and mass wasting. A short term increase in wave-generated sediment would also result, since the average annual low pool elevation would be lowered by 10 feet.

The lower Snake River projects would be significantly affected, as the drawdown to near spillway crest would cause erosion problems similar to, although not as extensive as, that under the other drawdown alternatives. At Lower Granite alone, approximately 1.5 million cubic yards (1.15 million cubic meters) of sediment would be mobilized during the first year. Approximately 4.3 million cubic yards (3.2 million cubic meters) of eroded sediment would be generated at the other lower Snake River projects during the first year, assuming typical weather conditions. Erosion and mass wasting would decrease rapidly after the first year. It is estimated that after about 6 years, the sediment influx from erosion would stabilize at a background level.

At Grand Coulee and John Day, the P_R would increase, but not enough to make a detectable change in shoreline erosion. Albeni Falls would experience a slight decrease in the amount of shoreline erosion, since P_R would decrease slightly.

Under SOS 9b, erosion and mass wasting would decrease slightly over the long term at Libby, Hungry Horse, and Grand Coulee. These would increase at Brownlee and Dworshak, as additional draft/refill cycles would be added to each. John Day and the lower Snake River projects would experience effects as under current conditions.

SOS 9c would significantly change the operations of a number of the project reservoirs. Due to the 36 percent decrease in P_R, erosion and mass wasting at Libby would significantly decrease. Similarly, Hungry Horse would experience a 20 percent decrease in P_R, leading to a noticeable decrease in erosion and mass wasting. Albeni Falls would be operated as under 9b, and thus effects would be the same.

The lower Snake River projects, being drawn down to near spillway crest, would experience significant effects. The 40-foot (12.2 m) drawdown would cause approximately 1.3 million cubic yards (994,000 m) of sediment to be eroded. The patterns of erosion and mass wasting would be similar to those under SOS 6, with a peak each year at the beginning of a drawdown, tapering off during the middle of the drawdown, and a small increase during the refilling. Slumping would occur in the unconsolidated sediments, especially in deltas and embayments. Erosion and mass wasting would decrease rapidly within a few years after the initial drawdown, but would eventually reach a background level.

Effects of SOS 9c on John Day would be similar to those under SOS 5, with a slight increase in erosion and mass wasting.

SOS PA: Preferred Alternative—Under this option, shoreline erosion and mass wasting would experience a net decrease at Libby and Hungry Horse, due to significant decreases in P_R. At Albeni Falls, Grand Coulee, and Brownlee, shoreline erosion and mass wasting would be similar to that under current operations. At Dworshak, P_R would increase, resulting in a slight increase in shoreline erosion and mass wasting.

At John Day, a temporary increase in erosion and mass wasting would occur as the pool level was lowered to MOP. The effects of the lowering might be short lived. If the pool level were held at about 257 feet (78.3 m) year round, shorelines would be able to establish equilibrium profiles eventually. Long-term erosion due to pool fluctuation would thus be minimal and similar in amount to that under current conditions. However, use of the 3- to 5-foot (1- to 1.5-meter) seasonal fluctuation allowed under the Biological Opinion might prevent the equilibrium condition and result in long-term erosion comparable to other run-of-river projects.

Sedimentation

The amount of sedimentation is linked with the amount of erosion and has two sources—river scour and bank erosion. Appendix M, Water Quality, presents the results of the HEC-5Q and HEC-6 studies. Conclusions presented in this section are based on these studies, which consider both sources of sediment.

The results show the effects of the operation alternatives on silt concentrations along the length of the Snake River. Silt concentrations are a proxy for sedimentation; where the silt concentrations are high, the river velocity is low. Deposition of sediment, particularly the coarser silt and sand particles, is likely in these areas. Smaller-size particles were not modeled, but numerous studies show that fine silt and clay particles stay suspended much longer than the coarser particles.

SOS 1, Pre-ESA Operations—Sedimentation would remain within historical ranges. Upstream reservoirs would trap much of the sediment, while tributaries to the lower reaches of mainstem rivers—the Columbia, the Snake, and the Kootenai—would contribute some sediment to lower-elevation reservoirs. Tributaries ending at reservoirs would continue to extend their deltas out into the water.

Serious sedimentation problems have developed at Lower Granite under pre-ESA operations. Sediment has accumulated at a maximum rate of 0.23 foot per year (0.07 m/yr). Dredging is already necessary to maintain shipping channels and port facilities in the Clarkston area (Corps, 1985). Under these operations, dredging would be necessary in the future to keep the freeboard capable of containing floods within the levee system.

Sedimentation in most downstream reservoirs would be limited to gradual filling of the reservoirs and occasional, minor redistribution of sediment within the reservoirs. The water quality studies did not specifically address SOS 1; however, because the operations do not

vary significantly between SOS 1 and SOS 2, the results from the SOS 2 analysis can be assumed to approximate the conditions under SOS 1. These results are discussed below.

SOS 2, Current Operations—Sedimentation patterns would change slightly in the reservoirs where erosion would decrease. This would be predominantly a redistribution of sediment in the reservoir, and not a net change in sedimentation. Therefore, there would be essentially no impact on sedimentation systemwide, relative to historical conditions. The water quality studies show that the maximum silt concentration on the Snake River would be at 20 milligrams per liter (mg/l) at the upper end of Lower Granite Reservoir.

SOS 4, Stable Storage Project Operation—SOS 4c would generally reduce the rate of sedimentation within reservoirs, due to the decrease in erosion. Sediment would continue to accumulate in essentially the same locations as at present.

SOS 5, Natural River Operation—Significant changes in sedimentation would result under both SOS 5 options. Sediment previously trapped behind the lower Snake River dams would be flushed to the Columbia River, with McNary Reservoir (Lake Wallula) trapping most of the sediment. Navigation channels could be affected and would possibly need dredging. Most of the sediment influx from upstream currently occurs during the spring and early summer. Because this sediment would be transported through the lower Snake River reservoirs during the annual drawdown period, the reservoirs would experience little if any net sedimentation under both options, but particularly under SOS 5c, since no retention of sediment would occur. The water quality studies show that the greatest increase in sediment accumulation would occur upstream of McNary, at RM 320 to 325 on the Columbia River and RM 0 to 10 on the Snake River. The maximum accumulation would be approximately 230 kg/m^2. The lifespans of the four lower Snake River projects would be extended; however, the lifespan of McNary would be shortened.

SOS 6, Fixed Drawdown—A pulse of fine sediment would be flushed out of the Snake River system and into the Columbia River under SOS 6b or 6d. The coarser sediments would be retained behind the Snake River dams. McNary Dam would trap most of the sediment released into the Columbia River. According to the water quality analysis, the pulse of sediment would be significantly smaller than that of SOS 5 and, after 2 years, would be comparable to background tributary inputs. The net decrease in sediment accumulation would add slightly to the life of the lower Snake River projects, while the life span of McNary would decrease slightly. Under SOS 6d, a smaller pulse of sediment would be deposited in Little Goose. Lower Granite's lifespan would not be increased significantly.

SOS 9: Settlement Discussion Alternatives—The major effect of SOS 9a would be sedimentation of McNary Reservoir. The sediment eroded from the lower Snake River projects would be deposited mostly at the confluence of the Snake and Columbia Rivers. Shipping lanes could be affected. Sedimentation in the lower Snake projects would decrease, however, since they would be releasing significant amounts each year.

Storage projects would experience a decrease in the amount of shoreline-derived sediment as shoreline erosion decreases. Sedimentation would decrease significantly at Libby and Hungry Horse; it would decrease slightly at Albeni Falls. Shoreline-generated sedimentation would increase at Brownlee and Dworshak due to accelerated shoreline erosion. Grand Coulee would experience the same patterns and amount of sedimentation as under current operations.

Under SOS 9b, sedimentation from shoreline erosion would decrease slightly at Libby, Hungry Horse, Albeni Falls, and Grand Coulee. However, similar to 9a, sedimentation would increase at Brownlee and Dworshak. On the four lower Snake River projects, sedimentation patterns would remain within historical ranges.

Sedimentation from shoreline erosion and mass wasting would decrease significantly under SOS 9c at Libby, slightly at Hungry Horse, and at Albeni Falls. This is due to the decrease in shoreline erosion and mass wasting resulting from less pool level fluctuation. At Brownlee, an extra draft/refill cycle would increase erosion and thus sedimentation, while sedimentation at Dworshak and Grand Coulee would remain within historical ranges.

As under SOS 9a, the lower Snake River projects and McNary would experience major changes in sedimentation patterns, with McNary receiving large amounts of sediment from the eroding shorelines and reservoir bottoms on the lower Snake River projects. The lifespan of McNary could decrease, while sedimentation in the Snake River projects would decrease. Minor increases in sedimentation near shore would occur at John Day, due to a slight increase in shoreline erosion.

SOS PA: Preferred Alternative—Sedimentation from shoreline erosion and mass wasting would increase slightly at Dworshak, but would decrease slightly at Libby, Hungry Horse, Grand Coulee, and Brownlee. At John Day, a pulse of sedimentation would occur during the first few years following lowering of the pool level. Gradually, sedimentation from shoreline erosion and mass wasting would return to within historical ranges. Sedimentation at other run-of-river projects would remain within historical ranges.

Groundwater

SOS 1, Pre-ESA Operation—Historical patterns of groundwater fluctuations would continue with future operation under SOS 1a and SOS 1b. The water table near the storage reservoirs generally fluctuates greatly during the year as a result of fluctuations in reservoir elevations, with the degree of effect decreasing with distance away from the shoreline. The magnitude of seasonal fluctuations would differ among the storage reservoirs; pool level fluctuations are relatively minor at Lake Pend

Oreille, for example, but are much greater at Dworshak or Hungry Horse. Very little fluctuation in water tables near run-of-river projects occurs with normal operations. Historical operations may have decreased the yields of some groundwater wells near the storage reservoirs on a seasonal basis. This condition would continue under SOS 1a or 1b.

SOS 2, Current Operations—Groundwater fluctuations under SOS 2 would follow patterns generally similar to those under historical operating conditions. There would be a slightly greater fluctuation in groundwater levels at Libby and Brownlee during the spring and summer. The water table near the lower Snake River reservoirs would drop by up to 5 feet (1.5 m) from its normal spring and summer elevation. This effect would only occur very close to the reservoirs, and would not be noticeable in groundwater wells. Similar conditions would occur at John Day, but the decrease in elevation would be 5.5 feet (1.7 m) or less.

SOS 4, Stable Storage Project Operation—Water table fluctuations around Libby and Hungry Horse under SOS 4 would decrease significantly compared to historical conditions. A slight decrease would occur at Albeni Falls, Grand Coulee, and Dworshak. Unconfined aquifers near other reservoirs would experience fluctuations similar to those under current or historical operations.

SOS 5, Natural River Operation—The 1992 drawdown test of Lower Granite decreased the water table level up to 0.5 mile (0.80 km) from the reservoir. A similar pattern of groundwater conditions would occur under this alternative. However, the effects of SOS 5 would be greater in magnitude, extent, and duration. The natural river operation would lower the water levels in the reservoirs by approximately 100 feet (30.5 m), while the 1992 test involved a drawdown of up to approximately 40 feet (12.2 m). Therefore, SOS 5 would lower the water table much more than did the 1992 drawdown test. The greater water table reduction would translate into a wider zone of effect around each

reservoir, probably extending up to 1 mile (1.6 km) away from the reservoirs. The groundwater effects of the 1992 drawdown test were also limited to a 1-month period, while SOS 5b would affect water tables for 5 or 6 months each year, and permanently under SOS 5c.

The natural river operation under SOS 5b would seasonally affect shallow groundwater wells within the zone of water table reduction. Most of the affected wells would be in the Lewiston-Clarkston area or near Ice Harbor east of Pasco. Some wells might temporarily go dry, and alternate sources of water might have to be obtained. The yield from other wells might be reduced.

Under SOS 5c, water tables near the lower Snake reservoirs would decrease dramatically and approach pre-project levels within the first year. Some wells would go dry and others would experience decreased yield.

Storage projects would experience only slight changes in water table fluctuation, relative to historical conditions, under SOS 5. The prescribed operation for these projects is similar to that for SOS 1a, and differences in respective pool levels between SOS 1 and SOS 5 would generally be 10 feet (3 m) or less.

Under both options, some wells along the John Day reservoir could be affected, experiencing decreased yield. The City of Boardman Ranney well would not be affected, however, due to the limitations of its pump capacity (CH2M HILL, 1992).

SOS 6, Fixed Drawdown—Groundwater levels would drop in the aquifers hydraulically connected to the lower Snake River reservoirs under SOS 6. Effects on groundwater would be similar to those described for SOS 5, but would be significantly less in magnitude and extent. The depth of drawdown under SOS 6 would only be one-third as much as under SOS 5. Consequently, the water table decline would be much less under SOS 6 and would not extend as far from the reservoirs. Nevertheless, wells within the groundwater impact zone would be

significantly affected. Again, effects on wells would be concentrated near Lewiston-Clarkston and near the western end of the Ice Harbor pool (Lake Sacajawea). Because of its greater seasonal duration, SOS 6b would lower the water table and affect wells. Under SOS 6d, these effects would be limited to groundwater levels near Lower Granite only, and to wells near the Lewiston-Clarkston area. Some wells near Lake Umatilla could be affected by the decrease in pool level to MOP.

Groundwater effects at the storage projects under SOS 6 would be essentially the same as those reported previously.

SOS 9, Settlement Discussion Alternatives—Groundwater fluctuations near reservoirs would change significantly on some reservoirs, depending on the option.

Under all three options, groundwater fluctuations at Grand Coulee would decrease very slightly, and water table elevations would be slightly lower near the reservoir during the summer.

Under SOS 9a, groundwater fluctuations would increase at Dworshak, while under 9b and 9c, they would decrease.

At Brownlee, fluctuations would be similar to those under current operations for all three options, except that there would be an additional fluctuation caused by the extra draft/refill cycle.

On the four lower Snake River projects, options 9a and 9c would cause significant groundwater fluctuations near the reservoirs, as under SOS 6b. Wells in the Lewiston/Clarkston area within 0.5 mile of the reservoir shoreline would be most affected, and the water table near the shoreline would drop. Some wells might go dry, and others might experience a decreased yield. The effects would be somewhat more extensive under 9c than under 9a because the drawdown level is lower.

The water table near Lake Umatilla would be affected slightly by the 9 foot (2.7 m) drop in pool level under options 9a and 9c. The effects

would be similar to those under options 6b and 6d, except that the water table would be low during April through August. Although the Ranney well in Boardman would not be affected (CH2M HILL, 1992), other wells near Lake Umatilla could experience decreased yield.

SOS PA: Preferred Alternative—The only significant changes in groundwater fluctuations from current operations would occur at Libby, Hungry Horse, Dworshak, and John Day. Due to decreased pool level fluctuations, groundwater in unconfined aquifers connected hydraulically to the reservoir would experience a decrease in annual fluctuations compared to current conditions at both Libby and Hungry Horse. In addition, the higher average annual pool level elevation at Hungry Horse would mean a higher near-reservoir water table.

At John Day, numerous wells would be affected by permanent lowering of the pool elevation to 257 feet (78.3 m). Wells developed in the Pasco Gravels aquifer could be directly affected, losing yield or going dry. Increases in pumping costs could occur.

4.2.2 Water Quality

Columbia River system operations can influence water quality by regulating streamflows and pool elevations. The quantity of flow is regulated throughout the basin—from the headwaters downstream to the mouth. Regulation at the dams causes the flow to be either stored in, withdrawn from, or passed directly through the pools. Pool elevations fluctuate in response to releases at the dams and to natural inflows. Flow and elevation are critical factors in controlling water volume and velocity within reservoirs. The volume of water spilled and the volume and velocity in the reservoirs influence the three significant water quality issues analyzed in the SOR: water temperature, dissolved gases, and sediment transport.

The influences of flow and elevation on these three main issues are described first, followed by identification of the potential effects of specific alternatives. More detailed information

can be found in Appendix M, Water Quality. The effects are compared to a baseline condition. SOS 2c is used to represent this condition for evaluation of water temperature and dissolved gases.

Two of the three main water quality parameters could be analyzed in a highly quantitative manner because of the large amount of monitoring data available on them. Total dissolved gases and water temperatures are monitored in real-time at the dams. Sediment data were collected primarily during the 1992 Lower Granite Dam Drawdown test. This limited set of data provided the basis for the sediment transport analysis. Less data were available for all other water quality parameters, so only three were selected for quantitative analysis. Ammonia, lead, and DDT were selected to represent nutrient, metal, and organic pollutants known to exist in the river system. The lesser amount of data available on these water quality parameters resulted in a more qualitative evaluation of their effects.

Water Quality Impact Issues

Exceedance Threshold Levels

The SOR Water Quality Work Group selected value measures for the analysis and threshold levels for the value measures. The thresholds are not necessarily the current water quality standards. The group then predicted the number of days that the threshold would be exceeded for each SOS.

The value measure for water temperature is the predicted number of days exceeding 63°F (17°C). This temperature is below the current regulatory standard of 68°F (20°C) on the Columbia River. The value measure for dissolved gas is the predicted number of days exceeding 110-, 120-, and 130-percent saturation of total dissolved gases. The current regulatory standard for the Columbia River is 110 percent. Fishery interests have requested the regulating agencies consider increasing the 110-percent standard. Therefore, 120- and 130-percent thresholds were also evaluated. The value

measure for sediment is the predicted number of days exceeding a suspended silt concentration of 25 mg/l. There is no regulatory standard for suspended silt. Turbidity is closely related to silt, however, and there is a turbidity standard. However, this standard is based on increases of 5 Nephelometric Turbidity Units (NTU, see Glossary), or 5 percent, above ambient conditions which are not constant. The suspended silt threshold was selected on the basis of protection for fish.

Influence of Streamflow and Pool Elevation

Streamflow is the volume of water that passes a point during a specific period of time. Dilution, gas entrainment, flow velocity, and scour are partially functions of streamflow. The concentration of a substance in a water body will be diluted when mixed with streamflows having a lower concentration. The same holds true for mixing water of different temperatures.

Gas entrainment is the process that mixes gas from the atmosphere into the water. Gas entrainment generally increases with streamflow volume, particularly if high streamflows require spill at dams. Tailwaters at a dam become supersaturated when high volumes of water plunge down a spillway.

Sediment transport is the process in which inorganic clay, silt, and sand soil particles, and organic phytoplankton (algae) particles and other organic detritus are swept away or deposited in the water column (flow). Water velocity (speed) and depth influence sediment transport, and are a function of streamflow.

Pool elevation relates to the volume of water stored in the pool, the pool surface area, the velocity and residence time of flow through the pool, and exposed bank area. Each of these attributes affects water temperature, total dissolved gas saturation, and sediment transport.

Water Temperature

The major effect of the dams on the Columbia River on water temperature has been

to delay the occurrence of maximum temperatures in late summer, and to delay early autumn cooling. Regulating streamflow alters the timing of river heating and cooling relative to the natural patterns normal to the life history of fish.

Air and water attempt to exchange heat to reach an equilibrium temperature. Radiant heat from the sun warms both the atmosphere and water bodies, but water heats up and cools down more slowly than air. Air temperature, wind, humidity, and solar radiation determine the equilibrium temperature. Water temperatures generally change towards ambient air temperatures. Also, water heating and cooling rates increase and decrease indirectly with the volume of water. High streamflows will tend to remain close to mean water temperatures, whereas low streamflows will vary more. In addition, the velocity of flow generally increases directly with streamflow. The higher the velocity, the less time water in the system is exposed to the air, and the less time there is for heating or cooling. Higher flow velocities are typically shallower in depth and lower in volume, however, thus counteracting the temperature attenuation effect of higher streamflows. The SOR water temperature model accounted for all of these temperature relationships.

Pool elevation adjustments can be used to control water temperatures, but the relationships are complex and differ between storage and run-of-river projects. Storage pools are deep and stratify thermally during the summer. Run-of-river pools are shallow and have a more uniform temperature distribution. In either case, more water is stored at higher pool elevations, and water temperature is more resistant to rising air temperatures. Resulting increases in pool surface areas can offset this temperature attenuation effect by increasing the heat exchange with the atmosphere. Lower elevations can reduce this exchange and reduce residence and heating times in the pool.

Because storage reservoirs are usually thermally stratified during the summer, their

deep waters are much cooler than inflows during this time. Discharges from storage projects (with multi-level intakes) can be adjusted to a desired temperature. Projects that do not have selective withdrawal facilities typically are restricted to discharges from deep storage. In some cases, this results in discharging excessively cool water during the summer, while in other cases, cool discharges are desired to reduce downstream water temperatures.

Dissolved Gas

Gas saturation is mainly caused by spill—water sent over the spillways of a dam. Total dissolved gas saturation is directly related to the amount of spill. Dissipation of gases is incomplete between projects with little or no lateral inflow. Forced spill is always a potential, especially during high run-off years, since projects have fixed hydraulic capacities. When there is more water in the river than the power system can use, forced spill cannot be easily controlled. Voluntary spill is done mainly for fish passage, and usually happens during the spring and summer at selected projects on the juvenile fish outmigration routes.

Everything else being equal, the potential for gas entrainment in the tailwater increases with the vertical distance that water falls over a dam spillway. Spilling water mixes with air, then plunges into the tailwater stilling basin. Spilling at high heads allows for deeper plunging and more gas entrainment, but the volume of spill has a greater influence on dissolved gas saturation than the vertical distance of the fall.

Sediment Transport

Increased streamflows result in increased sediment transport and turbidity. The friction forces created by water flowing across river beds mobilizes of the bed sediments. This scouring phenomenon is attributable to flow velocity and depth, both of which generally increase directly with streamflow. Scoured sediments entering the water column either settle out or remain in suspension and are transported farther downstream. Spring runoff generates the

greatest sediment transport and turbidity levels during the year. Tributary sediment inflows generally settle out near their confluence with the main river, forming deltas that are periodically scoured away. Coarser sediments entering a reservoir typically deposit at the head of pools. The finer sediments, such as silt and clay, are deposited near or transported past the dams. Higher streamflows will carry sand downstream. Pollutants entering the mainstem can adsorb to sediments, mostly to silt and clay, and be transported and accumulate with them.

Pool elevation influences the amount of bank area exposed to erosive elements, the length of the pool, and the volume of sediment accumulation. Bank erosion is accelerated when pool elevations fluctuate, as described in Section 4.2.1. Sediments delivered from local and upstream inflows settle out in a pool. Higher pool elevations, a longer pool, and more local tributaries and adjacent land area contribute to greater sediment accumulation in the pool. Sediments slowly fill in the pool over time. If the pool elevation were lowered significantly, the accumulated sediments could be scoured and transported downstream. The distance of transport for suspended sediments would depend on the final drawdown pool elevation, the hydraulics of the stream, and the amount of flow.

General Effects of Key Operations Measures

The seven strategies include varying mixes of flow augmentation, stable storage, and drawdown operations. The effects of these river regulation schemes on water temperature, dissolved gases, and sediment transport are discussed at a conceptual level in the following text. These concepts are then applied in the subsequent assessment of the model results for the specific SOS alternatives.

Flow Augmentation

Flow augmentation causes more streamflow to be discharged through the system at selected times. Therefore, forced spill and increased gas

supersaturation would be more likely with flow augmentation than without. Flow augmentation would also lead to higher volumes of spill at projects operating for voluntary spill, unless the spill percentages were reduced.

Water temperature control capability in the Columbia River Basin is limited. There are few reservoirs that are large and deep enough to provide adequate storage of cold water. Currently, flow augmentation water is stored over the winter in Lake Roosevelt, Arrow Lakes, and Brownlee and Dworshak Reservoirs. Augmentation releases in the summer should work, in a limited way, to decrease temperature immediately downstream. Flow augmentation should help support water temperature control objectives, because it entails storage of cool water in the spring and later release of that water in the summer.

The temperature of the flows released from augmentation sources is critical to the degree of temperature control. Grand Coulee, Hungry Horse, and Brownlee do not currently have selective withdrawal capabilities. Libby has selective withdrawal facilities but is too far upstream to be effective in reducing temperature to benefit anadromous fish. Dworshak's storage is too limited in relation to Snake River streamflows to have a large effect on river temperature. Flow augmentation water from the middle and upper Snake Rivers would probably be at equilibrium temperature by the time it reaches Brownlee Reservoir and would not decrease receiving water temperatures significantly. The SOR water temperature model predicted that any water released from Brownlee would reach equilibrium water temperature before it flowed out of Hells Canyon.

Stable Storage Operations

Stable pool operations would likely affect sediment transport, gas saturation, and water temperature. Stable pools would mean there would be little change in storage, and discharges would be similar to inflows at most times of the year.

Higher average pool elevations would result from stable storage operations. This would generally reduce sediment transport. More bank area is exposed to surface erosive forces at lower pool elevations causing greater delivery of sediment into the pool. Little downstream sediment transport would occur because most of the sediments from the eroded banks should settle out and deposit in the slow flowing pools.

Stable storage operations would result in higher discharges from storage projects during the spring runoff. This could contribute to a higher spill volume with an increased gas saturation. High pool elevations could also increase the potential for greater gas saturation because of the greater head at the dam, but this is a much lesser factor than spill volume.

Streamflows would be passed more directly through pools with a stable storage operation, resulting in little effect on water temperature. This operation would provide little or no summertime water temperature reduction because there would be no cool water releases from storage projects in summer.

Drawdown

Drawdown operations would increase flow velocity through affected pools, but would not add streamflow to the system. Drawdown effects would be greatest on sediment transport, but should provide some temperature and total dissolved gas saturation reduction.

Drawdown operations could reduce water heating rates on the Snake River due to increased flow velocity. Refilling the lower Snake River projects with cool Dworshak releases could have an additional cooling effect. As in a stable storage operation, the lower pool elevations would account for shorter heating periods. This effect could be offset by accelerated heating from low streamflows.

A drawdown operation should not increase gas supersaturation in the Snake River over current conditions. Snake River drawdowns would begin in late winter or early spring,

before peak runoff, so it should be possible to draft the pools through the turbines. This would avoid spill and ensuing gas supersaturation.

Drawdown would be the only type of operation that would significantly increase sediment transport. Flow augmentation and stable pool operations should not induce nearly as much scouring as drawdown operations. Generally, the greater the drawdown in elevation and in duration, the greater the sediment transport. The Snake River and the Columbia River immediately downstream of the confluence (McNary pool) should be the only reaches in the system affected by these operations.

The redistribution of pollutants that have accumulated in the lower Snake River pools is an issue associated with sediment transport. The Corps has detected nutrients, pesticides, heavy metals, and dioxins in the Snake River pool bed sediments. Point and non-point sources of these pollutants are likely to include industrial discharges, sewage treatment plants, and agricultural, urban and mining activities. Most of these pollutants remain adsorbed to sediments, but some could become dissolved in the water column when disturbed by drawdown. The duration of sediment suspension increases the extent of downstream transport and desorption.

Effects of Alternatives

The following discussion summarizes the results of the model analysis of the SOS alternatives. The results are presented in value measures termed exceedance days. These are the predicted number of days per year that an operation would raise the water temperature, percentage gas saturation, or silt concentration above the specified thresholds. Appendix M, Water Quality, describes the analysis methods in full and contains the entire set of modeling results. Only the outstanding differences in exceedances, defined as a difference of 7 or more days, are included in this discussion.

Water Temperature

The greatest impact on water temperature is expected in the lower Snake River (Table 4-5). Releases of cool water from Dworshak Reservoir could reduce water temperatures throughout the lower Snake River reach. Releases from Grand Coulee and Brownlee Dams could reduce water temperature even more in the mid-Columbia and mid-Snake during years when a large volume of cool water is stored behind these dams. Elevated temperatures are most frequent during low-flow. During low-flow years, releases from Brownlee from flow augmentation would counteract the cooling effect of Dworshak releases on the lower Snake River water temperature.

SOS 1, Pre-ESA Operation Current—Water temperatures predicted for SOS 1 operations are not significantly different from the current (SOS 2c) operations. Compared to the other SOSs, SOSs 1a and 1b would be two of the best water temperature reducing alternatives, but only during high-flow years.

The only major difference between SOSs 1a and 1b involved Little Goose and Ice Harbor. Under high-flow conditions, SOS 1a had 11 more exceedance days than SOS 1b at Little Goose. Under low-flow conditions, SOS 1a had 28 fewer days than SOS 1b at Ice Harbor. By itself, the difference between 10 and 28 days exceeding 63°F (17.2°C) for 13 stations may be significant for one form of aquatic life, but not another.

SOS 2 Current Operations—Both SOS 2c and SOS 2d would create water temperatures near the average for all SOSs. The number of days exceeding 17.2°C at The Dalles for SOS 2c is among the best of all SOSs, but the range of exceedance from the best to the worst SOS is only 4 days. In the mid-Columbia (represented by Priest Rapids), the SOS 2 alternatives would be near the lower end of the exceedance day range for all SOSs. The opposite would occur in the lower Snake (represented by Lower

Table 4-5. Temperature model simulation results, number of days exceeding 63°F[a/]

SOS	Low-1929			Average-1962			High-1974			5-year Average		
	LG	PR	TD	LG	PR	TD	LG	PR	TD	LG	PR	TD
1a	79	79	93	71	71	93	79	66	83	74	71	89
1b	66	75	93	70	71	93	79	63	83	69	70	89
2c	67	67	90	81	70	92	82	67	83	78	70	88
2d	82	77	94	70	74	94	84	70	86	79	74	91
4c	74	70	90	74	70	89	80	64	83	75	68	88
5b	58	82	90	58	79	90	65	58	83	61	72	88
5c	71	85	93	73	83	94	76	68	88	74	77	92
6b	62	72	91	70	70	93	81	67	83	69	70	89
6d	61	72	90	69	70	92	80	67	83	68	70	88
9a	79	76	93	82	73	94	86	72	88	82	74	92
9b	84	75	93	85	72	93	84	71	87	84	74	91
9c	81	80	95	81	73	93	86	71	88	82	76	92
PA	69	77	92	74	71	92	78	67	87	76	73	91

LG = Lower Granite Dam
PR = Priest Rapids Dam
TD = The Dalles Dam
5-year Average (1929, 1959, 1962, 1973, 1974)
a/ 17.2°C

Granite). Here, the SOS 2 alternatives would be near the upper end of the water temperature exceedance day range for all SOSs.

SOS 4, Stable Storage Project Operation—The only significant departures from baseline simulated temperatures were found in the mid-Columbia and lower Snake. Exceedance days computed for SOS 4 were greater than for SOS 2 under low-flow conditions in these reaches.

SOS 5, Natural River Operation—Overall, SOS 5b would exceed of the 17.2°C water temperature threshold the least of all alternative. It would have fewer exceedances in the lower Snake and throughout the entire Columbia River than SOSs 2c and 5c. Temperatures in the upper and lower Columbia River would exceed the threshold more often for SOS 5c than SOS 2c. Model simulation results indicated that temperature exceedances for specific high- and low-flow years were lowest for SOS 5b. Temperatures under SOS 5b would not be

reduced as much for the lowest flows.

SOS 6, Fixed Drawdown—For extremely low-flow years, SOS 6b and 6d would have the least system-wide temperature threshold exceedances. However, compared to SOS 2c, the temperature reductions are insignificant.

SOS 9, Settlement Discussion Alternatives—These alternatives have the most severe effects on water temperature. Exceedances are high under all conditions in every major reach of the system. The difference in exceedance between the No Action Alternative (SOS 2c) and SOS 9 is significant.

SOS PA, Preferred Alternative—Overall, water temperatures are not significantly different under SOS PA compared to SOS 2c. However, for individual low- and average-flow years, exceedances were among the worst under SOS PA.

Dissolved Gas

Table 4-6 presents the model results for gas supersaturation. For clarity of presentation, Table 4-6 shows gas supersaturation simulation results for only one dam on each of the three main trunks of the Columbia River Basin. The results at other dams are described in the text where differences in results are significant.

SOS 1, Pre-ESA Operation—The results for the two SOS 1 options are not significantly different at the 130- and 120-percent gas supersaturation exceedance levels. Comparisons of the predicted 110-percent gas saturation level exceedance between SOS 1a and the No Action Alternative indicated that the No Action Alternative would reduce gas supersaturation in the mid-Columbia reach, but increase gas levels in the lower Snake and lower Columbia Rivers. The computed exceedance days for SOS 1a in the mid-Columbia reach were 11 fewer than the No Action Alternative because of generally less spill in May and June at the mid-Columbia dams under SOS 1a. The higher exceedance differences were predicted for the lower Snake River. The computed exceedance days for SOS 1a in were 22 to 31 more than the no action alternative at Ice Harbor.

SOS 2 Current Operations—Neither SOS 2c nor SOS 2d would create extraordinary gas supersaturation exceedances of the 110 percent standard relative to all the other SOSs. Relative to each other, SOS 2d would have significantly less exceedances than SOS 2c (No Action Alternative). On the lower Snake (Ice Harbor), SOS 2d would be in the low end of the exceedance range for all SOSs, and SOS 2c would be mid-range. On the mid-Columbia (Priest Rapids), SOS 2d would be mid-range, and SOS 2c near the high end. On the lower Columbia (The Dalles), both would be mid- to low range.

SOS 4, Stable Storage Project Operation—The overall ranking of SOS 4c is among the best for gas supersaturation for medium flow years. However, the 6-year average exceedance of 110 percent saturation at

Priest Rapids is the highest of all SOSs. Nevertheless, compared to the No Action Alternative, the mid-Columbia reach would not significantly increase exceedances over current operations. On the lower Snake and Columbia, SOS 4c exceedances would be slightly less than the No Action Alternative.

SOS 5, Natural River Operations—The model simulations show that dissolved gas exceedance levels computed for current operations would significantly decrease in the lower Snake River as a result of natural river operation. Additionally, the overall rankings of SOSs 5b and 5c are the best of all alternatives. SOS 5c would have significantly less exceedances than SOS 5b on the lower and mid-Columbia during low and average flow years. However, during high flow years, SOS 5b would have the least exceedance on the lower Snake. On the Columbia during high flow, SOSs 5b and 5c would have typically high exceedances at Priest Rapids, but only SOS 5c would significantly reduce exceedances at The Dalles. The 6-year average exceedance for SOS 5c was the lowest of all the alternatives on the Columbia, and nearly equal to the lowest on the Snake. SOS 5b had the lowest 6-year average exceedance at Ice Harbor.

SOS 6, Fixed Drawdown—The simulations indicate that fixed drawdown of all lower Snake River projects should result in decreased gas supersaturation from Lower Monumental to John Day. The computed number of days exceeding the 110-percent level in the affected Snake River reach for SOS 6b ranged from 11 to 25 fewer than for the No Action Alternative for all flows. Predicted differences in the Columbia were insignificant.

SOS 6d had significantly higher exceedances at Ice Harbor than SOS 6b for all flows. The difference between SOS 6b and SOS 6d would be insignificant on the Columbia.

SOS 9, Settlement Discussion Alternatives—These alternatives are the worst for gas supersaturation from an overall and reach-specific perspective. The only reach

Table 4-6. Total dissolved gas model simulation results, number of days exceeding 110-percent saturation

	Low-1973			Average-1959			High-1974			6-year Average[1]		
	IH	PR	TD	IH	PR	TD	IH	PR	TD	IH	PR	TD
1a	68	19	46	77	28	34	83	86	97	77	32	51
1b	67	21	44	77	32	36	83	85	100	75	33	50
2c	47	28	36	37	45	36	61	97	101	46	43	48
2d	23	14	13	18	54	49	23	79	78	21	33	33
4c	40	34	32	33	62	41	61	96	92	43	49	45
5b	2	27	23	2	43	25	1	94	83	2	42	32
5c	0	2	0	4	14	0	26	87	38	5	19	6
6b	22	27	30	20	43	32	50	94	97	27	42	42
6d	43	27	34	29	43	33	65	94	102	42	42	47
9a	49	27	132	32	61	131	82	90	127	65	38	130
9b	85	13	138	47	109	128	91	97	122	93	36	129
9c	49	12	134	65	31	106	58	82	102	60	28	117
PA	24	14	135	20	42	119	24	97	116	23	34	125

IH = Ice Harbor Dam forebay
PR = Priest Rapids Dam forebay
TD = The Dalles Dam forebay
1/ 6-year average based on 1938, 1959, 1962, 1973, 1974, and 1977 water conditions.

where these SOSs were not worst was the mid-Columbia (SOS 4c was worst). The worst 6-year average exceedance at The Dalles was from SOS 9a (82 days greater than the No Action Alternative). The worst 6-year average exceedance at Ice Harbor was from SOS 9b (91 days greater than the No Action Alternative). In the mid-Columbia, the 6-year average exceedance would be less than the No Action Alternative, but not by more than 15 days (SOS 9c). SOS 9c would have the least exceedance of all SOS 9 alternatives.

SOS PA, Preferred Alternative—This alternative is exceptionally poor for gas supersaturation in the lower Columbia as indicated by the predicted high exceedances at The Dalles. The 6-year average exceedance of

110 percent for SOS PA was only 5 days less than the worst alternative (SOS 9a), and 77 days more than the No Action Alternative. In the mid-Columbia and lower Snake reaches, the exceedance for SOS PA was in the mid- to low range for all SOSs.

Sediment

Sediment effects were evaluated for the No Action Alternative and for all the drawdown options in SOSs 5 and 6. The SOS used as the No Action Alternative for the full-scale sediment analysis was SOS 2c without upper Snake River flow augmentation. In the Draft EIS, this alternative was SOS 2a, but it is referred to as the No Action Alternative in this section. The SOR Water Quality Work Group concluded that

the results from simulations of current operations adequately estimate the sediment transport during all non-drawdown SOSs (1, 2, 9b, and PA) SOSs 9a and 9c were not simulated in the enhanced HEC-5Q modeling, but its sediment transport should be similar to SOS 6, because SOS 9 drawdown depths and durations are about the same as in SOS 6. Table 4-7 shows the exceedances of the 25 mg/l silt concentration (about 18 NTUs) threshold for these alternatives as annual percentages. The maximum exceedance for the first simulation year is shown to demonstrate the predicted worst-case, short-term effects. The flow condition corresponding to this case is also shown here. The 15-year average exceedance computed from the entire 5 years of simulations for low, average, and high flow conditions was used to show persistence of sediment transport after the initial scouring expected during the first year. Long-term cumulative exceedances are also indicated in the 15-year average columns of this table.

Silt transportation from the Snake River to Lake Umatilla on the Columbia River is not expected to increase due to the proposed drawdown SOSs. The simulated silt concentrations for Lower Granite, Ice Harbor, Priest Rapids, and John Day represent the sediment transport in each of the major trunks of the Columbia River in the SOR study area. Table 4-4 shows zero exceedance in the lower and mid-Columbia trunks, and exceedances of over 30 percent in the lower Snake. The models indicate there would be transport of sediment from the lower Snake River during drawdown, and deposition in the Columbia River near the confluence.

SOS 2, Current Operations—The No Action Alternative represents baseline conditions and effects from SOSs 5, 6, and 9. The exceedance of the 25 mg/l silt level for the No Action Alternative is zero percent. This essentially means that significant sediment transport does not currently occur, nor should it occur with operations other than drawdown.

SOS 5, Natural River Operation—The natural river operation would generate the most

lower Snake River sediment transport of all the SOS alternatives. The computed exceedance at Lower Granite and Ice Harbor under SOS 5b was 36 percent. High flows should create the maximum silt concentrations in the lower Snake River during the initial drawdown under SOS 5. The percent exceedance for SOS 5b should drop a third of the first year's value to 25 percent in the long term. The remaining sediment transport is likely to come from continued bank erosion and scour of the channel bed. The longer 12-month drawdown (SOS 5c) would transport more silt than the 4.5-month drawdown.

SOS 6, Fixed Drawdown—Model results indicate that fixed drawdown on all the lower Snake River dams should generate one-half to two-thirds of the sediment transport level of SOS 5b during initial drawdown. The decrease is expected at Ice Harbor because sediment scoured from upstream is deposited and scoured again in Lake Sacajawea. Simulations of the 4.5-month drawdown did not produce different exceedances. Most of the sediments would still likely settle out during the drawdown period. The computed long-term exceedances for both lower Snake River locations were down to 3 to 5 percent. The remaining sediment transport would likely come from lateral inflows from bank erosion, and not from continued channel scouring.

The modeling also showed that no transport of silt exceeding 25 mg/l would be expected at Ice Harbor if only Lower Granite were drawn down (SOS 6d). Any silt scoured from the bed of Lower Granite pool should be deposited upstream of Ice Harbor Dam.

SOS 9, Settlement Discussion Alternatives—Of the three SOS 9 alternatives, only SOS 9b did not involve a drawdown of any lower Snake reservoir. Therefore, SOS 9b sediment transport impacts would be insignificant as in the No Action Alternative. SOS 9a and SOS 9c both involve a 4.5 month drawdown of the four lower Snake reservoirs. These SOSs would create sediment transport impacts similar to SOS 6b. SOS 9c sediment

Table 4-7. Sediment simulation results[a]

| SOS | Lower Granite | | | | Ice Harbor | | |
	15-Year Average	1st-Year Maximum	Flow		15-Year Average	1st-Year Maximum	Flow
2a	0	0	[b]		0	0	[b]
5a	21	29	High		21	29	High
5b	25	36	High		23	36	High
6a	5	18	High		5	24	High
6b	5	17	High		3	21	High
6d	5	17	High		0	0	[b]
9a	5	17	High		3	21	High
9b	0	0	[b]		0	0	[b]
9c	5	17	High		3	21	High
PA	0	0	[b]		0	0	[b]

| SOS | Priest Rapids | | | | John Day | | |
	15-Year Average	1st-Year Maximum	Flow		15-Year Average	1st-Year Maximum	Flow
2a	0	0	[b]		0	0	[b]
5a	0	0	[b]		0	0	[b]
5b	0	0	[b]		0	0	[b]
6a	0	0	[b]		0	0	[b]
6b	0	0	[b]		0	0	[b]
6d	0	0	[b]		0	0	[b]
9a	0	0	[b]		0	0	[b]
9b	0	0	[b]		0	0	[b]
9c	0	0	[b]		0	0	[b]
PA	0	0	[b]		0	0	[b]

a/ Measured by long- and short-term percentage exceedance of 25 mg/l silt concentration threshold.
b/ Simulated silt concentrations did not exceed 25 mg/l under any of the flow conditions modeled.

transport would be closer to SOS 6b because both do not involve flow augmentation from the upper Snake River.

SOS 9a includes some flow augmentation during the drawdown period so flow velocity through the lower Snake reservoirs would be greater than SOS 6b and SOS 9c. However, the relative increase in flow velocity due to flow augmentation would cause an insignificant increase in reservoir bed sediment scouring. Therefore, SOS 6b sediment transport adequately represents SOS 9a.

SOS PA Preferred Alternative—SOS PA sediment transport would be the same as the No Action Alternative because neither SOS involves reservoir drawdowns on the lower Snake.

Other Water Quality Parameters

The full-scale water quality model was used to simulate the transport of lead, DDT, and ammonia in the mainstem Columbia and lower Snake Rivers. As in the analysis of sediment transport, the concentrations of these parameters were compared using exceedance thresholds that were selected to determine differences between the drawdown alternatives and other operations. The results indicate that only DDT and lead exceedances would vary between SOS 2 and drawdown operations.

SOS alternatives that would result in marked changes in water flow and circulation patterns could indirectly affect a variety of other water quality parameters by modifying the mixing of point-source discharges to the river system. The potential for this type of impact is acknowledged in the following discussion, but such site-specific effects could not be modeled in the full-scale analysis.

Exceedance Thresholds—The lead, DDT, and ammonia thresholds were chosen to show differences between SOSs. Like the thresholds selected for water temperature and sediment transport, these also do not necessarily coincide with water quality standards. The exceedance threshold is 15 micrograms per liter (μg/l) for

lead, 0.0004 μg/l for DDT, and 0.1 mg/l for ammonia. They are water column total concentrations. Generally, the thresholds are below water quality standards.

The standards for lead and ammonia are dependent on other factors that vary within the system and over time. The U.S. Environmental Protection Agency (EPA) standard for lead (based an average hardness in the Columbia River of 57 mg/l) is 25 μg/l, and for ammonia (based on an average water temperature of 59°F [15°C], and a pH of 8.0) is 0.75 mg/l $NH_3 + NH_4$. The model results show no exceedance of the ammonia standard. The only variation between the computed exceedances of SOS 2 and drawdown operations was shown for SOS 5b. This variation was relatively minor, so details of ammonia exceedances will not be discussed.

The standard for total DDT in the water column is 0.001 μg/l. The DDT threshold for the analysis is actually below current detection limits. The model showed that this DDT standard was not exceeded, so the analysis threshold was lowered to show the differences between SOSs. The DDT water column total concentrations computed by the model are most likely attributable to desorption of pollutants that have accumulated in the Snake River bottom sediments, which would get scoured into the water column during drawdown operations. Only sediment data were available for DDT, so it was assumed that DDT was not detected in the water column. The model results verify this assumption.

Lead and DDT—The model results for lead and DDT show trends similar to those found for silt (see Figures 4-4 and 4-5). SOS 5b should generate the greatest lead and DDT exceedances of all the options. Again, no significant departure from SOS 2 is expected at the Columbia River locations—Priest Rapids and John Day Dams. The reduction in exceedance between SOS 5b and SOS 6a/b, and between Lower Granite and Ice Harbor Dams, is also similar to that for silt.

The similarity of exceedance patterns between silt, DDT, and lead in the lower Snake River is because when silt is eroded and transported, lead and DDT will also be transported. The lead and DDT that were measured in pond sediments in 1992 were input into the full-scale model. The model computed total lead and DDT water column concentrations using estimations of silt in transport and sediment chemical data on Snake River reservoir beds. The range of computed total lead and DDT concentrations at Lower Granite are 10 to 40 μg/l and 0.0002 to 0.0004 μg/l, respectively. At Ice Harbor, lead and DDT concentrations ranged from 6 to 40 μg/l and 0.0002 to 0.0009 μg/l, respectively.

The exceedance difference between SOS 2 and SOS 5b at Lower Granite Dam is better shown by exceedance curves. At an exceedance threshold of 25 μg/l lead, the model shows an exceedance increase of about 25 percent for SOS 5b over SOS 2. This result is closer to the silt trends expected at Lower Granite Dam. Figures 4-4 and 4-5 show lead and DDT exceedance curves for SOS 2a and SOS 5b generated from model simulations at Lower Granite and Ice Harbor Dams.

The trends in the computed exceedances indicate that lead and DDT accumulated in the lower Snake River sediments would be transported downstream with the sediments during drawdown. For the natural river operation, lead and DDT would deposit in the Columbia River just downstream of the confluence with the Snake River. For the SOS 6
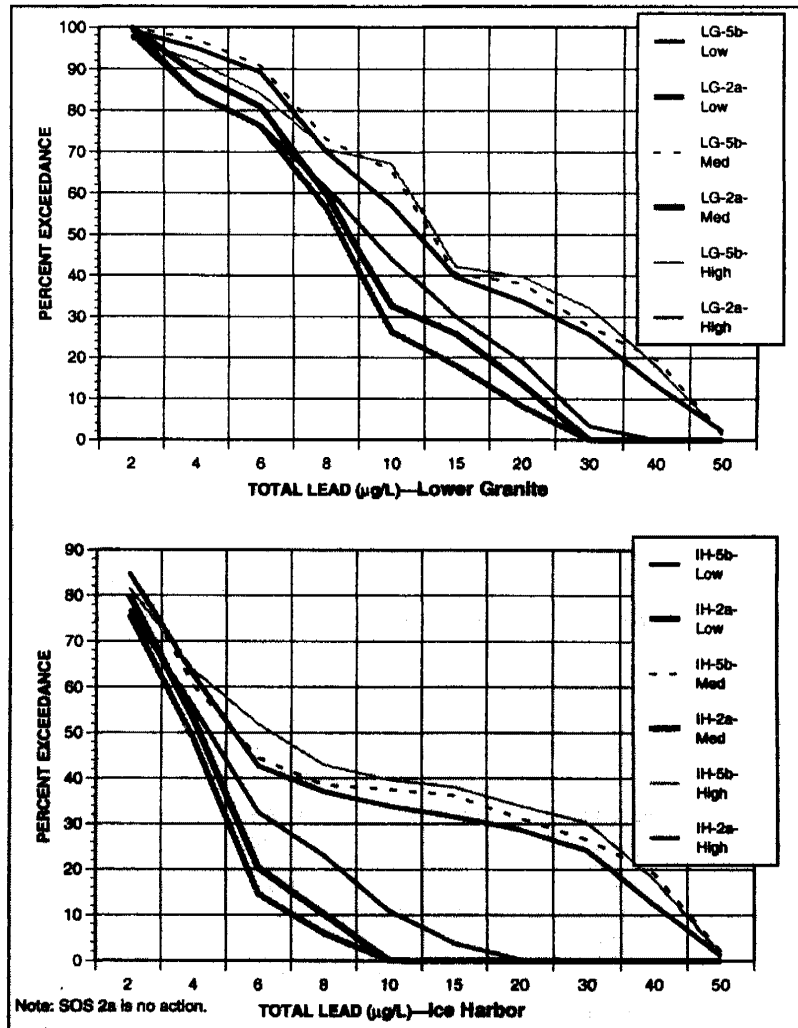
Figure 4-4. Simulated total lead exceedance curves for Lower Granite and Ice Harbor

options, the lead and DDT would deposit in the partially drawn down pools. The process of desorption of the contaminants from sediment particles could produce a sediment-cleansing effect, but it might also cause water quality standard exceedances in the water column. There may be impacts on sediments in upper Columbia storage reservoirs (e.g., Lake Roosevelt) as well.

Point Source Discharges—As noted in Section 2.1.2, a number of urban and industrial users discharge point-source effluents to the river system under NPDES permits. These

permits require that the discharges be diluted sufficiently that water quality standards for the spectrum of regulated parameters are not violated beyond a specified mixing zone. Any changes in water elevation, flow, or circulation patterns could influence the mixing and dilution of these discharges. Consequently, SOS alternatives that would markedly change flow and circulation patterns at specific locations could conceivably diminish the ability of dischargers to meet the terms of their NPDES permits. Determining the extent, frequency, and magnitude of this potential problem for the

entire study area would require highly site-specific and detailed analysis that is beyond the scope of the SOR investigation. (Through prior studies and comment on the Draft EIS, the SOR agencies are aware that effluent discharge from the Potlatch Corporation mill in Lewiston could be affected by SOS alternatives that include drawdown of Lower Granite Reservoir. Potlatch has estimated that discharge modifications to accommodate drawdown would cost from $0.5 million to $1.0 million.) Monitoring measures incorporated as part of the SOS implementation should detect any operations effects on NPDES-permitted discharges, however. Any problems identified through monitoring could be addressed by ongoing short-term operational adjustments or in future revisions of the SOS.

4.2.3 Air Quality

The SOR assessment of air quality impacts focused primarily on dust blowing from exposed reservoir sediments. The following discussion of air quality issues and SOS alternatives has been summarized from Appendix B, Air Quality.

Air Quality Impact Issues

Although air quality is not a major resource issue for the SOR, scoping indicated that dust blowing from exposed reservoir shorelines was a concern for some people. The SOR agencies identified specific potential issues related to direct air quality impacts, including exceedances of air quality standards, nuisance effects of blowing dust, health effects from fine particulate matter and airborne chemicals attached to dust; and to indirect
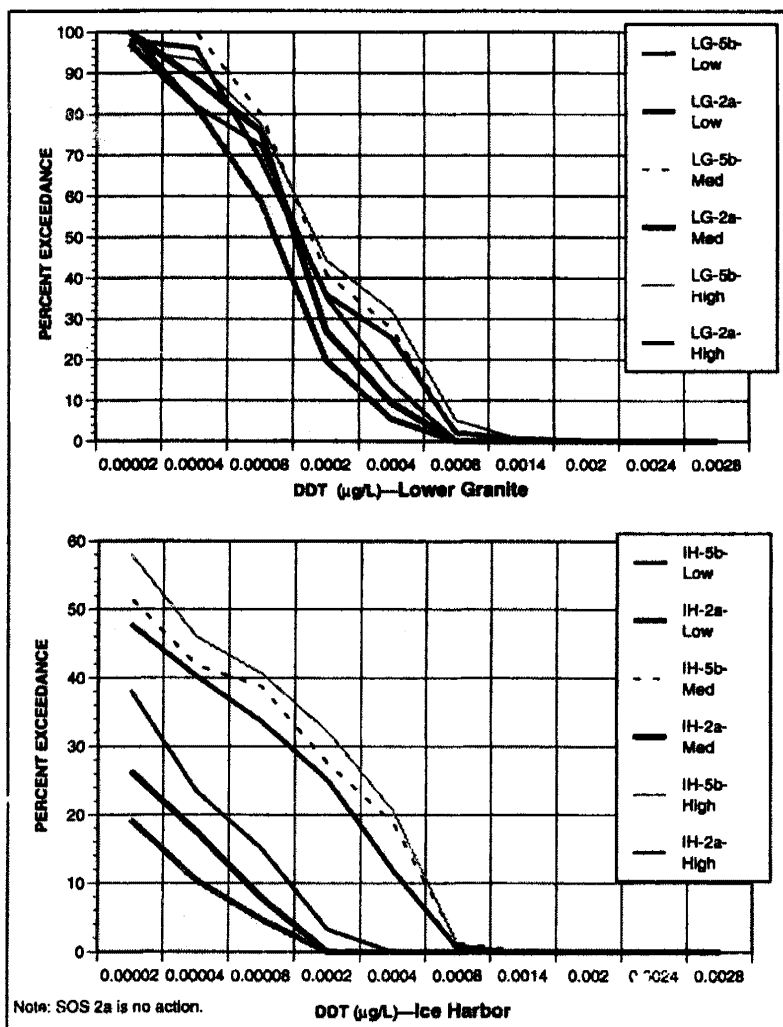
Figure 4-5. Simulated DDT exceedance curves for Lower Granite and Ice Harbor

air quality impacts associated with replacement power sources.

Direct Air Quality Impacts

Reservoir drafting exposes shoreline areas that are normally underwater to the drying action of the sun and wind. In the Columbia River system, most of these shoreline areas are covered with fine sediments, such as silt and clay. Dry lake sediments are typically crusted, limiting the potential for wind erosion. If the crust is disturbed, high speed winds (greater than 9 m/sec or 20 mph, the threshold velocity for generating wind-blown emissions) will begin to remove the finer surface particles. Later, a faster wind may remove the larger particles from the exposed surface. If the surface is disturbed again, additional material will become available for wind erosion. Particulate matter concentrations are dependent upon the area of sediment exposed and the weather conditions at the time of exposure. Clear, windy summer days typically provide the weather conditions most conducive to high levels of blowing dust.

Large suspended particles will quickly settle within a short distance of their origin. Finer particles will be carried greater distances. Impacts would occur primarily around reservoirs located in the drier portions of the Columbia River Basin, and would affect both local residents and recreational users of the projects. An estimated 40,000 people live within 1 mile (1.6 km) of the shorelines of the key reservoirs. Approximately 4.5 million people visit these shorelines each year for recreation.

AAQSs establish limits on pollution concentrations, frequencies, and exposure times for sources of air pollution other than point sources (such as industrial stacks). They include standards for toxic pollutants and for particulate matter less than 10 microns in diameter (PM_{10}) that can be inhaled into the lungs. Although air quality in the Columbia River Basin generally meets AAQSs, the most common types of entries on the nonattainment area list involve PM_{10}. Ambient PM_{10} and TSP monitoring is conducted throughout the Columbia River Basin. Most of

the monitoring stations are located in known areas of air quality problems. Only a few monitoring stations are near SOR reservoirs. It is very difficult to distinguish between particulate matter originating from exposed lake sediments and other background particulate matter.

Effects people could experience from windblown dust include poor visibility; irritation of the eyes, nose, and mouth; and accumulation of dust on objects. As a result, blowing dust may interfere with recreational activities and cause discomfort to local residents. Residents of Rexford, Montana, for example, have complained to the Corps about dust blowing from exposed shorelines at Lake Koocanusa.

PM_{10} is the portion of particulate matter that is small enough to bypass the nose and upper airways, enter the lungs, and be absorbed into the bloodstream (EPA, 1986). Adverse health effects can occur when air levels of PM_{10} are high. These effects can include worsening of asthma and bronchitis. They are more likely to occur in young children, older adults, smokers, and people with underlying lung problems, such as asthma or emphysema (Lambert et al., 1992; Pope, 1991; Dockery et al., 1989). In addition to health effects from the PM_{10}, health problems from inhalation of chemicals that are bound to the particulate matter could occur if the chemical concentrations in the air are high enough. These potential health problems could include cancer or non-cancer effects (such as nerve damage) and would vary depending on which chemical is inhaled.

Indirect Air Quality Impacts

Changes in river operations could decrease the amount of hydroelectric power generated, at least on a seasonal basis, and require replacement generation from thermal powerplants (such as gas- or coal-fired plants). Additional thermal generation would increase air pollution around the affected thermal plants. Chemical emissions from these powerplants could be a problem if they cause air quality standards to be exceeded or if levels are high

enough to cause health problems. Since the powerplants that serve the region are located in Washington, Oregon, and California, these indirect air quality impacts could occur locally or in other regions.

Effects of Alternatives

Fugitive Dust Emissions

Lake sediments that are exposed by drafting will be subject to drying and wind erosion. Factors that contribute to the generation of windblown dust are wind speed, the amount of exposed shoreline, the amount of fine material in the surface of the sediments, the moisture content of the sediments, the frequency of winds strong enough to begin to move the sediments, the frequency with which the surface is disturbed (thus making more material available for wind erosion), and the roughness of the exposed surface. The nature of these factors as they pertain to the Columbia River reservoirs are not well understood at this time.

Using representative data, PM_{10} emissions were estimated for three projects (Lower Granite, Libby, and John Day) for all of the SOS alternatives. These three projects were selected because they were considered representative of the key sediment exposure scenarios that could occur under one or more SOS alternatives. Specifically, Libby represents potential exposure and dust emissions from seasonal drafting of a storage reservoir; Lower Granite represents lower Snake River drawdown conditions; and John Day is a special case in which a shallow drawdown could expose a relatively large shoreline area.

PM_{10} emissions (mass per unit area) are a function of wind speed at the surface of the sediments; the magnitude of the wind speed greater than the frictional threshold velocity will determine the PM_{10} emissions. Short-duration, high-speed winds are responsible for most of the emissions. The analysis used wind data from Kalispell, Spokane, and Yakima and followed EPA guidance in calculating emissions (EPA, 1990). The analysis used three wind speeds

(fastest mile, maximum 1-hour wind speeds, and highest 99th percentile 1-hour wind speeds) to provide a range of expected emission rates. Emissions calculated using the fastest mile result in the highest emissions. The fastest mile also occurs the least frequently (once in 30 years). Emissions calculated with the maximum 1-hour wind speed will occur at a frequency of about once or twice every 5 years. The 1-hour 99th percentile wind speed will occur at a frequency of about 9 hours per year. However, this wind is sometimes is not sufficient to generate emissions.

Total PM_{10} emissions are dependent on the exposed area. The relationship between the surface elevation and area of the reservoir was used to estimate the area and width of exposed sediments for each alternative, for the three projects investigated. PM_{10} emission rates for three projects, three wind speeds, and all SOS alternatives are presented in Appendix B. Following the EPA methodology, TSP emission rates would be twice the estimated PM_{10} emission rate.

For Lower Granite Reservoir, the maximum PM_{10} emissions would initially result from SOS 5b or 5c, as the natural river operation would result in the greatest area of exposed sediments. The calculated emission rates for SOS 5b ranged from about 400 kg/km of exposed shoreline for 99.9th-percentile winds to over 5,500 kg/km for fastest-mile winds (see Appendix B, Section 3.1). For SOS 5b, the reservoir would be drafted from April through July. During the rest of the year, the sediments would be partially replenished. Under SOS 5c the sediments would be exposed all year. PM_{10} emissions for this alternative would resemble those of SOS 5b for a period of years, until the sediments were vegetated or washed away. Estimated emissions for SOSs 6b, 6d, 9a, and 9c are all about the same magnitude, and are approximately one-quarter to one-third as much as the emissions for SOS 5.

The estimated PM_{10} emissions for the Libby project are larger than emissions for Lower Granite. Libby would typically be drafted in

March and April, resulting in lower maximum winds than the winds used to estimate Lower Granite emissions. However, a much larger area would be exposed at Libby, resulting in higher emission rates for all alternatives. Estimated emissions for Libby are about equal for all SOSs.

Predicted PM_{10} emissions for the John Day project are moderate for SOSs 5b, 5c, 6b, 9a, and 9c, and are much lower for the remaining alternatives.

It may be somewhat difficult to put these emission rates into perspective. Following the EPA (1990) guidance, a 30-ton (27,216 kg), fully-loaded, 10-wheel dump truck traveling 30 mph (48 km/h) on a gravel road will generate 44 kg/km of PM_{10} emissions. Using the 99.9th percentile wind speed for the Lower Granite project, only four alternatives (SOSs 6b, 6d, 9a, and 9c) result in emissions greater than the dump truck example. All of the alternatives for the Libby project result in PM_{10} emissions greater than the dump truck example. Small changes in surface elevation result in large areas of exposed sediments at Libby. For the John Day project only two alternatives (SOSs 9a and 9c) are predicted to result in PM_{10} emission greater than the dump truck example, for the 99.9th percentile wind speed.

PM_{10} Concentrations

Windblown dust is transported and diluted by the wind. Estimated PM_{10} emissions were modeled using a standard Gaussian dispersion model, wind speeds representative of the conditions that will result in windblown dust, and a straight uniform shoreline configuration. Emissions representative of most of the alternatives for each of the three projects investigated were used in the modeling. All emissions were assumed to take place during a 1-hour period. Several wind directions were considered; winds nearly parallel to the shoreline will result in the largest concentrations adjacent to the source of the emissions, and winds perpendicular to the shoreline will produce the

largest concentrations at some distance from the shore area.

The maximum PM_{10} concentrations calculated through this analysis were 206 $\mu g/m^3$ for Lower Granite, 157 $\mu g/m^3$ for John Day, and 139 $\mu g/m^3$ for Libby. The highest PM_{10} concentrations are predicted to occur immediately adjacent to the source of emissions, and will quickly diminish with distance from the shore area. The PM_{10} concentrations for all three projects decrease rapidly within 0 to 200 meters of the source (the beach), and decrease much more slowly for distances beyond 200 meters (see Appendix B, Figure 4-1). Concentrations greater than the 150 $\mu g/m^3$ AAQS are predicted to occur only within 20 to 30 m of the area of exposed sediments. Windblown dust in concentrations significantly greater than background concentrations (5 $\mu g/m^3$) are predicted to occur within 3 to 5 km of the exposed sediments. These distances will be greater for the alternatives that result in larger areas of exposed sediments (SOSs 5b and 5c for Lower Granite, for example), and for higher wind speeds (the fastest mile wind speeds, for example).

In summary then, the PM_{10} concentration estimates indicated that reservoir drafting as a result of SOS alternatives would intermittently generate sufficient dust to be noticeable only for residents or recreationists on or very near the beach. PM_{10} concentrations over a greater distance from the reservoir would be elevated over background levels, but this effect would consist of a relatively small absolute increase over a low background level. Any of the SOS alternatives could produce those kinds of dust effects at Libby, while only drawdown and/or natural river alternatives would produce the PM_{10} concentrations discussed above at Lower Granite and John Day.

The analysis results for the three representative projects can be applied to the remaining SOR reservoirs by comparing respective elevation patterns. The hydroregulation model predicted annual average surface elevations of all SOR reservoirs for each

alternative. The annual average reservoir elevations for SOS 2c represent a base case. For a given reservoir, the elevation difference between SOS 2c and the other alternatives is related to the amount of shoreline exposed for that alternative. These elevation differences provide a means of estimating which alternatives have the greatest potential for windblown emissions. A lower surface elevation will result in a greater amount of exposed shoreline and, therefore, a larger potential for high PM_{10} emissions and concentrations. The differences in the annual average surface elevations by project and alternative are presented in Section 5.1 of Appendix B.

There is little or no variation in simulated annual average reservoir elevations at the McNary, The Dalles, Bonneville, and Chief Joseph projects for all of the alternatives. Deep drawdowns would occur under SOSs 5b, 5c, 6b, and 9a for Ice Harbor, Lower Monumental, and Little Goose projects. Large drawdowns for Lower Granite are expected for SOSs 5b, 5c, 6b, 6d, and 9a. The average surface elevation at the Dworshak project would decrease for SOSs 2d, 9b, and PA. Large drafts are predicted for Grand Coulee for SOSs 9a and 9b. Lower elevations are expected at Libby for SOSs 9a and PA, while large drawdowns are expected at Hungry Horse for SOS 9a.

Consequently, the analysis results for Lower Granite illustrate the potential physical conditions from drawdown or natural river operations at Little Goose, Lower Monumental, and Ice Harbor, although there are much smaller resident and recreationist populations at the latter three projects than at Lower Granite. Because Libby is a very large project and has the deepest simulated drafts among the storage reservoirs for virtually all SOS alternatives, PM_{10} emissions and concentrations for Hungry Horse, Dworshak, and Grand Coulee would generally be much less than the Libby estimates for a given SOS.

PM_{10} monitoring is conducted in areas with known or suspected air quality problems. Only a few of the projects are located in areas where

monitoring is conducted near the reservoirs (see Section 2.2). Only one area, the Sandpoint area located on Lake Pend Oreille, is a PM_{10} nonattainment area. The shallow areas of Lake Pend Oreille are located a considerable distance to the east of Sandpoint. It is not expected that the SOR reservoirs would contribute to ambient concentrations greater than the AAQS at any of the monitoring locations. Several SOR reservoirs are located in areas where nearby monitoring data indicate that the background PM_{10} concentrations are high. These areas include Ice Harbor (located near Kennewick and Wallula Junction), Grand Coulee (located near Spokane), Albeni Falls (located near Sandpoint), Libby (located near Libby), and Hungry Horse (located near Whitefish). Large background concentrations in areas such as Spokane are associated with industrial emissions and wood smoke, and will take place during periods of stagnant winds and low-level atmospheric inversions. Conversely, high wind-generated emissions from the SOR reservoirs would occur during periods of high wind speeds and good atmospheric dispersion. Wind-generated emissions resulting from exposed lake sediments would result in large PM_{10} concentrations immediately adjacent to the source of the emissions.

The upstream end of Lower Granite Reservoir is located adjacent to Clarkston, Washington and Lewiston Idaho, which are both TSP nonattainment areas. The possibility for elevated particulate matter emissions adjacent to the emission sources has been demonstrated by the analysis presented in Appendix B. A detailed evaluation of the air quality impacts associated with drafting Lower Granite would have to wait until site-specific data can be collected.

The lake sediments may contain contaminants which, when dry, could become part of the windblown emissions. If large concentrations of these contaminants were present, they could result in a health threat. Data sufficient to rigorously estimate emissions of hazardous and toxic air pollutants resulting from reservoir drafting are not available. Chemical

concentrations have been measured for selected
locations in Lake Roosevelt by EPA (1992).
The Corps has also sponsored limited sampling
of sediments in the Lower Granite, Little Goose,
and Ice Harbor pools on the lower Snake River
and in the Columbia River near the confluence
with the Snake (Pinza et al., 1992; Crecelius and
Gartisen, 1985; Crecelius and Cotter, 1986).
Most of this work has focused on Lower
Granite. While data coverage is not sufficient
for a specific analysis, it can be assumed that
alternatives that would expose the greatest
amount of sediments in areas where industrial
discharges have contaminated the sediments
would have the greatest potential for hazardous
and toxic emissions.

Lake Roosevelt and Lower Granite are the
key reservoirs for which chemical sediment
concentration data are available. These two
projects also are more likely than others to
contain significant amounts of chemical
contaminants. Lake Roosevelt receives smelter
and municipal discharges from sources just
upstream in British Columbia. Lower Granite
receives discharges from industrial operations
and municipal wastewater discharges from
sources just upstream (including a pulp and
paper mill) in the Lewiston and Clarkston area.
Pollutants of concern include sediments
contaminated with arsenic and iron. The
hydroregulation models indicate that drafting of
Lake Roosevelt would be essentially the same as
or less than current operations under most of the
SOS alternatives, including SOS PA. The only
alternatives that would create significant
potential for dispersion of exposed sediments
from Lower Granite are the natural river and
drawdown operations (SOSs 5, 6, 9a, and 9c),
which would require further environmental
analysis before they could be implemented.
Consequently, the SOR agencies do not believe
that the issue of human health concerns from
potential air emissions of contaminated sediments
requires further analysis at this time.

Indirect Air Quality Impacts

Changes in river operation could decrease the
amount of hydroelectric power generated, at

least on a seasonal basis, and require
replacement generation from thermal power
plants (such as gas- or coal-fired plants). One
response to this power impact would be to
acquire new generating resources, and the other
would be to purchase power from existing
sources. Either response could require energy
generation from thermal powerplants, which
would result in impacts to air quality. Both
cases are described in more detail in Appendix I,
Power.

With respect to acquiring new resources, the
alternative resources available and their
respective impacts on air quality are described in
detail in BPA's Resource Programs EIS (BPA,
1993a). Air emissions vary considerably for
most pollutants among the different thermal
power technologies, with conventional coal-fired
technology producing the greatest emissions.
Natural gas-fired plants are relatively clean-
burning and efficient and have accounted for all
recent additions to Northwest thermal power
capacity. The SOR Power Work Group
assumed that gas combustion turbines would be
built if power system managers adopted the new-
resource response.

Purchasing replacement power supplies
would also involve several options. Depending
upon future resource availability when a given
SOS might be adopted, BPA could conceivably
purchase power from utilities in the Northwest,
Canada, or California. Each of these three
sources has a different resource mix with a
different potential for indirect air quality
impacts. Other Northwest utilities operate a mix
of hydroelectric and thermal resources. Most
electricity in British Columbia is generated by
hydroelectric plants. California power resources
are predominantly thermal with a mix of nuclear
and oil-fired plants.

Natural gas-fired power plants have
accounted for all or nearly all the recent
additions to the power generating capacity of the
Pacific Northwest. Given the diversity of
choices available for replacing Columbia River
hydropower, air quality impacts resulting from
use of thermal generation for replacement power

can only be addressed in a generic sense. For this evaluation it has been assumed that all of the lost power would be replaced by natural gas-fired generators. The nature of these power plants, whether combined cycle, cogeneration, or peaking units, is not specified in this analysis. Furthermore, the actual size and location of individual units cannot be determined at this point.

The total emissions resulting from replacing power normally generated by the Columbia River system can be estimated for a mix of combustion technologies, including new natural gas-fired combustion turbines, existing gas and oil fired combustion turbines, existing coal-fired power plants, and purchasing power (BPA 1995). Total emissions for criteria air pollutants were estimated for each SOS alternative for the years 1996 and 2004 (Appendix B).

The emission estimates for 1996 represent an older mix of sources including coal-fired power plants and older combustion turbines. Emissions from this mix are greatest for SOSs 5b, 5c, 9a, 9b, and 9c, but do not vary widely for the entire set of alternatives. For example, estimated sulphur oxide (SO) emissions ranged from 33,000 metric tons (SOS 1b) to 35,000 metric tons (SOSs 5b, 5c, 9a, 9b, and 9c) per year. Nitrous oxide (NO_x) emission estimates range from 86,000 metric tons (SOS 1b) to 94,000 metric tons (SOSs 5c and 9a). By 2004, replacement power generation would likely rely on new combustion turbines burning mostly natural gas. The pollutants of concern for these facilities would be primarily NO_x. NO_x emissions would be greatest for SOSs 5b and 5c, at 111,000 and 109,000 metric tons per year, respectively. Again, however, the range among the SOS alternatives is relatively small, with the lowest emission rate being 98,000 metric tons per year (for SOSs 9a and PA).

Overall, the air pollutant emission estimates indicate that all of the SOS alternatives would result in measurable indirect air quality impacts, with the level of emissions generally proportional to the amount of replacement generation involved. However, the relatively close range of the emission estimates indicates that there would not be major differences among the SOS alternatives on this impact measure.

It is likely that new generating units would be built with emission control devices such as Selective Catalytic Reduction (SCR) for CO and NO_x emission reduction, advanced low-NO_x combustors, and water injection for NO_x control. Construction of new generating plants would be subject to local, state, and Federal air quality regulations, and would require that the project owners obtain construction and air discharge permits. The new generating facilities would probably also be subject to Prevention of Significant Deterioration (PSD) regulations and to New Source Performance Standards (NSPS) set forth in 40 CFR Part 60, Subpart GG. New facilities would be built only if they comply with all applicable emissions and ambient standards, including the AAQS.

4.2.4 Anadromous Fish

The Anadromous Fish Work Group evaluated the SOS alternatives primarily on their ability to increase the survival of anadromous fish migrating through the Columbia River system. They looked at both juvenile downstream passage and adult upstream return. The work group divided the alternatives into four categories: flow control, drawdown, natural river, and combination. The flow control alternatives include all options for SOSs 1, 2, and 4. These alternatives share the same current system configuration but differ in regard to flow quantity and timing. These alternatives include the No Action Alternative (SOS 2c) and the NMFS 1994 Biological Opinion operation (SOS 2d), which represent how the system was operated in 1992-93 and in 1994, respectively. The SOS 6 drawdown options involve lowering either one or four lower Snake River reservoirs approximately 33 feet (10 m) below normal operating level. The natural river options (SOSs 5b and 5c) involve lowering the four lower Snake River reservoirs to near original streambed level for 4.5 months (5b) or permanently (5c). There are four combination alternatives that include various actions. SOSs

9a (DFOP) and 9c (Balanced Impacts) involve major drawdown of the four Snake River projects and high spill levels at all projects, while 9a eliminates all fish transport. The remaining alternatives, SOS 9b (Adaptive Management) and SOS PA (Preferred Alternative), use a combination of flow targets, drawdown to MOP, and moderate spill as methods intended to enhance survival.

This section summarizes the anadromous fish impact assessment, based on the detailed report on methods and results presented in Appendix C, Anadromous Fish. The discussion of issues that affect anadromous fish is followed by a quantitative assessment of the effects of the SOS alternatives on selected stocks of anadromous salmon and steelhead. The assessment is based on models of downstream passage survival for juvenile fish and life-cycle projections of adult returns. The quantitative section includes assessments of downstream passage survival with and without transport, and of the effects different transport survival hypotheses have on overall survival and alternative rankings.

Anadromous Fish Impact Issues

The anadromous fish issues can generally be grouped according to whether they affect juvenile salmonids, adult salmonids, other anadromous stocks, or hatcheries. Another issue is the effect fish transport has on overall survival. The primary impact issues concern interrelationships among flow, water particle travel time, fish travel time, species, river reach, and survival.

Effects on Juvenile Salmonids

The two primary areas of juvenile salmon mortality within the hydrosystem are dam passage mortality and reservoir mortality. Dam passage mortality is associated with smolts' ability to successfully pass through the various routes. Differing levels of mortality are associated with the various passage routes through each dam.

Reservoir passage mortality occurs throughout the system of reservoirs. Sources of reservoir mortality are primarily predation and gas bubble trauma. Flow and temperature also play a large role in these survival mechanisms. Many smolts are collected from the bypass channels as they pass the dams. These fish are then transported downstream, avoiding the mortality factors associated with subsequent reservoirs and dams.

Flow also plays an important role in initiating and sustaining migration for some stocks. Some scientists also believe that higher flows reduce travel times, thus reducing the threat of predation and disease.

The various factors associated with smolt mortality are presented as follows:

Dam Passage Effects
- Juvenile bypass and collection facilities
- Turbines and spillways

Reservoir Effects
- Predation
- Dissolved gas
- Flow
- Rearing habitat

The following discussions summarize current knowledge of these factors and how they affect survival, and describe how the SOS alternatives would affect these survival factors.

Juvenile Bypass and Collection Facilities—Submerged traveling screens divert fish migrating past lower Snake and most lower Columbia River dams away from the turbines (see Section 3.3.3). Mid-Columbia River dams currently do not have these screens, but may have them in the future. Many of the fish diverted at Lower Granite, Little Goose, Lower Monumental, and McNary Dams are transported downstream by barge or truck and released below Bonneville Dam. Researchers estimate that more than 70 percent of Snake River steelhead and yearling spring and summer chinook smolts, and up to 40 percent of subyearling fall chinook arriving downstream,

are transported around dams. The percentage of mid-Columbia River fish transported is lower because they are only collected at McNary Dam.

Some migrating fish are killed at juvenile bypass and transport facilities. Mortality through juvenile bypasses, excluding outfall mortality, ranges from much less than 1 percent up to 3 percent (Ceballos et al., 1991; Monk and Williams, 1991; Brege et al., 1987). Additional mortality, estimated at 2 percent, occurs during transport. Opinions vary on whether additional mortality occurs to fish as a result of transport, and whether there is a net benefit to fish being transported compared to remaining in the river. A quantitative evaluation of the response of salmonids to transport is provided in subsection *Effects of Alternatives—Quantitative Assessment.* The quantitative effects of transport are summarized in the main CRiSP model results subsection; the complete analysis is presented in Appendix C.

The turbine diversion and transport effects of SOSs 1, 2, 4, 9b, and PA on anadromous salmon and steelhead would be similar. SOSs 5, 6, 9a, and 9c would substantially reduce diversion and/or transport from the Snake River projects under traditional operating procedure, because the lower Snake River projects would be drawn down to or below spillway crest level under these alternatives. The effects of transport are included in the main quantitative analysis model for all alternatives.

Turbines and Spillways—Fish passage through turbines or over spillways would change substantially under some of the alternatives. Some of the migrating fish still go through turbines, although current operations attempt to prevent this. Turbine mortality results from turbine blades hitting fish or from hydraulic pressure or shear forces. Overall fish mortality is affected by the number of fish passing through turbines and the efficiency of turbine operation. Higher mortality occurs when turbines operate either below or above peak efficiency. Estimates of turbine passage mortality range from 2 to 32 percent (Ledgerwood et al., 1990; Weber, 1954; Long et al., 1968). A mortality

range of 9 to 20 percent, with an average of 6 to 15 percent, is considered typical (Fisher et al., 1993). Many turbine (and spillway) mortality studies done several decades ago may be outdated. Recent preliminary tests in spring 1993 estimated yearling chinook turbine survival of 82.3 and 90 percent at Lower Granite and Little Goose Dams, respectively (Iwamoto et al., 1994).

Spillway mortality is estimated to be an average of 2 percent per project (NPPC, 1986). Estimates range from 0 to 27.5 percent (Long et al., 1968) depending on operation and structural modifications such as the presence of spillway flow deflectors (flip lips). Iwamoto et al. (1994) estimated preliminary Little Goose spillway survival of yearling chinook at 100 percent during moderate spill conditions. During higher spill (flows over 10 kcfs per bay), the efficiency of flip lips could be diminished and mortality could increase. Direct spillway mortality results primarily from abrasion, but many juvenile salmonids may die later through indirect means such as descaling, stress, predation, or reduced viability due to dissolved gas supersaturation exposure. However, accurate estimates of the portion of delayed mortality from spillway or turbine passage are unavailable.

Stunned or disabled fish are more susceptible to predation. Indirect mortality, such as increased susceptibility to disease and/or immediate or later predation, can occur with turbine or spillway passage.

Turbine and spillway mortality under the flow control alternatives and, to a lesser extent, SOSs 9b and PA, would correspond to the existing conditions described above. SOSs 5, 6, 9a, and 9c would have highly varied effects on these two mortality factors. The model analysis addresses the differences. However, in these cases, the estimated effects are more speculative because the major changes in the system structures and operation have not been tested before.

Predation—One of the major causes of juvenile fish loss during migration is predation by

resident fish (Poe and Rieman, 1988). Predation is considered by some to cause mortality equal to or greater than that caused by passage at dams (Rieman et al., 1991). The primary predator in many areas of the Columbia River system is the northern squawfish (Beamesderfer et al., 1990). In some areas, such as Lower Granite Reservoir, smallmouth bass might be a more important predator on subyearling chinook (Curet, 1993). Predation within the Columbia River system occurs throughout the reservoirs, but is often concentrated just below and above the dams (Poe and Rieman, 1988). Much of the predation on subyearling chinook might occur in shallow water areas along the shore (Curet, 1993). The level of predation is affected by many factors, including velocity, turbidity, location, predator abundance, prey abundance, and temperature. Of these, temperature is a major controlling factor (Beamesderfer et al., 1990).

The SOS alternatives could significantly influence predation. In many cases, a given action would likely have positive and negative effects on predation, so the net effects are unclear. Operations that result in reduced temperature during migration should reduce overall predation if other factors remain the same.

Predators often avoid high-velocity areas, so higher river velocity should reduce predation. The major predators also require slow water areas for egg incubation and subyearling rearing. Among the major predators, smallmouth bass would be affected most by increased velocities because they are more dependent on shallow, low-velocity areas. Squawfish would be affected less because they are more adapted to a flowing river environment than are smallmouth bass.

Reduced reservoir size could have negative effects by concentrating predators, or it could have positive effects by reducing predators' habitat area. Both outcomes were reflected in different model runs for each of the SOS alternatives in the smolt survival analysis.

SOSs 5, 6, 9a, and 9c would increase turbidity. This increase would restrict predators'

ability to see juvenile salmon and steelhead and thereby reduce predation. Turbidity increases would be most pronounced in the first year of any drawdown operation and less in following years, with corresponding effects on predation.

Dissolved Gas—Some of the alternatives could increase mortality for salmon and steelhead juveniles from gas bubble disease. This disease is well documented on the Columbia River system (Ebel et al., 1975; Weitkamp and Katz, 1980). Factors that contribute to this disease include the level of supersaturation, duration of exposure, water temperature, physical condition of the fish, swimming depth of the fish, and its life stage (Ebel and Raymond, 1976; Weitkamp and Katz, 1980). Flip lips constructed at most dams have generally reduced the potentially high levels of gas supersaturation that caused significant fish mortality in the 1970s.

Currently, Federal and state agencies and tribes disagree about the severity of effects of gas supersaturation levels that exceed the existing Federal and state standard of 110 percent. Current beliefs are based on different interpretations of historical and current gas effects studies in the Columbia River system and the laboratory. More details on the various documentation addressing dissolved gas effects were presented in Draft EIS Appendix C, Volume C-1, Exhibit D and Appendix 6 of the Detailed Fishery Operating Plan (CBFWA, 1993).

Limited recent documentation of excessive fish mortality from gas bubble disease exists because of inadequate monitoring efforts. Although current operations during lower flow years provide for limits on continuous spill, dissolved gas concentrations known to be detrimental are exceeded annually. The cause-and-effect relationship of gas bubble disease symptoms is not easily demonstrated because bubbles can grow internally throughout a fish's body, disrupting neurological, cardiovascular, respiratory, osmoregulatory, and other physiological functions (Weitkamp and Katz, 1980; Stroud et al., 1975). At some levels of

adverse gas effects, external symptoms of gas bubble disease are not apparent; therefore, assessing effects to fish populations by external examination only is unreliable and would not reflect behavioral effects (Draft SOR Appendix C, Volume C-1, Exhibit D). The gas bubble trauma monitoring during 1995 at the dams indicated very limited effects of elevated gas levels (occasionally greater than 120 percent) (FPC weekly reports for 1995). However, studies below Ice Harbor during early May 1995 found very high mortalities when fish were restricted to shallow (1- and 4-m-deep) cages when measured gas levels were 128 percent (FPC weekly report #95-10, May 12, 1995).

The current national and state standard is a maximum of 110-percent saturation. Adverse effects in the Columbia River system are observed at higher levels. Some suggest that near 120-percent saturation is an acceptable level because laboratory evidence shows that some fish may adjust their behavior to compensate for the elevated levels (CBFWA, 1993). However, Alderdice and Jensen (1985) found that substantial numbers of fish exposed to gas saturation of 110 to 112 percent did not move to greater depths, which would reduce the effects of elevated gas saturation, even when these depths were available. They concluded that this indicated there was a physiological component that affected the fish's ability to select greater depths at higher gas saturation levels. However, this has not been demonstrated in the field condition of the river.

Dissolved gas levels below dams currently peak at 120 to 140 percent during high spill years and 110 to 120 percent during low spill years. While gas saturation is a complicated issue depending on such variables as spill pattern, tailwater conditions, operations upstream, and specific spillway characteristics, the most important factor affecting gas saturation is the amount of spill. Data from the 1992 Lower Granite physical drawdown test show that periods of moderate spill (greater than about 40 kcfs) resulted in tailwater gas saturation over 120 percent (Wik et al., 1993). Most alternatives would have little effect on increased

gas saturation compared to existing conditions. However, SOSs 9a, 9b, and 9c would allow gas saturation levels from increased spill to reach 120 percent. SOS PA also would increase gas saturation levels to a lesser degree (maximum controlled level of 115 percent) from enhanced spills, possibly increasing risk to migrating fish.

Flows and Water Velocities—There is general consensus among the scientific community that there is some degree of positive relationship between increased river flows and juvenile fish survival. However, the relationship is only a general one, and there is considerable disagreement about exact survival benefits of increased flow, particularly at flows greater than moderate levels. Past studies indicate that the quantity of flow has various correlations with travel time and smolt survival (Sims and Ossiander, 1981; Sims et al., 1983; Berggren and Filardo, 1993; memorandum from Michele DeHart, FPC, Portland, Oregon, October 16, 1991; Petrosky, undated). The general relationship between flow and survival emerged primarily from early studies on the Snake River by Sims and Ossiander (1981) and Sims et al. (1983), who found that survival of yearling chinook and steelhead appears to be higher during years with higher flow. Later analyses of this study, as well as additional data, developed relationships that were considered to peak at certain flow levels in the range of 85 to 140 kcfs in the Snake River (Sims et al., 1983). These conclusions were clouded by the effects of high dissolved gas levels that occurred in the river during those years with higher flows and only about one-half of the existing turbine complement in operation. Dissolved gas levels were reduced considerably in later years by addition of a full complement of turbines and the addition of flip lips on dam spillways.

No recent studies have been conducted that directly measure the effects of flow on yearling chinook smolt survival in the Snake or Columbia Rivers. However, NMFS/University of Washington researchers conducted smolt survival studies in the Snake River during 1993 and 1994 (Iwamoto et al., 1994 and Muir et al., 1995). The 1993 study was a pilot study that used

hatchery spring chinook in the Lower Granite pool over a limited flow range and time period. This study was done with fish releases between April 15 and 21, 1993. Flows were from 60 to 70 kcfs (1,680 to 1,960 cms) over most of this period, and ranged up to 90 kcfs (2,520 cms). No mortality was detectable (i.e., 100 percent survival) over the 20-mile (32 km) Lower Granite pool reach between release and recapture at the dam.

The 1994 study was more extensive, occurring from a release period of April 16 to May 10 and at flows ranging from about 40 to 90 kcfs (1,120 to 2,520 cms). Muir et al. (1995) found survival of hatchery spring chinook of 92 percent from the release point (about 22 miles [35 km] above Lower Granite Dam) to the Lower Granite tailrace. Survival from the original release point to the Lower Monumental tailrace was 66 percent. Survival estimates over this same reach were slightly higher for the limited number of wild spring chinook sampled, and lower for hatchery steelhead. Muir et al. (1995) concluded that little of the mortality measured to the Lower Granite tailrace could be attributed to reservoir passage, considering the mortality that occurs from dam passage (primarily turbine mortality). They also believed that similar low reservoir mortality would be expected at the other lower Snake River reservoirs for the same reasons. That is, with exception of poor tailwater conditions at one dam, most of the mortality measured was a result of dam passage and not reservoir passage. They did not attempt to interpret the effects of flow on survival in these studies. However, most of the data in these studies were collected at flows less than the 85 to 140 kcfs (2,380 to 3,920 cms) range in which historical data indicate peak downstream passage survival has occurred (Sims et al., 1983).

There remains uncertainty about which stocks respond to increased flows, whether the response occurs or is continued in all geographical areas of the river, the importance and level of increased flow, the effects on travel time, and the optimum ranges of flows (Giorgi, 1991; Kindley, 1991; Stevenson and Olsen, 1991;

Marsh and Achord, 1992; Sims and Miller, 1982). Flow and travel time relationships have sometimes been found to be significant for yearling chinook and steelhead at low flows in the Snake and lower Columbia Rivers with the dams in place. However, this relationship is not clear at higher flows (Giorgi, 1991; Kindley, 1991; Hilborn et al., 1993 as cited in Cada et al., 1993).

The effects of flow on yearling chinook and steelhead in the mid-Columbia River have been evaluated by the Fish Passage Center (1994). Through regression analysis they indicated that flow correlates with the migration rate to McNary Dam for these stocks. Other factors such as date of release, temperature, and origin (for steelhead only) are significant and often more important than flow in determining the migration rate of these fish.

McNeil (1992) included stocks from the mid-Columbia and found that for five "species" (brood runs) of juvenile salmonids in the Columbia and Snake Rivers, only 5 of 117 tests of the linear correlation of migration timing to flow quantity had a significant positive relationship. Three of those relationships were found for yearling chinook and the other two for subyearling chinook (four of these are based primarily on mid-Columbia stocks). McNeil (1992) did not contradict or modify any significance of uncertainty associated with existing flow/survival or flow/travel time relationships.

Recent analyses indicate the flow travel/time relationship is weak in some areas of the system. In the John Day pool, no significant relationship was found between flow and travel time for yearling chinook in 1989 and 1990 (Stevenson and Olsen, 1991). Marsh and Achord (1992) concluded that the outmigration of yearling chinook through Lower Granite Reservoir appeared to be independent of flow.

The relationship between subyearling chinook travel time and flow levels is unclear. Travel times correlated moderately or weakly with flow in some tests (Berggren and Filardo, 1993;

NMFS, 1993) and not at all in other tests (Sims and Miller, 1982). The FPC (1994) found no significant relationship between travel time and flow for subyearling chinook from Rock Island Dam to McNary Dam. This relationship is made unclear by the level of smolt development (Kindley, 1991), the size of fish (memorandum from Michele DeHart, FPC, Portland, Oregon, October 16, 1991), and the relative distance traveled or relative changes in flow (Berggren and Filardo, 1993).

Conflicting results concerning the effects of flow on fall chinook survival from the mid-Columbia were recently presented by Hilborn et al. (1993) and Norman (1992), with Hilborn et al. (1993) showing significant positive effects and Norman (1992) showing negative effects on survival of adult returns of discharge during juvenile outmigration.

Selected flow/survival relationships developed through past research are incorporated directly or indirectly in the computer models used to analyze the SOS alternatives (see Appendix C). The effects of flow on survival are incorporated in the discussion of model results.

Rearing Habitat—Rearing habitat is important during migration for all stocks. It is especially important for subyearling fall chinook and mid-Columbia River summer chinook because they spend more time in the mainstem rivers during migration. Factors that affect the quality and use of the habitat include species, depth, velocity, substrate, benthic and pelagic food supply, temperature, and turbidity. Salmonids use backwater and slough habitat in the lower Columbia River during the spring and summer (Zimmerman and Rasmussen, 1981; Parente and Smith, 1981). Underyearling chinook in the mid-Columbia River also use shallow-water, low-velocity areas (Dauble et al., 1989). Fall chinook in the Snake River reservoirs prefer low-velocity sandy habitat less than 20 feet (6 m) deep (Bennett et al., 1993; Curet, 1993). Fall chinook in Lower Granite pool rear about 75 to 112 days before migrating downstream (Curet, 1993), while those in Columbia

reservoirs, such as John Day, may rear longer (Sims and Miller, 1982). Much of this rearing, however, occurs away from the shallow-water areas prior to migration (Curet, 1993). The rearing period of steelhead and yearling chinook (and probably sockeye) in any reservoir is no more than a few days. These fish are less oriented to shallow shorelines, although they probably rely on food sources produced in these areas, so changes in shallow-water habitat would be less critical for these stocks.

Stranding of juvenile salmonids during drawdown with SOSs 5, 6, 9a, or 9c is also a possibility, particularly in shallow pocketed areas. During the March 1992 drawdown test, 21 juvenile salmonids were found stranded (Wik et al., 1993). The stranding effects might be worse than in 1992 because the drawdown would occur when more fish would be present in the reservoir. The gradual drawdown rate of 2 feet (0.6 m) per day would limit the number of fish stranded, allowing fish to move out of the area and avoid stranding.

Rearing habitat quality and quantity could be greatly reduced under some SOS alternatives but changed little under others. Shallow-water fall chinook rearing areas would be most adversely affected by SOS 5 because these areas would be dewatered. In the long term, these habitats would reestablish under SOS 5c. SOSs 6, 9a, and 9c would have similar effects on Snake River stocks. Snake River fall chinook would be most affected because of their longer residence time and greater reliance on these areas. Stocks using rearing habitat in the lower Columbia River would be affected less. SOSs 5, 6, 9a, and PA would dewater much of the shallow backwater habitat in Lake Umatilla. This dewatering would primarily affect Columbia River summer chinook. SOSs 2, 4, 9b, and 9c would also dewater shallow rearing habitat in Lake Umatilla, but to a much lesser degree.

SOSs 5b, 6, 9a, and 9c would reduce the available food supply for the affected stocks in two primary ways. One would be by dewatering the shallow areas where most of the benthic food

organisms originate (Bennett, 1991). The second would be by increasing flushing, thereby reducing the zooplankton that are another important food source for rearing and migrating salmon and steelhead. Food sources for Snake River fall chinook may already be in short supply in the reservoirs (Curet, 1993).

The permanent natural river drawdown option (SOS 5c) would have similar effects the first year. However, in subsequent years the establishment of a river environment may improve food supply as stream insect populations, common food for salmonids, become established.

Temperature reductions in most areas would benefit rearing salmonids. The preferred temperature for salmon and trout is typically less than 59°F (15°C), while normal conditions in the reservoirs exceed this temperature in the late spring and summer. As discussed previously, SOS 5 would reduce Snake River temperatures most often, while SOSs 6, 9a, and 9c would reduce high temperatures to lesser degrees. These temperature changes would be beneficial to rearing fall chinook in the Snake River. None of the alternatives would have much effect on temperatures in the other reaches of the Columbia River System.

Some alternatives would increase suspended sediment, which could have adverse effects on some species and life stages of salmon and steelhead. This would be particularly true during the first year the alternatives were implemented. The models indicate that the highest suspended sediment concentrations would occur under SOS 5, with peak average water-column concentrations approaching 5,000 mg/l during the first year. SOS 6 would have the next highest levels, with peak concentrations of less than 500 mg/l. Similar levels would be expected for SOSs 9a and 9c. After the first year, estimates of peak values decrease to less than 200 mg/l for SOS 5b and less than 50 mg/l for SOSs 6, 9a, and 9c. SOS 5c would not have elevated levels after the first year because the river level would remain unchanged from the first year's drawdown. The highest

concentrations should occur as drafting is completed (approximately April 15) in the lower Snake River reservoirs. Based on 1992 drawdown test measurements, these peak values would persist for about 1 week or less if weather and hydraulic conditions remained unchanged (Wik et al., 1993). However, if storm events occurred or flow increased markedly, higher levels could persist longer, but would likely remain lower than the peak values at the end of the drafting period.

Water quality standards for protection of fish habitat usually require suspended sediment concentrations of less than 30 mg/l for high protection and less than 100 mg/l for moderate protection (Lloyd, 1987). Some studies indicate short-term exposure causes direct mortality at a concentration of less than 1,200 mg/l (Noggle, 1978; Stober et al., 1981). Direct mortality of salmon and trout from short-term exposure (usually less than 4 days) generally requires concentrations of over 7,000 mg/l and more commonly over 18,000 mg/l (Servizi and Martens, 1991; Newcombe and MacDonald, 1991). Therefore, direct mortality of migrating Snake River spring and summer chinook and steelhead from the expected concentrations would be unlikely under any alternative. Snake River fall chinook that rear in the reservoirs for several weeks or months could suffer direct mortality under SOS 5, depending on the duration of the elevated levels and location of the fish. These impacts would be limited to the first year's actions. Secondary short-term effects, which include avoidance of turbid waters, reduced feeding success, reduced resistance to disease, and increased stress, are triggered at much lower concentrations— typically in the hundreds of mg/l (Noggle, 1978; Newcombe and MacDonald, 1991; Servizi and Martens, 1992; Alabaster and Lloyd, 1982; Lloyd, 1987). These effects would apply to Snake River stocks under SOS 5 and possibly SOSs 6, 9a, and 9c.

Salmonid Response to Transport

The fish transportation program is an integral part of the Federal Columbia River Power

System (FCRPS). Because this operation affects a large number of fish, transport survival has a very significant effect on overall juvenile fish survival and return of stocks that originate above McNary Dam. Recently, questions have been raised about the benefits of this program.

The issue of the relative benefits of transportation in protecting juvenile salmonids from dam and reservoir mortality was first raised in 1990 during the scoping phase of the SOR. At that time, and continuing through the early study phases, the Anadromous Fish Work Group analyzed the benefits of transportation in its juvenile fish passage models and life-cycle models.

In December 1993, in a suit unrelated to the SOR, Judge Malcolm Marsh ruled in *Northwest Resource Information Center (NRIC), Inc. et al. vs. NMFS et al. 93-870MA (9th Cir.)* that the Corps and NMFS had not adequately analyzed the benefits of transportation. The judge required the Corps to take a "hard look" at the program.

The Juvenile Fish Transportation Program Technical Appendix (Appendix C, Volume C-2) of the SOR Draft EIS took a "hard look" at the fish transport program. This appendix evaluated in detail the effects of current transportation procedures in both a quantitative and qualitative fashion. The Final EIS Appendix C includes a less detailed version of this analysis. It also evaluates, in a qualitative fashion, alternatives to transportation, alternative methods of transportation, and new collection facilities. Alternatives to current transportation evaluated include dam removal, increased spill, canal/pipeline, and others. Alternative methods of transport evaluated were varied means of conveyance (e.g., net pens) and changed operating tactics and technology (e.g., size separation, reduced collection density, barge temperature and sound control, varied timing of transport, and further downstream release location). Two new facilities were also evaluated including a further upstream collector above Lower Granite pool and surface collectors at dams. Some of the activities will be

implemented in the future such as the size separator and reduced density, while others like a surface collector are receiving more intensive evaluation in the future.

The main purpose of the SOR is to evaluate, in quantitative fashion, the effects of selected alternatives on fish survival. Therefore, the EIS does not include the analysis of possible future alternatives to the current transport procedure or detailed qualitative evaluation of transport; these discussions can be found in Appendix C.

Transport Evaluation Summary

The following summarizes current knowledge on the effects of transportation on juvenile survival and two of the major survival factors affecting this survival, stress and disease (see Appendix C of the Final EIS and Appendix C, Volume C-2 of the Draft EIS for a complete discussion of these factors).

The major method of measuring the effectiveness of transportation on survival is that indicated by the Transport/In-River Ratio (TIR). In the Draft EIS, the TIR was referred to as the Transport Benefit Ratio (TBR) or the Transport Control Ratio (TCR). The TIR is a ratio of the number of adults returning to a given location from a transported group of marked juveniles, to the number of adults returning to the same location from the control group of marked juveniles released to migrate downstream in-river. Basically, whenever the true TIR exceeds 1:1 there would be more benefit to transporting fish than allowing them to migrate downriver untransported.

Transport/In-River Ratio—The Corps has funded 17 TIR tests with spring and summer chinook smolts transported from the lower Snake River dams to downstream of Bonneville Dam between 1968 and 1989. Fourteen tests produced enough adult returns to be considered useful. Eleven of the 14 showed transport benefits significantly greater than 1:1, two were not significantly higher than 1:1, and one (1976) showed benefits significantly less than 1:1. Given changes in the migration corridor since

1968, the 1986 and 1989 TIRs are considered the most (although by no means totally) representative of current in-river conditions. These tests yielded TIRs of 1.6:1 (1986) and 2.46:1 (1989).

For fall chinook and steelhead, Matthews (1992) concluded that research indicates a clear benefit to survival with transport. Studies from 1978 to 1983 found a TIR of 1.8:1 to 8.0:1 for fall chinook from McNary Dam. Too few fish have been present to conduct direct studies of Snake River fall chinook. Subsequent studies at McNary Dam in the late 1980s again yielded TIRs averaging 3.5:1 (ranging from 1.7:1 to 7.1:1) (Harmon et al., 1995). For steelhead TIRs were apparently higher in the late 1970s than recently (Matthews et al., 1992). But lower values are reflective of better in-river passage conditions than decreased benefits of transport (Williams and Matthews, 1994). Matthews (1992) also concluded that straying (fish returning to areas other than the stream or hatchery of origin) was not a significant factor for returning transported adults.

Transport of sockeye from the mid-Columbia did not yield a clear benefit from transport. The TIR was less than 1:1 for studies conducted from 1984 and 1986. While some later studies have indicated increased survival from transport, apparent technical problems with some of the studies possibly affected the results.

The Ad-Hoc Transportation Review Group (TRG), consisting of representatives of the USFWS, Washington Department of Fisheries (WDF), Columbia River Inter-Tribal Fish Commission (CRITFC), Idaho Department of Fish and Game (IDFG), and Fish Passage Center (FPC), reviewed available information concerning the benefit of transport on Snake River spring/summer chinook and steelhead, mid-Columbia spring chinook and sockeye, and McNary fall chinook (Olney et al., 1992). They concluded that the measures of benefit from transporting fish (i.e., TIR greater than 1.0) for most of these stocks, particularly wild stocks, were not accurate. They based this conclusion on returns of wild stocks to selected areas and

questions of the validity of the way studies were conducted. The primary concern has been that "control" fish are not true controls because they are handled, marked, and in some cases, transported above or below dams before being released to migrate in-river. Other researchers (Williams and Matthews, 1994) pointed out that transport and in-river conditions have improved considerably since much of the transport research was done and that new research is needed to more accurately assess current conditions. This analysis was begun by NMFS for the Corps in 1995.

Because of the controversy over transportation benefits to fish survival among regional groups and agencies, the USFWS contracted with Mundy et al. (1994) to conduct an independent peer review of transport studies. This evaluation concluded that transportation improves relative survival of certain species and life stages under certain situations. Mundy et al. (1994) stated, "While juvenile salmon transportation may not be discounted as a recovery measure, the factual basis is insufficient to determine the relative efficacy of transportation as a mitigative measure for recovery of salmon populations listed as threatened and endangered in the Snake River Basin." However, information was inadequate in many areas to draw specific conclusions about benefits.

Stress—Stressful situations and continued exposure to stress decrease juvenile survival. Smolts collected for transportation are known to be stressed during collection and loading. However, the juveniles recover during the actual barge or truck journey. There is a brief period of stress again upon release.

During in-river passage, on the other hand, fish are stressed each time they pass through the turbine, bypass, or spillway. Therefore, fish passing from Lower Granite Reservoir to the river below Bonneville Dam are subject to eight repeated stressful situations. If spill is causing gas supersaturation, they may be subjected to additional prolonged high stress levels.

Since the beginning of the transportation program, stress research has led to modifications in facilities or operations that have resulted in minimizing stress and reducing mortality in the collection and transportation program.

Disease—Elliott and Pascho (1994) have demonstrated that Bacterial Kidney Disease (BKD) disease organisms are prevalent in the river as well as in the collection and transportation system, and that the majority of fish, both hatchery and wild, are infected by the time they reach Lower Granite Dam.

Adult Anadromous Salmon and Steelhead

Adverse effects on survival of adult salmon and steelhead while passing upstream can also be categorized as dam passage effects and reservoir effects. Effects of dam passage relate to the ability of fish to find and ascend the ladders and not fall back downstream. Reservoir conditions affect the ability of adult fish to pass upstream and the amount of available spawning area in the mainstem reaches of the Columbia and Snake Rivers. Successful passage of reservoirs is related to the water quality of the reservoir, including dissolved gas levels and temperatures, which directly or indirectly affect survival. Large numbers of adult salmon and steelhead die while passing through the reservoirs and over the dams of the Columbia and Snake Rivers. How this mortality is distributed among natural causes, the dam and reservoir system, and other human causes is not known. NMFS (1994) considered the loss from passage through the dam and reservoir system to be one of the main sources of loss of adult chinook salmon. Overall, losses during migration are higher for fall chinook than spring and summer chinook (NMFS, 1994). Those of sockeye are much lower (Ross, 1993), while steelhead losses may be comparable to spring chinook (Bjornn and Peery, 1992). Snake River stocks appear to have higher losses than Columbia River stocks. While measured losses of fish are higher (memorandum from Chris V. Ross, Fisheries Biologist, NMFS, Portland, Oregon, January 30, 1995) NMFS (1995) considered losses of Snake River spring/summer chinook, fall chinook, and

sockeye attributable to passage through the federal hydroelectric system from Bonneville to Lower Granite Dam to be 20.9, 39.4, and 15.2 percent, respectively.

Dam Passage—While adult salmon appear to migrate faster through reservoirs than through rivers, passage delays do occur at dams. Delays can contribute to mortality because adult salmon rely on food stored in their body once they enter the river. Passage rate at dams is influenced by whether the fish can find entrances to fish ladders. This is often affected by the quantity and location of spill and turbine flow (Bjornn and Peery, 1992). The proper mix of flow through turbines and over the spillway is often needed for the most effective passage conditions at dams. Based on an assumed migration rate of 1.8 mph through reservoirs, Turner et al. (1983) found that migration through Little Goose pool and over Lower Granite Dam took about 1 day longer than expected during spill levels of zero to 25 kcfs, and 7 days longer at spill levels of 25 to 125 kcfs. Bjornn et al. (1992, 1993) noted that the effects of low nighttime spill on relative delay of migration was not apparent in the lower Snake River. This conclusion was based on the similarity of migration rates at Lower Monumental Dam, with nighttime spill rates ranging from about 10 kcfs in 1991 and 20 kcfs in 1992, to those with no spill at Little Goose Dam. During 1993, only the highest spills affected migration rates at Little Goose and Lower Granite Dams (Bjornn et al., 1994). Researchers noted high spills (greater than 60 kcfs) at the Snake River projects made fish ladder attraction flows difficult to locate (Turner et al., 1983). During high spill tests (100 kcfs) without turbine operation at Lower Granite Dam in 1991, researchers also observed that flow patterns near ladder entrances would have made it difficult for fish to locate ladder entrances (Wik et al., 1993). This conclusion was based on observations of flow patterns, not observed fish behavior.

There is also the problem of fish falling back over the dams; it is related to spill quantity. For spring and summer chinook on the Snake River, researchers found that at low or no spill flow,

fallback was less than 10 percent, while at high spill fallback was about 40 percent (Bjornn and Peery, 1992). Based on limited Snake River studies relating to fallback, high flow would be flows greater than 150 kcfs and spill over 100 kcfs (Bjornn and Peery, 1992). These low fallback rates during low or no spill were confirmed at Lower Granite Dam in 1991 and 1992 at 5 percent and 3 percent, respectively (Bjornn et al., 1992, 1993). Fallback for steelhead at low flow is higher than for salmon. While some fish may be lost in this manner, most fish reascend and pass upstream after they fall back.

All of the alternatives would have little effect on adult passage success for Columbia River stocks. The same is true of the effects of flow control alternatives on Snake River stocks; however, marked reductions in passage success might occur with the natural river operation and some of the alternatives that include drawdown. Experience gained over the years from operational testing at the older dams improved the fish passage designs at dams built later. Site-specific testing at later facilities has also improved their operation. This experience would be of little use in developing functional fish passage facilities for SOSs 5, 6, 9a, and 9c because they would have very different hydraulic conditions. The effect of the natural river alternatives (SOSs 5b and 5c) is not known, but it could be detrimental to adult fish. Because of the sensitivity of salmon and steelhead to flow patterns for detecting passage routes, it is possible that adult passage could be greatly restricted under these alternatives. This restriction would primarily affect Snake River spring and summer chinook and sockeye salmon. SOSs 6b, 6d, 9a, and 9c could also impede or prevent adult passage. Because the fish ladders at the four lower Snake River dams would not function at proposed drawdown levels (except the Lower Granite Dam exit), the ladder entrance and exit locations and supplemental attraction flow would have to be greatly modified from current designs. With drawdown to near spillway crest (SOSs 6b, 6d, 9a, and 9c), reduced tailwater depth would require deepening and lengthening the ladder entrances to

accommodate fish passage at all flow levels. While the intent is to design entrances so they meet agency-specified flows (velocity at the entrances and attraction flows), this may not be possible. Research to develop optimum fish passage with existing facilities is still ongoing. The potential to increase adult delay by making major modifications to the existing system is quite high. As an example of the effect of changes that might occur, the physical model effort at WES indicates that as little as 15 percent of the flow as spill could create undesirable tailwater flow patterns. The changes in hydraulics even without spill might substantially affect adult fish ability to find the ladder entrance even with design modifications. The modifications could result in less adult fish passage. Lower Granite Dam has a functional, but relatively untested, lower-level fish passage facility that could be used under SOSs 6b, 6d, 9a, or 9c. Whether this facility would help adult fish pass the dam is not known, and it could be worse than the existing facilities.

Reservoir Delays—The general migration rate for adult salmon through reservoirs is faster than through comparable river areas (Bjornn et al., 1992, 1993). Past estimates of rates have indicated a decrease for steelhead during "zero-flow" periods in reservoirs when spill and turbines are not operated. However, these lags in migration rate might be related to high temperatures that often occur during test periods (Bjornn and Peery, 1992). More recent steelhead migration studies designed to test the effect of zero flow have found no evidence of delay. Temperatures, high in the early summer and low in the fall, have played a more important role in migration rates through reservoirs (Bjornn et al., 1992, 1993, 1994). The increase in reservoir velocity with some drawdown alternatives (SOSs 5, 6, 9a, and 9c) might cause some slight delay in upstream migration depending on the magnitude of increase.

Suspended Sediment—Elevated suspended sediment levels, as would occur in the first year of the natural river or drawdown operations, could delay adult migration. UW laboratory

studies of adult chinook salmon found that these fish avoided natal stream waters (waters they were reared in as juveniles) when concentrations of suspended sediment (volcanic ash) of 350 mg/l occurred (Whitman et al., 1982; Brannon et al., 1981). These studies suggest that suspended sediment concentrations in this range could delay or inhibit upstream migration of chinook salmon. The first year Snake River concentrations of up to 5,000 mg/l under SOS 5 and 500 mg/l under SOSs 6, 9a, and 9c would occur. The second year concentrations would be less than 250 mg/l for these alternatives, except SOS 5c, which would be less. This sediment would affect primarily Snake River spring chinook, because the peak levels would occur during their migration period. Other alternatives are not predicted to elevate suspended sediment to levels that would hurt adult fish migration.

Dissolved Gas—As with juvenile fish, gas supersaturation can cause mortality in adults. It caused significant losses before the installation of flip lips. Dissolved gas concentrations occasionally still reach levels that can be harmful to adults during migration. From 1965 to 1970, it was estimated that 6 to 60 percent of adult salmon were killed by gas supersaturation (Wietkamp and Katz, 1980). Levels where effects were noted were most often over 120 percent saturation. Levels above those considered safe (110 percent) still occasionally occur on the Columbia and Snake Rivers, but some of the fish mortalities associated with dissolved gas supersaturation are believed to have been reduced through changes in operations and construction of flip lips (Ebel, 1979). Additional mainstem generating units and upstream storage capacity have also contributed to reduced gas levels. However, recently adverse effects of high spill on adult salmon have been observed. Bjornn et al. (1994) studied the migration of adult spring chinook and noted that, of radio-tagged fish released at John Day in 1993, 24.3 percent recaptured at Lower Granite had signs of "head burns." None of the fish had these burns at the time of tagging. However, none of these fish had any external physical signs that could definitely be identified as characteristic of gas bubble trauma such as

blisters, hemorrhages, or distended eyes (FPC, 1994). During this migration, high spill occurred at several of the Snake River projects. These physical characteristics were observed during periods of high spill in the 1960s and 1970s; they suggest a relation between injuries observed on adult salmonids and conditions during years with high levels of spill. However, no cause/effect relation to gas bubble disease has been documented.

Compared to existing conditions, most SOSs would have little effect on gas saturation. The natural river alternative, however, would reduce the occurrence of higher gas saturation levels in the Snake River. Increased spill under SOSs 9a and 9c, and to lesser degree 9b and PA, would markedly increase occurrences of elevated concentrations in the spring and summer in the Snake River. This increased gas saturation would increase the mortality risk for adult migrants, primarily for Snake River spring chinook and some summer chinook.

Temperature—In the past, elevated temperatures caused the death of adult salmon migrating through the Columbia and Snake Rivers. Temperatures over 70°F (21°C), which occur frequently in the Snake River during fall chinook migration, may impede upstream salmon and steelhead migration (EPA and NMFS, 1971).

Most alternatives would have little effect on the occurrence of higher temperatures (greater than 62.9°F [17.2°C]) during normal years (see water quality results). The greatest differences would occur under SOS 5, which would result in a higher frequency of cooler temperatures during most years in all lower Snake River reservoirs, although temperatures in the mid-Columbia River would increase markedly only during warm and low-flow years under this alternative. This temperature change could make migrating conditions better for Snake River fall chinook, but worse for mid-Columbia fall chinook. The magnitude of these effects on adult salmon and steelhead remains unknown.

Spawning Habitat—Historically, much of the mainstem Columbia and Snake Rivers contained spawning regions, primarily for fall chinook (Fulton, 1968). Some of these regions are currently submerged under the existing mainstem pools. However, the lower Snake River contained only limited spawning habitat for Snake River fall chinook (Waples et al., 1991). Some of these areas may also have been used by steelhead, as mainstem areas currently are in the Hanford Reach of the Columbia River. The quantity and importance of this region for steelhead spawning is not known. With the exception of SOS 5c, which would have year-round natural river drawdown of the lower Snake River, no alternative would have any effect on current or past spawning areas of salmon or steelhead. SOS 5c, however, would increase the available mainstem Snake River spawning area for fall chinook and possibly steelhead. The drawdown would increase sediment transport within the lower Snake River reach, and after an unknown number of years, would clear much of the fines from bottom gravel, thereby increasing the potential spawning area for fall chinook and possibly for steelhead.

Effects of Alternatives—Quantitative Assessment

Model Descriptions—Overall

The Anadromous Fish Work Group used computer models to determine the overall survival of juvenile fish and adult returns to the tributaries for non-transported fish. Computer modeling was used because models can look at the combined effects of the alternatives, present quantitative results, and compare the alternatives with respect to their effects on the survival of anadromous salmon and steelhead stocks.

Over the last 10 years, several computer models have been developed to assess the effects of river operations and mitigation on Snake and Columbia River salmon and steelhead. These models fall into two categories: juvenile passage and life-cycle. Juvenile passage models predict downstream survival of juvenile salmon and

steelhead from the time they leave the tributaries until they arrive below Bonneville Dam. Life-cycle models predict adult return (escapement) to the major tributaries above Federal dams. The life-cycle models typically use the juvenile passage models, in addition to consideration of other factors affecting adult survival, to predict adult returns.

Three juvenile passage models are currently in use within the region. Requests were made by the Anadromous Fish Work Group for all three passage models to be used in the analysis of smolt migration. However, only two were available for use in the Draft EIS: PAM (Passage Analysis Model, NPPC) and CRiSP 1.4/1.4.5 (Columbia River Salmon Passage Model, UW). In addition, the Draft EIS reported results of model runs from the State and Tribal Fisheries Agencies (STFA) Fish Leaving Under Several Hypotheses/Empirical Life Cycle Model (FLUSH/ELCM) system. The Anadromous Fish Work Group also solicited the use of this life-cycle model for the Final EIS, but it was not available. Because of competing workload demands from related study processes, the NPPC and STFA modelers were unable to analyze SOS alternatives for the Final EIS.

For the Final EIS analysis, the Anadromous Fish Work Group used one juvenile passage model: the Columbia River Salmon Passage (CRiSP) Model. The Center for Quantitative Sciences at the UW's School of Fisheries developed CRiSP. The Stochastic Life Cycle Model (SLCM), developed by Resources for the Future, was the only model used to predict adult returns. A more thorough discussion of these models is presented in Appendix C, Anadromous Fish.

The passage models for the analysis depended on the HYDROSIM model to supply estimates of flow conditions at dams and reservoirs under the SOS alternatives. HYDROSIM estimates flow conditions, based on a 50-year historical flow record from 1929 through 1978, to predict average monthly flows

for each 50-year period (April and August have bi-monthly output). The model estimates flow, spill, and reservoir elevation for each alternative for a 50-year period.

The model analysis considered the effects of the SOS alternatives on juvenile survival and adult return for different stocks from selected regions of the basin. Selected stocks of spring, summer, and fall chinook and summer steelhead were evaluated. The CRiSP1.5 model evaluated the effects of the alternatives on 10 fish stocks from the middle (four stocks) and lower Columbia (two stocks) and Snake (four stocks) Rivers. SLCM used the CRiSP juvenile passage survival estimates to predict adult escapement for six of these stocks.

CRiSP1.5 uses several submodels to describe the various elements of mortality, including fish travel time, predation rate, gas bubble trauma, and the multiple routes of dam passage (see Appendix C). The CRiSP version 1.5 differs slightly from the CRiSP versions 1.4 and 1.45 used in the Draft EIS primarily in three ways: how gas saturation affects mortality, how subyearlings respond to flow, and in the calibration methods. Generally, lower mortality is assigned to in-river migrants during saturation levels of less than 120 percent than was assigned in earlier versions of the model, resulting in lower in-river mortality during dam spill periods. One of the largest differences from earlier CRiSP versions was that the model had greater insensitivity of subyearling chinook migration rate to flow velocity; that is, changes in flow velocity had less effect on migration rate. The changes in calibration are discussed in Appendix C. A detailed description of the model and its calibration mechanisms can be found in *Columbia River Salmon Passage Model—CRiSP1* (Anderson et al., 1993).

Juvenile survival was analyzed using two sets of assumptions. The first was that all fish traveled in-river and were not transported. The second was that an alternative specific portion of downstream migrating fish would be collected and transported from various hydroelectric facilities and released below Bonneville Dam.

The alternatives range from transport of nearly all fish that are collected at Lower Granite, Little Goose, Lower Monumental, and McNary dams to total eliminations of all transport from any facilities. The portion of fish transported is dependent both on ability to collect fish (e.g., during total drawdown in the Snake River no fish could be collected in this reach) and on alternative-specific requirements concerning how collected fish are treated (e.g., some alternatives require release of a portion of the fish collected directly back to the river below the dam where they were collected). Under this second analysis, various assumptions of the survival rate for transported fish were used. These transport survival assumptions are summarized in the subsection *Model Description-Juvenile Transport*, and are discussed in detail in Appendix C. Adult returns were determined using the resulting passage survival calculated from one of the transport survival models.

SLCM is a simulation model that includes a series of components corresponding to various stages within the life cycle of salmon and steelhead, with transitions from one life stage to the next. The life stages include downstream survival, ocean mortality and harvest, escapement upriver, and survival from spawning ground to juvenile production. The outmigrating smolt survival for SLCM was generated from CRiSP1.5. A unique feature of SLCM is its ability to incorporate a stochastic variation into each step of the life cycle to account for the natural variability and uncertainty of the estimates.

The model was used to estimate returning stocks for 30 to 40 years in the future. The SLCM estimates reflect only the effects of each SOS alternative, considering no other actions beyond system operations. All alternatives, except SOS 9a, include analysis of effects on stocks with and without transport of fish. The only SLCM parameter that changes with system operations in this analysis is smolt passage survival. The model's primary purpose is not to predict actual numbers of surviving juvenile fish or adult fish returning in the future, but to compare the results of different system operation

alternatives. A detailed description of this model can be found in Lee and Hyman (1992).

In adjusting parameter values (such as survival rates) for the model analysis, the work group chose to address only those values that would be directly affected by SOR actions and for which reasonable current estimates could be made. The group did not consider the potential effects of many other actions independent of the SOR that have been taken or may occur in the future. While changes in these other parameters could affect future juvenile survival and adult returns, many are highly speculative with respect to their effects on fish and their implementation prospects. In addition, changes in other parameters would have complicated the analysis of effects of the SOR actions.

The juvenile passage model estimates three types of effects: fish travel time through the Columbia and Snake River system, survival of juvenile fish migrating solely in the river, and overall juvenile fish survival with transportation included. Overall survival, which includes proportional survival of all juveniles transported and not transported, is assessed for all stocks and alternatives. The life-cycle model estimates adult escapement with transport of juveniles based on one transportation survival model for each stock. Most fish usually have been transported from the collector dams (Lower Granite, Little Goose, Lower Monumental, and McNary) to below Bonneville Dam. Transport and in-river migration are two fundamentally different travel modes for juvenile fish. In addition, the fish transport program is controversial within the region, and the choice between transport and in-river migration is a major issue in the regional anadromous fish debate. Fish transport models are discussed in the next subsection. Appendix C presents a more detailed discussion.

A key component in analyzing fish survival is the inclusion or exclusion of fish transportation. All alternatives except SOS 9a include analysis of effects on stocks with and without transport of fish. SOS 9a includes no transportation, while SOSs 5b, 5c, 6b, 6d, and

9c include an evaluation of transport from McNary to below Bonneville (except for Snake River fall chinook, which would be transported from Lower Granite under SOS 9c). The two lower Columbia River stocks—Deschutes spring chinook and Rock Creek steelhead—cannot include transportation because no facilities exist below their area of origin.

The models evaluated results for juvenile fish travel time, juvenile fish survival, and adult returns. The survival results were examined and compared to average flow years. Juvenile survival was estimated for fish migrating in-river and for those transported.

Model Descriptions—Juvenile Transport

Transportation of smolts downstream might cause mortality from high levels of stress or increased disease transmission. These biological uncertainties raised the question of whether to continue transporting fish, and/or under what river conditions. Because of these uncertainties, transportation modeling was conducted to answer two questions. The first was to determine under what conditions, if any, different stocks of fish would be better off remaining in the river and not being transported. The second question was what would be the overall survival of stocks under each of the SOS alternatives using varied transport survival hypotheses. The EIS discussion emphasizes the second task because the primary goal of the SOR is to evaluate different operations alternatives. Survival with transport is compared with in-river survival for all alternatives except SOS 9a, which has no transport. All stocks, except the two lower river stocks (8 of 10 stocks), were evaluated for effects of transport on overall survival.

The CRiSP1.5 model was used for survival estimates with transport and in-river fish for all alternatives and stocks.

Transportation Survival Hypotheses

The analysis used three categories of transport hypothesis: fixed barge survival, fixed survival for 1986 TIR, and adjusted survival.

The latter two transportation survival hypotheses attempted to account for any differential mortality, compared to in-river migrants, that transported smolts may experience in the estuary and during early ocean residence.

Fixed Barge Survival Estimates—The simplest transport survival hypothesis is that of observed barge survival of 98 percent to a release point below Bonneville Dam. This hypothesis was included for all transported stocks evaluated.

Fixed Transportation Survival Based on 1986 TIR—These values were derived from the TIR studies. These values were used for spring/summer chinook and steelhead.

Assuming that adult returns parallel juvenile survival, it follows that—

Example:

$$TIR = \frac{\text{returning 90 "transported" adults}}{\text{returning 90 "control" adults}} = \frac{\text{survival of transported juveniles}}{\text{survival of "control" juveniles}}$$

therefore:

$$\text{Juvenile Transportation Survival} = \frac{TIR \times \text{Juvenile "Control" Survival}}{}$$

Table 4-8 shows the transport survival values calculated for the four stocks assessed in this way. Only 1986 and 1989 migration years had sufficient data to develop these relationships. However, the 1989 data were not used in the final analysis because the results were similar to the fixed barge survival value of 98 percent.

This analysis assumes that the transportation survival estimates do not vary with flow, or with the location from which the smolts are collected. So that once a smolt is loaded into the barge, it will survive at the fixed rate derived above regardless of flow and location.

Fixed Transportation Estimates Based on Adjusted TIR Values—Some authorities, particularly the state agencies and tribes, question the accuracy of the TIRs in estimating survival. Because of this, it has been suggested that the 1986 TIR value be adjusted downward to 0.7:1 for spring chinook to account for any biases produced by the TIR study methods (STFA, 1994). Table 4-9 shows the resulting survival values for Snake River and Methow River spring chinook. (For a complete discussion of the assumptions relating to the Juvenile Fish Transport Program (JFTP) survival values, see the Draft EIS Appendix C-2, Technical Exhibit I, *Assumptions Underlying the Evaluations of the Juvenile Fish Transportation Program.*)

Values Not Used: Variable Transportation Survival TIR Estimates Based on 1977 and 1986 TCR—Another transport survival hypothesis is that survival decreases with reduced flows because fish arriving at the dams for collection and transportation in low flow years are in poorer condition than fish arriving in high flow years. This hypothesis was evaluated in detail in the Draft EIS Appendix C-2. For various reasons, including changes in the hydrosystem and fish passage facilities since 1977, as well as operation of the CRiSP1.5 model, this hypothesis was not included in the Final EIS. A detailed discussion is presented in Appendix C. Included in the Draft EIS is a comparison of the effects of transported to in-river survival during various flows and alternatives. For all SOSs evaluated in the Draft EIS using the variable transport survival hypothesis, total Snake River spring chinook survival was estimated to be higher with the inclusion of transport at all but the highest flows.

Model Results Comparing Transportation Survival Estimates to In-river Estimates

Once the theories on transportation survival have been defined, they can easily be compared to calculated in-river survival estimates. In-river survival estimates are calculated for each of the 50 historic water conditions using CRiSP1.5.

Table 4-8. CRiSP1.5 fixed (1986) transport survival

Stock	1986 "Control" Survival (Percent)	1986 TIR	Derived Transport Survival (Percent)
Snake River Spring and Spring Chinook	48	1.6:1	76
Dworshak Hatchery Steelhead	45	2:1	90
Methow Spring Chinook	48	1.6:1	76
Wenatchee Steelhead	45	2:1	90

Once this is complete, the results of the transportation hypothesis and the in-river survival estimates are calculated for each alternative.

The comparison of average in-river survival to transportation survival among the previously mentioned transportation theories (up to three per species as described above) for the selected alternatives using CRiSP1.5 are included in the overall juvenile survival comparison that follows.

Downstream Passage Model Results, (CRISP1.5)

The stocks discussed below are grouped according to three river reaches. The first group includes stocks that begin their migration in the Snake River, mostly above Lower Granite Dam. The mid-Columbia River stocks originating in the Hanford Reach and above Priest Rapids Dam form the second group, and the lower Columbia River stocks are the third.

CRiSP1.5 results are applicable to transported and non-transported fish. Traditionally, a small portion of most Snake River and a moderate portion of mid-Columbia River stocks are not transported. There were minor differences in in-river survival for mid- and lower-Columbia River stocks among the alternatives. None of the alternatives would appreciably increase survival of mid-Columbia or lower river stocks. The natural river alternative, SOS 5, had a substantially higher estimated in-river survival for all Snake River stocks than any other alternative. The natural river alternative is estimated to substantially increase the in-river survival of Snake River stocks over existing conditions. Because of the uncertainty of dam passage survival values, the drawdown and combination alternatives, particularly SOSs 6b, 9a, and 9c, could markedly increase or decrease in-river survival of Snake River stocks relative to any flow-control alternative. Snake River fall chinook had the widest range of survival among the

Table 4-9. CRiSP1.5 1986 adjusted transport survival

Stock	1986 "Control" Survival	1986 Adjusted TIR	Derived Transport Survival
Snake River Spring and Spring Chinook	51%	0.7:1	36%
Methow Spring Chinook	51%	0.7:1	36%

alternatives, showing the largest relative increase with SOS 5 and decrease with SOS 9c.

The ranking of alternatives and relative survival changes, from in-river to with-transport, was primarily dependent on which transport model was assumed. This was especially true for Snake River and some mid-Columbia River stocks. The fixed survival model, which was used for all transported stocks, resulted in much greater overall survival for all stocks where transport occurred for all alternatives. Overall survival based on the 1986 TIR transport model, although lower, was still much higher than in-river survival in most cases. These two transport survival models usually resulted in higher overall survival for Snake River stocks occurring with flow control alternatives or SOS 9b or SOS PA. The overall survival results of the natural river alternatives were usually close for the Snake river stocks, although fall chinook results were much lower. Except for Methow River spring chinook, the mid-Columbia stocks had much higher overall survival with transport than for in-river migration for all alternatives under these two transport hypotheses. Little difference occurred among alternatives for mid-Columbia river stocks.

The results of the 1986 adjusted TIR transport model, which was used only for Snake River spring and summer chinook and Methow River spring chinook, had overall survival values similar to in-river for most alternatives, with the natural river alternative having the highest overall survival. The lower-river stocks were unaffected by the transport models because they are downstream of all transport facilities.

Snake River Stocks—
Spring Chinook In-River: Below are the survival estimates for Snake River fish, modeled as though the whole population were migrating in-river. Predicted survival of in-river migrants parallels the observed travel time measures (see later section). In reality, however, very few of these fish remain in-river during their juvenile migration. Depending on flow conditions and the level of spill, up to 85 percent of Snake River stocks are transported by truck or barge to

below Bonneville Dam. Overall juvenile survival estimates, including transport, follow. The greatest average survival for spring chinook in-river migration was with the natural river options. These options showed an average survival of around 45 percent to below Bonneville Dam under 50-year average water conditions (Figure 4-6). SOSs 6b, 6d, 9a, and 9c have the potential to either increase or decrease juvenile survival compared to existing conditions depending on the use of either optimistic or pessimistic assumptions about juvenile survival in this untested operation. Of these, the Lower Granite drawdown (SOS 6d) with optimistic assumptions is only slightly higher than any of the flow control alternatives at 27 percent survival. The average survival value varies only slightly for the flow control alternatives, averaging about 25 percent smolt survival. SOSs 9b and PA have survival slightly higher than the flow control alternatives at 27 percent.

Spring Chinook—With Transport: Based on the fixed barge and 1986 TIR transport hypotheses, total survival was usually double or higher than the in-river survival for SOSs 1, 2, 4, 9b, and PA (Figure 4-6). Other alternatives' total survival were also higher than in-river survival, although differences were less for these two transport hypotheses. Under the 1986 adjusted TIR hypothesis, total survival was nearly the same as in-river survival for SOSs 1, 2, 4, 9b, and PA, while lower for the drawdown (SOSs 6b, 6d, 9a, and 9c) and natural river (SOSs 5b and 5c) alternatives.

The fixed barge and 1986 TIR have similar rankings among the alternatives. All flow control alternatives had similar overall survival (64 to 65 percent fixed; 51 percent 1986 TIR) and were higher than other alternatives. Slightly lower overall survival occurred for SOSs 9b and PA (60 to 63 percent fixed; 48 to 50 percent 1986 TIR). The natural river alternatives were also slightly lower (52 percent fixed; 47 to 48 percent 1986 TIR). Even with optimistic assumptions, the drawdown alternatives have much lower survival (less than 52 percent and
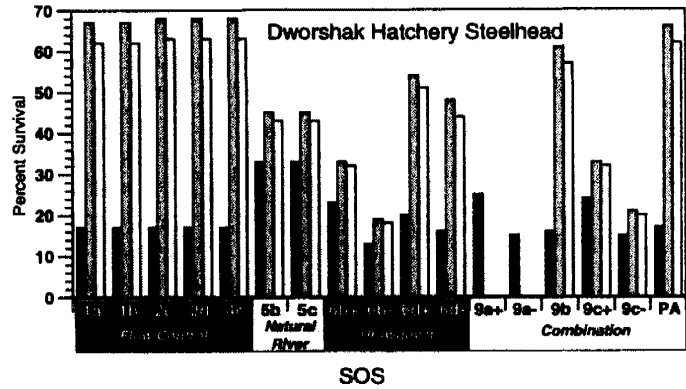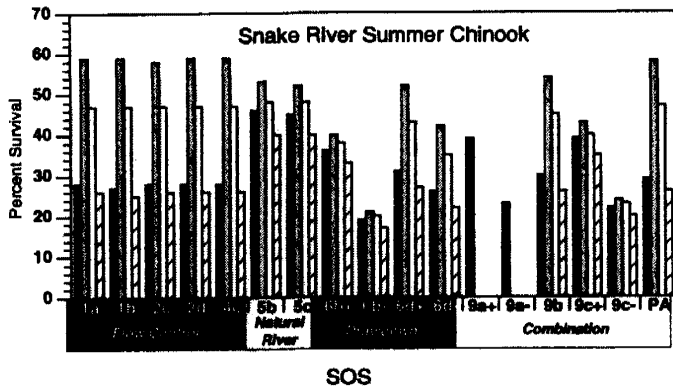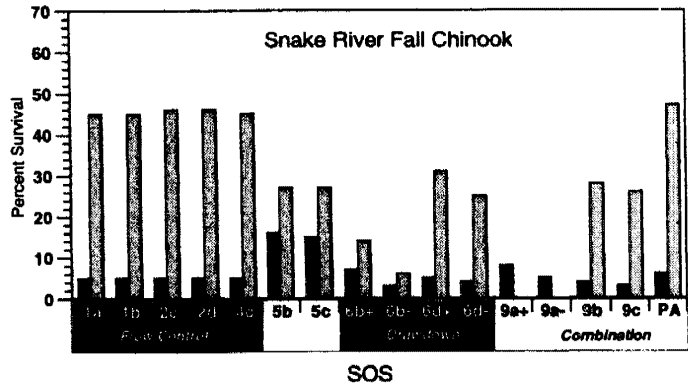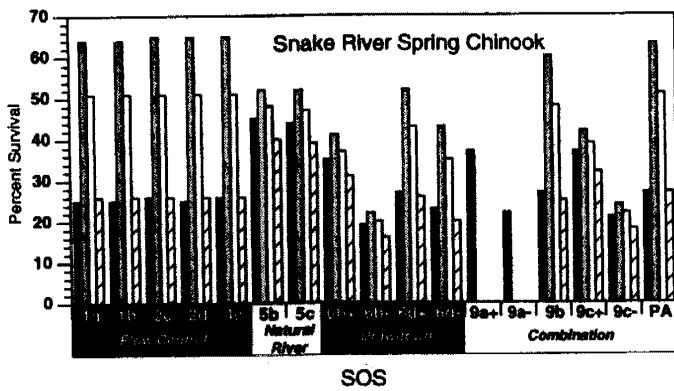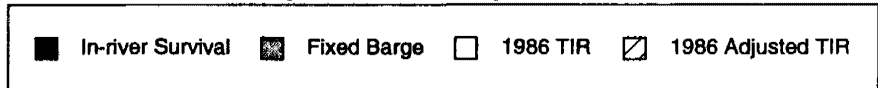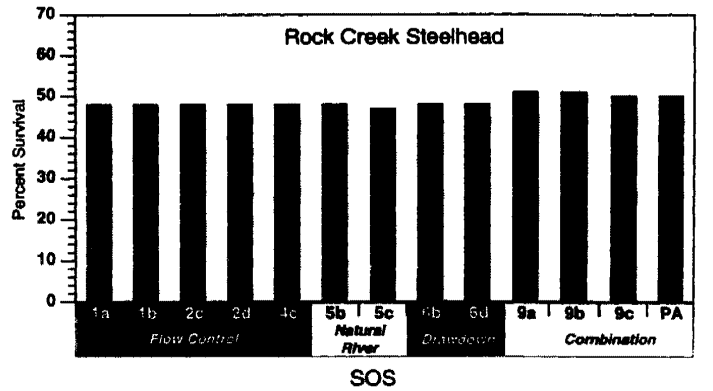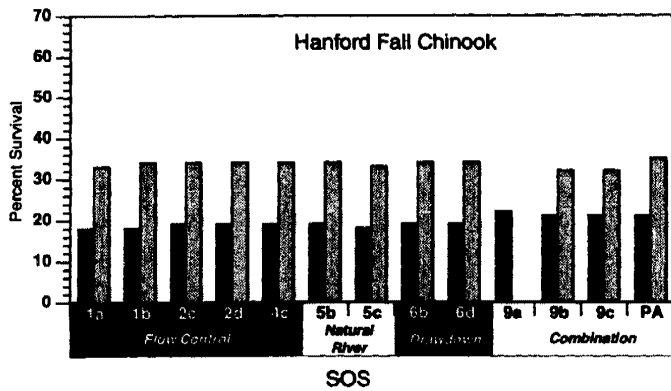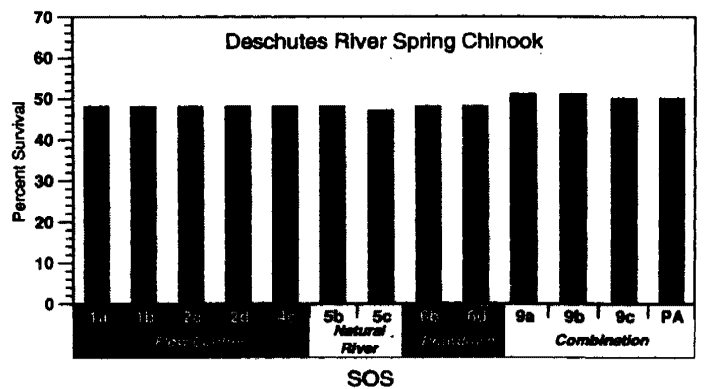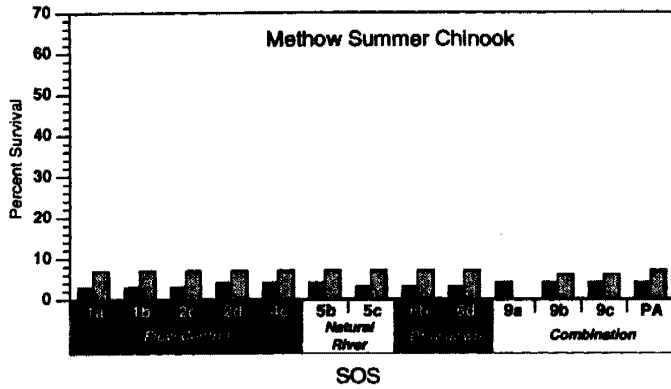
Figure 4-6. CRiSP1.5 estimated juvenile passage survival assuming average water year for in-river only
Page 1 of 2 migration, and with fish transport using varied transport survival models (source: Appendix C).
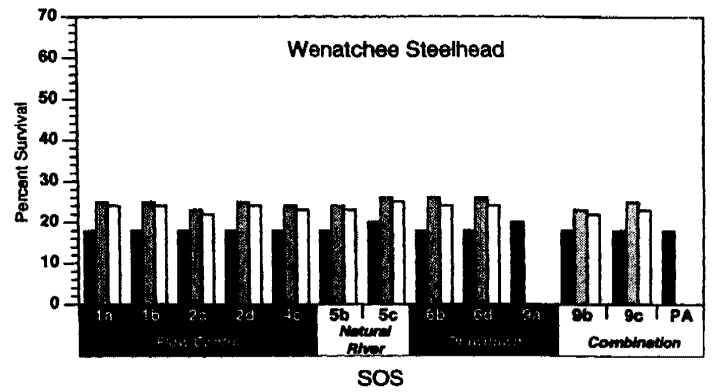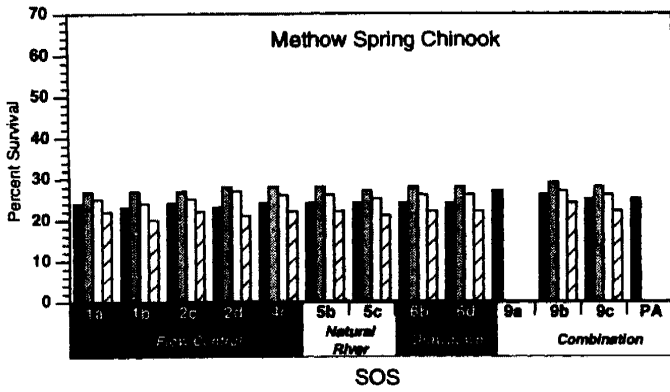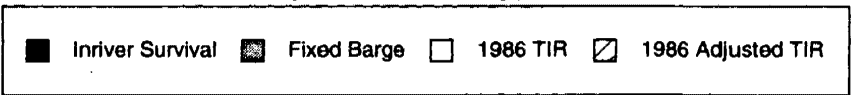
Figure 4-6. CRiSP1.5 estimated juvenile passage survival assuming average water year for in-river only
Page 2 of 2 migration, and with fish transport using varied transport survival models (source: Appendix C).

43 percent, for fixed and 1986 TIR hypotheses, respectively) than other alternatives.

The 1986 adjusted TIR hypotheses results, which assume much lower transported fish survival, altered the overall ranking of the alternatives. The natural river alternatives had the highest survival at about 40 percent. The optimistic alternatives, SOSs 6b+ and 9c+, were next highest at 31 to 32 percent. With pessimistic assumptions, however, these had the lowest total survival (16 to 18 percent) among alternatives. The flow control alternatives, optimistic SOS 6d+, SOS 9b, and SOS PA, had an intermediate range of overall survival (25 to 27 percent).

Summer Chinook—In-River: Snake River summer chinook estimates follow much the same trend as spring chinook for average in-river survival (Figure 4-6). Natural river options provide the best survival results with about 46 percent in-river survival.

Summer Chinook—With Transport: The trends were similar to spring chinook among the transport hypotheses, with total survival being much higher with transport than in-river migration only for the fixed and 1986 TIR hypotheses for all but SOSs 6b and 9c (and SOS 5 for the 1986 TIR hypothesis). The reason that some alternatives did not have higher survival with transport was because little transport occurred with these alternatives. The highest survival among alternatives was for flow control alternatives, and SOS PA for these two transport hypotheses, and for natural river for the 1986 TIR hypothesis. The adjusted 1986 TIR hypothesis indicated highest survival among the alternatives with natural river; however, total survival was less than in-river survival for the same alternatives with this transport hypothesis.

Fall Chinook—In-River: Snake River fall chinook in-river survival trends were similar to other chinook stocks (Figure 4-6). The natural river options are still preferable to any other in-river migration, with mean survivals being about 16 percent and all others less than 9 percent. Flow control alternative survivals, while much lower than natural river at 5 percent, are about

in the middle range of the remaining alternatives for in-river survival. The alternatives with drawdown components range around the flow control alternative survival, depending on assumptions. Those alternatives with optimistic passage assumptions (SOSs 6b+, 6d+, and 9a+) range from 5 to 8 percent survival; alternatives with pessimistic assumptions range from 3 to 5 percent survival. SOSs 9c had the lowest in-river survival of 3 percent primarily because drawdown does not occur during the major migration period for this stock, while the higher spill that would occur during migration would reduce survival due to increased gas saturation. SOS PA had a survival in the middle range of the alternatives at 6 percent.

Fall Chinook—With Transport: Under the fixed barge hypothesis, survival with transport is much higher, typically 2 to 9 times higher for the same alternatives than in-river survival alone. The flow control alternatives and SOS PA have the highest survival, ranging from 45 to 47 percent. The one-pool drawdown (SOS 6d), four-pool drawdown (SOS 9c), natural river, and SOS 9b have similar survival values about half those of flow control alternatives, ranging from 25 to 31 percent. The highest and lowest values of this group are for SOSs 6d+ and 6d-. The lowest values were for extended period four-pool drawdown alternative SOS 6b (6 to 14 percent). These lower values were primarily because fewer fish are transported from McNary Dam.

Dworshak Hatchery Summer Steelhead—In-River: The trends for other Snake River stocks also hold true for Dworshak hatchery summer steelhead. The natural river alternative still has the highest in-river survival results at 33 percent average. As with spring chinook, the primary reason for this higher survival for natural river is from the elimination of turbine mortality in the Snake River. The next highest average survival (23 to 25 percent) was for alternatives having drawdown and optimistic dam passage assumptions (SOSs 6b+, 6d+, 9a+, and 9c+). These same alternatives with pessimistic assumptions had the lowest survival values, 13 to 16 percent. The flow control alternatives, including base case (SOS

2c), and combination alternatives (SOSs 9b and PA) had only a slightly higher average survival (16 to 17 percent).

Dworshak Hatchery Summer Steelhead—With Transport:

The results of the two survival hypotheses used, fixed barge and 1986 TIR, were nearly identical. For all alternatives that included transport (SOS 9a has none), overall survival was much higher than in-river survival alone. Increase in survival ranged from about 25 to 400 percent over in-river values for the same alternatives. Highest average total survival occurred with all flow control alternatives and SOSs 9b and PA, with most exceeding 60 percent survival. The one-pool drawdown alternative (SOS 6d) with optimistic assumptions was the next highest (51 to 54 percent for the two hypotheses). The one-pool drawdown with pessimistic assumptions (SOS 6d-) and natural river alternatives were next highest, at 43 to 48 percent, considerably lower than the highest group. The remaining alternatives (SOSs 6b and 9c) were much lower than the highest group at 18 to 33 percent for both transport survival hypotheses. These results are generally reflective of high survival values used for transported fish, causing those alternatives that transported the greatest portion of steelhead to have the highest total survival.

Snake River In-River Summary:

In-river survival estimates for the natural river options are greater than for all other alternatives. The four-pool drawdown scenarios, with optimistic assumptions (SOSs 6b+, 9a+, 9c+), increase survival estimates over the in-river estimates produced for flow control alternatives. The one-pool drawdown, with optimistic assumptions, has usually only slightly higher survival than most flow-control alternatives and SOSs 9b and PA. The drawdown scenarios with pessimistic assumptions (SOSs 6b-, 6d-, 9a-, and 9c-) did not improve survival for any stock.

Snake River Transport Summary:

The overall survival and ranking of alternatives was highly dependent on which transport survival model was used. The 1986 adjusted TIR transport hypothesis, which assumes low transport survival, applied only to spring and summer chinook. This hypothesis resulted in overall survival and alternative ranking about the same as in-river conditions. The natural river alternatives were highest in overall survival followed by the four-pool drawdown alternatives with optimistic assumptions (SOSs 6b+ and 9c+). The flow control and PA alternatives were in the middle rank of survival for this hypothesis.

In contrast, the fixed barge and 1986 TIR transport hypotheses resulted in much higher overall survival for alternatives that included a large amount of transport than for in-river survival. This was most noticeable for fall chinook that had overall survival ranging from 2 to 9 times higher with transport than for in-river only. These two hypotheses had all of the flow control alternatives and SOS PA with the highest overall survival. SOS 9b usually was next in ranking, followed by natural river. The optimistic assumption four-pool drawdown alternatives (SOSs 6b+ and 9c+) were usually next, except for fall chinook which had its lowest survival for SOSs 6b+ and 6b- due to the lack of transport during the 4.5-month drawdown in the Snake River. The one-pool drawdown (SOS 6d) and pessimistic assumption four-pool drawdown alternatives (SOSs 6b- and 9c-) were generally the lowest in overall survival.

Mid-Columbia Stocks— Methow River Spring Chinook In-River:

As expected, there is little difference in survival for Methow River spring chinook among any of the alternatives over the 50-year in-river migration. The drawdown and natural river alternatives do not substantially affect flows for mid-Columbia stocks. Mean survival ranges from 23 (SOSs 1b and 2d) to 27 (SOS 9a) percent for all alternatives.

Methow River Spring Chinook—With Transport:

Overall survival increased slightly with transport under both transport hypotheses for all alternatives. Similar to in-river survival, there is little difference among alternatives. The fixed barge total survival ranged from 27 to 29

percent, while the 1986 TIR model values ranged from 24 to 27 percent. These values equal an increase of about 12 to 20 percent and 4 to 17 percent (most less than 8 percent) in relative survival over in-river survival for the same alternatives, for the two transport hypotheses, respectively. Transport has less effect on this stock than on the Snake River stocks because no fish transport occurs before McNary Dam for Mid-Columbia stocks.

Methow River Summer Chinook: Like that of Methow River spring chinook, summer chinook in-river survival shows slight differences among the alternatives for the 50-year period, ranging from 3 to 4 percent for all alternatives (Figure 4-6).

Methow River Summer Chinook—With Transport: Relative survival increased substantially (50 to over 100 percent by alternative) with transport for summer chinook, with total survival ranging from 6 to 7 percent based on the fixed barge hypothesis. However, overall survival, even with transport, remains low and differences among alternatives remain slight.

Hanford Reach Fall Chinook—In-River: Hanford Reach fall chinook respond about the same as the Methow River summer chinook. But their overall in-river survival values are higher because they have fewer dams to negotiate. In-river survival averaged 18 (SOS 1) to 22 (SOS 9a) percent for 50 years.

Hanford Reach Fall Chinook—With Transport: Like summer chinook, transport increased relative survival substantially (50 to 90 percent) based on the fixed barge hypothesis. Total survival varied little among alternatives ranging from 32 to 35 percent.

Wenatchee Steelhead: All alternatives provided similar in-river survival for Wenatchee steelhead, averaging 18 to 20 (SOSs 5c and 9a) percent for the 50-year period.

Wenatchee Steelhead—With Transport: The two transport hypotheses had similar results with average survival ranging from 23 to 26 and 22 to 25 percent for the fixed barge and 1986 TIR hypotheses, respectively. These values are typically greater than 20 percent higher than in-river survival estimates for the same alternatives.

Mid-Columbia In-River Summary: Natural river and drawdown alternatives would not affect mid-Columbia stocks in-river survival. Changes in Snake River flows would be attenuated by the time they mix with the flows from the Columbia River.

Mid-Columbia stocks had slight overall in-river survival improvement with alternatives that relied primarily on spill for fish passage (SOSs 9a and 9b), especially in combination with lower John Day pool levels (SOS 9a).

Mid-Columbia with Transport Summary: Based on the fixed barge 1986 TIR transport hypothesis, overall survival of all stocks was improved with transport. Except for Methow spring chinook, these survival increases were substantial for all alternatives with these two hypotheses, with some exceeding 100 percent increase. A decrease in survival with transport, relative to in-river survival, occurred for Methow spring chinook with the adapted 1986 TIR transport hypothesis. However, even with transport, survival remained low for Methow summer chinook. No alternative was consistently better for all stocks and little difference occurred in overall survival among alternatives based on either transport model.

Lower Columbia Stocks—The Deschutes spring chinook are not transported, because they enter the mainstem below McNary Dam, the last fish transport facility. There was little difference among alternatives for this stock, with survival averaging 47 (SOS 5c) to 51 (SOSs 9a and 9b) percent during the 50-year period.

The Rock Creek steelhead, which is also below transport facilities, had trends similar to Deschutes spring chinook. This stock showed little variability of survival among the

alternatives, ranging from 35 to 37 percent for the 50-year period.

Survival varied little among alternatives primarily because mainstem flows varied little among alternatives. Also, changes in dam configurations for some alternatives occurred upstream of these stocks' origin.

Summary: Natural river and drawdown alternatives would not directly affect lower Columbia stocks. Changes in Snake River flows would be less noticeable by the time they mix with the larger flows from the Columbia River. These fish enter the river downstream of the last transport site; hence, they are not transported. Lower Columbia river stocks showed some slight survival improvement for the combination alternatives that emphasize spill for passage at dams, including SOSs 9a, 9b, and 9c.

Downstream Travel Time

The CRiSP1.5 model calculated travel time for in-river migration from the stream of origin to below Bonneville Dam. Table 4-10 summarizes the results.

Although there are differences among stocks, as expected, the natural river operation (SOS 5) would provide the fastest in-river travel times for Snake River stocks. Travel times for SOS 5 were followed by alternatives having four-pool drawdown (SOSs 6b, 9a, and 9c). The shortest travel times for fall chinook occurred with SOS 5 and 4-pool draw down alternatives (SOSs 9a and 6b).

Other than the much lower travel times of natural river alternatives, average differences among alternatives were slight for Snake River stocks, ranging from 0 to 4 days between slowest to fastest.

Travel time for mid-Columbia stocks varied little among alternatives, ranging from only 1 to 3 days (about 10 percent difference or less). The combination alternative SOS 9a was consistently among the lowest in travel time.

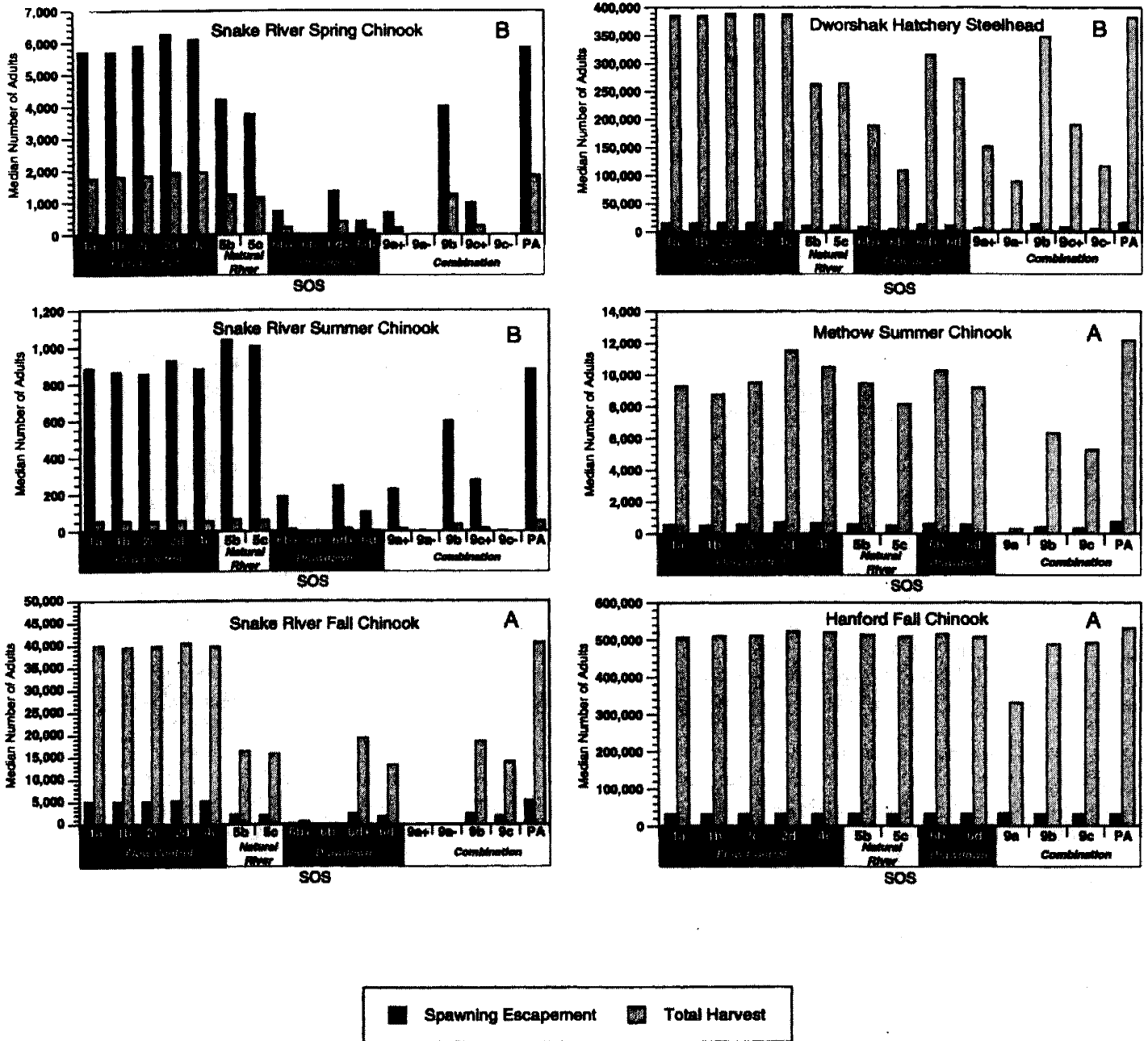No differences in travel time occurred for lower Columbia River stocks.

Returning Adults

The purpose of this analysis was to compare changes in adult return and harvest numbers across several operating strategies; it was not to evaluate salmon recovery. The SOR analysis includes only changes in system operations that affect juveniles. The estimated number of returning adults is based on changes in in-river juvenile survival rates, so, among the alternatives, adult trends mirror those of estimated juvenile survival. Effects from other factors, which can have major impacts on adult returns, were not modeled. These changes include ocean conditions; harvest (reduced or increased ocean and in-river); and adult migration (e.g., improved or decreased dam passage, reduced fallback through turbines, increased gas saturation, and temperature changes). Adult passage factors may be affected by different SOS actions, particularly those involving drawdown or natural river operations. The SOR staff recognizes that these factors affect the number of returning adults.

Numbers of adults returning to the subbasins were estimated for migration with transport only using the SLCM model (Figure 4-7). The transport survival models presented in the EIS Main Report were those the staff believed most representative of the actual barge survival conditions for the specific stocks. Adult escapement and harvest estimates based on other transport survival models, that were included for juvenile survival discussion, are presented in Appendix A of the Anadromous Fish Appendix C. The optimistic and pessimistic assumptions are determined separately. SLCM results in some cases overestimate total harvest numbers. The harvest numbers for Dworshak hatchery steelhead and Snake River fall chinook are too high, while mid-Columbia summer chinook might be too high. This affects neither the ranking of the alternatives nor the estimated escapement numbers.

Table 4-10. Average in-river juvenile travel time (days) for surviving fish during 50 average water year conditions based on CRiSP 1.5 model

Stock	Group 1: Flow Control (1a, 1b, 2c, 2d, 4c) Flow control in-river		Group 2: Drawdown (6b+, 6b-, 6d+, 6d-) (6b+, 6b-) Four-pool drawdown; no transport; includes drawdown of John Day to MOP	(6d+, 6d-) Lower Granite Reservoir drawdown; no transport at LGR; continued transport at other projects; John Day to MOP	Group 3: Natural River (5b, 5c) Natural Snake River, including John Day to MOP	Group 4: Combination (9a+, 9a-, 9b, 9c+, 9c-, PA) Varied drawdown; varied Snake River spill, with and without transport
SNAKE RIVER				*Days (Range)*		
Spring Chinook	21 (1b) to 20		18	20	15	20 (PA,9b) to 17 (9c-)
Summer Chinook	25 (1) to 24 (2,4)		23	24	19	24 (PA,9b) to 22 (9a+, 9c)
Fall Chinook	57 (1,4) to 56 (2)		56	56	29	55 (PA,9b,9c) to 54 (9a)
Dworshak Hatchery Summer Steelhead	23 (1b,2d) to 22 (1a,2c,4c)		20	22 (6d-) to 21 (6d+)	16	22 (PA,9b) to 18 (9a+)
MID-COLUMBIA RIVER				*Days*		
Methow River Spring Chinook	27 (4c) to 26		26	26	26	26 (PA, 9c) to 25 (9a,9b)
Method River Summer Chinook	36 (1,2c) to 35 (2d, 4c)		36	36	36	35 (PA) to 33 (9a)
Hanford Reach Fall Chinook	23 (1,2c) to 22 (2d,4c)		23	23	23	22
Wenatchee Hatchery Summer Steelhead	33 to 33		32	32	33 (5c)-32(5b)	33 to 32 (9a)
LOWER COLUMBIA RIVER				*Days*		
Deschutes River Spring Chinook	12	12	12	12	12	12
Rock Creek Steelhead	16	16	16	16	16	16

Note: A = fixed barge survival transport hypothesis; B = 1986 TIR transport hypothesis; no transport for 9a, 9a+, or 9a-.

Figure 4-7. Estimated total harvest and spawner escapement for 30 to 40 years into the future, based on selected transport survival hypotheses using SLCM analysis

Snake River Stocks—

Spring Chinook: The median number of adults produced in 30 to 40 years, as predicted by SLCM using the 1986 TIR transport survival hypothesis, was highest for the flow control alternatives, including the base case alternative (SOS 2c) and combination alternative SOS PA (Figure 4-7). There was little variability among these alternatives with escapement ranging from 5,700 to 6,300, and harvest 1,800 to 1,900 fish, with SOS 2d having the highest values. The natural river options and alternative SOS 9b had slightly lower adult production estimates with 3,800 to 4,200 escaped, and 1,200 to 1,300 harvested. The other alternatives had much lower estimated adult spring chinook production with the optimistic dam passage assumptions. The one-pool drawdown (SOS 6d+) was next highest at 1,400 escaped and 400 harvested fish, respectively. The alternatives with four-pool drawdown and optimistic dam passage assumptions (SOSs 6b+, 9a+, and 9c+) had a total escapement of 700 to 900, and a harvest of 200 to 300 fish. The four-pool drawdown alternatives with pessimistic dam passage assumptions had very low adult production of less than 20 fish total escapement and harvest.

Summer Chinook: Using the 1986 TIR transport hypothesis, summer chinook showed slightly different trends in median adult production in 30 to 40 years than spring chinook using the same models and transport hypotheses. The natural river alternatives had the highest adult production (estimated escapement of 1,000, harvest of 60). The flow control alternatives (including SOS 2c) and SOS PA were only slightly lower with an escapement of 900 and harvest of 50 to 60 fish. SOS 9b has about half the highest values with 600 escaped and 40 harvested. As with spring chinook, four-pool drawdown alternatives (SOSs 6b+, 9a+, and 9c+) with optimistic passage assumptions were much lower with 200 to 300 escaped and 10 to 20 harvested. Less than 5 total fish were estimated to be produced, assuming pessimistic dam passage parameters for these same alternatives.

Fall Chinook: Median fall chinook adult production estimates, assuming fixed barge survival, showed essentially no change among the five flow control alternatives and SOS PA, with estimated median escapement of 5,100 to 5,300 and harvest of 40,000 to 41,000. The natural river alternatives would produce about half as much as the flow control alternatives with an estimated 2,000 escaped and 16,000 harvested. The optimistic one-pool drawdown (6d+) and SOS 9b were nearly the same as natural river, with 2,300 and 19,000 escaped and harvested, respectively. With assumed pessimistic dam passage conditions, SOS 6d- had lower adult production of 1,700 escaped and 13,000 harvested.

Under SOS 6b, where all four Lower Snake projects would be drawn down to near spillway crest during the fall chinook out-migration period, Snake River fall chinook would either become extinct or maintain a minimal population, depending on whether optimistic or pessimistic dam passage conditions are assumed. This is likely due to the absence of transportation for this stock. Under SOS 9a, where there is no transportation assumed, Snake River fall chinook became extinct. Under SOS 9c, even though all four Lower Snake projects would be drawn down to near spillway crest, the pools would be refilled by June 30 each year in time for the transportation program to collect the out-migrating juvenile fall chinook. Under SOS 9c, production is estimated to be about 1,800 spawners and 14,000 harvested.

Dworshak Summer Steelhead: Adult production with transport, using the 1986 TIR transport hypothesis, is estimated to be similar among the flow control alternatives and SOS PA. These SOSs had escapement of about 15,000 and harvest ranging from 382,000 to 388,000. SOS 9b has only slightly less adult numbers, with escapement and harvest of 14,000 and 348,000, respectively. The one-pool drawdown alternative (SOS 6d) with both pessimistic and optimistic assumptions was moderately lower at 11,000 to 13,000 escaped and 316,000 to 273,000 harvested. Natural river alternatives follow with 10,000 escaped

and 263,000 to 264,000 harvest. The four-pool drawdown alternatives (SOSs 6b, 9a, and 9c) had the lowest adult production. Assuming optimistic dam passage conditions, these three alternatives had returns ranging from 6,200 to 7,800 escaped and 151,000 to 191,000 harvested in 30 to 40 years. The pessimistic passage versions of these alternatives returned only 3,600 to 4,800 escaped and 90,000 to 119,000 harvested. SOS 9c, which had no transport at the lower Snake River projects, had similar results to the other drawdown alternatives because little transport of steelhead would occur until McNary Dam, allowing much of the same in-river and dam passage mortality to occur with all three alternatives. Generally, except for natural river alternatives, those alternatives with less disruption to the current operation of reservoirs and transport system had higher overall adult steelhead production.

Snake River Summary: The results of life-cycle modeling, which use hypotheses containing favorable transport survivals, indicate that the greatest number of adults in most cases would occur with any of the flow control alternatives and with SOS PA. With the exception of summer chinook, adult production within 30 to 40 years was estimated to be markedly higher with these alternatives than any of the others. Slight differences among the higher return alternatives occurred within each stock. The one exception to this was for summer chinook, which had slightly higher adult production with either of the natural river alternatives. The natural river alternative for the other three stocks was in the middle range of returns among alternatives, but considerably lower than returns of the highest alternatives. SOS 9b, which includes flow targets, reservoirs to MOP, and frequent spill, also had some of the higher adult production numbers, especially for steelhead. But it too was much lower than the highest producing alternatives. All of the alternatives containing drawdown did considerably worse for adult production, even with optimistic dam passage assumptions, with the one-pool drawdown alternative being the best of this group. With pessimistic passage assumptions, these alternatives were extremely poor, driving

some stocks to extinction within the 30- to 40-year period.

Mid-Columbia Stocks—
Methow River Summer Chinook: Adult production in 30 to 40 years, assuming fixed barge survival, would be similar among all alternatives except SOSs 9a, 9b, and 9c, which would be much lower. The estimated escapement of the higher-producing alternatives, including SOS 2c, range from 500 to 700 with a harvest of 8,800 to 12,200. Of these, the highest number of adults was produced with SOSs PA and 2d, which exceed SOS 2c returns by over 20 percent. SOSs 9b and 9c are considerably lower (escapement of 300 to 400, harvest of 5,300 to 6,300). This might be because of reduced fish transport from increased spill at McNary Dam. SOS 9a has extremely low estimated adult production (20 escaped, 300 harvested), primarily because no transport occurs with this alternative, which is assumed to be a great benefit to survival with the fixed barge transport hypothesis.

Hanford Fall Chinook: Other than SOS 9a, there was little difference among the alternatives in adult production estimates of Hanford fall chinook using the fixed barge transport hypothesis. All alternatives have nearly the same escapement (32,000 to 33,000) because of the imposition of a minimum escapement cap of 50,000 at McNary (to simulate the effects of *US v. Oregon* harvest regulations). Harvest of all but SOS 9a is similar, ranging from 492,000 to 532,000. Similar to summer chinook, the highest producing alternatives were SOSs PA and 2d, which were less than 5 percent higher in adult production than SOS 2c. Lack of transport from McNary Dam is the primary reason SOS 9a was greatly lower than the other alternatives, with an estimated 331,000 harvested fish in 30 to 40 years.

Mid-Columbia River Summary: Most alternatives would provide adult production similar to what would occur under existing conditions for Methow summer chinook and Hanford fall chinook. The exception would be SOS 9a for both stocks and SOSs 9b and 9c for

Methow summer chinook. Changes from existing conditions are minor with SOS PA, which has the highest estimated adult production for both stocks and exceeds SOS 2c values. Hanford fall chinook are affected less than most stocks by differences among the alternatives. This is because their outmigration is restricted to a short region of the mid-Columbia and the lower Columbia, where only slight differences in flow and operational characteristics occur among alternatives.

Lower Columbia River Summary: The number of lower river returning adults were not estimated in the Final EIS. Because the adult returns are calculated as a direct function of juvenile survival, and juvenile survival from this region changed little among the alternatives, little or no adult production difference would be expected among the alternatives.

Other Anadromous Stocks

Commercial and recreational anglers fish for other Columbia River anadromous stocks, including white sturgeon, American shad, and Pacific lamprey. Minor or no effects would occur to most of these stocks under the flow control alternatives. Major drawdowns (SOSs 5, 6, 9a, and 9c) could have marked effects on some portions of these stocks. Fish that rear primarily in the specific shallow pool areas that would be dewatered during drawdown would be most affected, primarily juvenile American shad and lamprey in the lower Snake River. Minor effects to rearing fish could occur from operating John Day pool below normal elevations (SOSs 2, 4, 5, 6, 9, and PA). These effects would be worse under SOSs 5, 6, 9a, and PA, which require the lowest elevation for this reservoir. The lowered elevation could reduce the rearing area for shad and lamprey, which use shallow, sandy water areas to rear. This is, however, a relatively small portion of the total rearing area used by these stocks and would likely have only minor effects. Effects may be more pronounced for shad than lamprey; most juvenile lamprey rearing is in tributary streams, while shad rely exclusively on the reservoirs.

American Shad: American shad rearing and spawning habitat in the Snake River would be reduced by the natural river alternative, and to a lesser extent by drawdown under SOSs 6, 9a, and 9c. The numbers of Snake River shad would diminish because of a decrease in shallow, slow-water juvenile rearing habitat or decreased food supply in these areas. Effects on habitat would be worse under alternatives with drawdown past July (e.g., SOSs 5, 6, and 9a) because major juvenile rearing occurs from July through October. Modified adult passage facilities under SOSs 5, 6, 9a, and 9c could also reduce the number of adult upstream migrants that successfully pass over the dams. Dam counts indicate, however, that the relative numbers of fish that use the Snake River or just Lower Granite are less than 10 percent or 1 percent, respectively, of the Columbia River total. Therefore, any reduction in numbers under these alternatives would have a minor overall effect on the Columbia River system population.

Pacific Lamprey: Effects on Pacific lamprey under the natural river and drawdown alternatives and SOSs 9a and 9c should be minor. Most spawning and rearing apparently occurs in tributaries, and drawdown would have little effect on these areas. Dewatering of shallow areas could, however, cause losses of some juveniles that rear buried in the mud and sand for up to 5 years. Based on the fact that fewer juvenile lamprey were counted at Little Goose Dam in 1992 following the experimental spring 1992 drawdown, losses might occur under these alternatives. Depending on how successful future upstream passage facilities would be if the Snake River dams were modified, migration upstream in the Snake River for adults could also be jeopardized under the natural river and drawdown alternatives. The effect of water particle travel time on migration of lamprey is unknown. However, if there is a positive effect on migration, outmigrating juveniles would benefit the most under the natural river alternative and to a lesser extent under SOSs 6, 9a, and 9c. Also, because of increased spill, the natural river alternative and, to a lesser extent, SOSs 9a, 9c, and PA would reduce dam passage

mortality by eliminating or reducing turbine mortality on the Snake River.

Sturgeon: The anadromous form of white sturgeon is mostly restricted to below Bonneville Dam; green sturgeon occur exclusively below Bonneville. These fish should not be affected by any of the alternatives. Primary factors affecting white sturgeon appear to be deep-water habitat and flows below Bonneville Dam, neither of which would be markedly affected under any SOS alternative. Because changes in the lower river are not proposed, the green sturgeon should not be affected.

Isolated populations of white sturgeon in individual reservoirs could, however, be affected under the natural river and drawdown alternatives (see Section 4.2.5, Resident Fish). Spawning success in the mainstem reservoirs is affected by water velocity during spawning, with better spawning success occurring in higher flow years (Hanson et al., 1992). Alternatives that substantially increase reservoir velocity during the April and July spawning period (SOSs 5, 6b, 9a, and 9c) might benefit sturgeon populations in reservoirs by improving spawning conditions. Lower Granite's spawning white sturgeon are unlikely to be affected because of ample spawning area in the Snake River above the reservoir. The preferred rearing habitat is the deeper water in most reservoirs; Lower Granite Reservoir is one exception, where sturgeon make greater use of shallower (less than 66 feet [20 m]) areas (Bennett et al., 1993). While little reduction in this habitat would occur under most alternatives, the natural river options would reduce this area substantially in the Snake River reservoirs. Whether the benefit of increased flows on spawning success would be offset by reduced rearing area in the Snake River reservoirs is unknown.

Hatcheries

SOSs 5, 6b, 9a, and 9c could threaten the water supply pipeline of the Lyons Ferry Hatchery. If this pipeline were lost, the production from this hatchery could be interrupted or reduced, unless or until an

alternative water supply were developed. The hatchery is designed to rear 116,400 pounds (52,798 kg) of steelhead, 101,800 pounds (46,175 kg) of fall chinook, 8,800 pounds (3,922 kg) of spring chinook, and 45,000 pounds (20,412 kg) of rainbow trout.

Operation of John Day pool near elevation 262.5 feet (80.01 m) (SOSs 2, 9b, and 9c) or 257 feet (78.3 m) (SOSs 5, 6, 9a, and PA) could reduce water supply to the Umatilla Hatchery. The current well system has apparently been affected by a low reservoir pool level. Water supply problems could reduce fish production at this facility (Corps et al., 1993).

4.2.5 Resident Fish

Resident fish populations in the Columbia and Snake Rivers are affected by dam operations in a variety of ways. Most potential effects are related to spawning success, early survival of juveniles, and the availability of food sources. The potential that each of these factors has to change the overall reservoir and riverine fish populations depends on the duration and extent to which populations are exposed to a given factor and whether populations are limited by it. For instance, if food levels normally present in a reservoir far exceed levels required to maintain the fish populations, reductions in food production may not affect those populations. How resident fish populations may be affected by system operations is described below, with special emphasis on those resources identified as special concerns during SOR scoping. Appendix K, Resident Fish, presents a more detailed discussion of the impacts.

Resident Fish Impact Issues

Spawning Success

The effect of variations in water level on spawning success typically has a greater direct influence on fish production than any other factor. Most of the exotic fish species in the SOR reservoirs spawn in shallow-water areas, often in clean rock, or on vegetation, when it is available. Lower water levels in the reservoirs

during the spring and summer spawning season often reduce the volume of shallow-water habitat by draining backwaters and shallow embayments along the perimeter of the reservoir. The shallow-water area remaining is normally devoid of aquatic vegetation and tends to contain more silt than areas at higher elevation. The remaining habitat, therefore, is often of poorer quality than is normally found at higher pool levels. Egg survival might be reduced as a result.

Variations in water level while eggs are developing, as is often encountered with peaking power production or longer term drawdowns in spring and early summer, can expose the developing eggs to air and dry them out before they hatch. Such drawdown situations during the incubation period are not uncommon and can result in the loss of an entire year's fish production.

Reductions in water level can also expose the shallow deltas at the mouths of tributaries. The resultant water depth across these deltas is often very shallow and can prohibit fish from entering streams and reaching upstream spawning grounds. Likewise, low flows in riverine stretches may also prevent the upstream movement of fish out of the reservoirs to spawn.

Some native resident fish species (e.g., white sturgeon) require higher water flows in the spring and early summer to stimulate spawning. In some areas, the absence of sufficiently high flows has resulted in substantial reductions of fish populations.

Food Availability

Food in reservoirs includes plankton and small fish; organisms that reside in and on the rocks and silt in the bottom of reservoirs (benthic organisms); larvae of terrestrial insects that lay their eggs in water; and terrestrial insects that fly near and often fall into the water. Food sources in rivers include plankton introduced from upstream reservoirs, benthic organisms, and terrestrial insects (both larvae and adults).

Terrestrial insects are most abundant in waters that are clean and have abundant overhanging vegetation. When reservoirs are drawn down or river flows reduced, the water's edge recedes from the surrounding riparian vegetation, reducing the number of terrestrial insects available as food for fish.

Benthic organisms are most common in shallow-water areas. When water levels are reduced, those organisms present in the shallow-water areas often dry out and die, thereby reducing the availability of an important food source. Increases in siltation can also affect the production of benthic organisms, both in shallow and deeper waters.

Plankton production in reservoirs is highest with warm-water temperatures, moderately high nutrient levels, and longer water retention times. Increases in flow rates reduce water retention time and flush nutrients from the reservoir. Phytoplankton growth is subsequently reduced. Zooplankton, which are important in the diets of many reservoir fish species, feed on phytoplankton. Therefore, a reduction in the abundance of phytoplankton also tends to reduce in the abundance of zooplankton. Finally, increased flows increase the loss of plankton past the dams.

Survival of Juveniles

The reductions in food availability described above can reduce the feeding success of young fish and, as a result, reduce growth and survival of those fish. Decreases in the number of juvenile fish in the reservoirs subsequently limit the food available for adult fish that prey on smaller fish species.

Variations in flow also affect the rate at which fish are lost passing through the dams (entrainment). Larval and many juvenile fish are unable to swim against heavy currents. Hence, increased flows tend to carry these small fish into the turbines where an unknown percentage of them die.

Reductions in water level in the reservoirs and the resulting reductions in the total volume of water stored in the reservoir tend to concentrate the reservoir's fish population into a smaller area and away from the full-pool littoral areas, which are the most productive. If the volume of water has been reduced significantly, competition for the available food resources increases and feeding success might decrease. The smaller volume of water also reduces the area available for smaller fish to hide from predators.

Small fish often congregate in shallow-water areas, such as backwater pools, where food is abundant and larger predators are less common. Rapid reductions in the water level in the reservoirs can strand fish in backwater pools, which become separated from the main body of the reservoir. Many of the fish stranded in these areas die due to increases in water temperatures above tolerable levels and predation by seagulls and other birds. These backwater areas often dry up while water levels are down, in which case all fish stranded in these pools die.

Water Quality Effects

Substantial changes in the water level in the reservoirs and changes in flow in the riverine stretches of the Snake and Columbia Rivers can affect river temperature. Shallower waters warm more quickly in the sunlight as do slow-flowing waters in rivers. Increasing temperatures tend to increase phytoplankton production. Provided that growth of algae is not great enough to begin choking waters, the increased temperature and phytoplankton growth will tend to increase feeding success and growth of most warmwater fish species in the Columbia and Snake Rivers.

Some species, however, do not respond well to increases in temperature. For instance, bull trout, a species warranting protection but currently precluded from listing under the Endangered Species Act, prefer temperatures of 59°F (15°C) or less. All species have an upper temperature tolerance level above which growth is reduced and mortality occurs. If temperatures increase above 72°F (22°C), growth of many

native species such as trout may begin to decrease. At temperatures in excess of 79°F (26°C), some of these temperature-sensitive native species might not be able to survive.

In riverine stretches of the rivers downstream of storage reservoirs, water released from the dams is often drawn from the depths of the reservoir where water is typically very cold. Increased water releases during the summer growing season might decrease water temperature in the river. The decreased temperatures decrease metabolic rates which reduce the growth rates of fish present in those reaches. Cold-water releases can also delay spawning of some cool-water species; this delay has been observed for smallmouth bass in the Hanford Reaches. Cold-water releases, however, may benefit cold-water species (e.g., trout) during summer months.

Large changes in the temperature regime in a river or reservoir over a period of many years might cause changes in species compositions of the plankton and fish community. Those species better adapted to the new temperature regime will reproduce more quickly than those that are adapted to the old temperature pattern. Hence, the most abundant species might change over several generations. The plankton community might change substantially in a single season. The fish population, however, would change much more slowly. An occasional year of warmer or colder water temperatures is not likely to have a substantial overall effect on the fish community.

Changes in turbidity can also affect plankton and fish growth and survival. Increases in turbidity reduce the sunlight entering the water and, hence, reduce phytoplankton production. The change in phytoplankton production can subsequently reduce zooplankton production, which will affect fish feeding success and growth. Increases in turbidity also reduce the ability of fish to see through the water. Those fish that depend upon sight to find food will therefore be less successful at feeding. The reduced feeding success and resulting decreased growth may be offset by reduced mortality due

to predation since larger sight-feeding fish are less likely to see and, hence, catch smaller fish. Phytoplankton can be the cause of turbid conditions, especially in high-nutrient situations.

Finally, release of water over the spillways of dams often increases the quantity of gas in the water to levels in excess of 100-percent saturation. If the gas levels are sufficiently high, they can kill fish exposed to the saturated waters. The resident fish populations can move downstream of the saturated waters; however, fish are often attracted to the tailrace of dams where large numbers of dead and stunned fish exiting the turbines provide an ample and readily available food source. Therefore, a substantial number of fish may be exposed to supersaturated waters.

Trends In Resource Management That Might Affect Future Fish Production Independent of Dam Operation

The listing of species under the ESA has had, and will continue to have, a substantial effect on the management of waterways. Additional future listings may affect the management of water resources to protect and enhance aquatic habitat. Changes in resource management in response to additional listings could include restriction of development in key watersheds, mandated flow releases, restriction of water withdrawals, and the development of active habitat restoration programs. The Kootenai River white sturgeon is a resident fish species listed under the ESA. White sturgeon are found downstream of Libby Dam. Bull trout, which are present in many of the system reservoirs, have "warranted but precluded" status for listing under the ESA. Protection of species that are designated as state Threatened or Endangered Species or Species of Special Concern may also motivate changes in watershed management. Species with State listings include westslope cutthroat trout (Montana), redband trout (Montana, Idaho), shorthead and torrent sculpin (Montana), Snake River white sturgeon (Idaho), sandrollers (Idaho), and burbot (Idaho).

Other trends that may affect resource management in the future include recent developments in the use of a watershed approach to forest and range management. These efforts are likely to emphasize protecting riparian habitats and restoring aquatic habitat. In other instances, resource managers have turned their attention to the protection and enhancement of native fish species in the hope of reducing the potential for additional listings under the ESA. Management agencies have, consequently, become less inclined to stock non-native sportfish species, which may compete with native populations. Therefore, future conditions are likely to include increased protection of native fisheries resources and aquatic habitats which would be expected to benefit, or at least reduce the rate of decline of, resident fish populations.

Effects of SOS Alternatives

The following discussion summarizes the general direction of projected trends in fish populations in the Columbia and Snake Rivers for each of the SOS alternatives relative to baseline conditions. There are two benchmarks or baseline conditions; SOSs 1a and 2c are both relevant points of reference for comparative analysis. This summary is based on the analysis results reported in detail in Appendix K, Resident Fish.

To assess the differences among the alternatives, the Resident Fish Work Group used models developed to provide an index of fish production under various water management scenarios. These models were developed for four storage reservoirs in the Columbia River portion of the system (Lake Pend Oreille, behind Albeni Falls Dam; Hungry Horse Reservoir; Lake Koocanusa, behind Libby Dam; and Lake Roosevelt, behind Grand Coulee Dam), two storage reservoirs in the Snake River drainage (Dworshak and Brownlee); one run-of-river project on the Snake River (Lower Granite); and one run-of-river project on the lower Columbia River (John Day). Each model was tailored to the specific fish populations of concern and characteristic biological and physical processes

for the specific reservoir. The models provided an index of fish abundance or production for each reservoir under each alternative. Values of the indices are not directly comparable between reservoirs.

Sufficient data were not available to develop quantitative models for all areas or species potentially affected by the alternatives. The work group used qualitative evaluations in such cases, including interviews with local fisheries experts, reviews of scientific literature on fish populations and habitat use in the specific reservoirs, or similar information on comparable reservoirs where specific information was lacking. Evaluations concentrated on biodiversity, species-specific concerns, and sportfisheries. Where biology and hydrology of a modeled system were similar to one of the unmodeled areas and the expected effects of the alternatives on hydrology were also similar, estimates of the effects of alternatives were extrapolated from the modeled system to the unmodeled one.

The discussion below summarizes the expected effects of the alternatives relative to the baseline situations on a geographic basis. Where possible, areas where the effects of the alternatives are expected to be similar are discussed together. Overall basinwide effects are summarized at the end of the discussion.

Lake Koocanusa (Libby)

Lake Koocanusa is a storage reservoir, and water surface elevations have historically fluctuated widely on an annual basis. Large fluctuations in water surface elevation (exceeding 100 feet [30 m]) and frequent failure to refill have limited the quantity of food available for resident fish populations and reduced fish growth and reproductive success. These events have occurred under operating patterns that correspond to SOSs 1a and 1b.

The annual pattern of modeled water surface elevations is substantially the same under SOSs 1a and 1b. Therefore, fish production would be

very similar in each case, although SOS 1b would be slightly worse in drought years.

Competition for the decreased abundance of food concentrated in a smaller area results in reduced growth of kokanee at lower water elevations. Insect-eating species, such as cutthroat trout, rainbow trout, and mountain whitefish, feed on aquatic insect larvae found along the shores of the reservoir near terrestrial vegetation, which serves as a food source for the adult insects. Lowering water elevations dewaters the shoreline areas, desiccating larvae present in these areas. Refill failure reduces the shoreline area available to support larvae and increases the distance between pool margins and terrestrial vegetation. Hence, the availability of aquatic larvae can be substantially reduced. Large variations in reservoir elevations have dramatically changed the species composition of the insect population. Species of terrestrial insect larvae favored by fish, such as mayflies and caddisflies, are rarely found in the reservoir. Chironomids, a smaller midge that can prosper in deeper waters, currently dominate the larval insect populations in the reservoir. Refill failure, by increasing the distance from the shoreline to the water, also reduces availability of terrestrial insects to fish who feed on them.

Water temperature is also an important factor in both food production and kokanee growth. The deeper waters of the reservoir tend to be colder than optimum for aquatic production. Reduced reservoir volumes also reduce the volume of water at optimum temperatures for fish growth and food production. At lower reservoir elevations, fish are concentrated in a smaller volume of water where they compete for reduced prey populations. The size of the fish populations in Lake Koocanusa has stabilized at low numbers, reflecting the effects of large fluctuations in reservoir elevation.

SOSs 2c and 2d result in essentially identical annual water surface elevation patterns and refill probability. The primary differences are that SOS 2d has a slightly higher probability of refill during drought conditions than SOS 2c, and drawdown is not as great during median and

high-flow years. In both cases, the depth of reservoir drafting is slightly reduced in wet years, and for SOS 2c in extreme drought years, compared to SOS 1. In moderately dry years, however, the depth of drafting would be slightly greater. The probability of refill is very similar to SOS 1 except in drought years, when the more shallow drafting would increase the probability of refill. The differences in water surface elevation would provide for slight increases in phytoplankton, zooplankton, and benthic production (Figure 4-8). These would result in slight increases in kokanee growth. Although the abundance of reservoir food resources would increase slightly, variations in reservoir elevation would continue to allow for only minimal production of preferred prey items.

Minimum reservoir elevations and the probability of refill would be better for resident fish under SOSs 2c and 2d than under SOSs 1a or 1b in most years. In drought years, however, the reservoir might be drafted deeper under SOS 2 than under SOS 1. The difference in water surface elevations would provide for improved overall prey production and fish growth, although production in low-water years

would be reduced. The long-term impacts of deeper drafting during low-water years would depend on the extent and duration of such drought periods.

SOS 4c was intended to enhance reservoir elevation and, hence, productivity in the reservoir. SOS 4c would maintain water elevations at substantially higher levels during wet and dry years than is predicted for SOS 2, although reservoir levels would still fluctuate between 64 and 111 feet (19.5 m and 33.8 m) annually. The increase in water levels would slightly enhance phytoplankton and zooplankton production. As modeled, benthic production, the volume of warmer water, and, consequently, fish growth would substantially increase, providing the highest productivity of all SOS options in Lake Koocanusa.

Elevation patterns for SOSs 5 and 6 are similar to SOS 1; consequently, the model predicts that they would support poor productivity relative to SOSs 2 and 4.

Of any alternative, SOS 9a has the least chance of refill; consequently, SOS 9a has the lowest overall predicted aquatic production, except for benthic production (Figure 4-8). SOS 9b also has low probability of refill most years, but overall drawdown is less than most alternatives, resulting in aquatic production similar to or higher than most SOSs except SOSs 4c and 9c. SOS 9c is essentially the same as SOS 4c, resulting in relatively high levels of aquatic production.
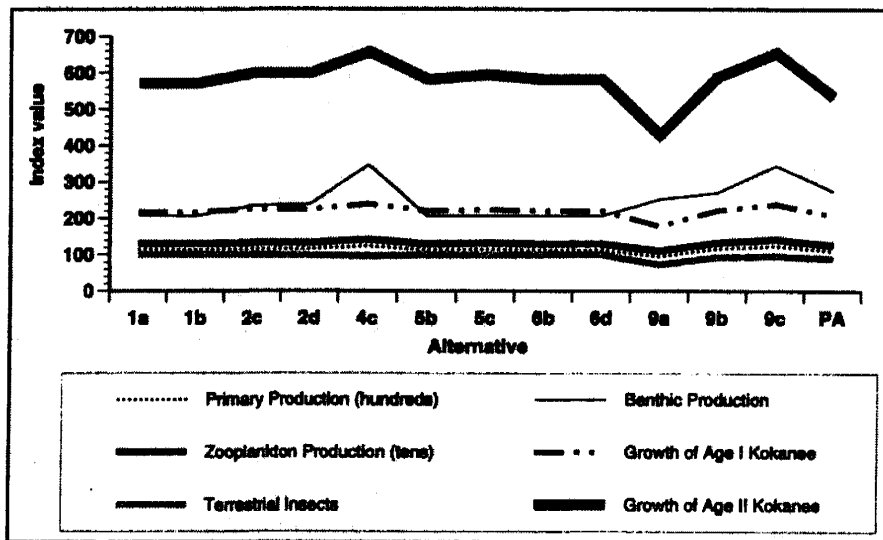

Figure 4-8. Comparison of index values representing aquatic production at Lake Koocanusa for median water years

SOS PA has moderate drawdown compared to other alternatives but also frequently does not refill, except during the highest flow years. The lack of refill influences modeled aquatic production, which was second only to SOS 9a for lowest predicted production for all parameters except benthic production.

Based on modeled results, SOSs 4c and 9c would provide the highest aquatic production in Lake Koocanusa of all SOSs. SOS 9a would have the lowest aquatic production of any alternative, by a substantial margin. The remaining alternatives were generally similar. SOSs 2c, 2d, and 9b all would have slightly higher production than the historical conditions, as represented by SOS 1a and 1b. SOSs 5 and 6 would be similar but slightly lower, and SOS PA would be second only to SOS 9c in having the lowest modeled aquatic production in most categories.

Kootenai River

Spawning of Kootenai River white sturgeon, listed as endangered under the ESA, is believed to be triggered by increasing flows and river temperatures in the spring and early summer (May through June), with peak spawning in June (Apperson and Anders, 1991). The exact flows required to trigging spawning are unknown. The last recorded successful production of a white sturgeon since Libby Dam was built occurred when spring flows were about 35 kcfs (1,000 cms) (Apperson 1991). Recently, spawning was documented when eggs were collected at flows of 20 kcfs (566 cms) (Marcuson 1994), and in 1994 at flows of 13 to 20 kcfs (368 to 566 cms). Biologists believe that flows of 20 to 25 kcfs (566 to 708 cms) at Bonners Ferry may be

necessary for movement and spawning of fish. A range of target flows has been established in the Bonners Ferry Reach of the Kootenai River for May, June, and July, depending on whether the water year is wet, medium or dry. The highest June flow target during wet years has been set at 35 kcfs (1,000 cms). Flow recommendations during these months are intended to stimulate spawning and protect egg incubation and rearing of larval sturgeon. However, these flow targets are not solely designed to enhance white sturgeon. Other water factors that affect spawning, such as temperature and substrate composition, were also considered. Because of the uncertainty of the exact flows needed to produce successful spawning, the SOSs were evaluated by comparing 1) how closely they met the target flows for May, June, and July for three representative years (wet, medium, and dry); and 2) whether they produced average monthly flows of 20 and 35 kcfs (566 and 1,000 cms) in June, the primary spawning month (Figure 4-9).

Considering the three categories of flow evaluated, SOSs 1, 2, 5, and 6 produced fewer occurrences than other alternatives. The flow targets were generally met about 40 percent of the time for the average of 3 wet, medium, and dry years. Average June flows of 35 kcfs
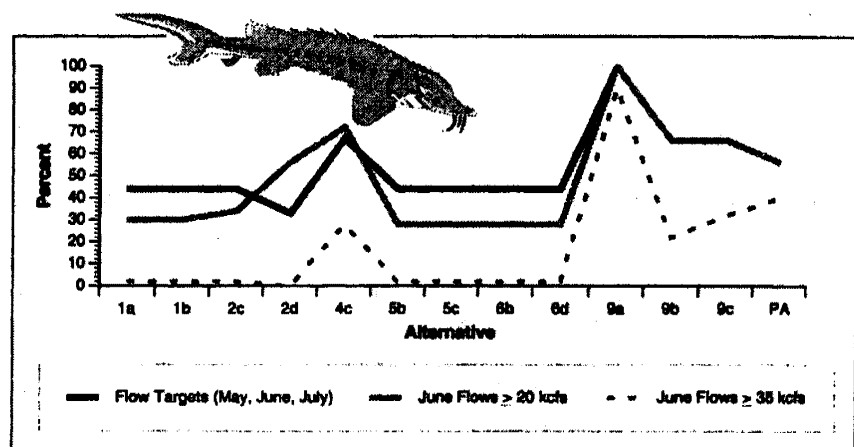

Figure 4-9. Percent of years that June average flows equal or exceed specified sturgeon flow levels for May, June, and July at Bonners Ferry

(1,000 cms) would occur less than 2 percent of the time with these alternatives. Flows of 20 kcfs (566 cms) would occur about 30 percent of the time for these alternatives except for SOS 2d when it occurs 56 percent of the time.

SOS 4c increases frequency of all flow over the previous SOSs. Overall, flow targets would be met 67 percent of the time. High June flow of 35 kcfs (1,000 cms), which stimulates spawning, would occur 28 percent of the time, and 20 kcfs (566 cms) flows would occur in 72 percent of the years.

SOSs 9a, 9b, 9c, and PA have the highest frequency of occurrence of most of the evaluated flows of all SOS alternatives. This is especially true for SOS 9a, which meets targeted flow and 20 kcfs (566 cms) flow all years, and the high spring flow category (35 kcfs [1,000 cms]) 90 percent of the years. With flow the major factor that limits spawning, spawning should be triggered in nearly all years under SOS 9a. The high June flows of 35 kcfs (1,000 cms) occur from 22 to 40 percent of the years for SOSs 9b, 9c, and PA, with PA having the greatest occurrence. The targeted flows and 20-kcfs (566-cms) June flows would occur from 56 to 66 percent, and 72 to 86 percent of the years, respectively. All of these alternatives would likely enhance white sturgeon spawning significantly over past operations.

SOS 9a would supply the greatest enhancement of white sturgeon in the Kootenai River, while SOSs 4c, 9b, 9c, and PA would also greatly improve spawning conditions.

Hungry Horse Reservoir

Hungry Horse Reservoir contains two fish species of special concern. Genetically pure strains of westslope cutthroat trout have been reduced to less than 10 percent of their historic range, making the relatively healthy population in Hungry Horse Reservoir a particularly valuable resource. Additionally, the reservoir contains a substantial population of bull trout, which are considered suitable for listing under the ESA. This population is apparently stable

and one of the strongest known. The factors affecting fish populations in Hungry Horse Reservoir are essentially the same as those described for Libby Reservoir.

The hydrologic consequences of SOSs 1, 2, 5, 6, and 9a would all be essentially the same at Hungry Horse (Figure 4-10). The model shows that these alternatives would provide the lowest levels of aquatic productivity and fish growth. Slight variations in productivity relate mainly to the depth of the draft and refill probability during dry years. Among this group of options, water levels under SOS 9a would be the worst for resident fish.

SOSs 4c, 9b, 9c, and PA would substantially improve the production of prey and fish growth compared to the other SOSs. Of these alternatives, SOS 4c would provide the highest aquatic production in Hungry Horse Reservoir. These four alternatives have the least deep drafting and result in complete or near refill of the reservoir in all but the lowest flow conditions, enhancing aquatic production in the reservoir. Phytoplankton and zooplankton production would increase during the summer months because of a fuller reservoir, and moderated pool fluctuations would enhance the production of benthic organisms. Growth of trout in the reservoir would be enhanced by the increased concentrations of prey populations and larger volumes of warm water. Refill timing would also enhance access to spawning and rearing habitat in tributaries to the reservoir. The reservoir would have an average minimum elevation 31 feet (9.4 m) higher in normal water years under SOSs 4c, 9b, 9c, and PA than under SOS 1, and roughly 27 feet (8.2 m) higher in wet years. This difference in pool elevations provides for the predicted differences in growth and production in the reservoir. Hence, SOSs 4c, 9b, 9c, and PA have the greatest potential for preservation and/or enhancement of the resident westslope cutthroat trout and bull trout populations in the reservoir (Figure 4-10).
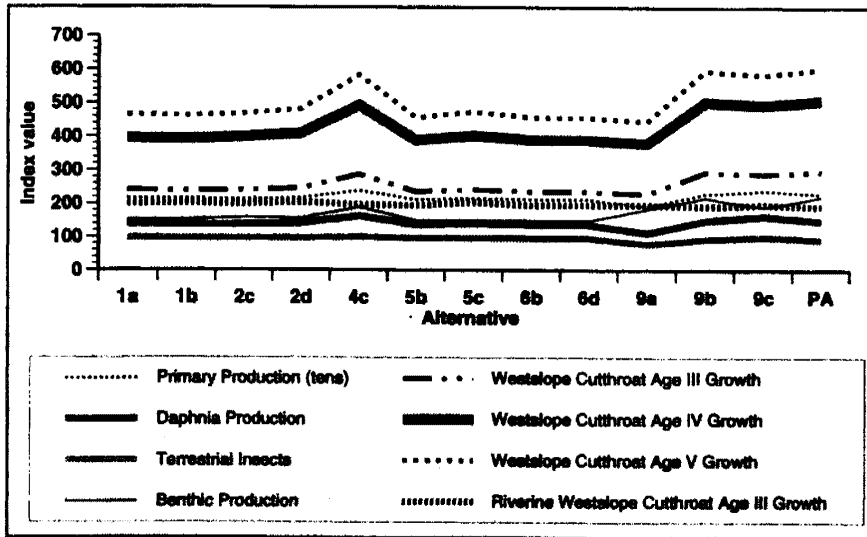
that a temperature control facility (which would allow for release of water from variable depths) would be installed on Hungry Horse Dam (construction plan to begin in 1996). The difference in the growth rate of westslope cutthroat trout varied little among alternatives. Without this facility, alternatives with high reservoir elevations (e.g., SOSs 4c and 9c) would have lower production as cold water would be released from the

Figure 4-10. Comparison of index values representing aquatic production at Hungry Horse Reservoir for median water years

Flathead River

The primary factors affecting fish production in the Flathead River downstream of Hungry Horse Reservoir appear to be: 1) erosion of streambanks and subsequent introduction of sediment into the stream channel due to power peaking operations; 2) stranding of fish and desiccation of benthic organisms due to daily peaking; and 3) release of cold water into the river from the deeper waters of the reservoir, which reduces the growth of riverine fish and invertebrates. SOS 4c attempts to address the erosion and sedimentation problems by providing higher flows periodically in the spring to wash sediments from the streambed. This release of water was conceived, and would be implemented, as a short-term event (less than 1 month). The hydroregulation models could, however, only model this release as a month-long event; therefore, they do not provide sufficient information to assess whether sufficient flows would be released to benefit river habitat under SOS 4c or any other SOS.

The effect of cold-water releases on trout production in the river is not apparent in the modeled results. This is because it was assumed

deep intake. As modeled, SOSs 9b and PA would have slightly lower trout production than other alternatives.

Lake Pend Oreille (Albeni Falls)

Lake Pend Oreille supports substantial fisheries for kokanee, rainbow trout, bull trout, cutthroat trout, and a variety of warm-water species including bass. Populations of kokanee and trout have been declining for 40 years. The decline is thought to be at least partially related to fluctuations in reservoir elevations, which affect spawning success. Unlike other storage reservoirs, Lake Pend Oreille is normally maintained at a relatively constant elevation. The annual fluctuation in water surface elevations ranges from approximately 7 to 12 feet (2.1 to 3.7 m). Nevertheless, spawning success of fish populations can be significantly affected by these fluctuations.

Kokanee that spawn in the reservoir are shore spawners. Drawdown more than 6 to 7 feet (1.8 to 2.1 m) from full pool can force these fish to spawn in sediment-laden gravel when elevations are reduced in September through November. Reservoir drawdowns in

November through May, after the fish have spawned, can also desiccate eggs. Because the trout species prey on young kokanee, declines in kokanee also reduce the feeding success of other resident fish. Variations in water elevation in spring and early summer can also affect the spawning success of warm-water species that spawn in shallow waters (such as bass). In fluctuating waters, the eggs can become desiccated and the young stranded in drying backwater pools. In addition, fall and early winter drawdowns can block access to tributary spawning grounds by river-spawning fish, such as bull trout and overwintering largemouth bass. The long-term decrease in fish abundance in the reservoir may have been further aggravated by the introduction of mysid shrimp, which feed on the same prey as kokanee.

SOS 4c is the only alternative that would substantially improve nearly all of the production categories (Figure 4-11). This alternative reduces drawdown most often to 7 feet (2.1 m) or less most years, with up to an 11-foot (3.4 m) drawdown occurring every sixth year. This would primarily benefit kokanee spawning and egg incubation, and cutthroat, bull trout and warm-water fish production. Because the

kokanee production model was relatively insensitive to improvements in specific model parameters, including spawning and incubation factors, these improvements were included in Figure 4-12 as part of the kokanee production model to demonstrate the area where this alternative is most beneficial to this stock. The benefit to bull trout would be from increased kokanee production, which increases their food supply, and increased stream access for spawning. The warm-water species would benefit from improved spawning success by reducing egg desiccation and stranding. Warm-water species also would benefit from increased access to overwintering habitat. However, if stream access remains limited for bull trout from drawdown from any alternative in the late summer or fall, mitigation would be recommended to modify stream mouths to improve passage. The larger drawdown that would occur about every 6 years with this alternative would reduce the available winter habitat to all age groups of warm-water fish, and reduce spawning success of other species during those years.

The second category of alternatives, including SOSs 9a, 9b, and 9c, result in slight improvements in some resident fish parameters such as bull trout, warm-water fish, and spawning conditions for kokanee over historical conditions and other alternatives. All other alternatives, including SOS PA, result in lower resident fish production levels similar to existing conditions.

Lake Roosevelt (Grand Coulee)

Key fish species in Lake Roosevelt include kokanee, walleye, rainbow trout, and smallmouth bass. Under existing conditions, all fish populations exhibit
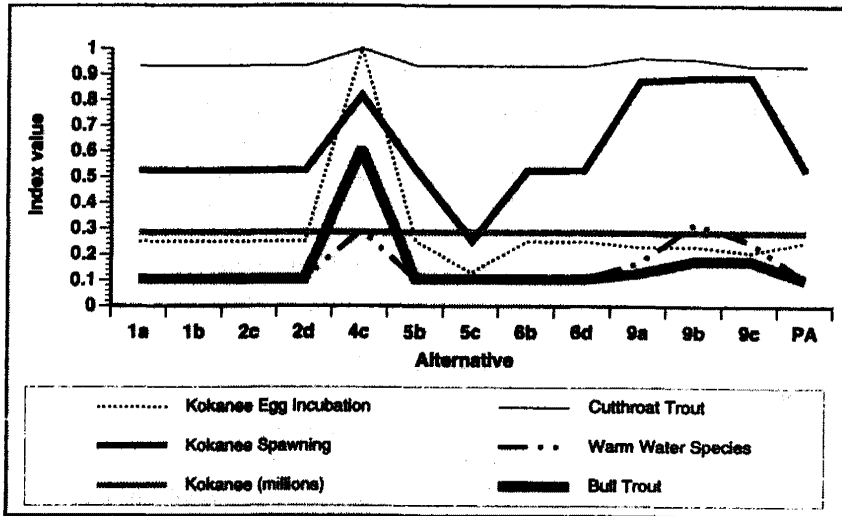

Figure 4-11. Comparison of 2-year index values for fish species in Lake Pend Oreille
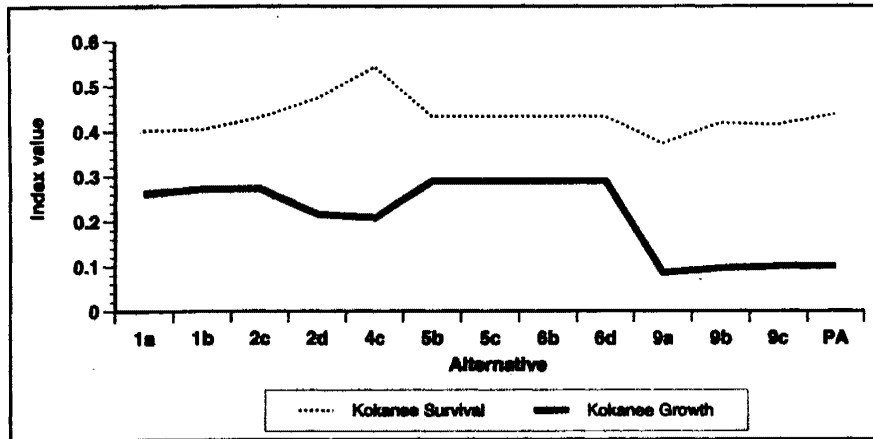
Figure 4-12. Comparison of 2-year index values for kokanee growth and survival in Lake Roosevelt

good growth and have fairly high catch rates relative to other Northwest waters. Fluctuations of the water surface elevation up to 82 feet (25 m), however, limit the natural reproduction of several fish species in the reservoir. During the annual winter-spring drafting, the retention time of water in the reservoir is reduced by 20 to 30 days. Nutrients entering the reservoir are quickly flushed through, becoming unavailable for phytoplankton production. Phytoplankton and zooplankton produced in the reservoir during this period are also flushed from the reservoir.

Typically, when the reservoir elevation and water retention time are high in the spring, zooplankton populations are also high, peaking in late summer. Low spring elevations tend to result in smaller populations of plankton that peak later in the year. Because kokanee, rainbow trout, and the young of other species rely upon zooplankton as a major food source, low spring elevations limit fish growth during the season. A minimum water retention time of 30 to 35 days in spring appears to be critical to reservoir productivity. The production of kokanee and other fish species is further reduced when young are flushed through the dam by drafting.

Spring drafts further affect fish production in the reservoir by reducing spawning success of several species, such as yellow perch (fed upon by walleye) and bass. The lower elevation drawdowns can strand eggs and young in drying shallows, resulting in their death.

The effects of the SOS alternatives were evaluated using a model for kokanee, a plankton feeder, under the assumption that SOSs that provide good conditions for kokanee would also provide good conditions for other fish species. Larger populations of zooplankton were assumed to result in better fish growth. Hence, the index of growth of kokanee was developed using estimates of zooplankton production during the summer growing season. The index of fish survival is related to the numbers of fish entrained during the spring drawdown, when water retention time is low. Figure 4-12 shows the effect of the SOS alternatives on kokanee survival and growth during 2-year flow recurrence intervals. These effects are described below.

Lake Roosevelt would be drafted in spring for extended times under both SOS 1 options, resulting in spring water retention times of less than 30 days in January through May for approximately 90 percent of the years examined. The drawdown would result in moderate levels of index survival during the short-term interval. Modeled zooplankton production, however, suggests low growth in the upper range of alternatives evaluated. In the short- and long-term, entrainment losses are high for SOS 1.

SOSs 2c and 2d would have very similar water retention times and spring drawdowns. Generally, these SOSs were estimated to have water retention times of less than 30 days for

January to May in 80 percent of the years examined. The short-term entrainment survival index particularly for SOS 2d is better than that under SOS 1, reflecting the somewhat improved water retention time. The long-term survival values are reduced from short term but SOS 2d remains one of the highest of all alternatives. The growth index is similar to SOS 1 for SOSs 2c and 2d. The short-term growth index for SOS 2d is reduced, probably reflecting the lower water surface elevation for some years compared to SOSs 1 and 2c.

SOS 4c would provide for improved water retention times that reduce entrainment of fish, but not zooplankton, during the short term. Hence, the entrainment survival index value is very high for this SOS, and the growth index value is moderately low compared to other SOSs. During infrequent (once every 10 years) flow events, survival and growth would be reduced because of sporadic increases of entrainment and lost zooplankton.

At Grand Coulee, operations under SOS 5 or 6 would be very similar to those under SOS 2c. As a result, the index values calculated for these SOSs are very close or identical to those described for SOS 2c.

Under SOS 9a increased flushing and low reservoir elevation during winter and the growing season would result in the lowest survival and growth in the short term. In the long term, like other alternatives, these index values decrease and this alternative consistently would have the lowest survival and growth of kokanee of any alternative.

SOSs 9b and 9c are similar but would be slightly improved over SOS 9a in the short term. SOS 9a would have survival in the lower range of alternatives and much lower growth than others. The lower growth is the result of increased spring flushing.

SOS PA is very similar to SOSs 9b and 9c in the short term but would have slightly higher survival. Over the long term, this alternative would experience decreases in growth and

survival, but survival would become higher than any other alternative possibly because of fewer low-water conditions during the winter.

Generally, during infrequent flow years survival and growth of kokanee would be lower, and differences among alternatives would be slight except for SOS 9a, which is much lower.

SOSs 2d and 4c would provide the best protection against kokanee entrainment losses. The best growth is achieved under SOSs 1b, 2c, 5, and 6. Fish production conditions would be worst under SOS 9a, considering growth and environment.

SOS PA would provide moderate protection against fish entrainment for the short term and the best protection under infrequent flow conditions. Kokanee growth, as measured by zooplankton production, would be one of the lowest under all conditions.

Brownlee Reservoir

Key sportfish species in Brownlee Reservoir include crappie, channel catfish, smallmouth bass, and rainbow trout. These species were all included in the model used for impact analysis. The model evaluated food production in the reservoir and changes in water surface elevation that could affect fish spawning and egg development.

Brownlee elevations and outflow would change little among SOSs 1, 2, 4, 5, and 6 but more so for SOSs 9 and PA (Figure 4-13). Hence, the model predicts that food production, spawning success, and overall fish production vary little among most alternatives, except SOSs 9 and PA. The alternatives were much lower in overall production values. Production parameters were generally good for rainbow and channel catfish under most alternatives, but moderate to low for smallmouth bass and crappie. SOS 4c would have slightly higher production values for smallmouth bass and crappie than other alternatives probably because of reduced reservoir drawdown during spring spawning periods of these warm-water species.
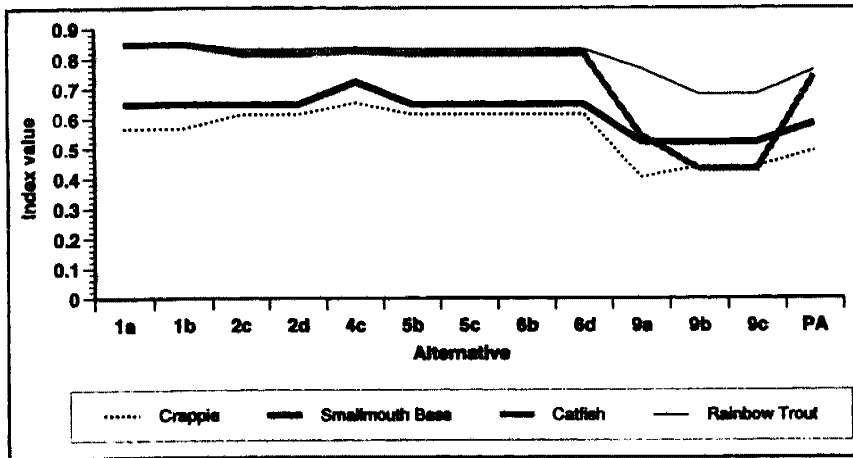
Figure 4-13. Comparison of 2-year index values for fish species in Brownlee Reservoir under the various alternatives

feet (47 m) in fall and winter, which reduces the surface area as much as 50 percent. Water retention time averages 10.2 months and ranges from 6 to 22 months. Primary sport species in the reservoir include kokanee, rainbow trout, cutthroat trout, bull trout, and smallmouth bass. Redside shiners are preyed upon by several fish species.

Cutthroat trout and bull trout spawn in the fall in tributaries to the reservoir. The fish model used to predict the effects of the SOSs on trout in the reservoir assumes that fish production is related to food production in the reservoir.

Channel catfish would fare better because reservoir fluctuations would be reduced in the summer when this species spawns. SOS 1 would have slightly higher overall production of rainbow trout and channel catfish than the other alternatives because more stable summer reservoir conditions. But, SOS 1 would experience slightly lower smallmouth bass and crappie production than SOS 4c. SOSs 2, 5 and 6 were near the highest production index levels of all alternatives.

SOSs 9 and PA had much lower overall production for most fish indexes species because of greater water level fluctuations during warm-water species' spawning periods. Of these SOSs 9b and 9c had the lowest values for all but crappie, which was lowest for 9a. SOS PA was the best of this group for all four stocks and only slightly worse than the current conditions for rainbow trout and channel catfish. The low values under SOS PA for crappie and smallmouth bass is probably because of the higher spring water level fluctuations.

Dworshak Reservoir

Dworshak Reservoir is a deep, relatively unproductive reservoir with a steep-sided shoreline. It has a maximum depth of about 636 feet (194 m) and is typically drafted up to 155

Shallow-water spawning habitat for smallmouth bass is limited in the reservoir, but the bass population appears to be healthy and growing. Spawning success of bass can be affected by decreases in pool elevation, potentially causing dewatering of nests from mid-May through mid-August. Increases in elevation can expose eggs to cold waters, causing fish to abandon nests or interrupting egg development. The model used in the evaluations estimated spawning success as it is affected by changes in reservoir elevation as well as food production (both plankton and shiners).

Kokanee mortality rates in the reservoir appear to be near 80 percent. Entrainment of fish through the dam may be at least partially responsible for this high mortality rate. Initial studies suggest that large numbers of fish are entrained with releases greater than 8 kcfs (240 cms). Low water levels may also limit access to spawning grounds in tributaries by kokanee. The kokanee model incorporates factors for entrainment, tributary access, food availability, fishing mortality, and adult habitat availability.

Both SOS 1 options would provide relatively good conditions for kokanee. SOS 1b would have slightly better conditions than SOS 1a, likely due to differences in entrainment rates. Predicted index values for bass and trout are slightly lower than the highest SOSs, with SOS 1b being better than SOS 1a. The lower values are likely due to limited food production compared to some of the other SOSs, and to increasing pool levels in June, which can interfere with egg development of the bass. Drawdown under this SOS inhibits shallow-water plant growth and inhibits spawning of redside shiner, a forage fish.

Reservoir drafts under SOS 2c are not as great as under SOS 1, but are greater under SOS 2d. Fluctuations in elevation and discharge occur more frequently under SOS 2d compared to SOS 2c. Deep drafts in excess of 100 feet (30.5 m) can be expected in wet and moderately wet years but are not as deep in normal to dry years. The pool would fail to refill in most years. Monthly discharge would be substantially increased in the summer. Increased flows would result in increased entrainment of kokanee and higher than SOS 1, potentially driving the population to such low levels that it could not rebound. Failure to refill the reservoir would reduce adult habitat and access to tributaries for spawning. Reproduction of bass might be affected by interruption of spawning due to inundation by cold water in June and dewatering of nests in July with SOS 2d having some of the lowest index levels of all SOS alternatives. Trout production under SOS 2 is predicted to be markedly lower than under SOS 1 because of the reduced food production. SOS 2d has one of the lowest trout production index values of all alternatives.

SOS 4c would generally provide excellent conditions for all fish species in the reservoir. Full-pool elevations during the summer rearing and spawning months would be expected in virtually all years under SOS 4c. The high pool would provide access to all spawning areas, and protect bass and shiner spawning and egg development. Zooplankton production would be enhanced. Because of high flows out of the

reservoir, fish entrainment would be fairly high in most years and very high during wet years. This entrainment occurs more with SOS 1 but less than SOS 2.

SOS 4c has the highest smallmouth bass production of any alternative because the relatively stable spring and summer water levels increased the spawning success of smallmouth bass and redside shiner and increase overall food production.

Dworshak would typically fill in July under SOS 5. The reservoir would remain near full through August during wet years. In normal to dry years, however, pool elevations would be expected to decline during the summer. Predicted trout, kokanee, and smallmouth bass production is similar to (although slightly lower for most than) levels described for SOS 4c.

Fish production under SOS 6 would be very similar to that described for SOS 5. Food production would be somewhat better under SOS 6 than under SOS 5b but worse than 5c.

Moderate-to-deep drafting and moderate-to-high outflow would occur under SOS 9. Drafting under SOSs 9a and 9c is similar to SOS 2, but drafting under SOS 9b is higher. Mid- to late summer drawdown occurs for all SOS 9 options but is especially pronounced with SOS 9b, which is drafted deeper than SOS 9a or 9c to augment flows in the Snake River. SOS 9b is also less often refilled than SOS 9a or 9c.

SOS 9 is one of the worst alternatives for all fish stocks, with SOS 9b being the lowest of the three for all indexes. The food production index, which is a measure of bull and cutthroat trout production, is the lowest under SOS 9b. Probable high entrainment and reduced food production cause very low kokanee production, similar to SOS 2. Changing spring water levels and summer drawdown cause smallmouth bass production to be very low, similar to levels of the lowest alternatives.

SOS PA would have severe drawdown in the summer, up to 80 feet (24.4 m) below full pool

by the end of August. SOS PA would often result in pool levels of 80 to 120 feet (24.4 to 36.6 m) below full pool. The reservoir often would not completely refill. High outflow would also occur often during flow augmentation in the summer. This alternative would result in severe impacts to all species of resident fish in Dworshak Reservoir. The kokanee production index would be by far the lowest because of the increased entrainment, drawdown, and reduced food production. This alternative also would be one of the worst for smallmouth bass and trout. The increasing pool level in June would be detrimental to smallmouth spawning, and summer drawdown and high outflow would adversely affect both smallmouth bass and trout production by reducing food supply.

The long-term effect would be to keep production low within the system for all stocks.

Overall, SOSs 4c, 5c, and 6 are predicted to provide similarly high fish production in Dworshak Reservoir (Figure 4-14). Fish production would be worse under SOSs 2, 9, or PA.

Lower Granite Reservoir

Lower Granite is a run-of-river project that normally has water surface elevation fluctuations in the range of 5 feet (1.5 m). In recent years, however, the reservoir has been operated near MOP during the spring and summer to enhance outmigration of juvenile salmon. Key resident fish species in the reservoir are smallmouth bass, white sturgeon, and northern squawfish. All three species can be affected by changes in reservoir elevation, which can have substantial effects on spawning and rearing areas in the reservoir. The resident

fish model incorporated estimates of the amount of suitable habitat available. In Lower Granite Reservoir, within-month variations in water elevation can have as much or more effect on rearing success as variations from month to month. Hence, the effects of the SOSs were evaluated assuming a range of within-month variations in water elevation. These effects are shown in Figure 4-15 and described below.

Under SOSs 1a and 1b, Lower Granite operations would reflect water level fluctuations within the normal range, from minimum pool of elevation 733 feet (223 m) to full pool at elevation 738 feet (225 m). Effects on resident fish habitat would depend upon daily and weekly cycling of the project and the resulting within-month variations in water elevation. The greater the within-month pool fluctuations, the greater the impacts.

SOSs 1a and 1b would have some of the highest index values for squawfish and sturgeon, and some of the lowest values for smallmouth bass. The higher values for sturgeon would result from more deep-water habitat. Squawfish would benefit from reservoir levels remaining higher, which would provide more suitable habitat than other alternatives. However, the sturgeon model does not consider the essential need for high-velocity water for spawning.
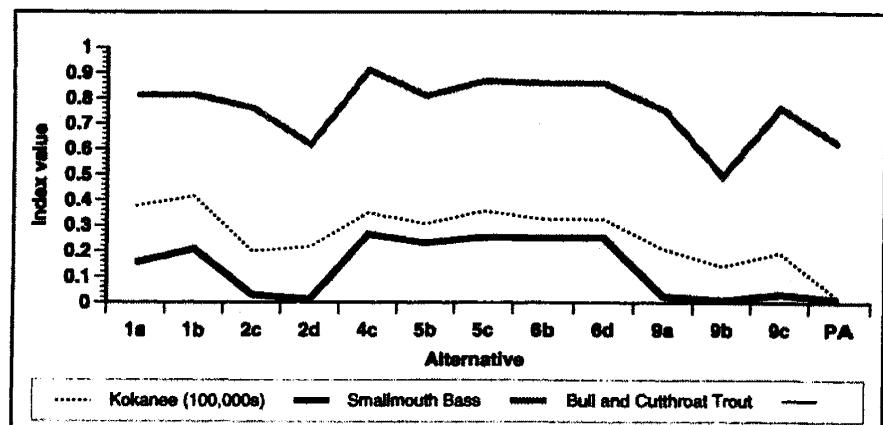

Figure 4-14. Comparison of 2-year index values for fish species in Dworshak Reservoir
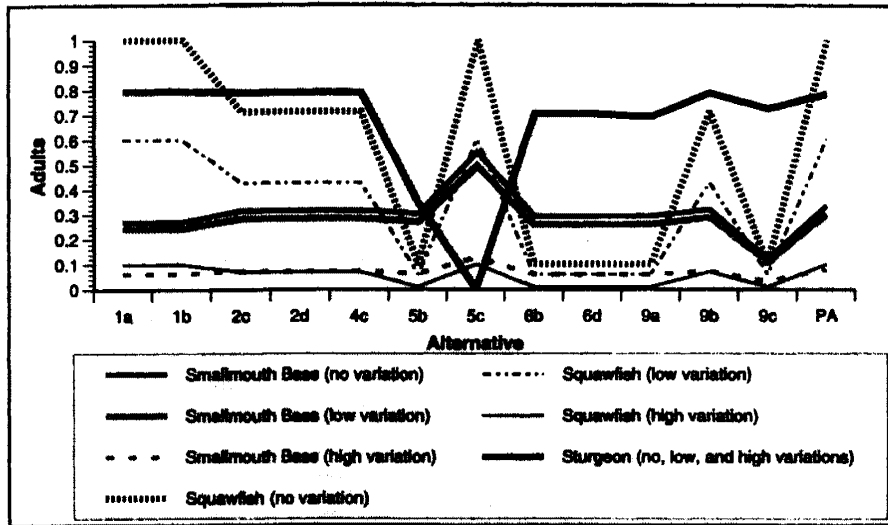
Figure 4-15. Comparison of 2-year index values for fish species at
Lower Granite Reservoir

SOS 5b or 5c would result in the most significant changes in operations and fish production compared to current conditions. Under this alternative, Lower Granite would be drawn down by approximately 95 to 115 feet (29 to 35 m) to the original riverbed level by mid-April the first year. SOS 5b would maintain the low elevation through August, refilling in September each year, and this repeat of drawdown and refill would occur annually. The pool elevation could fluctuate up to 5 feet (1.5 m) during the drawdown period. SOS 5c would remain at the river bed level year-round with only natural river level fluctuations occurring.

Water surface elevations under SOS 2 would be held within 1 foot (0.3 m) above MOP (733 feet [233 m]) in spring and summer, returning to normal elevations, as under SOS 1, during the rest of the year. The model indicates that smallmouth bass habitat would benefit from SOS 2. The slight decrease in water elevation under SOS 2 would normally be expected to decrease smallmouth bass habitat somewhat compared to SOS 1. Conversely, stabilized pool elevations would tend to ensure that spawning would occur in areas that are submerged throughout incubation. The net result would be a slight increase in smallmouth bass habitat over SOS 1. Sturgeon index values would remain high because deep-water habitat would remain unchanged, while squawfish habitat would be substantially reduced because of slight elevation fluctuations compared to SOS 1. The overall index values would be about mid-range of all alternatives evaluated.

Operations and water surface elevations under SOS 4c would be identical to those for SOS 2. Resident fish habitat conditions would consequently also be identical under all of these SOSs.

SOS 5b would provide stable water levels during the egg development period that should be favorable to bass, with index values only slightly lower than SOS 2 or 4c. SOS 5c would result in stable smallmouth bass spawning and rearing habitat year-round, providing the best habitat of any SOS alternative. The resulting river environment is likely to improve both food supply and egg incubation. Assuming moderate fluctuations in reservoir level in the summer, SOS 5 would not appear to be good for northern squawfish because of degradation to fry rearing habitat. However, reduced reservoir elevations might provide an increase potential spawning habitat by providing additional high-velocity spawning areas, which are preferred by squawfish.

SOS 5c apparently would result in excellent conditions for northern squawfish because of the permanent establishment of high velocity habitat for spawning, resulting in the highest index

values. SOS 5, particularly SOS 5c, apparently would provide poor rearing habitat for sturgeon because of reduced deep-water habitat. The important high-velocity spawning habitat, which would be substantially increased with SOS 5, is not included in this model.

SOSs 6b and 6d include 4.5-month Lower Granite drawdowns that would be similar to SOS 5b. Under SOS 6, the depth of drawdown would be 33 feet (10 m), much less than under SOS 5. Because timing of drawdown and not depth would be the controlling factor, the effects of these SOSs would be likewise similar to SOS 5b.

SOSs 9a, 9b, and 9c as a group have divergent effects on resident fish production. SOS 9a and 9c both have drawdown of 33 feet (10 m), similar to SOS 6, but 9a is for 4.5 months and 9c for only 2 months. The result is some of the lowest production index values, especially for 9c, for northern squawfish and smallmouth bass. The longer drawdown period of SOS 9a allows for less habitat disruption, enabling smallmouth bass habitat to remain fairly stable and having moderate levels of production similar to SOSs 5b and 6. SOS 9c, with its mid-summer refill, disrupts fry rearing habitat, causing the lowest production index of any alternative for smallmouth bass. SOSs 9a and 9c are both poor for northern squawfish habitat, which is reduced because of the drawdown. These SOSs would be similar to SOSs 5b and 6. The reservoir level for SOS 9b is operated similar to SOS 2, with Lower Granite near MOP during the spring and summer. The result is higher smallmouth bass and northern squawfish index values than SOSs 9a and 9c because of the more stable water level and greater amount of suitable habitat, similar to SOS 2. Sturgeon habitat is only slightly reduced for SOS 9a and 9c because of reduced deep-water habitat, while SOS 9b is near the highest index value. The fluctuating water levels under SOSs 9a and 9c would likely have greater adverse effects than indicated in the model for sturgeon. The spill under SOSs 9b and 9c would likely increase

nitrogen saturation that would be adverse to resident fish. This effect was not included in the models.

SOS PA would have reservoir levels operating similar to SOSs 2 and 9b, near MOP during the spring and summer and high summer spill similar to SOSs 9b and 9c. The index values for resident fish are in the upper range of those evaluated for all three stocks. The relatively stable reservoir level without large drawdown is apparently beneficial to northern squawfish and would have the highest values of all alternatives. Smallmouth bass would also have relatively high levels because of stable reservoir levels during spring spawning and summer rearing being similar to SOS 2 and 9b. White sturgeon index values would also remain high because deep-water habitat remains high. The important high-velocity spawning habitat is not included in the sturgeon model; this habitat would change little from current conditions. As with SOS 9, the high summer spill under SOS PA could be detrimental to resident fish from increased gas saturation levels that at times could be lethal to resident fish.

Deep-water habitat for sturgeon would not be significantly affected by any of the SOSs, except for SOSs 5b and 5c. Under these options, drawdown to natural river levels would reduce the amount of deep-water habitat. The model does not address the effects of flow on spawning of sturgeon. SOSs that substantially increase reservoir velocity during the April and July spawning period (primarily SOSs 5, 6, and 9c) might benefit sturgeon populations in the reservoir by improving spawning conditions. As discussed above, sturgeon-rearing habitat would decrease under SOS 5. Whether the benefit of increased flows on spawning success would be offset by reduced rearing area in the reservoirs is unknown.

Overall, SOS 9c would be the worst alternative for resident fish resources in Lower Granite Reservoir. SOSs 5b, 6b, 6d, and 9a are also expected to produce poor conditions for fish. All other SOSs would likely provide relatively good conditions for fish production.