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Walla Walla District

Columbia River Salmon Mitigation Analysis System Configuration Study Phase I

Biological Plan--Lower Snake River Drawdown Technical Report

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Prepared in Response to
Northwest Power Planning Council
Columbia Fish and Wildlife Program

February 1995

Executive Summary

This document outlines what is know about the biological environment of fish migrating through the Snake River system and analyzes the potential impacts/benefits to anadromous juvenile and adult salmonids, resident fish, wildlife, terrestrial resources, and other ecosystem components from the drawdown of Snake River reservoirs to below minimum operating pools. The Plan include a summary of existing data and control conditions, as well as data generated during experimental testing of drawdown. The Plan also includes a brief description of other, non-drawdown alternatives (*i.e.*, upstream storage, collection and transportation of anadromous fish, and completion of existing system improvements) and a discussion of the potential impacts of these alternatives to biological resources. Although the Plan does not recommend any alternative, it recommends making a biologically driven decision on the issue of drawdown in the face of uncertainties.

Drawdown is one of four major alternatives described in this document. The objective of drawdown is to lower pool elevations, increase river velocities through the lower Snake River, and reduce travel time of smolts through the river system to the ocean. Each drawdown option will require modifications to the dam or spillways, existing facility operations, adult fish passage facilities and, with the exception of the natural river option, new juvenile fish bypass facilities. Current fish barging operations on the lower Snake River would cease during drawdown. Also, because hydraulic capacities would be reduced under drawdown conditions, hydropower production would also be reduced. Five types of alternatives that could be maintained once drawdown is achieved include: 1) natural river option; 2) variable pool with existing powerhouse; 3) variable pool with modified powerhouse operation; 4)constant pool with existing powerhouse operation; and 5) constant pool with modified powerhouse operation. Variations of these five general groups are described in the plan, and include nine drawdown options.

Several impacts to physical conditions in lower Snake River reservoirs will occur during drawdown. Under each drawdown scenario, water transport times decrease markedly, with the greatest increase in transport time achieved under the Natural River Option. In all cases, reservoir surface area and volume decrease with lowered surface elevation. Also, although there is little change in the relative proportion of low-velocity (lentic) habitat among the different alternatives (with the exception of the Natural River Option), the amount of free-flowing or lotic habitat relative to the total varies with discharge. One of the most significant adverse impacts of reservoir drawdown is dissolved gas supersaturation from increased spilling. Spilling potentially impacts resident and anadromous fish populations that reside downstream of the projects, including early life stages of fall chinook salmon. Increased turbidity and suspended solids resulting from drawdown could impact fish and other aquatic life by reducing primary and secondary production, and nutrient flow. However, the relative magnitude of change and net effects of alterations in water quality that result from drawdown operations remain uncertain.

Operation of Snake River reservoirs under the various drawdown scenarios can be expected to have potentially significant impacts on anadromous fish. These impacts may be expected to be both beneficial (positive) and detrimental (negative), although the magnitude of the impacts of specific factors (and even whether they will positively or negatively impact anadromous fish) has not been precisely defined. For example, while it is generally agreed by three modeling teams that drawdown will positively impact juvenile salmonids by decreasing travel times, and accordingly decreasing reservoir predation, the quantitative magnitude of that effect is disputed. The magnitude of another intended benefit of drawdown scenarios, an increase in the fraction of fish passed through spills, is also disputed. In the Natural River Option case, however, effective bypass of the dam by downstream migrants and decreases in dam mortality rates are agreed upon as being significantly beneficial. Some perceived negative impacts to anadromous fish include possible stranding of smolts during the initial drafting period, a higher percentage of fish passing through the turbines after having been forced to lower depths by the decrease in forebay water level, the concentration of existing predators within a smaller volume of water, and increase in difficulty for upstream migrant adult salmonids returning to their spawning grounds.

In general, increased migration rate (*i.e.*, decreased travel time) is expected to increase survival of smolts through the reservoir environment mainly because of the potential for decreased contact with predators. However, if overall smolt survival is to be increased, passage mortality by other mechanisms must not be increased from current levels. Thus, smolt mortality during each route of dam passage (*i.e.*, bypass, turbine, and spill mortality) must not increase markedly during drawdown. Intuitively, the Natural River Option would: 1) decrease travel time; and 2) would decrease mortality from dam passage. The other drawdown alternatives may give rise to offsetting factors (including loss of transportation, increased gas supersaturation, decreased fish guidance efficiency, increased turbine mortality, decreased food and habitat availability, and negative impacts o adult migration) which could cause the overall benefit to salmonid species to be open to question. Models that assume these offsetting factors to be negligible, and that predict low smolt survival rates under current conditions, predict significant positive benefits under drawdown scenarios. Models that directly incorporate some of these offsetting factors, and that predict relatively higher survival under current conditions, lead to diminished estimates of drawdown benefits and, in some cases, even overall negative impacts.

Potential impacts of drawdown to resident fish will vary according to fish species and operating strategy. Resident fish species that use shallow-water habitat for spawning, rearing, and adult feeding will be affected by reservoir drawdown. Shallow-water habitat is deemed important rearing habitat for smallmouth bass, northern squawfish, channel catfish, yearling chinook and steelhead, as well as 0-age chinook. The substrate quality, or lack thereof, will be the limiting factor as to whether juvenile fish will utilize "new" shallow habitat uncovered by drawdown. It is likely that much of this shallow-water habitat has silt deposited from upstream areas. Thus, its value for spawning and/or rearing would be reduced. Native species such as white sturgeon and northern squawfish that prefer more lotic environments could benefit from the increased flowing water habitat provided during drawdown.

The impact of drawdown alternatives on wildlife resources will be determined by both the timing and duration of drawdown and the extent of construction-related activities. Effects of inundation, dewatering, land bridging, and reduced capacity for irrigation will impart the most significant effects on populations. Additionally, loss or conversion of entire compliments of species by replacement may occur if aggressive competitors and noxious species become established in shoreline areas that are dewatered during drawdown.

The cumulative impact to aquatic production was also considered. Drawdown of lower Snake River reservoirs may impact smolt-to-smolt survival through alterations to food web components of the ecosystem. Periphyton or attached algae and macrophyte beds will be adversely impacted during drawdown. Their ability to reestablish will depend on the length of the drawdown and availability of suitable substrate. Dewatering of nearshore areas would severely impact littoral and benthic zooplankton, and densities would further decrease if the zooplankton are entrained during drawdown. Impacts to benthic invertebrates will depend on the length of the drawdown and operational surface level. Substantial loss of benthos that inhabit riprap will occur. Large invertebrates, including crayfish and molluscs, will be desiccated unless they can reach suitable habitat. Juvenile fish will be more vulnerable to predation during drawdown because of higher densities of predators, decreased shallow-water habitat, and the potential for prey switching.

The second major alternative discussed in the Plan is upstream storage. The objective of this alternative is to augment flows on the Snake and Columbia Rivers to facilitate spring migration of juvenile salmon and steelhead. Flow augmentation would be accomplished by modifying the operation of Dworshak Dam on the North Fork of the Clearwater River and Brownlee Dam on the Snake River. This action is intended to increase water velocities and subsequently increase the survival of juvenile fish by decreasing the time to complete outward migration. A total of 414 on- and offstream potential upstream storage sites were evaluated for suitability to augment lower Snake River flows. A detailed description of the Galloway site in the Weiser River Basin is given in the text to provide additional background on all aspects of site consideration. In general, impacts to water, land, and wildlife are expected to occur through changes in water quality, and inundation of vegetation, wildlife, and cultural resources through filling of reservoirs.

The third major alternative for increasing juvenile salmonid survival is anadromous fish collection and transport. Upstream collection facility and migratory canal construction are two possible alternatives. These methods are meant to remove fish from the system and thus eliminate the hazards of slow-moving water in reservoirs and dam passage.

A new collection system upstream of Lower Granite Dam is expected to improve upon current juvenile fish collection systems and reduce fish mortality resulting from passage through hydropower turbines and migration delay in reservoirs. Juvenile fish would be collected, transported, and then released in the Columbia River at locations downstream of Bonneville Dam. Two general options for the collection of juvenile salmonids are being considered. The first option would collect juveniles at a large screen system in a low-velocity area located about 7 miles downstream of the confluence of the Snake and Clearwater Rivers. The second option would collect fish upstream of Lower Granite Reservoir in the free-flowing portions of the Snake and Clearwater Rivers. These structures would be designed to withstand greater flow velocities than the reservoirs site. Operation of the fish conveyance system is anticipated to be seasonal, with full operation occurring from March through October of each year.

Possible means for conveying fish downstream from headwaters or from the upstream end of the reservoir system to below the last dam include transport vessels (similar to the trucks and barges currently in use for this purpose), a migratory canal, and a pipeline system. A migratory canal would consist of a channel, where fish would travel downstream, and of resting ponds, placed at 10-mile intervals where fish could rest and feed. Collection facilities feeding into the canal would be placed at the screening bypass systems of the dams and at an upstream site on the Snake or Clearwater River or at the Silcott facility. The pipeline, very similar to an open canal, would consist of steel or concrete pipe sections. Open-air resting ponds would still be provided at 10-mile intervals.

Both upstream collector facilities and migratory canal alternatives present many unproved technological ideas. As an example, while current approach-velocity criteria were used in the initial design of collection facilities, these criteria were established for much smaller screening devices with short exposure times for fish and may be unsuitable for designing new facilities. Thus, if the upstream collector is to be considered further, design concepts addressing these concerns would need to be developed. Another drawback of the upstream collection alternative is that fall chinook salmon could be collected before they are physiologically ready for migration from the Lower Granite Reservoir rearing area. Collection screens may also impact resident fish by restricting fish movement, causing impingement and possible mortality during collection and transport of salmonids.

Different impacts are associated with each of the proposed sites for upstream collection and transportation. Impacts from a migratory canal would include, among other things, the replacement of existing natural habitat along the river with manmade structures, destruction of some wetland habitat, some degradation of water quality during canal construction, and the creation of a transportation corridor for invasive plant species. Also, disturbance from human activity along the canal would likely increase, reducing wildlife value.

The final alternative discussed in the plan is to complete existing system improvements. Various improvements have been proposed to increase adult returns to the Snake River. These proposals include modifications to fish hatchery operations, juvenile collection and bypass systems, juvenile transportation, adult passage systems, and dam operations. Details of these plans and their expected impacts for individual dam facilities are discussed in the body of the report.

The objective, heretofore described as increased smolt survival, has an unknown relationship to the long-term fitness, reproductive success, and genetic integrity of the Snake River salmonids. Therefore, the objective for any strategy related to the management of the Snake River should instead be described as increased adult returns, not smolt survival. In addition, the specific strategy and reasonable alternatives need to be better defined. Currently, there is some confusion as to the "preferred" strategy. There are five classes of alternatives that describe or define drawdown and a total of nine specific alternatives, each requiring modification to the dams or spillways, existing facility operations, and adult passage facilities. All alternatives, with the exception of the "natural river" option, will require new lower-level juvenile fish bypass facilities and modulated operations and structures for adult passage. Specific drawdown strategies and alternatives, including barging, surface condition, flow augmentation, and artificial production, must be better defined.

Some of the uncertainties associated with assumptions underlying drawdown strategies will involve selecting a strategy while accepting a degree of risk that could result in not meeting the stated objective and even lead to the extinction of the target species. Tasks should be initiated to resolve the following uncertainties: 1) relationship between smolt survival and adult returns; 2) correlation between migration timing and ocean survival for smolts; 3) correlation between water velocity and smolt survival; 4) relative survival of hatchery and wild fish during outmigration; 5) methods for estimating smolt survival during outmigration; 6) relationship between drawdown and smolt behavior; 7) potential effects of gas bubble trauma on smolts during outmigration; 8) potential effects of drawdown on bubble trauma on smolts during outmigration; and 9) potential facility and operational changes at the dams (bypass, turbine, fish guidance, *etc.*) that will adversely affect smolt survival.

Without a quantitative objective, the benefits and risks of drawdown cannot be monitored or evaluated. Thus, future decision makers will not be able to balance benefits and risks if drawdown is selected at this time. A successful plan will require regular evaluation of benefits and risks. Only when benefits outweigh risks will it make sense to continue the selected strategy.

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I. Introduction and Background

Fisheries managers in the Pacific Northwest are currently expanding the investigation of options to increase survival of juvenile salmonids in the Columbia River Basin. These options are necessary to address concerns about depressed populations of anadromous salmonids, especially Snake River stocks listed as threatened or endangered under the Endangered Species Act (ESA). Survival options considered for the Snake River salmon include various reservoir drawdown and non-drawdown alternatives, such as system improvements (including bypass, transportation, hatchery, and dam), upstream juvenile fish collection and transports, upstream water storage, and a migratory canal or pipeline.

Several related efforts, directed at protecting and enhancing existing fisheries resources, are ongoing in the Columbia River Basin. The System Operation Review (SOR) is being conducted by the U.S. Army Corps of Engineers (COE), the U.S. Bureau of Reclamation (BOR), and the Bonneville Power Administration (BPA) to analyze the environmental impacts of changes in the Columbia River System operations. The SOR concentrates on 14 Federal hydroelectric projects, five storage dams, and nine run-of-river dams, as well as three Canadian dams.

Ideas for improving conditions at the Federal dams and reservoirs along the Columbia and Snake Rivers are also being evaluated through the COE's System Configuration Study (SCS). The study examines improvements designed to enhance the survival of anadromous fish. These improvements include changes to existing fish passage systems on the lower Snake River projects, the juvenile fish transportation program, and existing Corps-constructed fish hatcheries serving the lower Snake River, as well as modifications to the lower Snake and lower Columbia River dams. Drawdown is one of several reconfiguration options being considered under the SCS. Broader comparisons among drawdown alternatives and other options considered for the Snake River will be made through full-scale analysis of operating strategies and impacts in the SOR Environmental Impact Statement, the 1995 to 1998 Federal Columbia River Power System Biological Opinion drafted by the National Marine Fisheries Service (NMFS), and accompanying Record of Decision by the COE.

A regional team, comprised of academics and private consultants, known as the Snake River Salmon Recovery Team, analyzed specific issues relating to the status of stocks listed under the ESA, and provided recommendations. The NMFS considered these recommendations in drafting their Recovery Plan, including recovery goals and delisting criteria, protection and restoration of habitat, artificial propagation programs, and natural production and augmentation.

Additionally, the Northwest Power Planning Council has requested that BPA, COE, and BOR establish a committee to coordinate analyses conducted by the Federal agencies (COE, BPA, BOR, NMFS, U.S. Fish and Wildlife Service) and to oversee development of a series of plans that address Snake River drawdown. The primary role of this interagency committee is to assess benefits and impacts to the Snake River environment, with and without drawdown, by developing an Operations Plan, Design Plan, Mitigation Plan, and Biological Plan.

This Phase I Biological Plan (this document) outlines what is known about the biological environment of fish migrating through the Snake River system, and analyzes the potential impacts/benefits to anadromous juvenile and adult salmonids, resident fish, wildlife, terrestrial resources, and other pools. The Plan includes a summary of existing data and control conditions, as well as data generated during experimental testing of drawdown. Additional testing of biological drawdown (COE and NMFS, 1994), originally scheduled as early as 1995, is being reviewed, pending further analysis of specific alternatives, and with a revised test design. Although the Plan does not recommend any alternative, it provides biological assessments, both qualitative and quantitative, and recommendations for making a biologically-driven decision on the issue of drawdown in the face of uncertainties.

The Plan also includes, where possible, a brief description of other, non-drawdown alternatives (*i.e.*, upstream storage, upstream collection facilities, bypass system improvements, migratory canal, and continuation of existing operations), and a discussion of the potential impacts of these alternatives to biological resources. The first section of this report briefly summarizes the status of existing anadromous fish stocks in the lower Snake River, discusses factors causing their decline from historical levels, and presents background on the proposed mitigation measures.

A. Status of Anadromous Fish Stocks

Snake River salmonids that migrate past mainstem hydroelectric dams on their way to the ocean (figure 1-1) include spring, summer, and fall chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), and steelhead trout (*O. mykiss*). Before non-native Americans developed the region, annual runs of anadromous fish to the Columbia River were estimated to be 8 to 16 million fish (COE, 1994a, SEIS). Currently, 2 to 2.5 million fish (mostly hatchery fish) return to the Columbia River system to spawn, approximately 20% of the original runs. Despite greatly increased releases of juvenile salmonids from hatcheries, runs of chinook salmon and steelhead returning to the Snake River have been declining since the late 1960's (Collins *et al.*, 1975). Coho salmon (*O. kisutch*) populations historically occurred in the Snake River, but are now extinct. In December 1991, the Snake River sockeye salmon was listed as endangered; and the Snake River spring, summer, and fall chinook salmon were listed as threatened under the ESA in May 1992. I December 1994, NMFS made a proposed emergency rule that the Snake River fall chinook salmon be reclassified to endangered under the ESA.

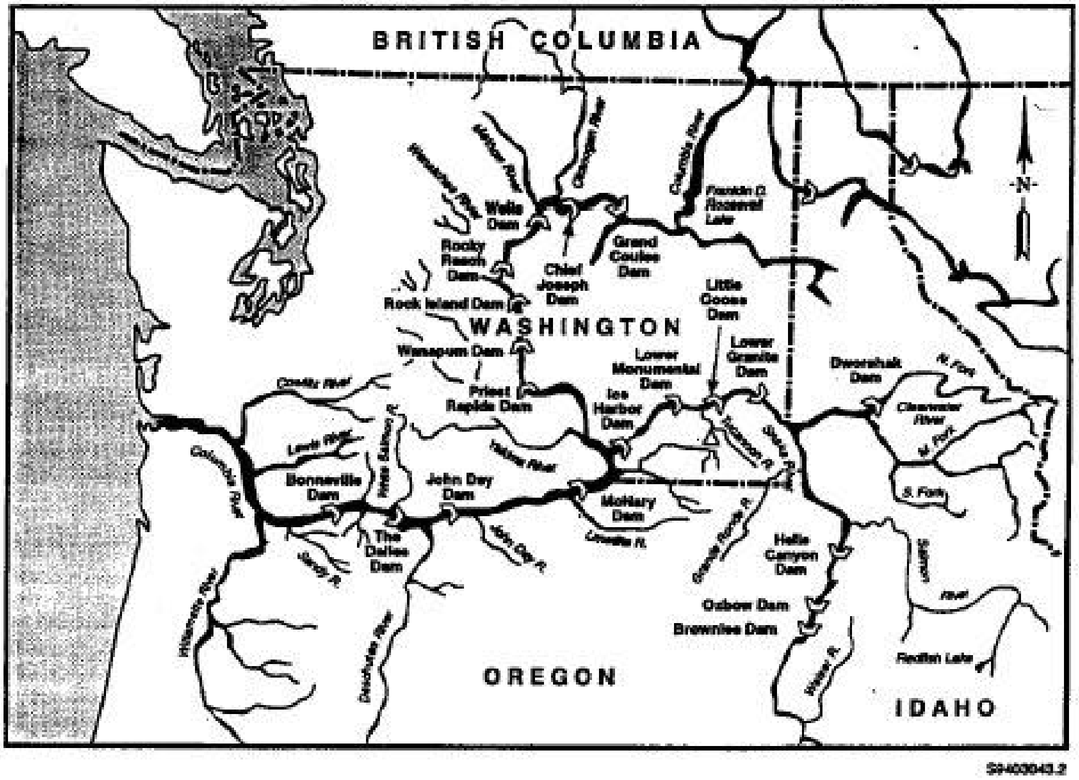

Figure 1-1. Dam locations in the Columbia River drainage basin

The population decline of adult fish returning from the ocean to their freshwater spawning grounds paralleled the development of dams, irrigation direction, livestock grazing, mining, municipal and industrial development, and overfishing of the salmon and steelhead runs. By 1938, when Bonneville Dam was completed, the returning steelhead and salmon spawning run had fallen to 5 to 6 million fish, mainly as a result of overfishing and the effects of upstream activities that blocked spawning access or degraded habitat. Of the total present run of about 2.5 million fish, including known fish harvested in the ocean, about 0.5 million of these are wild fish. In 1990, 1.2 million salmon and steelhead entered the Columbia River (excluding ocean harvest); about 0.3 million of these were wild fish (WDF/ODFW, 1992).

B. Summary of Factors Causing Decline

In conjunction with the direct effects of hydroelectric dam operation, factors such as habitat loss and degradation, poor harvest management, water-quality degradation, low river flow, and interactions between hatchery and wild fish, also have played a role in the decline of Snake River salmon (figure 1-2). Many of these factors were in effect prior to construction of hydroelectric facilities in the Columbia River Basin. This Phase I Biological Plan addresses all these factors, although focusing primarily on those related to dam operation, to evaluate the risks involving alternative strategies for managing Snake River flows.

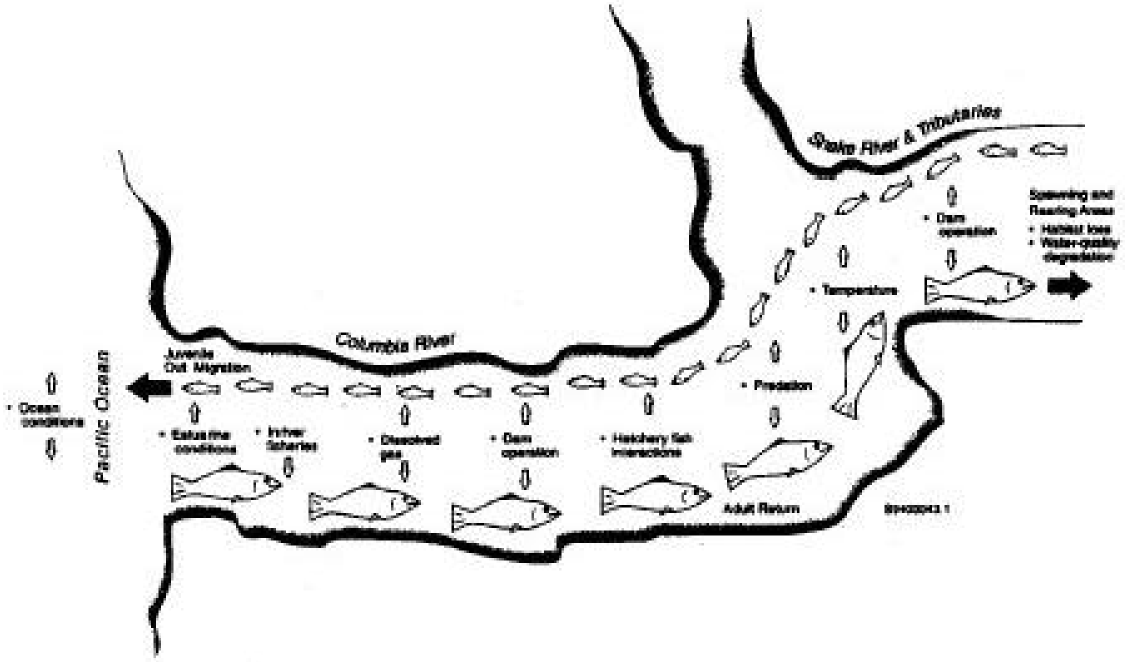

Figure 1-2. Environmental factors contributing to the decline of anadromous salmonids of the Snake River Basin

1. Habitat Loss and Degradation

a. Habitat Range

The loss of Pacific salmon habitat is illustrated dramatically in figure 1-3 (NPPC database), which compares the pre-1900 and present extents of salmon and steelhead spawning and rearing habitat within the Columbia River Drainage Basin. It is apparent that much historical range has been lost. About 31% of all anadromous fish habitat (stream miles) existing in predevelopment times has since been blocked by dams. Major habitat has been lost from blockage by dams (both Federal and non-Federal) in nearly all major drainages of the Snake River system, equivalent to 46% of the pre-development habitat range. The entire area upstream of Chief Joseph Dam on the Columbia and the Hells Canyon Dam on the Snake River are now inaccessible to salmon and steelhead. Added to this is the habitat destruction caused by water diversion projects, loss of suitable riparian vegetation, *etc.* It is important to note that the single largest area of remaining spawning and rearing habitat for wild salmon and steelhead in the entire Columbia system is found in the Snake River Basin (including the Salmon River Basin) upstream of Lower Granite Dam and downstream of Hells Canyon Dam.

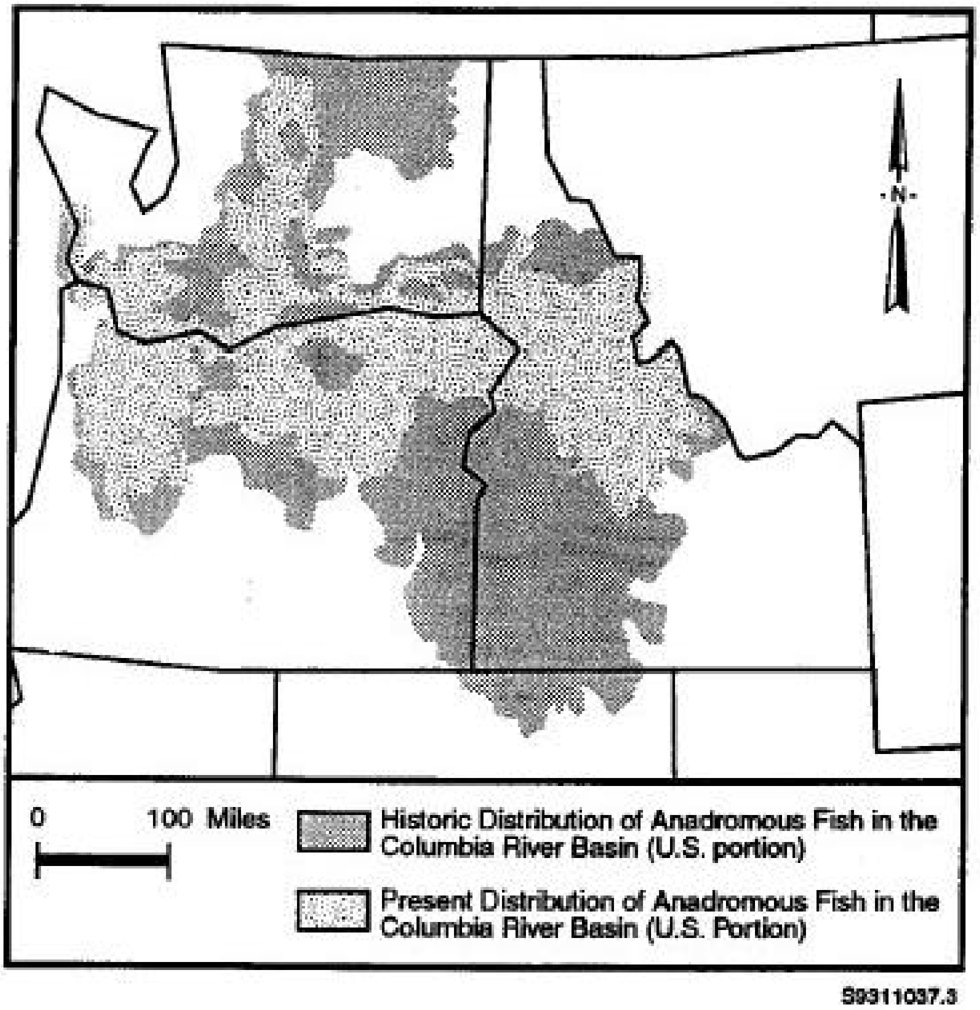

Figure 1-3. Historic vs. present distribution of anadromous fish in the Columbia River Basin (NPPC database)

b. Habitat Quality

It is difficult to quantify the impacts to fish from habitat degradation because much of the impact preceded historical records and also because few scientific methods can directly assess these effects. Taking into consideration only the habitat still currently accessible to anadromous stocks, the National Marine Fisheries Service (NMFS, 1992) cited the difficulty of determining the level of impact from degradation of spawning and rearing habitat on overall survival of endangered spring and summer chinook stocks. In light of this uncertainty, NMFS estimated that overall habitat damage was responsible for fish mortalities of 10 to 40% before the smolts even reached the mainstem Columbia and Snake River dams.

Calculations and interpretations vary on the overall level and importance of impacts from regional habitat degradation to threatened stocks of spring/summer chinook. The Subbasin Planning Reports for the Salmon River indicate that 67% of Salmon River Basin streams may have experienced up to 10% reduction in harvest production potential (IDFG *et al.*, 1990), with 25% of streams experiencing up to 20% reductions. Factors listed as major contributors to the habitat degradation in the Salmon River Basin were primarily logging, road building, grazing, irrigation withdrawal, and (to a lesser extent) mining. In the Clearwater River Basin (IDFG *et al.*, 1990), 65% of streams are listed as having lost up to 10% of anadromous salmon and steelhead production potential, with the remainder equally divided among greater and lesser reductions in potential production. The primary factors affecting fish production in the Clearwater River Basin include forestry, agriculture, and mining, with forestry-associated road-building generally causing the greatest impacts to fish production through sedimentation and degradation. However, losses from irrigation withdrawal and predation that could increase the overall loss of smolts before their arrival at Lower Granite Reservoir should also be considered.

The other major drainage in the system producing these stocks, the Grande Ronde, also has experience habitat degradation. Here a total 379 miles, or 60% of the stream miles, are considered to have degraded habitat caused by stream channelization for field development, livestock grazing, poor agricultural practices, poorly designed roads, and timber removal (IDFG *et al.*, 1990). Mining and recreation development have also contributed to riparian habitat problems.

Although somewhat degraded, the overall quality of spawning and rearing habitats currently available in the Idaho Snake River drainage is generally considered good. It has been concluded that implementation of all the considered habitat improvements in regions under State of Idaho jurisdiction would result in an estimated 17% increase in potential smolt production for chinook and 9% for steelhead because the productive capacity remains high for the majority of Idaho anadromous fish streams (Rich *et al.*, 1992).

There are a variety of possible effects of degraded habitat on current Snake River salmon stocks, even when the overall seeding level (*i.e.*, proportion of fish present relative to habitat production potential) is low. Fine sediment from many types of human activities can reduce egg survival and emergence. The decreasing volume of stream pools from sediment deposition affects both adult holding and juvenile rearing habitats. Reduced pool areas in streams force juvenile chinook, which use pools extensively for both summer and winter rearing, to travel greater distances to find this preferred habitat. Pool volume and availability of interstitial spaces (between rocks) often affect chinook overwintering in streams. When pool volume has shrunk and interstices fill with sediment from land-use activities, fish will often leave the stream in the fall in search of overwintering areas in mainstem channels. This additional movement subjects fish to greater predation potential from birds and fish.

2. Harvest Management

Columbia River harvest of chinook and sockeye beginning in 1886 is presented in figure 1-4. Before about 1940, most Columbia River stocks were harvested in the river; thus, river harvest numbers are a good indication of run trends during this period. After an initial sharp decline around 1890, harvest of chinook salmon in the Columbia River remained fairly constant to about 1920, when it began gradually decreasing until 1966 (Fulton, 1968).

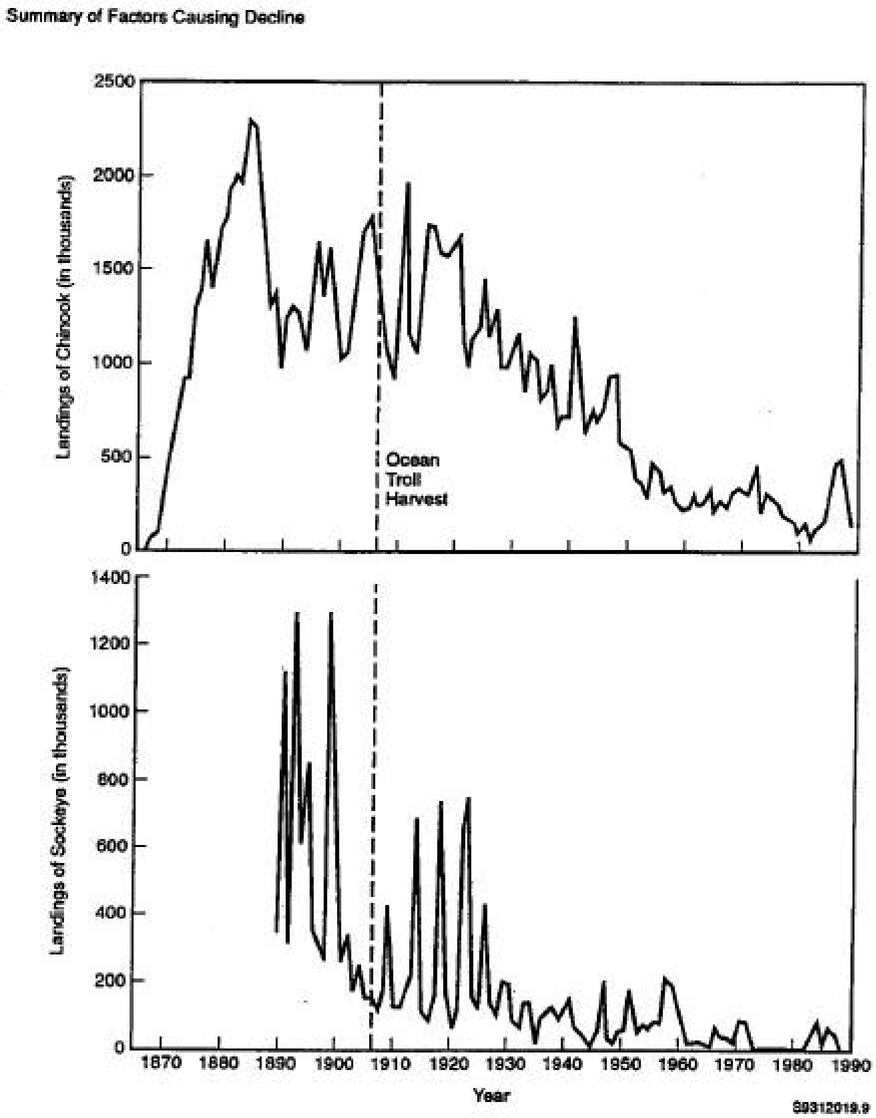

Figure 1-4. Total commercial landings of chinook and sockeye salmon in the Columbia River, 1866-1990 (from NPPC 1986, ODFW and WDF, 1991)

Actually, a decreasing trend in in-river commercial harvest levels is apparent for both chinook and sockeye from the late 1800's to the present. These levels, however, do not account for all harvest of Columbia River stocks, particularly after the middle of the 19th century. Ocean troll harvest of chinook salmon began to compete with river harvest in 1912 (NPPC, 1986). In the 1970's, more than 60% of the total chinook run harvest was taken in the ocean, predominantly off Alaska and British Columbia. Typically, less than 10% of the total chinook run was harvested in rivers during this period (NPPC, 1986). The 1985 U.S.-Canada salmon treaty has reduced harvest of U.S. fish in Canadian and Alaskan waters.

A Columbia River Fish Management Plan (CRFMP) was adopted in 1988 to help restore runs and allocate harvest of fish in the mainstem Columbia River and tributaries. The CRFMP was agreed to by the United States, the states of Oregon and Washington, and four treaty Native American tribes (Yakima, Warm Springs, Umatilla, and Nez Perce). Since 1988, management of Columbia River fish runs and fisheries has been based principally on the CRFMP. Each of the state fisheries management agencies has regulatory authority over sport and commercial fisheries within their boundaries. In addition, the tribal governments have the authority to regulate the conduct of the tribal fishery.

The potential of each salmon and steelhead stock to be affected by commercial or harvest varies, depending on the total run size and the harvest management objectives for that year. Fall chinook salmon stocks that return to the Snake River are vulnerable to impacts from commercial harvest because up to 50% of the total run may be harvested in the mixed-stock fishery that occurs in Zones 1 to 6 (Dauble and Mueller, 1993). The potential for impacts to the summer chinook salmon is extremely low because there is no fishing during their migration interval. Mainstem ceremonial and subsistence fisheries constitute the primary harvest impact (~7% per year) for Snake River stocks of spring chinook salmon. Terminal ceremonial and subsistence fisheries in tributaries of the Snake River take <1% of the escapement of spring chinook salmon over Lower Granite Dam. Depending on whether escapement goals are met at Bonneville and Priest Rapids Dams, up to 30% of the adult run of sockeye salmon could be harvested. However, if these minimum run-size objectives are not met, there would be no impact to Snake River sockeye salmon from harvest. Recreational fisheries are not a mortality factor for sockeye salmon or summer chinook salmon, but may remove up to 10% of the upriver run of spring and fall runs of chinook salmon. There is no commercial harvest of steelhead; however, adult steelhead are caught inadvertently during the gillnet fishery for fall chinook and sockeye salmon.

3. Water Quality Impacts

Water quality of the Snake River varies depending on location. River reaches from Brownlee Reservoir to the confluence of the Salmon River are influenced by the water quality of the middle Snake River, which is generally considered poor because of human-caused and natural conditions (COE, 1992b). For example, inputs from irrigation and non-point grazing area sources contribute to high loadings of nutrients, suspended sediments, and bacteria. It is also likely that organic residuals from pesticides and herbicides are present from human development activities in the Snake River basin (COE, 1993b). Downstream of the confluence with the Salmon River, and especially downstream of the confluence of the Clearwater River, water quality in the lower Snake River somewhat improves because of mixing with water from the Salmon and Clearwater systems. Water quality (dissolved gas levels and temperature) from Dworshak Reservoir, on the North For, of the Clearwater River, is controlled to meet requirements of Dworshak National Fish Hatchery.

The two water-quality parameters most likely to be impacted by dam operation in the Snake River system are supersaturation of dissolved gases and water temperatures.

a. Supersaturation

Dissolved gas is supersaturated in the Snake River when water passes over a dam's spillway. The spilling water traps atmospheric air and carries it deep into the waters of the plunge pool or "stilling basin" where increased hydrostatic pressure dissolves the air into the water. At depth, this dissolved gas is "supersaturated" relative to conditions at the surface. When brought to the surface, the gas either comes out of solution and equilibrates with atmospheric conditions, or it forms bubbles. Evidence shows that bubbles forming within the tissues of aquatic organisms may cause injury or death (Fidler and Miller, 1994). Because dams slow the velocity, lessen the streambed-oriented turbulence, and shorten free-flow sections of the Snake River, the river is unable to equilibrate the excess dissolved air during its flow between dams and, consequently, supersaturation conditions can persist and perhaps accumulate over extended distances. This is especially evident during periods of high flow and continuous spillage.

Spill over the dams in the lower and middle Snake River has increased gas supersaturation, although certain natural pre-dam conditions may cause supersaturation. Levels in the lower Snake River are influenced by flow from the Clearwater River (including releases from Dworshak Reservoir) as well as the middle Snake River, typically ranging between 105 and 110% saturation in the Lower Granite forebay during the spring in high-flow years. Levels successively increase downstream through the Little Goose, Lower Monumental, Ice Harbor, and McNary Dam forebays when all projects are spilling. Installation of spillway deflectors at Lower Granite, Little

Goose, and Lower Monumental Dams has reduced levels of dissolved gas supersaturation associated with spillway discharges. However, maximum supersaturation ranging from 110 to >140% has been observed for extended periods during high-flow events. Thus, Washington State and Federal EPA standards are exceeded during certain periods of the year, when high spilling occurs. Further, the spillway deflectors do not function as designed with pools at MOP and spills that are not "involuntary" (*i.e.*, those operations that take away from powerhouse flow and not just in excess of powerhouse flow (Wik *et al*., 1993).

b. Water Temperature

Water storage capacity at the four lower Snake River reservoirs is very limited, with retention time approximately 8 to 20 days. Therefore, thermal stratification (vertical temperature gradients decreasing from top to bottom) is rare, except for short periods during some low-flow years (with augmentation from Dworshak) when it may occur within a 7ºF (3.9ºC) range. Vigg and Watkins (1991) have characterized temperature in the Snake River and found that under current and historical conditions, the Snake River can be 4 to 5ºF warmer than the Columbia River at the confluence. This condition normally occurs in late August or early September. Historical data (Vigg and Watkins, 1991) indicate that warm temperatures at the confluence of the Snake and Columbia Rivers may have impeded migration of fall chinook salmon into the Snake River. Thus, operational strategies that reduce temperatures during the late summer and early fall could enhance upstream migration of adult salmonids.

4. Flow Alterations

The system of dams and reservoirs constructed along the lower Snake and Columbia Rivers has provided many benefits to the region. However, these projects, together with increased irrigation withdrawal, have also drastically altered the water flows that both juvenile and adult salmonids encounter during the migration to and from the ocean. Historically, downstream migration of juvenile salmonids coincided with seasonal high flows. However, regulated flows are lower in the spring and summer and higher in the fall and winter than before construction of the dams (Berggren and Filardo, 1993). The slower flow rate increases the time required for juvenile salmon to migrate from their freshwater rearing areas to the Pacific Ocean. For example, Raymond (1979) estimated that smolts move through the impounded river at about one-third to one-half as fast as they do through free-flowing stretches. Some biologists have concluded that longer migration times decrease juvenile salmonid survival by increasing the changes of predation and interfering with the natural physiological changes necessary for adaptation from freshwater to saltwater.

The relationship between improved flow conditions and increased survival of salmon in the Snake and Columbia Rivers is based on the assumption that the rate of travel of juvenile salmonids is related to water velocity. Increased water velocity, resulting from releases of larger volumes of water from storage reservoirs, decreases water travel time through the Columbia and Snake River reservoirs and generally results in reduced travel time for migrating smolts (Berggren and Filardo, 1993). Many investigators postulate that the quicker fish can pass through the system, the more will survive. For example, a shorter travel time provides reduced exposure to predators, less chance of residualism, and fewer opportunities for physiological stress (COE, 1992b). However, factors other than flow can also influence how fast juvenile salmonids migrate to the ocean. The level of smoltification water temperature, day length, and turbidity are a few of the variables affecting migration rates (Hoar, 1976; Wedemeyer *et al.*, 1980; Zaugg *et al.*, 1985).

5. Effects of Project Operations

Storage and run-of-river project operations can affect both upstream and downstream passage of salmonids. Whereas all dams on the lower Snake River were constructed with passage facilities for adult salmonids, juvenile passage facilities were not identified as necessary until the 1960's. State-of-the-art facilities, including turbine intake screens, have been in operation at Little Goose Dam since 1970, and screens and bypass systems at Lower Monumental have operated since 1992. Ice Harbor Dam currently uses sluiceways and had a bypass system installed in 1994. Currently, juvenile mortality resulting from passage through dams or by predators during migration through the reservoir is regarded as a significant impact to salmonids in the Snake River system. Subsequently, NMFS developed a program (Ebel *et al.*, 1973) to collect juvenile fish at Lower Granite, Little Goose, and McNary Dams for transport around the dams. However, because only 22 to 38% of all chinook estimated to be released are transported (Wik *et al.*, 1993), methods are being sought to improve in-river passage, including extended-length turbine intake screens and flow augmentation. Factors affecting survival as salmon pass through the dams include relative numbers bypassed, turbine operation and discharge, powerhouse capacity, and spilling.

a. Habitat Loss

Major habitat loss from blockage by dams has occurred in nearly all major drainages of the Snake River system. Loss in production potential for anadromous fish in this system equals 46% of the predevelopment habitat range. More than two-thirds of this loss occurred in areas upstream from Hells Canyon Dam. Blockage of the North Fork Clearwater by Dworshak Dam equaled 140 miles of habitat

(4% of the total Snake River Basin loss). Additionally, many miles of stream still accessible to fish have been converted from free-flowing water to slackwater reservoir conditions; accessible reservoirs account for 362 miles on the mainstem Columbia River and 140 miles on the Snake River. These reservoir environments no longer supply spawning habitat for anadromous stocks, although juvenile rearing is possible. Limited fall chinook spawning may occur in tailrace areas where adequate velocities can be maintained over suitable substratum.

While the loss of habitat has been pronounced, its effect on total runs has often been overshadowed by other environmental and habitat effects. For example, it has been estimated that approximately 8 million salmon and steelhead below historical levels (of an estimated total 10 million lost from all factors) have been lost from hydroelectric development alone (NPPC, 1987). Of this, almost half (~4 million) of these losses are considered the result of habitat loss from the Chief Joseph and Grand Coulee Dams on the upper Columbia and Hells Canyon Dam on the Snake. However, other factors were already affecting runs when these dams were constructed.

Some dams no longer operating on the system also influenced historical runs, and may have resulted in a long-term depletion of adapted stocks. One of the dams with a major influence on past runs was the Lewiston Dam (IDFG *et al.*, 1990). This dam was built 4 miles from the mouth of the Clearwater River by Washington Water and Power in 1927, with an inadequate passage system for chinook. Chinook access to the Clearwater Basin above Lewiston was almost totally blocked by construction until about 1940, when the ladder was reworked. Counts of spring/summer and fall chinook over Lewiston Dam from 1950 to 1964, when the ladder was again improved, were usually less than 100 fish per year (IDFG *et al.*, 1990). The dam was finally removed in 1973 because Lower Granite Reservoir would have reduced its use for power production (Winter, 1990).

Sunbeam Dam on the upper Salmon River near Stanley, Idaho, may have blocked passage of sockeye after its construction in 1910, because it was apparently constructed with an inadequate fish ladder (Chapman *et al.*, 1990). After several years of disuse and partial erosion, the dam was partially breached in 1934, allowing better access to fish upstream of the dam. There is some question as to whether sockeye could have successfully passed the dam during the early years after its construction. However, sockeye were either maintained or reestablished in Redfish Lake upstream of the dam by at least the mid-1950's. Sockeye salmon abundance had been greatly reduced even before any additional dams were built downstream from Redfish Lake on the mainstem Snake River. Escapement of only 11 fish to Redfish Lake was reported in 1961 (Hall-Griswold, 1990), although later escapement in the 1960's was much higher.

b. Impeded Migration

i. Juveniles

Juvenile salmon and steelhead migrating downstream must pass each dam they encounter in one of several ways (figure 1-5). Fish may travel over the spillway when water is being spilled or, alternatively, travel with the river flow toward the powerhouse. Fish screens and/or sluiceways are in operation at all run-of-river dams on the Snake and lower Columbia Rivers. These systems divert a portion of the downstream migrants away from the turbines. Collection systems convey fish away from the powerhouse and either bypass them back to the river downstream of the dam or route them to holding facilities for later transport by barge or truck. Some fish at these dams are not guided, and pass through the turbines. At dams without screens and collection facilities, the only downstream passages are over the spillway or through the turbines or sluiceways.

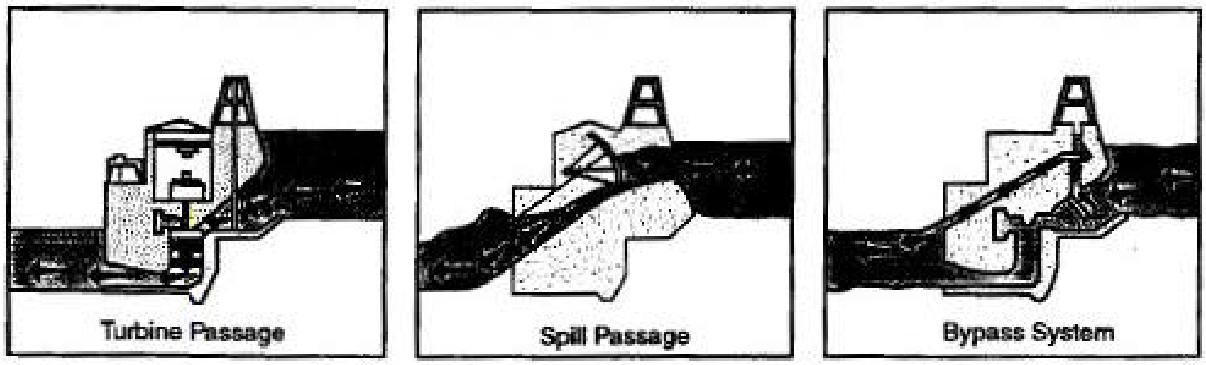

Figure 1-5. Major routes of passage for juvenile salmonids at Snake River hydroelectric projects

Each passage route has distinctive fish mortality risks. Evidence suggests that juvenile fish passing through the turbines suffer 1 to 17% morality (Schoeneman *et al.*, 1961; Stier and Kynard, 1986; Giorgi and Stuehrenberg, 1988). Juvenile mortality also occurs when the fish pass over the spill and in bypass facilities. The proportion of guided fish [expressed as fish guidance efficiency (FGE)] is affected by water velocities through turbine intakes, which in turn are affected by the amount of water passing through the turbines, which in turn is a function of head and turbine settings. The full relationship of these factors is not clearly defined, and it is not understood how FGE changes with changing operation. In addition to affecting fish guidance efficiency, flow past the project affects juvenile fish passage (*e.g.*, fish delay in forebays).

ii. Adults.

Evidence suggests that migration of adult salmon and steelhead into the Snake River has been blocked during some years because of elevated water temperatures. In the Snake River, high late-summer temperatures >70ºF (21ºC) in 1967 and 1968 appeared to impede migration by creating a thermal block (Stuehrenberg *et al.*, 1978). Yet historical temperatures in the Snake River prior to construction of lower Snake River dams were actually higher than those recently recorded, at least through August (USFWS, 1960). Major temperature effects on Snake River reservoir shave been less a factor of increased maximum temperature than a time-shift in the occurrence of the maximum temperature such that it occurs later in the year and for a longer time period.

Adult migration can be directly and indirectly impeded by dams, resulting in mortalities. Inter-dam losses are estimated at 5% of the adult spring and summer chinook salmon for each dam on the lower Columbia and Snake Rivers (Chapman *et al.*, 1991). Bjornn *et al.* (1991) estimated that passage success from spring and summer chinook salmon past the four lower Snake River dams was 87% in 1991. Returning adults may have difficulty locating entrances to fish ladders, consequently spending excess time milling about below dams. Turbine discharge affects adult guidance as well. Units are operated to attract adults to the collection system. Although turbine intake screens protect juveniles from turbines, they divert only an undetermined number of adults from the system. The main concern with delays to migration is increased energy expenditure and associated stress that may contribute to reduced reproductive success or prespawning mortality. However, there is currently no evidence that migration delay, although substantial at some dams, results in measurable mortality to adult salmonids (Dauble and Mueller, 1993).

6. Interactions Between Wild and Hatchery Fish

Currently, a large portion of total salmon and steelhead trout runs to the Columbia River system originate from hatcheries. Therefore, factors affecting the success of hatchery fish greatly influence total runs to the river. Several problems occur with hatchery fish compared with wild stocks. Generally, hatchery stocks have poorer smolt-to-adult survival rates than do wild stocks. Survival from a given hatchery also tends to decline over time. The Pacific Salmon Commission (PSC, 1990) has kept records on the relative survival of 32 stocks of chinook salmon (all but 2 hatchery origin) from Alaska, British Columbia, Washington, and Oregon. They found that 17 stocks (55%) had a long-term decreasing trend in survival, independent of fishing mortality, while only 5 stocks (16%) showed an increasing trend. Trends for the other stocks were either indeterminate (1 stock) or based on insufficient data (9 stocks). This included stocks from areas above the dams on the Columbia River and from other areas not affected by the dams.

Hatchery-released fish and naturally-produced offspring of returning adults could interact genetically and ecologically with existing native populations. In some cases, potential impacts could be considered adverse (*e.g.*, result in decreased growth rate or numbers of existing populations). A primary concern involves the potential for hatchery populations to affect the genetic diversity of endangered or petitioned stocks in other basins through straying or other mechanisms. Genetic concerns may be grouped into four general categories: Type 1 - extinction, Type 2 - loss of within-population genetic variability, Type 3 - loss of between-population genetic variability, and Type 4 - domestication selection (*i.e.*, rendering the hatchery fish less fit for natural survival than their wild counterparts and ancestors) (Busack, 1990). The possibility exists that hatchery and resident salmonids may interact through several mechanisms including: competing directly for food and space during the freshwater rearing phase, preying on one another, and altering migratory responses (Steward and Bjornn, 1990).

Hatchery fish that spawn in the wild may reduce stock viability. Chilcote *et al.* (1986) found that natural-spawning hatchery steelhead in the Kalma River produced smolts with a survival rate only 28% of that of wild fish. The extent of wild spawning by hatchery stocks in the basin varies, greater in areas with large hatchery runs ultimately reducing the viability and production of wild fish. In the Snake River, despite large outplanting of hatchery fish to streams, wild spawning of hatchery releases of spring and summer chinook is apparently low (Matthews and Waples, 1991). However, since 1983 stray hatchery fall chinook from the lower river may be entering the spawning areas of wild fall chinook in significant numbers, and hatchery fish from earlier activities (1983 or earlier) in the basin could have been spawning in the wild (Waples *et al.*, 1991b).

Another hatchery problem with possible serious consequences for fish survival is the incidence and severity of disease. One of the most severe problems of fish in the Columbia River is bacterial kidney disease (BKD), most seriously affecting spring chinook smolts. The bacterium that causes this disease can be transmitted from parents to their eggs. Outbreaks of the disease are most often associated with artificial propagation of salmonids, although it may also be transmitted to uninfected fish in the river. Additionally, there is a potential for hatchery stocks to transmit BKD to wild stocks during collecting and transport.

C. Background of Measures Evaluated Under the Phase I Biological Plan

Most measures being evaluated in the System Configuration Study were identified in the Northwest Power Planning Council's Fish and Wildlife Program Phase 2 and 3 amendments (NPPC, 1992a) and their *Strategy for Salmon*. Others, as noted below, have been developed in consultation with regional fisheries personnel and interested parties.

1. Reservoir Drawdown

The purpose of reservoir drawdown is to reduce the cross-sectional area of the reservoir pools, thereby increasing water velocity. Velocities are increased substantially at the upstream end of the reservoir area because a portion of the pool is returned to a free-flowing river. Velocity increases throughout the reservoir depending on the shape of the channel cross-section and the overall reduction in depth.

Reservoir drawdown was proposed as a means to improve downstream passage conditions for juvenile salmonids at the Salmon Summit, which met during the fall and winter of 1990 to 1991. The concept was originally discussed by the Columbia Basin Fish and Wildlife Authority in their Flow Proposal (CBFWS, 1991b). Two types of reservoir drawdown were proposed, which are briefly discussed in the following paragraphs.

a. John Day Dam

John Day Reservoir has some flood-control storage capability, unlike the other seven Corps of Engineers' mainstem Columbia and Snake River dams. It was designed with an 11-foot operation range, which means that fish facilities, navigation, hydropower, *etc.*, can function over the entire range [257 to 268 feet above mean sea level (fmsl)]. While the dam was designed for this possibility, it was expected to operate at the lower end of the range very infrequently and for only short-time periods.

b. Lower Snake Reservoirs

The four lower Snake River reservoirs have a normal operating range of 3 to 5 feet. Below the normal minimum operating pool, existing fish facilities and navigation locks do not function. Drawdowns ranging from approximately 30 to >100 feet have been proposed for the lower Snake River reservoirs.

2. Flow Augmentation Through Additional Upstream Storage

For more than a decade, flow has been augmented through the mainstem Snake and Columbia reservoirs in an attempt to reduce juvenile salmonid travel time. This extra water (known as the Water Budget) has been obtained from upstream storage projects: Grand Coulee on the Columbia, and Dworshak and Brownlee on the Snake. While there are substantial water volumes in each of these projects, they are nonetheless limited, particularly in years of very low flow, such as 1992, when average flow in the Snake River was approximately 48,000 cubic feet per second (cfs) during the juvenile fish outmigration. (The Northwest Power Planning Council has identified a target of 85,000 cfs during the outmigration period of 15 April to 15 June.) Additional upstream storage capacity could be used to increase flow augmentation capabilities.

3. Improvements to Existing Fish Passage Systems

Since the construction of Bonneville Dam in 1938, fish facilities have been modified and improved at the eight COE dams on the lower Snake and Columbia Rivers. On subsequent dams, each new adult collection and ladder system improved upon its predecessor, and modifications were made to earlier dams incorporating new knowledge and technologies of fish passage. The later dams, John Day and those on the lower Snake, included some form of juvenile fish passage facilities, which also have undergone continual processes of evolution and improvements.

While many modifications have been made over the last 50 years, greater understanding and changes in technology allow personnel to continue to identify potential improvements. There are several ongoing fish facility (both adult and juvenile) improvement programs, including Project Improvement for Endangered Species and the Columbia River Juvenile Fish Mitigation Program discussed below. Since the start of these ongoing programs, other measures have been identified as potential improvements to fish passage and conditions at the mainstem dams. These measures are being evaluated in the SCS, and include improved adult collection and passage systems, juvenile fish bypass and collection systems, juvenile fish transport facilities, and hatcheries. One promising concept, the surface collection/bypass, has been accelerated with field testing of prototype systems scheduled as early as 1996.

4. Upstream Collection and Conveyance

While efforts have been made to improve in-river conditions for downstream juvenile salmonid migrants, the present system of reservoirs is vastly different from a natural, free-flowing river. Rather than trying to "fix" the reservoirs, some regional parties have advocated trying to remove the fish from the system using transport downstream. In theory, this would eliminate the hazards of slow-moving water in reservoirs, while allowing other reservoir uses to continue normally.

An upstream collection facility was initially proposed to collect all downstream migrants upstream of the first reservoir (Lower Granite) encountered on their journey. Since the initial proposal, others have suggested that 100% collection is not necessary, and appropriate facilities for this are also being evaluated. Collection methods undergoing evaluation include non-structural guidance systems, such as electrical and sonic fields.

Possible means for conveying fish downstream from the headwaters or from the upstream end of the reservoir system to below the last dam include transport vessels (similar to the existing trucks and barges of the juvenile fish transportation program), a migratory canal, and a pipeline system. Various types of canals, ditches, and pipelines have been proposed over the last 25 years by various parties in the region, but the ideas have not received detailed consideration until now.

5. Columbia River Juvenile Fish Mitigation Program

Improvements to existing juvenile fish facilities are ongoing under the Columbia River Juvenile Fish Mitigation Program. These efforts include new and/or improved facilities at the four lower Snake dams, McNary, and The Dalles, including turbine intake screens at those projects which have either not had them or used an ice-trash sluiceway for juvenile bypass in the past, and extended length turbine intake screens for Lower Granite, Little Goose, and McNary Dams.

II. Affected Environment

A. Physical Environment

1. Water Quality

This section discusses water quality in the lower Snake River, with emphasis on those parameters considered most likely to be impacted by reservoir drawdown and of particular concern with respect to the protection of anadromous fish. Impounded waterways are dynamic systems with physical, chemical, and biological properties characteristic of both free-flowing river and lake ecosystems. Hydrologically linked reservoir systems typically display significant longitudinal gradients, ranging from light-limited, turbidity-dominated, upper riverine zones to more quiescent pool zones that behave much like natural lakes (Kennedy *et al.*, 1985). Water quality in these complex systems is a function of many physical, chemical, and biological processes that regulate the input-output and distribution of a host of materials, including contaminants.

There is an extensive body of literature on the basic limnological principles or watershed processes that account for the existing water quality of the lower Snake River system (*e.g*., Wetzel, 1975; Baxter, 1977; Neel, 1963; and Margalef, 1975).

The U.S. Environmental Protection Agency (EPA) and the State of Washington have established water quality criteria and standards applicable to the lower Snake River. The State of Washington upholds a policy of antidegradation and beneficial use of surface waters that prohibits discharge or release of any toxic or hazardous materials or deleterious contaminants into waters of the state. Designated beneficial uses of the lower Snake River are: 1) water supply (*e.g.*, domestic, agricultural, industrial; 2) livestock watering; 3) fish and shellfish rearing; 4) spawning and harvesting; 5) wildlife habitat; 6) primary-contact recreation; 7) commerce and navigation; and 8) electricity production. At present, the State of Washington has classified the Columbia River, from Grand Coulee Dam downstream to the Pacific Ocean, and the Snake River as Class A (excellent).

a. Temperature

Temperature plays a key role in regulating many physiochemical and biological processes in aquatic systems, and has received considered attention as an important water quality parameter in the Columbia-Snake River system because of its impact on rearing and migrating anadromous fish. It is not surprising, then, that much debate has centered on impoundment and its effects on temperature regimes in the Columbia-Snake River system. Numerous models have been developed to better understand the impact of water management practices on temperature and associated water quality variables, although additional field testing and refinement are necessary if these models are to be useful in predicting the impacts of drawdown along the lower Snake River.

Damming dramatically alters the physical structure and function of riverine systems, with important consequences for heat transfer and distribution. However, predicting the cumulative effect of hydropower projects on river temperature is a complex problem because the processes that affect distribution, storage, and transfer of heat in these systems are dynamic. Interruption of natural flow changes the basic hydrologic cycle of rivers, thus affecting both the daily and seasonal patterns of heating and cooling. The relatively large surface areas created when reservoirs are formed allow for considerable heat gain during the summer months from direct inputs of solar energy. This may, however, be of greater importance to the heat budgets of storage reservoirs than for run-of-the-river reservoirs like those found along the lower Snake River. Heat accumulated in the upper layer of a reservoir is distributed both horizontally and vertically via the physical work of wind energy, currents, and other water movements. A significant portion of stored heat in reservoir systems can be lost as outflow water is spilled or as a result of other processes such as thermal radiation and evaporation.

Heat stored in the surface layers of upper Snake and Clearwater River reservoirs represents an important input to the lower Snake River during late summer to early fall. The temperature of the lower and middle Snake River is not affected by conditions above Brownlee Reservoir. Density differences between the inflowing water and reservoir water also affect mixing and the distribution of heat. Efforts to accurately model changes in water temperature are complicated further if reservoirs thermally stratify during the summer. This may be less likely during drawdown, however, if both reservoir volumes and retention times decrease.

The results of anthropogenic disturbance, including water diversion and land development, are believed to have altered maximum temperatures in the Snake River (Wik *et al.*, 1993). Under current and historical conditions, the Snake River can be 4 to 5ºF warmer in late August or early September than the Columbia River. Analysis of historical temperature records demonstrates that one effect of impoundment on the Columbia River system has been to delay the onset of summer temperature maxima (COE, 1992b). The net effect of impoundments on average river temperatures, however, is less clear. The passage of the Snake River through the Little Goose, Lower Granite, Lower monumental, and Ice Harbor reservoirs has resulted in an overall temperature increase of <1ºC (Funk *et al.*, 1979). Vigg and Watkins (1991) suggest that damming has resulted in a slight overall increase in temperature, while

Chapman *et al.* (1991) suggest that average temperatures may actually be lower following impoundment. Funk *et al.* (1991) states that passage of water through the four lower Snake River reservoirs has resulted in an overall temperature increase of<10ºC. Jaske and Goebel (1967) found that low-head reservoirs on the Columbia river have not significantly changed average water temperatures, although temperature shifts at Rock Island occurred 30 days later compared with temperatures pre-dating construction of Grand Coulee Dam. Construction of Chief Joseph Dam resulted in a 3-day delay in maximum water temperature at Rock Island Dam.

Funk *et al.* (1979) found that thermal stratification was minimal in the reservoirs during normal and high-flow years, with maximum surface-to-bottom temperature differentials on the order of 2ºC (4ºF). During low-flow years, temperature differences as great as 7ºC (13ºF) were reported for short periods. Homothermy occurred by mid-September during all flow years analyzed (Funk *et al.*, 1979).

Average monthly temperatures for Ice Harbor (1962 to 1992), Lower Monumental (1971 to 1992), Little Goose (1970 to 1982, 1991 to 1992), and Lower Granite (1975 to 1992) reservoirs are summarized in tables 2-1 and 2-4. All temperature data are from COE, Walla Walla District, reports and unpublished records. Monthly averages were calculated from daily temperature measurements, all taken in the turbine scroll-case (Tom Miller, COE, Walla Walla, personal communication). All of the reservoirs reached maximum temperatures during July through September. Average monthly temperatures for August exceeded 70ºF during most years at all four reservoirs. Maximum daily pool temperatures were 70 to 78ºF at Lower Granite, 70 to 77ºF at Little Goose, 70 to 75ºF at Lower Monumental, and 71 to 76ºF at Ice Harbor reservoirs. Maximum temperature variation between reservoirs during any single month was usually <2 to4ºF.

Table 2-1
Ice Harbor Dam Monthly Average Temperatures

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1962					54.0	59.2	69.4	73.5	68.3	58.8		
1963				49.7	55.1	60.6	68.3	73.3	69.5	63.3		
1964	38.6	38.0	40.8	47.5	51.6	55.1	67.2	70.5	64.1	58.3	50.2	41.3
1965	37.7	40.2	42.9	48.9	52.3	56.8	67.3	73.5	64.0	58.6	48.0	40.1
1966				49.8	54.5	60.2	69.5	73.7	68.4	60.2	51.5	
1967				49.6	53.2	56.7	69.5	74.8	71.0	60.5		
1968				49.0	54.5	59.1	69.4	71.6	66.3	55.8		
1969	35.3	36.1	42.5	49.3	53.9	62.6	67.7	71.6	68.5	58.9	47.2	40.9
1970				48.2	52.8	57.7	68.2	72.2	67.3	58.7	50.9	45.2
1971			41.8	48.5	52.9	55.8	64.8	73.4	68.1	59.1	49.7	41.7
1972				47.8	52.3	56.4	64.6	70.0	67.9	59.2		
1973			49.5	56.3	60.3	66.9	71.2	66.3	58.8			
1974				47.3	52.4	54.9	63.7	70.3	68.1	59.6		
1975				46.0	51.9	54.7	63.3	68.9	66.8	60.8		
1976				46.8	53.0	56.6	64.1	70.0	68.1	62.1		
1977				46.9	55.0	61.0	68.1	71.5	67.5	60.4		
1978				50.1	53.9	57.7	64.2	70.0	66.5	60.5		
1979			42.0	48.3	55.1	59.2	66.5	72.7	70.3	64.9	50.0	
1980			42.0	48.0	56.3	58.3	65.1	70.8	68.9	62.2	54.8	
1981			43.7	48.3	54.1	57.1	64.6	70.9	70.3	60.5	54.3	
1982			42.0	46.9	52.9	54.0	61.5	69.6	69.2	59.7	53.3	
1983				49.6	55.5	59.5	64.1	70.3	68.9	60.4		
1984					53.3	56.3	65.8	71.4	68.2	59.4		
1985			39.6	48.6	54.1	60.2	69.3	71.6	66.3	58.8		
1986			45.7	50.6	53.8	61.6	68.5	71.8	70.1	59.4		
1987				49.5	57.5	62.7	69.6	70.4	69.9	62.9		
1988				48.1	55.5	59.8	66.9	71.4	69.2	62.3		
1989				48.6	54.0	59.5	65.2	70.5	67.8	61.7		
1990	41.4	39.4	42.1	50.7	54.4	57.8	66.1	71.4	71.3	61.9		
1991		37.5	42.3	46.9	52.5	56.9	64.5	71.5	69.5	62.0	52.4	42.7
1992	40.5	41.2	45.0	52.6	57.4	62.9	68.7	68.7	67.4	61.5	51.8	44.8
Mean (1961-92)	**38.7**	**38.7**	**43.0**	**48.9**	**54.2**	**58.6**	**66.7**	**71.2**	**68.0**	**60.4**	**51.2**	

Table 2-2
Lower Monumental Dam Monthly Average Temperatures

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971			40.4	47.6	51.5	55.0	65.1	73.7	67.5	58.6		
1972				47.2	51.6	55.7	65.0	70.4	67.6	58.7		
1973				49.1	56.2	60.0	67.0	70.9	66.6	58.7		
1974				47.2	52.3	54.9	64.5	70.1	67.8	60.0		
1975				45.7	51.4	54.2	63.3	69.7	66.4	60.6		
1976				46.4	52.5	55.8	63.6	69.2	67.9	61.9		
1977				45.8	53.9	60.0	66.7	69.2	67.6	59.7		
1978				49.4	52.8	56.6	64.3	70.4	66.0	59.8		
1979				47.5	54.3	58.1	66.1	71.6	70.0	64.8		
1980				48.0	55.0	57.8	65.1	69.8	66.7	61.5		
1981				48.0	53.5	57.5	64.7	71.1	69.5	60.3		
1982				46.6	52.5	55.3	62.4	70.4	68.8	58.9		
1983				48.8	54.8	59.3	65.0	71.5	69.3	59.7		
1984				47.7	52.1	56.4	65.8	72.3	67.8	58.3		
1985				47.3	54.1	59.2	70.2	71.2	65.7	57.5		
1986				50.2	53.2	61.1	68.1	70.6	69.0	59.0		
1987				48.5	56.3	61.6	68.6	70.4	69.6	61.5		
1988				48.1	53.6	59.2	67.4	71.4	67.5	61.3		
1989			41.5	48.4	53.7	58.8	66.0	70.4	67.3	60.8		
1990	39.8	38.6	43.0	50.9	53.6	57.6	66.4	72.4	70.6	60.8	56.0	
1991				46.7	52.9	56.2	63.6	72.6	69.0	60.6	56.0	
1992				51.4	56.0	62.6	68.5	69.0	67.3	60.3		
Mean (1971-92)	**39.8**	**38.6**	**41.6**	**48.0**	**53.5**	**57.9**	**65.8**	**70.8**	**68.0**	**60.1**	**56.0**	

Table 2-3
Little Goose Dam Monthly Average Temperatures

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970				47.8	50.6	57.2	68.6	70.9	64.3	57.4	49.2	41.0
1971				47.7	51.9	55.2	66.2	73.8	66.6	58.1	47.6	40.7
1972			40.5	47.2	51.9	56.0	65.3	71.3	67.3	58.5	50.5	39.5
1973	36.4	35.2	44.2	49.3	55.8	60.0	68.2	71.5	65.8	58.5	48.6	42.8
1974	35.5	36.9	43.1	47.0	52.5	54.6	65.4	70.0	68.4	59.6	50.8	43.7
1975	36.3	38.5	41.7	45.5	51.1	53.6	64.1	69.5	66.9	60.0		
1976	37.6	35.9	41.0	46.1	52.0	55.6	64.3	69.9	67.7	62.2		
1977				46.2	54.4	61.3	67.2	69.5	67.0	59.0		
1978				49.3	53.0	56.7	64.0	69.8	65.5	59.9		
1979				47.6	52.8	57.8	66.6	72.7	70.2	64.7		
1980				48.1	54.1	58.4	66.5	71.4	68.0	62.0		
1981				49.7	53.9	57.1	66.0	72.2	69.7	60.5		
1982				47.2	52.2	55.9	63.4	71.5	69.1	59.3	55.0	
1991				50.3	51.9	57.3	66.5	73.7	68.5	60.7	51.0	46.0
1992				52.5	55.8	62.8	68.8	70.7	67.3	59.9	58.0	
Mean (1970-92)	**36.4**	**36.6**	**42.1**	**48.1**	**52.9**	**57.3**	**66.1**	**71.2**	**67.5**	**60.0**	**51.3**	**42.3**

Table 2-4
Lower Granite Dam Monthly Average Temperatures

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975			42.3	45.4	51.1	53.9	65.7	70.8	66.0	58.4	47.8	40.6
1976	36.9	36.9	40.6	47.4	52.1	55.2	65.8	70.7	68.1	60.4	51.5	42.1
1977	36.9	36.8	40.5	48.6	54.1	62.8	68.4	73.1	67.2	57.6	49.3	40.7
1978	39.2	39.8	43.2	49.5	51.8	56.2	66.0	71.4	65.6	59.7	49.0	40.0
1979	33.5	34.0	41.3	48.4	52.5	57.2	68.7	71.8	68.1	61.4	50.4	42.1
1980	38.1	36.8	42.3	48.3	53.2	58.4	68.1	71.0	65.9	60.8	51.5	43.5
1981	41.0	39.3	44.7	50.4	53.9	57.6	68.4	74.4	68.5	57.4	50.3	43.1
1982	37.2	36.9	41.8	47.2	52.0	55.9	63.6	71.6	67.4	57.5	48.3	42.3
1983	38.6	39.1	45.1	48.7	54.8	58.9	65.0	72.5	66.3	58.3	52.4	42.8
1984									64.8	57.2	48.2	39.8
1985	34.8	34.8	39.0	48.6	53.3	60.0	71.3	70.0	64.5	56.3	45.4	36.5
1986	33.7	36.5	44.5	50.0	52.6	62.0	68.9	73.2	66.9	57.8	50.0	45.0
1987			42.1	50.0	55.5	65.0	69.9	71.1	67.7	60.2	51.9	45.1
1988		43.0	42.2	48.5	54.0	60.6	70.2	71.9	69.1	61.7	53.4	45.1
1989	37.6	32.9	38.9	48.3	52.3	58.1	68.5	70.7	63.5	60.3	50.6	43.4
1990			42.2	50.4	53.7	57.5	70.7	74.2	69.0	60.1	49.8	42.0
1991			42.0	47.6	49.7	56.2	66.9	73.6	66.6	58.9	48.7	43.0
1992			45.4	51.1	55.5	60.9	64.2	69.9	64.2	59.6	51.5	
Mean (1975-92)	**37.1**	**37.2**	**42.2**	**48.7**	**53.1**	**58.6**	**67.7**	**71.9**	**66.6**	**59.1**	**50.0**	**42.2**

The State of Washington has adopted water quality standards to regulate thermal impacts to the Columbia and Snake River system. Human activities that increase water temperature above 68ºF (20ºC) are not permitted. Upstream of the confluence of the Snake and Clearwater Rivers, point-source activities that increase temperatures in the Snake River by >0.54ºF or large-scale activities that increase temperatures >2ºF (1.1ºC) when the river is above 68ºF (20ºC) are prohibited.

b. Dissolved Gases

Gas supersaturation probably existed in the Columbia River system long before the first dams were constructed (Weitkamp and Katz, 1980). Gas supersaturation is known to occur in unimpounded natural streams in areas of high water velocity, such as rapids and below waterfalls, and in regions where cold streams with high saturation concentrations warm to higher temperatures (Wik *et al.*, 1993). Gas supersaturation in lakes and reservoirs have been attributed to geothermal heating of groundwater, solar heating and photosynthesis (Bouck, 1976). Exposures to natural sources of gas saturation are likely to be restricted to isolated areas along streams, and are probably of shorter duration relative to exposures that occur in conjunction with hydropower projects. Furthermore, it is unlikely that natural sources contribute significantly to gas saturation problems along the lower Snake River.

The primary atmospheric gasses of importance in discussing gas supersaturation are nitrogen, oxygen and argon, which are present in air at partial pressures of 78%, 21%, and 1%, respectively. Pressure and temperature are the most important factors that determine gas solubility. According to Henry's Law, the mass of gas dissolved in a liquid at constant temperature is proportional to the pressure exerted on the solvent. The capacity of a water body to hold a dissolved gas is inversely related to temperature. Increasing the temperature of a volume of water decreases the volume of gas it will hold at equilibrium. Therefore, an increase in water temperature alone will produce supersaturation in water that is initially saturated (Weitkamp and Katz, 1980). Pressure is increased in water by hydrostatic head, and hydrostatic pressures increase rapidly with depth, greatly enhancing the capacity of deeper water to hold dissolved gases.

Dissolved gas levels in the lower Snake River are influenced by flows from the Clearwater River (including releases from Dworshak) and the middle Snake River. During the spring in high-flow years, the ranges of dissolved gas levels in the forebay of the Lower Granite Dam are typically 105 to 110% saturation. During years of no spill, this range is reduced to ~100 to 104%. Dissolved gas levels successively increase downstream when all projects are spilling. Therefore, when multiple dams are spilling, dissolved gas impacts are cumulative. During high-flow events, maximum supersaturation values of 110 to >140% have been observed for extended periods. Maximum total dissolved gas saturation values recorded during 1984 to 1990 were 111.0 to 121.7% at Lower Granite, 110.0 to 128.2% at Little Goose, 110.9 to 130.0% at Lower Monumental, and 114.6 to 140.6% at Ice Harbor reservoirs (COE, 1990).

Prior to 1994, spill occurred at Lower Granite/Little Goose only during high-flow conditions when river flow exceeds powerhouse capacity or electrical energy demand is low. At Lower Monumental and Ice Harbor during a portion of the juvenile outmigration period, some flow is spilled at night (6:00 p.m. to 6:00 a.m.) to aide fish passage. Of the total flow, >70% at Lower Monumental and 25% at Ice Harbor is spilled for this purpose. This spill typically increases dissolved gas concentrations directly below Lower Monumental Dam to levels that exceed the 110% water quality saturation limit established by the EP and the States of Washington, Oregon, and Idaho.

c. Turbidity

Turbidity is generally defined as the total suspended sediment load in water. In riverine systems, turbidity is produced by the scouring action of water on bedrock and sediments. The major source of turbidity along the lower Snake River is runoff from agriculture and forest lands, contributed by the Palouse River and upstream sections of the Snake. Therefore, highest turbidities are typically seen during the period of greatest flow. Other mechanisms, such as streambed and bank erosion, may be important sources of turbidity during summer and fall when runoff does not occur. Water velocity and certain riverbed and riverbank characteristics, such as the composition and particle size of bottom sediments and bank soils, and the extent of plant communities for shoreline stabilization, are all important factors that regulate turbidity along the lower Snake River.

Vegetation can be highly effective at decreasing shoreline erosion by binding soils, precipitating collidal clay particles, and damping waves in the littoral zone (Ploskey, 1983). Most reservoirs along the lower Snake River lie in relatively steep, narrow river valleys that have been largely inundated by project pools. The shorelines adjacent to the pools are generally steep and do not maintain extensive riparian zones. Littoral vegetation is sparse along the entire length of the lower Snake, with highest plant densities generally found along narrow vegetation corridors and backwater areas. The four Snake River reservoirs are bordered by approximately 285 acres of riparian habitat (scrub-shrub, forest-shrub, and forest-scrub). Woody plant communities are almost entirely comprised of drought-resistant species such as black locust, Russian olive, and various hybrid cherries.

There are approximately 116 acres of wetlands along the lower Snake River (Sather-Blair *et al.*, 1991). The largest concentrations of wetlands are around Lower Monumental Dam (87 cares), followed by Ice Harbor (15 acres), Little Goose (9 acres), and Lower Granite (4 acres). Plant communities in these systems are dominated by emergent species (Asherin and Claar, 1976). Cattails (*Typhus sp.*) and bullrush (*Scirpus sp.*) are common dominants within individual stands.

Funk *et al.* (1979) report that the range of turbidity in the lower Snake River was 1-90 nephaloetric turbidity units (NTU) during 1975 to 1977, with peak values occurring just before periods of high flow. Maximum values generally coincided with spring runoff, whereas minimum turbidity was usually found in late fall. Turbidity was typically greatest in upstream free-flowing sections of the river, and declined within project pools. Secchi disk measurements ranged from 1.3 to 15 feet, with maximum mean water transparency reported at river mile (RM) 108 (9.2 feet). Funk *et al.* (1979) compared pre- and post-impoundment data and report that all reservoir sampling stations in the Lower Granite/Little Goose area showed a marked increase in water transparency following completion of Lower Granite Dam.

Average monthly Secchi depth transparency measurements for Ice Harbor (1962 to 1992), Lower Monumental (1971 to 1992), Little Goose (1970 to 1982, 1991 to 1992), and Lower Granite (1975 to 1992) reservoirs are provided in tables 2-5 to 2-8. All water transparency data are from COE, Walla Walla District reports and unpublished records. Monthly averages were calculated from daily Secchi depth measurements. Because measurements were taken at the fish ladders, they may not be representative of turbidity conditions within the reservoirs (Tom Miller, COE, Walla Walla, personal communication).

Table 2-5
Ice Harbor Dam Monthly Average Secchi Depths (Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1962				2.1	2.7	3.5	4.7	5.6	6.0	4.9		
1963				2.5	2.4	2.1	4.2	4.6	4.9	5.5	5.2	5.2
1964	3.7	2.0	2.4	1.4	1.6	1.3	3.5	5.0	5.7	6.0	6.1	2.0
1965	1.1	0.7	1.4	1.2	1.4	1.1	2.4	3.3	2.3	2.7	2.7	
1966				1.7	2.0	3.3	4.0	4.5	3.1	3.0		
1967				1.9	1.3	1.3	3.2	5.1	5.6	4.9		
1968				2.0	2.0	2.4	5.0	4.6	4.6	3.7	3.2	2.4
1969	2.5	3.0	1.9	1.1	1.4	1.9	3.9	5.4	5.3	4.1	5.1	5.5
1970			1.9	2.0	1.5	2.7	4.8	4.4	4.5	5.0	5.9	
1971			1.7	1.2	1.0	1.1	2.9	4.9	4.1	4.4		
1972				1.0	1.4	1.1	3.2	4.8	4.1	4.0		
1973			1.9	2.2	2.3	4.3	4.4	3.8	3.7			
1974				1.3	1.7	0.9	2.2	4.8	4.3	4.3		
1975				1.4	1.1	1.0	2.0	2.6	3.3	3.4		
1976				1.1	1.2	1.7	3.3	3.7	4.5	3.9		
1977				4.5	3.9	4.5	4.7	4.9	4.6	3.9		
1978				2.4	2.0	2.7	3.1	4.3	4.9	5.0	5.0	
1979			1.6	3.1	1.5	3.0	4.3	4.9	4.3	4.5	4.5	
1980			1.0	2.2	2.4	1.9	4.1	4.9	4.4	3.8	4.7	
1981			1.9	2.6	2.1	2.3	4.2	5.0	4.9	4.8	5.0	
1982			0.8	1.4	2.0	2.4	3.2	4.7	4.8	4.6		
1983				1.8	2.4	2.2	4.2	5.0	4.4	4.3		
1984				1.5	1.6	1.7	3.8	4.5	4.3	4.9		
1985			1.8	2.1	2.6	3.6	6.3	5.6	5.1	5.5		
1986			1.5	2.1	3.1	2.4	4.4	6.5	6.0	6.3		
1987				3.0	3.5	5.6	6.7	6.7	6.9	6.7		
1988				3.7	3.2	4.9	5.5	7.8	6.3	6.3		
1989				2.0	3.0	3.7	4.8	6.2	5.1	5.1		
1990	6.2	4.3	4.5	4.2	4.2	3.1	5.4	6.6	7.3	7.7	6.1	6.4
1991		3.4	3.0	3.8	3.0	3.8	4.7	6.1	6.1	6.6	5.3	6.4
1992	7.5	7.2	4.5	6.5	5.2	6.0	6.0	8.5	6.8	7.2		
Mean (1961-92)	**4.2**	**3.4**	**2.1**	**2.3**	**2.3**	**2.7**	**4.2**	**5.1**	**4.9**	**4.9**	**4.9**	**4.7**

Table 2-6
Lower Monumental Dam Monthly Average Secchi Depths (Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971			1.8	1.2	1.2	1.3	3.5	4.6	3.5	4.5		
1972				1.3	1.6	1.3	4.1	5.0	3.3	4.3		
1973				2.4	2.6	3.1	4.4	4.3	3.9	3.2		
1974				0.9	1.4	0.8	1.9	3.6	3.2	3.1		
1975				1.5	1.2	1.0	1.8	2.4	2.9	2.7		
1976				1.0	1.2	1.7	3.3	3.2	3.3	3.4		
1977				3.7	3.2	3.3	3.2	3.6	3.4	3.3		
1978				1.7	1.8	1.9	2.2	2.9	3.3	3.7		
1979				3.3	1.6	2.8	3.8	4.0	3.8	2.9		
1980				1.9	2.1	1.7	3.6	4.4	3.5	3.3		
1981				2.3	2.1	2.1	3.6	4.3	3.3	3.0		
1982				1.1	1.9	2.5	2.9	4.0	3.4	2.8		
1983				1.6	2.2	2.1	3.3	4.2	3.7	3.6		
1984				0.9	1.3	1.8	2.5	3.0	3.1	4.0		
1985				1.5	2.0	2.8	3.5	3.3	2.8	2.8		
1986				1.2	1.5	1.2	2.6	3.3	4.0	3.2		
1987				1.9	1.9	2.6	3.3	3.5	3.8	4.1		
1988				2.8	2.5	3.3	4.5	4.4	3.0	4.0		
1989				1.3	2.2	2.5	2.9	3.2	3.2	3.8		
1990	3.3	1.5	2.4	3.1	3.1	1.9	3.3	3.8	4.0	3.3	3.0	
1991			2.5	3.1	1.9	3.1	3.4	4.5	3.5	3.5	3.0	
1992				3.1	3.0	3.0	4.0	3.8	3.7	3.9		
Mean (1971-92)			**2.2**	**1.9**	**2.0**	**2.2**	**3.3**	**3.8**	**3.4**	**3.5**	**3.0**	

Table 2-7
Little Goose Dam Monthly Average Secchi Depths (Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970				2.9	3.0	2.3	4.2	5.0	4.8	4.4	4.7	3.8
1971			2.2	1.2	1.1	1.5	3.4	5.0	4.2	4.3	4.8	3.1
1972	2.5	1.5	0.8	1.3	1.8	1.5	4.2	5.0	4.4	4.9	5.0	3.8
1973	2.6	3.9	3.4	3.9	3.7	4.7	5.0	5.0	5.0	5.0	3.3	2.9
1974	2.3	2.0	2.2	1.6	2.1	1.0	3.2	4.8	4.7	4.6	4.8	5.0
1975	2.8	2.8	2.7	2.0	1.4	1.4	2.6	3.7	4.2	4.4		
1976				1.5	1.4	2.2	4.7	4.5	4.8	4.8		
1977				4.1	4.4	4.6	4.7	4.9	4.7	4.3		
1978				2.3	1.9	2.8	3.5	4.0	3.6	4.5		
1979				2.0	1.6	3.3	4.7	4.3	4.0	4.1		
1980				2.7	2.3	2.9	4.7	4.6	4.6	4.4		
1981				2.7	2.7	2.4	5.0	5.0	4.8	4.0		
1982				1.4	1.8	2.0	3.3	3.8	3.7	3.6	2.8	
1991				3.6	3.1	3.6	4.8	5.1	5.7	5.4	5.0	5.0
1992				4.3	4.5	5.1	5.3	5.9	5.0	5.8	4.6	
Mean (1970-92)	**2.6**	**2.5**	**2.2**	**2.5**	**2.5**	**2.8**	**4.2**	**4.7**	**4.6**	**4.6**	**4.4**	**3.9**

Table 2-8
Lower Granite Dam Monthly Average Secchi Depths (Feet)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975					1.4	1.2	2.3	4.7	4.9	4.6	4.3	2.6
1976	2.2	3.2	1.3	1.3	1.4	2.7	5.0	4.2	5.0	5.0	5.0	5.0
1977	4.9	5.0	5.0	4.6	4.5	4.3	5.0	5.0	5.0	4.9	4.7	1.8
1978	3.5	2.9	2.0	2.5	2.1	2.9	4.0	5.0	5.0	5.0	4.8	4.8
1979	4.9	2.2	2.1	2.3	1.9	4.4	5.0	5.0	5.0	5.0	5.0	5.0
1980	4.1	2.6	2.0	3.2	2.8	3.3	4.8	5.0	5.0	4.9	5.0	4.5
1981	4.2	2.7	3.2	3.2	3.2	2.5	4.8	5.0	5.0	4.9	4.3	3.8
1982	4.1	2.3	1.6	1.7	1.8	1.9	3.1	5.0	4.8	3.8	4.2	4.5
1983	3.6	3.0	1.5	1.6	1.7	1.9	4.0	4.9	3.8	4.3	3.7	4.1
1984	3.3	3.3	2.1	1.7	1.5	1.5	2.9	4.2	4.3	4.1	4.0	4.4
1985	5.0	4.5	2.3	1.9	2.9	3.2	5.0	5.0	4.9	4.9	4.7	5.0
1986	4.3	1.9	1.3	1.9	2.2	1.7	4.1	5.0	4.9	5.0	5.0	5.0
1987			2.7	3.5	3.5	5.0	5.0	5.0	5.0	4.8	5.0	4.9
1988		4.3	4.3	3.2	4.4	4.8	5.0	5.0	5.0	5.0	4.9	4.9
1989	5.0	5.0	1.9	2.1	3.1	3.3	5.0	5.0	5.0	5.0	5.0	5.0
1990			3.6	4.1	3.6	3.6	5.0	5.0	5.0	5.0	5.0	5.0
1991			3.1	3.5	3.5	3.5	4.5	5.0	5.0	4.9	5.0	4.9
1992			2.3	4.5	5.0	5.0	5.0	5.0	4.9	4.8	4.7	
Mean (1975-92)	**4.1**	**3.3**	**2.5**	**2.8**	**2.8**	**3.1**	**4.4**	**4.9**	**4.9**	**4.8**	**4.7**	**4.4**

Water transparency was generally lowest at each of the reservoirs from January through June. Daily minimum water transparency ranges were 0.1 to 2.0 feet at Lower Granite, 1.0 to 3.0 feet at Little Goose, 0.8 to 2.6 feet at Lower Monumental, and 0.1 to 3.0 feet at Ice Harbor reservoirs. Lower Monumental consistently displayed the lowest water transparency of the four reservoirs in the lower Snake River system. Maximum water transparency at each of the reservoirs usually occurred July to November. Daily maximum water transparency ranges were 4.3 to 7.0 feet at Lower Granite, 5.0 to 7.0 feet at Little Goose, 3.8 to 6.8 feet at Lower Monumental, and 4.5 to 8.0 feet at Ice Harbor reservoirs. Water transparency was often highest in Ice Harbor Reservoir, although measurements taken here also tended to show the greatest seasonal and inter-annual variation. Over the period of record, Lower Granite Reservoir consistently displayed the highest water transparency during most months. It should be noted that comparisons of maximum transparency are limited by the length of measuring sticks used at the various dams, and by the location where measurements were taken.

Water quality standards for the State of Washington specify that increases in turbidity shall not exceed 5 NTU when background levels are less than or equal to 50 NTU, and prohibit a >10% increase in turbidity when background levels are >50 NTU.

d. Contaminants

Contaminants, including metals and organics, from Columbia River industries are present throughout the Columbia River drainage. However, detailed studies of these materials have not been conducted in the lower Snake River reservoirs. Upstream irrigation and grazing area non-point source returns likely contribute organic residuals from pesticides and herbicides to the lower Snake River reservoirs (BPA *et al.*, 1993). This observation is consistent with the quality of irrigation return water, which constitutes a high percentage of the middle Snake River flow. An EPA report to the Northwest Power Planning Council (EPA, 1992) identified pesticide (*i.e.*, DDT and DDE) problems in the Snake River above Hells Canyon and in the Salmon and Clearwater Rivers. The EPA has classified the middle Snake River as having marginal water quality [*i.e.*, receiving moderate or intermittent pollution (BPA, 1985)].

Two major facilities discharge regulated waste into the Snake River basin near Lewiston, Idaho: Potlatch Corporation and the City of Lewiston. Potlatch Corporation is a pulp and paper mill, and the City of Lewiston discharges domestic waste. The reaction of chlorine from municipal water treatment plants with naturally-occurring phenolic compounds is a common source of dioxins in many commercial waterways. Pulp and paper mills that employ the bleached kraft process have been identified as imporant sources of dioxins in the Columbia River Basin (Parsons *et al.*, 1991). Heavy metals, including lead and zinc, often accompany releases from domestic sewage treatment plants. Each of the identified facilities has strict discharge limitations established by the U.S. Environmental Protection Agency.

Lowering the lower Snake River reservoirs will significantly increase the concentrations of sediment-associated toxics in the water column. However, it is not possible to predict the magnitude of these changes because of the paucity of data on contaminants present in the bed sediments. The most recent work on dioxins and furans in Snake River sediments appears in Pinza *et al.* (1992a,b,c). Pinza *et al.* (1992a,b) analyzed dioxins and furans in sediments dredged from an area near the confluence of the Snake and Clearwater Rivers. A total of 37 samples were collected from three retention ponds located near RM 134.7 (9 of the samples were analyzed for 21 PCDD and PCDF congeners). The three ponds contained ~400,000 yard^3 of sediments dredged between 1986 and 1987. Contamination of the sediments was suspected because dioxins and furans had been identified in effluent originating from a kraft pulp mill in Lewiston, Idaho. Effluent and sludge samples collected at the mill in 1988 were found to contain 71 to 79 parts per quadrillion (ppq) and 78 parts per trilling (pptr), respectively, of 2,3,7,8-TCDD. Pinza *et al.* (1992a,b) reported concentrations of total TCDD and TCDF in dredged sediments of 1.40 to 3.50 ppt and 0.39 to 14.0 pptr, respectively.

Pinza *et al.* (1992c) analyzed sediments collected from the Columbia, Snake, and Clearwater Rivers during 10 to 24 August 1991 for 21 PCDD and PCDF congeners. Sediments were collected from 23 Snake River locations ranging from RM 2 at Burbank to RM 139 near the confluence of the Snake and Clearwater Rivers. Sediments were collected from five proposed dredging sites (Ports of Burbank, Almota, Wilma, and Clarkston, and the Sheffler Grain Terminal) and from six river stations between RM's 119.56 and 131.62. The later sites were chosen because they contained fine-grained sediments and there was concern that potential contaminants could be resuspended by precipitation and wind and wave action during the 1992 test drawdown of the Lower Granite and Little Goose reservoirs.

e. Other Water Quality Parameters

While temperature, dissolved gas supersaturation, and turbidity may be the parameters of greatest concern in evaluating impacts of drawdown on anadromous fish, they typically are not the most visible indicators of degraded water quality along the lower Snake River. Eutrophication, a condition of deteriorating water quality caused by excessive supply of plant nutrients, organic matter, and silt, is a pervasive water quality problem in some storage reservoirs (Baxter, 1977). Run-of-the-river reservoirs such as are found in the lower Snake and Columbia Rivers are less likely to become eutrophic from a build-u of nutrients. Excessive growth of phytoplankton and/or aquatic plants, decreased water transparency, dissolved oxygen depletion, noxious odors, and reduced capacity due to siltation, are typical signs of eutrophication in reservoirs. Economic consequences of eutrophication are often far-reaching and include quality of domestic water supplies, fish kills, decreased production of commercially important fish and increased importance of undesirable species, and decreases in property and recreational values.

The Snake River, as are most other rivers in North America, is increasing in nitrate content (Smith *et al.*, 1987). Nitrification is associated with farming practices and atmospheric deposition.

Green *et al.* (1975) performed algal assays on 18 Snake River and tributary sites during 1971, as part of the National Eutrophication research Program, to determine the impact of domestic, industrial, and agricultural effluents upon phytoplankton growth. They concluded that high concentrations of nitrogen and phosphorus resulted in excessive growth of algae, including occasional thick blooms, which was the most visible water quality problem in the Snake River Basin. However, most of their stations were located within tributaries or sections of the upper and middle Snake River that are known to be impacted by domestic and agricultural runoff. Sampling stations at Ice Harbor Dam and near the confluence of the Snake and Clearwater Rivers were shown to have low algal productivity, while relatively high productivity was reported from a station near Wawawai, Washington (RM 113.7).

Funk *et al.* (1979) provide a detailed description of the physical, chemical, planktonic, bacterial, and aquatic plant characteristics of the lower Snake River reservoirs. They measured 26 physicochemical parameters, bacteriological water quality indicators, primary production rate, algae (including algal assays) and zooplankton, and aquatic macrophytes. Based on Chlorophyll *a* and C^{14} productivity measurements taken over a 3-year period (1975 to 1977), they classified the lower Snake River reservoirs as mesotrophic to mildly eutrophic. They reported no thermal or chemical stratification in any of the reservoirs. Not surprisingly, their study revealed that impoundment shifted algal assemblages to those species commonly found in reservoirs systems. Nitrogen and phosphorus were occasionally found at levels determined to be limiting to algae. Blooms of the bluegreen algae (primarily Aphanizomenon *flos-aquae*) were occasionally reported in mid- to late-summer, especially when total phosphorus levels were high due to increased runoff.

Scuba surveys were performed during late summer and fall of 1976 to describe biomass levels of aquatic macrophytes in three (excluding Ice Harbor) of the lower Snake River reservoirs (Funk *et al.*, 1979). The study was designed to identify environmental variables associated with the growth of aquatic macrophytes and to identify environmental variables associated with the growth of aquatic macrophytes and to identify areas with potential nuisance concentrations of plants. In all habitats sampled, large areas were found to be totally devoid of aquatic macrophytes. In the Lower Monumental Reservoir, aquatic macrophytes were absent over wide areas of wave-washed riprap and along rocky shores. Heaviest densities occurred on silt and sand bottoms; gravel and large rocks permitted little development, and riprap was found to be the least desirable substrate for plant growth. Plants were found at depths ranging from 2 to 9.5 feet. Depths >9.5 feet were completely devoid of plants. Shallow occurrences were believed to be restricted by turbulence and unstable substrates created by wave action, while growth at lower depths was limited by low light intensities. Funk *et al.* (1979) suggested that aquatic macrophyte distribution might increase over time as wave action shapes wider underwater terraces along the shoreline.

Non-point-source inputs from irrigation returns and grazing areas are considered a source of pollution within the Snake River watershed (IDHW, 1982). Pre-impoundment studies have demonstrated that, at times, the Snake and Clearwater Rivers were of poor bacterial quality and below state water quality standards for primary contact recreation (Falter *et al.*, 1973). Bacterial, biological oxygen demand (BOD), and chemical oxygen demand (COD) measurements indicate that water quality has improved to some degree since Impoundment (Funk *et al.*, 1979). However, this may largely be the result of improved municipal and industrial wastewater treatment. Little information on biological indicators of water quality and general nutrient status of the lower Snake River system has appeared since Funk *et al.* (1979). This is significant because the reservoirs are now several years older and conditions have changed remarkably during the last 15 years.

Organic matter in sediments, originating from the production of algae and macrophytes as well as from income via tributaries and other external sources, provides energy for bacteria, fungi, protozoa, and invertebrate organisms (Cooke *et al.*, 1986). Respiration by these organisms can result in oxygen depletion, most commonly in the bottom waters of storage reservoirs during periods of thermal stratification. Under conditions of oxygen depletion, sediments may release phosphorus and other compounds into the water column, which can stimulate algal production. Phosphorus has no gaseous component in its biogeochemcial cycle; therefore, water column concentrations of phosphorus are determined by its rate of income and settling losses to bottom sediments, by reservoir volumes and water renewal rates (hydrologic residence times), and by release rates from the sediments and decomposing macrophytes and other sources within the drainage basin (Cooke *et al.*, 1986; Wetzel, 1975).

Dissolved oxygen (DO) concentrations in most reaches of the lower Snake River appear to be consistently higher than the Washington State standard of 8 mg/L for Class A waters. Funk *et al.* (1979) report surface water DO levels for the Snake River ranging from 70 to 144% saturation. During periods of high flow, concentrations tended to remain at or above saturation levels. Annual lows for DO >25 feet ranged from 27 to 70% saturation. Oxygen stratification was uncommon, but was occasionally reported during periods of thermal stratification. Deepwater concentrations were found to be inversely related to hydraulic residence times. River flow and mixing patterns were shown to influence DO as well. Mixing of flows from the Clearwater and Snake Rivers occurs very slowly. Discharge volume is the principal determinant of mixing speed. At high flows (140,000 cfs) total mixing of the two flows has been calculated at RM 122. At moderately low flows (30,000 cfs), mixing has been shown to occur by RM 132.5 (Funk *et al.*, 1979).

B. Biological Components

1. Anadromous Fish

The single largest area of spawning and rearing habitat that remains in the Snake River drainage for salmon and steelhead lies upstream of Lower Granite Dam and downstream of the Hells Canyon complex, including the Clearwater, Grande Ronde, and Salmon River basins. To reach these areas, adult anadromous fish returning from the ocean must pass through eight run-of-river reservoirs and dams. Four of these structures are on the lower Columbia River, and four are on the lower Snake River. Hells Canyon Dam on the mainstem Snake River and Dworshak Dam on the north fork of the Clearwater River block all further upstream migration. Effective rearing habitat for juvenile anadromous fish occurs in tributaries and the mainstem above Lower Granite Dam and, to a degree, in the reservoirs above the lower Snake River Dams.

Presently, several species and runs of anadromous fish use the Snake River as a migration route and as spawning and rearing habitat (table 2-9). However, the number and relative abundance of anadromous fish in these runs have changed considerably (COE, 1992b). Present-day runs include spring, summer, and fall races of chinook salmon, sockeye salmon, steelhead trout, and American shad. Coho salmon from the Snake River once comprised about one-third of the upriver run of coho (Horner and Bjornn, 1981a), but no longer enter the system and are now extinct. Sockeye salmon runs to the upper Snake River were listed as endangered in December 1991. Spring, summer, and fall chinook salmon runs in the Snake River, now at historically low levels, were listed as threatened in May 1992. White sturgeon in the lower Snake River are no longer considered anadromous because hydroelectric dams limit their upstream and downstream movements.

Table 2-9
Life-Stage Activity of Anadromous Fish Species
Occurring Within the Affected Environment of the Snake River System

Species and Activity	Interval	Location
Sockeye		
Adult spawning	Oct-Nov	Redfish Lake
Egg incubation	Nov-March	Redfish Lake
Juvenile rearing	April-April	Redfish Lake
Juvenile outmigration	April-May	mainstem
Adult upstream migration	June-Oct	mainstem
Fall Chinook		
Adult spawning	Oct-Dec	primarily above LGR Reservoir; limited spawning below LGR, LGO, and LMO
Egg incubation	Nov-Mar	mainstem
Juvenile rearing	Apr-Jun	mainstem
Juvenile outmigration	Jun-Jul	mainstem
Adult upstream migration	Aug-Oct	mainstem
Spring/Summer Chinook		
Adult spawning	Aug-Oct	tributaries
Egg incubation	Sep-Mar	tributaries
Juvenile rearing	Mar-Jun	tributaries
Juvenile outmigration	Mar-Jun	mainstem
Adult upstream migration	Mar-Aug	mainstem
Steelhead		
Adult spawning	Feb-Apr	tributaries
Egg incubation	Mar-Jun	tributaries
Juvenile rearing	Jun-Apr	tributaries
Juvenile outmigration	Apr-Aug	mainstem
Adult upstream migration	Jul-Dec	mainstem

American Shad		
Adult spawning	Jul-Aug	Ice Harbor
Egg incubation	Jul-Aug	Ice Harbor
Juvenile rearing	Aug-Oct	McNary Reservoir
Juvenile outmigration	Oct-Nov	mainstem
Adult upstream migration	Apr-Aug	mainstem
Pacific Lamprey		
Adult spawning	Mar-Apr	mainstem
Egg incubation	April	mainstem
Juvenile outmigration	Apr-Jul	mainstem
Adult upstream migration	May-Sep	mainstem

The upstream passage of chinook salmon has, historically, been a continuum altered with time by overfishing and environmental degradation. Today, the terms "spring," "summer," and "fall" chinook salmon are arbitrary groups based on timing of the upstream run as the fish enter the mouth of the Columbia River. In actuality; some "spring run" chinook salmon may enter the river after the cutoff date and thus be classified as "summer run" fish, "summer" fish may enter during the "spring" time period and also be misclassified. Also, dates of entry at the river mouth may differ from the dates that fish reach Bonneville Dam. For example, spring chinook salmon do not generally appear until mid-March, while counts of summer chinook salmon begin 1 June at Bonneville Dam. Counts at upriver dams, including those on the lower Snake River, also have cut-off dates to arbitrarily separate returning groups. Run timing or migration dates used to classify the three runs of chinook salmon vary by dam because of the distance that fish must migrate before ascending the next facility.

In the Snake River drainage, fall chinook salmon spawn at lower elevations, generally mainstem areas, and migrate to sea as subyearlings. Spring and summer chinook salmon spawn in smaller tributaries at higher elevations and outmigrate as yearlings (Waples *et al.*, 1991b). Elevation appears to be the key factor influencing timing of the return run and spawning for spring and summer chinook salmon (Matthews and Waples, 1991).

It is now known that spring and summer runs of chinook salmon to the Snake River are genetically distinct from the fall run. In addition, the fall run to the Snake River is genetically distinct from fall run chinook of the upper Columbia River (Chapman *et al.*, 1991). These groups have responded differently to fishing pressure, environmental changes, and hatchery practices. Because fall-run chinook salmon and spring- and summer-run chinook salmon use different spawning areas in the Snake River system, they are reproductively isolated (Waples *et al.*, 1991b). However, it is possible that substantial gene interchange takes place between spring- and summer-run fish (Matthews and Waples, 1991).

Redd counts of spring and summer chinook salmon on spawning areas in the Snake River system indicate a decline in escapement from the late 1950's through the late 1970's, an increase during 1980 to 1988, and a sharp decline in 1989 and 1990 (Chapman *et al.*, 1991). Fall chinook salmon escapements at Ice Harbor Dam declined sharply from a range of 10,000 to 20,000 in the late 1960's to just over 1,000 in most years during 1976 to 1981, and then increased to 3,000 to 6,000 by the late 1980's, although the 1990 count was only 391 fish (Chapman *et al.*, 1991).

a. Spring Chinook

Adult spring chinook salmon migrate upstream over the four dams along the lower Snake River to spawn in small streams at high elevations (Matthews and Waples, 1991). Five major spawning and rearing basins now support these runs. The larger are the Clearwater, Grande Ronde, and Salmon Rivers; the smaller are the Tucannon and Imnaha Rivers. Most large tributaries of the Salmon River Basin probably contained spring chinook in the upper segments (and summer chinook in the lower segments) before overfishing and habitat changes took place. Historically, the Snake River produced about 39% of the adult spring chinook salmon (and 45% of the adult summer chinook salmon) that once returned to the Columbia River system (Matthews and Waples, 1991).

Adult spring chinook salmon enter the Columbia River in March, April, and May. They cross Bonneville Dam from mid-March through the end of May, and Ice Harbor Dam about 2 weeks later (Bjornn and Perry, 1992). By July, most of the spring run has passed through the lower Columbia and Snake Rivers. The cut-off date for tally of spring chinook at Lower Granite Dam is June 15 (Chapman *et al.*, 1991).

The spring run usually returns to the Snake River earlier than the summer run, and typically spawns higher in the watershed and earlier in streams that have cool temperatures. In some areas, spring and summer runs may occupy the same spawning grounds because their migration times overlap. Gene flow between the spring and summer runs cannot be ruled out; thus, they could not immediately be classified as different stocks for listing under the Endangered Species Act (ESA). Other considerations may yet require them to be listed as two stocks (runs) under the ESA (COE, 1992b).

Juvenile spring chinook characteristically rear one winter in upstream tributaries, or in the mainstem Snake River above Lower Granite Dam, and migrate seaward as yearlings from about March through June. Most hatchery-produced spring chinook salmon tend to remain 2 years at sea before returning, while most wild spring chinook tend to remain 3 years (Chapman *et al.*, 1991).

Regional trends in spring chinook stocks in the Columbia-Snake River system show different patterns today. Recent counts at Bonneville and McNary Dams indicate that upriver spring chinook stocks (both hatchery and wild) reached lows in the early to mid-1980's, then rebounded until 1989 when they again declined, followed by a slight increase in 190 and 1991 (PFMC, 1992). Total escapements by wild and hatchery spring chinook to the upper basin (above McNary) increased sharply in 1992 to the highest level since 1988 (PFMC, 1992; FPC, 1992). Hatchery spring chinook stocks below Bonneville Dam have remained health; the largest in-river run since before 1971 occurred in 1990 and the 1991 run remained moderately high (PFMC, 1992). The Snake River wild chinook population, as indicated by the number of spawning redds for summer and spring chinook combined, declined from 13,000 redds in 1957 to 620 in 1980. The number increased gradually through 1988 to 3,395 redds, then declined again to 1,088 redds in 1989 and 1,224 in 1990 (Matthews and Waples, 1991). Recent counts were 1,200 and 1,595 redds in 1991 and 1992, respectively (published and unpublished WDF, ODFW, and IDFG data). Counts of natural-spawning spring chinook over Lower Granite Dam (constructed in 1975) averaged 27,200 fish from 1975 to 1979. Since 1979, estimated runs have averaged 6,900 fish, with a low of 2,400 in 1991 (NPPC, 1992b).

b. Summer Chinook

Adult summer chinook salmon begin entering the Columbia River in late May, June, and July, pass Bonneville Dam during June and July, and pass Ice Harbor Dam from mid-June to mid-August (Bjornn and Perry, 1992). The earlier part of the summer chinook run usually enters the Snake River system, and most have passed over the mainstem dams by mid-August. The cut-off date for counts at Lower Granite Dam is 17 August.

Summer chinook salmon spawn in upstream tributaries of the Snake, Salmon, and Clearwater Rivers, generally at lower elevations than spring chinook. The Salmon River historically has been favored spawning habitat (Horner and Bjornn, 1981b). The Clearwater River was also a prominent spawning area for summer chinook salmon, and small numbers still spawn there today.

Juvenile summer chinook salmon, as do juvenile spring chinook, characteristically rear in tributaries above Lower Granite Dam in early spring, and move seaward as yearlings from March through June (COE, 1992b). Most of these yearlings pass mainstem dams on the lower Snake River during their outmigration in April and May.

Studies in 1987 showed that juvenile chinook salmon >75 mm, presumably outmigrants of the spring and summer runs, appeared during the spring near the forebay of Lower Granite Dam (Bennett *et al.*, 1988). Day catches were high and night catches were low, suggesting that the outmigrants used the lower reservoir during the day as a staging area. Generally, these juveniles appeared in Lower Granite Reservoir earlier in the spring that would be expected from a normal, active outmigration (Buettner and Nelson, 1990).

There is a lingering legacy of human effort to enhance production of summer and spring chinook salmon in the upper Snake River Basin through supplementation and stock transfers, thus potentially altering gene pools. The basin most widely impacted was the Clearwater River. Indigenous chinook salmon populations were virtually or totally eliminated from the Clearwater River by construction and operation of Lewiston Dam (1927 to 1940). Subsequent efforts to restore Snake River runs include transfers of eggs from the Salmon River and massive outplants of juveniles from hatcheries throughout the Columbia River Basin (Matthews and Waples, 1991). On the other hand, some streams are known to have received only minimal numbers of outplants (*e.g.*, the Tucannon and Imnaha Rivers and Capehorn Creek in the middle fork of the Salmon River). Also, a number of streams in most other basins have no record of outplants.

Bonneville Dam counts indicate that upriver summer chinook populations rebounded somewhat from low numbers in the early 1980's to a slight peak in 1987, and have been declining since that time (PFMC, 1992). About 65% of these fish are wild stock (CBFWA, 1991a), and so this trend indicates a decline in wild runs. Natural spawning summer chinook decreased substantially from 1973 to 1979. Average counts over Lower Granite Dam, from 1975 to 1978, average 8,500 fish. Since 1979, estimated counts of natural stocks have averaged 3,100, with a low of 2,700 in 1988 (NPPC, 1992b). Snake River stocks showed an increase in escapement in 1990 over record low numbers in 1989 but decreased again in 1991 (PFMC, 1992). One of the lowest escapements on record occurred in 1992, with only 3,000 hatchery and wild fish passing over Lower Granite Dam during the counting interval (FPC, 1992).

c. Fall Chinook

Adult fall chinook salmon enter the Columbia River in July, and pass upstream over mainstem dams until the end of November. Most of the fall run consisting of "upriver brights" migrates from mid-August to November. Many of these fish are headed for the Hanford Reach (Chapman *et al.*, 1991). The relative proportion of fall chinook salmon entering the Snake River has declined to <10% of the McNary Dam escapement during the last 20 years (Dauble and Watson, 1990; figure 2-1). Fall chinook salmon characteristically spawn late in the fall (October to November), and most juveniles move seaward soon after emergence the first spring as subyearlings. Some subyearlings produced by fall chinook that spawn in the Snake River system now pause and rear during outmigration in lower Snake and Columbia River reservoirs, particularly in Lake Umatilla above McNary Dam (COE, 1992b).

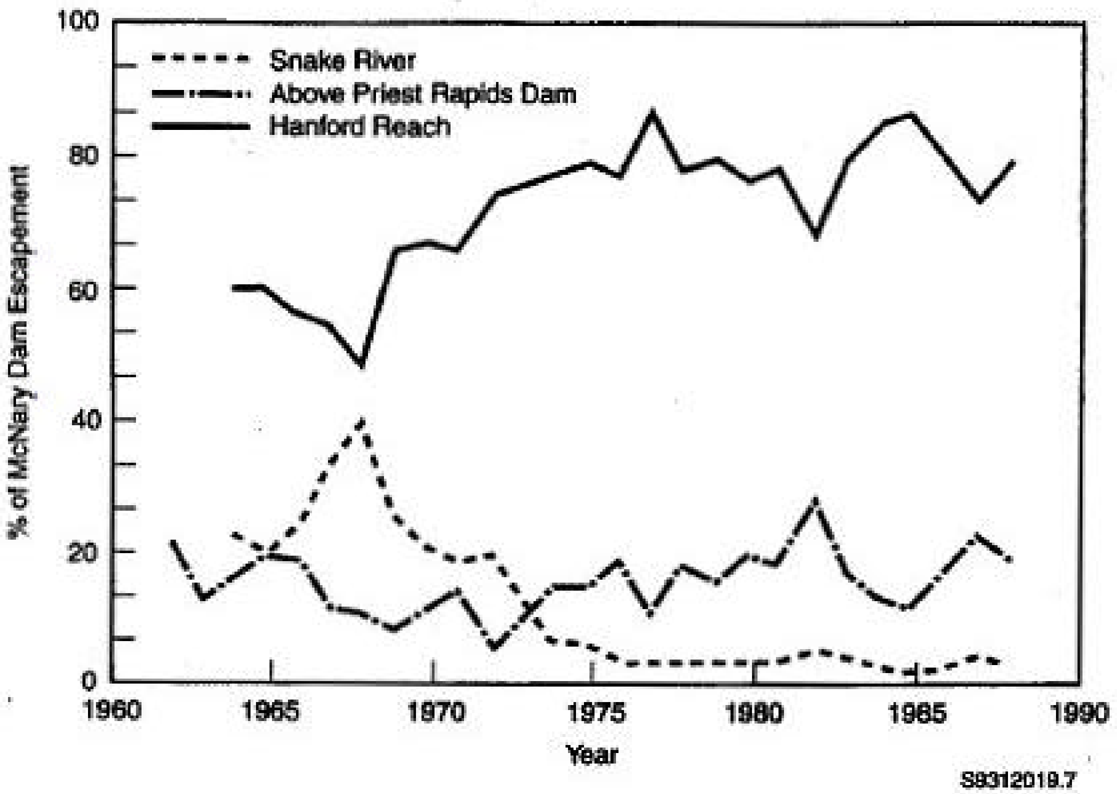

Figure 2-1. Destination of upriver stocks of fall chinook salmon passing McNary Dam (from Dauble and Watson, 1990)

Before Brownlee Dam was completed in 1958 on the upper Snake River, most fall chinook salmon entering the system spawned below Swan Falls Dam in the uppermost reaches (Fulton, 1968). Only limited spawning activity was reported below RM 439 (Waples *et al.*, 1991b). Thus, the major spawning area for fall chinook in the Snake River system was the 30-mile stretch between Marsing, Idaho, and Swan Falls Dam. Completion of Brownlee Dam in 1958, followed by Oxbow Dam in 1961 and Hells Canyon in 1967, blocked further access to this area.

Fall chinook salmon now spawn in the Snake River along about 103 miles of the mainstem from Hells Canyon Dam to the pool behind the Lower Granite Dam. They occasionally spawn in the lower Clearwater and Grande Ronde Rivers, and a few now spawn regularly in the lower Tucannon River (COE, 1992b; Chapman *et al.*, 1991; Waples *et al.*, 1991b). A few fall chinook salmon also spawn below the tailraces of Lower Granite, Little Goose, and Lower Monumental Dams (Bennett *et al.*, 1992; Dauble *et al.*, 1994).

Subyearling fall chinook salmon in the Snake River system typically outmigrate before mid-July. The lower Grande Ronde, Clearwater, and Salmon Rivers, and the lower portions of several of their tributaries, become too warm in the summer to support rearing chinook salmon (Chapman *et al.*, 1991). Further, high water temperatures may limit juvenile fall chinook salmon rearing in reservoirs along the mainstem Snake River after July (Waples *et al.*, 1991b). For example, surface temperatures exceed 20ºC throughout Little Goose Reservoir by mid-July (Bennett *et al.*, 1992). These conditions may also have adverse effects on returns of adult fall chinook entering, or attempting to enter, the lower Snake River during August and September.

Studies started in 1987 showed that juvenile fall chinook are common along low-gradients, sandy shorelines in Lower Granite reservoir during the late spring (Bennett *et al.*, 1990; Buettner and Nelson, 1990). Presumably, many subyearlings pause in shallow inshore areas, at or soon after the start of their outmigration, to feed and grow. The extent to which subyearling fall chinook salmon use shoreline ecosystems in other reservoirs of the lower Snake River is not known. Any young fall chinook that appear in Lake Wallula in the mid-Columbia River above McNary Dam are a mix composed of wild stocks from the Snake River and the Hanford Reach of the Columbia River, and of massive releases from several hatcheries on both streams. Having reached Lake Wallula from upriver areas, most subyearling fall chinook from wild stocks may have evolved to become active outmigrants. Subyearling chinook usually predominate in collection facilities at McNary Dam on June 1 (Mobbs, 1986), coinciding with high spring flows.

During the spring of 1991, the abundance of subyearling fall chinook salmon was studied in Little Goose reservoir with emphasis on the type of habitat occupied and timing (Bennett *et al.*, 1991). These fish were believed to be progeny of fall chinook salmon that spawned naturally in the Snake River above Little Goose Dam and in the lower Clearwater River, and possibly in the Little Goose pool. Beach seine collections (the only method used) showed that subyearlings were most abundant along the shoreline during June. Numbers decreased after early July, although some fish were collected until mid-July. The greatest numbers were taken from Almota to Central Ferry (Reach 2), a central region in the reservoir extending downstream from RM 103.5 to RM 83.5.

Habitats from which subyearling chinook salmon (*e.g.*, fall chinook) were collected in this study varied (Bennett *et al.*, 1991). Most came from inshore areas where the substrate was primarily sand or mud and sand bottom, the bottom had a low-grade slope, and the current velocity was greatly reduced. Surface temperatures throughout much of Little Goose Reservoir exceeded 20ºC by mid-June. No subyearlings were collected by beach seine during August, although some fish continued to be taken at the collection facility at Little Goose Dam. This suggests that some subyearlings moved offshore before they began to migrate downstream.

Life-cycle information, much of it derived from studies elsewhere, indicates that young fall chinook salmon typically move downstream from the Snake River in early spring almost immediately after they emerge from streambed gravel. Many of these fish linger temporarily along shoreline areas where current velocities are low to feed on aquatic insects, gain energy, and grow before continuing outmigration. This behavior is characteristic of many fall chinook salmon runs throughout the Columbia River system, including the Hanford Reach (Becker, 1973, 1985; Dauble and Watson, 1990; Mullan, 1987). Water temperatures approaching 20ºC in the lower Snake River during late spring may prompt continued outmigration.

A broodstock program designed to preserve genetic integrity and enhance production of fall chinook salmon was initiated in the late 1970's. The program has operated from the Lyons Ferry Hatchery since 1984, with its broodstock consisting of hatchery and wild adults taken at Ice Harbor Dam and adults that return to the hatchery (Waples *et al.*, 1991b). The program has encountered unexpected complications. Strays from hatcheries producing upper Columbia River fall chinook salmon have appeared in the Snake River in increasing numbers. Such strays constituted almost 40% of the adults used for broodstock at the Lyons Ferry Hatchery in 1989. The next year, in 1990, a high percentage of the fall chinook salmon adults taken at Lower Granite Dam and on spawning grounds were estimated to come from hatcheries, including strays from hatcheries using upper Columbia River fall chinook salmon (including releases to the Umatilla River). The result is that genes from upper Columbia River stocks of fall chinook salmon have introgressed strongly into the Snake River system (Waples *et al.*, 1991b).

The historical runs of fall chinook for the Snake River are unknown, but were probably a large part of the total chinook runs. Abundance decreased early in the century after construction of Swan Falls Dam in 1910 blocked 150 miles of spawning habitat. By 1958, another 165 miles of spawning and rearing habitat were lost with the construction of Brownlee Dam. Other dams, including Hells Canyon, completed in 1967, cut off access to prime upstream spawning areas. The four lower Snake River projects also reduced spawning area. Estimated annual escapement went from an average of 72,000 fish in 1938 to 1949 to an average of 29,000 fish during the 1950's (Waples *et al.*, 1991a). By 1964 to 1968, average counts over Ice Harbor Dam were 13,000 fish. Through 1980, all fall chinook in the Snake River Basin were of wild origin. The Snake River wild fall chinook gradually declined from these levels to about 1,000 in the mid-1970's. Escapement ranged from 200 to 400 fish during 1983 to 1989, with a sharp decline to an estimated 78 fish in 1990 (Waples *et al.*, 1991a). However, in the last 2 years, estimated wild escapement has increased to 318 and 533 (preliminary estimation) in 1991 and 1992, respectively, over Lower Granite Dam. The trend for Lyons Ferry Hatchery stock, the only active fall chinook hatchery on the Snake River, has been a decreasing return (Waples *et al.*, 1991a).

d. Sockeye Salmon

The sockeye run to the Snake River was listed as endangered in December 1991 by the National Marine Fisheries Service. Returns are currently limited to Redfish Lake in the Stanley Basin of Idaho, 900 miles upriver from the Pacific Ocean. These fish migrate upstream approximately 800 to 900 miles, compared to less than 100 miles for sockeye salmon stocks in more northern areas of the range.

Based on counts from Priest Rapids Dam, upper Columbia River wild stocks of sockeye salmon, excluding the Snake River, have remained health but have continued to decline since the large runs of 1984 and 1985. Recent sockeye returns to the Columbia River have ranged from about 50,000 to 200,000 fish. Historically, about 650,000 sockeye were produced in the system, the majority (~500,000) in the upper Columbia River (NPPC, 1986).

The historical run size of sockeye from the Snake River was estimated to be about 150,000 fish (NPPC, 1986). Much of the original rearing habitat, however, is no longer accessible. Current estimates of potential habitat availability for escapement to the remaining Sawtooth Valley lakes in the upper Salmon River is about 6,000 (CBFWA, 1991a). Much of this habitat, however, is currently inaccessible to sockeye. This lake has an estimated potential to produce 1,500 spawning adults (Chapman *et al.*, 1990), but counts as low as 11 sockeye passing the weir at Redfish Lake were observed in 1961. The returns of sockeye destined for Redfish Lake have averaged <1,000 fish since 1970, and <100 since 1981 (Chapman *et al.*, 1990). Based on counts past Ice Harbor, escapement averaged <20 fish from 1985 to 1993. Only two fish returned in 1989, and none in 1990. In 1991, eight sockeye passed Lower Granite Dam, and four returned to Redfish Lake. In 1992, 14 fish passed Lower Granite Dam, but only one arrived at Redfish Lake. Eight sockeye reached Redfish Lake in 1993. Clearly, returns have declined to historical low numbers (figure 2-2). Snake River sockeye presently receive special attention from resource management agencies and are the focus of the Sawtooth Valley Project funded by Bonneville Power Administration.

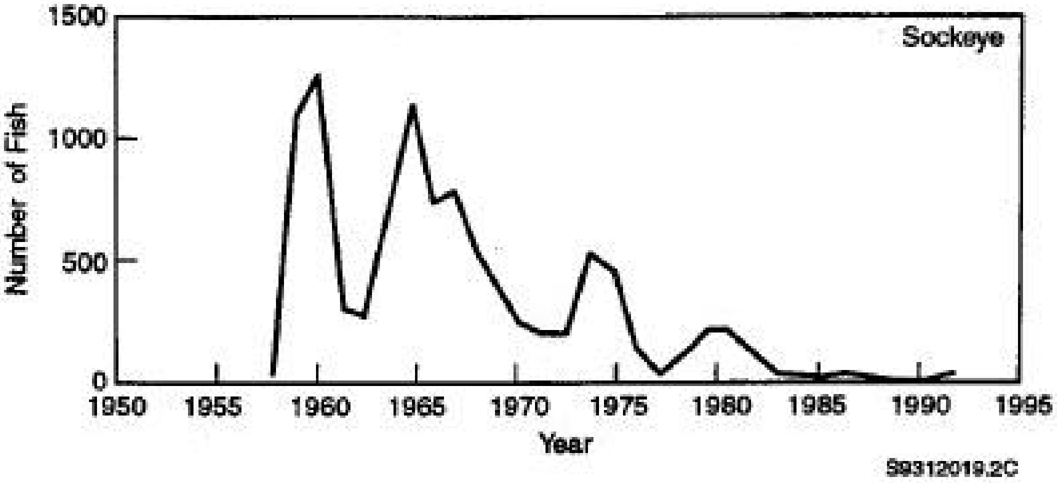

Figure 2-2. Fishway counts of sockeye salmon at Ice Harbor Dam (before 1975) and Lower Granite Dam (after 1974).
(Modified from Waples *et al.*, 1991; Matthews and Waples, 1991; COE, 1991)

Adult sockeye salmon begin entering the Columbia River in April, and continue to move upstream through October. Most of the run migrants upriver from June through early August. Sockeye salmon typically spawn and rear in systems with lakes, but today only a remnant run returns to the Snake River system (CBFWA, 1991a; Chapman *et al.*, 1990). Adult sockeye usually arrive at Redfish Lake from mid-July through August to spawn along beaches during October. Juvenile sockeye salmon rear in Redfish Lake 1 to 2 years before outmigrating. Outmigration occurs from April through mid-May. The sockeye smolt migration at Lower Granite Dam is later (7 to 32 days, mean=18 days) than that of other anadromous smolts. In recent years, most outmigrants have passed Lower Granite Dam by mid-June (Chapman *et al.*, 1990).

In the Snake River system today, only Redfish Lake is open to use by sockeye salmon (Chapman *et al.*, 1990; DOE, 1992; Waples *et al.*, 1991a). Populations of the non-migratory form of sockeye salmon, or kokanee, exist in Redfish, Alturas, Pettit, and Stanley on the Snake River system and in a few other lakes on other tributaries. Alturas Lake appears to produce some anadromous smolts as well (Chapman *et al.*, 1990). The Payette Lakes and Wallowa Lake are completed blocked to sockeye by hydropower or irrigation dams. Historically, sockeye salmon runs to the lakes of the Payette River drainage could have greatly exceeded those of the upper Salmon River because the size of available nursery areas was larger (Chapman *et al.*, 1990).

The estimated spawning capacity of Redfish Lake for migratory sockeye salmon is 1,500 adults, far more than its present use (Chapman *et al.*, 1990). Time and location of spawning in Redfish Lake now apparently prevent anadromous sockeye salmon and non-migratory kokanee salmon from interbreeding (DOE, 1992). After leaving spawning areas, however juvenile fish mingle in rearing areas n Redfish Lake. Thus, there may be interspecific competition between juveniles. There is no practical way of distinguishing juvenile anadromous and non-anadromous sockeye in rearing areas.

Some researchers believe that kokanee salmon contributed greatly in recent decades to the yield of sockeye salmon smolts from Redfish Lake via the natural phenomenon of anadromy. Specifically, they believe that most of the anadromous sockeye returning to Redfish Lake in 1955 to 1966, and nearly all of them in the 1980's, originated with young kokanee that migrated to the ocean (Chapman *et al.*, 1990). If this contention is correct, most of the sockeye smolts that now outmigrate pass Lower Granite Dam represent anadromous kokanee. Presumably, the kokanee population in Redfish Lake continues to produce anadromous smolts at numbers that do not differ significantly from those produced during 1955 to 1966 (Chapman *t al.*, 1990).

Those charged with determining the qualification of sockeye salmon runs to the Snake River for protection under the U.S. Endangered Species Act took an opposite, conservative view. As stewards of a public resource they were obligated to assume that adult sockeye salmon returning to Redfish Lake descended from the original gene pool of anadromous fish (Waples *et al.*, 1991a). If they assumed that recent anadromous sockeye in Redfish Lake were derived from kokanee, and the assumption proved wrong, the original anadromous gene pool could easily become extinct.

Resident fish, including rainbow trout and other salmonid species introduced from hatcheries for the sport fishery, also compete with juvenile sockeye salmon in Redfish Lake for rearing habitat and food. Some of these introductions may grow into predators on smaller sockeye. There is no evidence that juvenile sockeye hold and rear in reservoirs of the lower Snake River during outmigration. However, juvenile *O. nerka* (assumed kokanee from Dworshak) were collected from the first mile or so below Lower Granite Dam during the 1992 reservoir drawdown test (Wik *et al.*, 1993).

The current low returns of sockeye salmon to the upper Salmon River are due, in part, to actions of the Idaho Fish and Game Department (IDFG). This agency allowed the construction of Sunbeam Dam about 20 miles downstream of Redfish Lake in 1910, which impeded further passage of anadromous fish. Sunbeam Dam was eventually breached by dynamite in 1934; in the meantime, however, the original gene pool of anadromous sockeye returning to Redfish Lake had been placed in peril (Waples *et al.*, 1991a). The IDFG poisoned and eradicated kokanee sockeye in Yellow Belly, Pettit, and Stanley lakes and installed migration barriers to convert them to trout production. IDFG agents also introduced kokanee from Montana and Lake Pend O'reille to Redfish Lake in the 1940's, and sockeye salmon from Babine Lake to at least Alturas and Stanley lakes in the early 1980's (Chapman *et al.*, 1990).

e. Coho Salmon

From 1962 to 1979, coho salmon produced in the Snake River drainage made up about one-third of the upriver coho run in the Columbia River (Horner and Bjornn, 1981a). From 1967 to 1979, the number of adult coho salmon (excluding jacks) counted over Ice Harbor Dam averaged 1,300 fish, ranging from 3,800 fish in 1968 to 130 fish in 1979 (Horner and Bjornn, 1981a). Counts began at Ice Harbor Dam in 1962. The coho run to the Snake River system is now extinct.

The early literature gives no evidence of coho salmon in the upper Snake River system, the area now above Hells Canyon Dam (Fulton, 1970). During early settlement times, coho salmon were believed to have spawned primarily in the lower Clearwater River, and in such tributaries of the Grande Ronde River as the Wenaha, Lostine, and particularly the Wallowa (Fulton, 1970; Homer and Bjornn, 1981a). Some ere reported from the Tucannon River, the lowest Snake River tributary. Typically, coho salmon do not migrate far from freshwater to spawn, indicating that former returns to the Snake River were at the limits of their migrating range. After hatching, most juvenile coho spend a year rearing in freshwater before outmigrating in May of their second year. Evidence suggests that upriver runs were destroyed largely by impassable dams on migration routes, unscreened irrigation diversions on tributaries, and overharvest of adults in the lower Columbia River (Horner and Bjornn, 1981a; Mullan, 1983).

f. Steelhead Trout

The summer run of steelhead trout, in contrast to the winter run, is the only race passing the Bonneville pool and migrating into the upper Columbia River system. This run is separated into Group A and Group B on the basis of historical features. Group A fish were historically present in all upriver basins, including the Snake River drainage, while Group B fish were produced only in the Clearwater and Salmon Rivers of the Snake River drainage (Bjornn and Perry, 1992; CBFWA, 1991a). Historical levels are shown in figure 2-3.

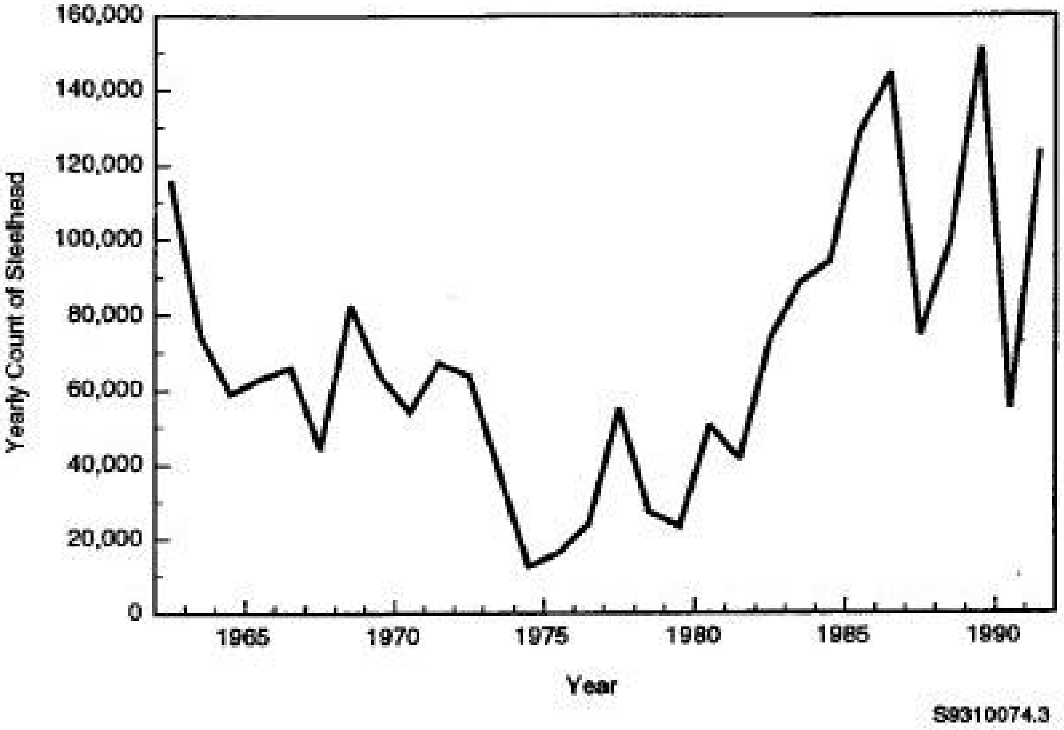

Figure 2-3. Monthly Counts of Steelhead at Ice Harbor Dam, 1962 to 1991

The summer run of steelhead starts to enter the Columbia River in February. Upriver passage at mainstem dams continues during spring, summer, and fall through December. Most Group A fish move into the Columbia River from June to early August, while Group B fish enter from late August into October (CBFWA, 1991a). Upriver runs of steelhead are noted for interdam "dawdling" where returning adults cease or delay their upstream movement (usually in response to high water temperatures) between Bonneville and McNary Dams. For this reason, most adult steelhead do not enter the Snake River until September (Bjornn and Perry, 1992). Runs of Group A and Group B fish are intermingled by the time they enter the Snake River.

Unlike chinook and sockeye salmon that spawn in the fall, returning steelhead do not spawn until early spring the following year. Group A steelhead, historically reproduced in lower-elevation tributaries (*e.g.*, Tucannon River) in the Snake River system and in smaller tributaries of the Clearwater and Snake Rivers, Grande Ronde River, Imnaha River, tributaries above mid-Snake River dams, and spring-fed streams such as the Lemhi and Pahsimerio Rivers. These fish spawn in April after runoff of snowmelt. In contrast, Group B steelhead historically reproduced in larger, high-elevation tributaries of the Clearwater and Salmon Rivers (*e.g.*, North and South forks of the Clearwater River, Lochsa and Selway Rivers, south and middle forks of the Salmon River, and the upper Salmon River near Stanley, Idaho). These fish usually spawn after runoff of snowmelt in late April and May (Bjornn and Perry, 1992).

Spawning areas downstream of Lower Granite Dam are limited for steelhead, with the exception of the Tucannon River. The Palouse River is blocked 10 km upstream of its outlet by Palouse Falls, and there is no record of use by salmon or trout in the lower reaches (Fulton, 1970). A few adult steelhead still enter and spawn in Alpowa Creek (RM 130.6), emptying into Lower Granite pool during April and May. Steelhead may use other smaller tributaries for spawning also; for example, a few adult steelhead were found in Almota Creek, a tributary to Little Goose pool, in April 1992 (Dauble and Geist, 1992).

Juvenile steelhead outmigrate as yearlings primarily from March through June, with the majority passing downriver in April and May (COE, 1992b). Later outmigrants may encounter unfavorably high water temperatures in lower Snake River reservoirs. Many yearling steelhead are known to overwinter in mainstem reservoirs, including tributaries of the Bonneville pool, and pass seaward in early spring. Juvenile steelhead show competitive dominance over juvenile chinook salmon in microhabitats shared by both species (Li *et al.*, 1987).

Recent studies in Lower Granite reservoir show a high extent of residualism by juvenile steelhead of "rainbow trout" (Bennett *et al.*, 1988, 1990). The origin of these fish (from hatchery or wild stocks), or whether they were predominantly resident (rainbow) or anadromous (steelhead) forms, was not indicated. Many of these fish apparently smolt and move seaward next year, showing the anadromous feature characteristic of steelhead.

g. American Shad

Adult American shad (*Alosa sapidissima*) enter the lower Columbia River in April and continue to pass upstream through August. Most pass Bonneville am from mid-May through July, and Ice Harbor Dam from mid-June through mid-July. The upriver distribution of shad has extended as their population numbers increased (COE, 1992b). Today, large numbers of shad spawn below Ice Harbor Dam, and a few spawn above Lower Granite Dam. In 1989, for example, a total of 119,199 shad were counted at Ice Harbor Dam (COE, 1992b). Shad populations continue to increase at Snake River dams in recent years, with nearly 22,000 adults counted at Lower Granite Dam in 1992.

Each female American shad, usually accompanied by several males, releases large numbers of eggs near the surface (Wydoski and Whitney, 1979). The eggs are semi-buoyant, and pass downstream in the current as they develop. Larvae and young rear in reservoirs. When about 4 inches long, the outmigrate during the early winter after water temperatures decline. Downstream movement ranges from October through December. Most young shad pass Columbia River dams on their way downstream in late October and early November.

The American shad was first introduced to the Sacramento River from its native Atlantic coast in 1871. It soon spread to other rivers along the Pacific coast, including the Columbia River. The impoundment behind dams, availability of fish ladders, and favorable reservoir conditions for rearing apparently allowed American shad to spread up the Columbia River and into the Snake River. Larval shad have been collected in Lower Granite reservoir, demonstrating that some adult shad now spawn there (Bennett *et al.*, 1991). Mortality of shad larvae in freshwater is high. Specific littoral habitats, such as eddies and backwater areas where river flows are reduced, are critical to the survival of shad year-classes (Crecco and Savoy, 1987).

The rapid expansion of shad in the Columbia River may interact adversely with anadromous fish runs. High densities of adult shad in fish ladders during May, June, and July restrict access to fish ladders by returning salmonids. Yearling shad in the Columbia River estuary compete for the same food organisms as salmonid smolts, and their presence may lead to the development of larger smolt-predator populations. Returning adult shad also prey on outmigrating salmonid smolts (Chapman *et al.*, 1991).

h. Pacific Lamprey

Mature Pacific lamprey (*Lampetra tridentata*) enter the Columbia River in late spring and early summer. They pass dams by ascending the walls with aid of their sucker-like mouths or by passing through navigation locks (*e.g.*, at McNary Dam; Mullan *et al.*, 1986). Thus, counts at fish ladders have limited value. Adult lampreys that reach a suitable spawning tributary deposit and fertilize their eggs the following March or April (Wydoski and Whitney, 1979). Both sexes build a depression or nest of riffles in the sandy gravel, and die after spawning. The eggs hatch in 2 to 3 weeks. The young lampreys, or ammoecetes, burrow in the mud somewhere downstream where they remain for up to 5 or 6 years. After transforming to the adult phase, they migrate to the Pacific Ocean with the spring freshet. Peak downstream movement occurs between April and June.

The extent to which Pacific lamprey now occur in the mainstem Snake River is unknown. Upriver populations may be at reduced levels (Simpson and Wallace, 1982), largely because dams have restricted their upstream movement and inundated former spawning and larval rearing areas in the mainstem. Variable numbers of returning adult lampreys are still seen at dams on the lower Snake River. Their reduced abundance in the lower Snake River may have slowed the growth of white sturgeon, which typically feed on them (Coon *et al.*, 1977). Some amnoecetes were exposed on mudflats of Lower Granite reservoir during the March 1992 drawdown (Dauble and Geist, 1992). Small, sexually mature adults of the Pacific lamprey are known to exist and spawn in parts of the Columbia River now made inaccessible from the sea by dams (McPhail and Lindsey, 1970) and in upriver lakes (Simpson and Wallace, 1982).

It is believed that lamprey spawn and rear mainly in Snake River tributaries, and use the mainstem for migration. However, ammocoetes are commonly collected in the juvenile bypass system of Little Goose Dam, suggesting some spawning may occur in the tailraces of some dams (BPA *et al.*, 1994). Number of juvenile lamprey estimated to bypass Little Goose Dam averaged almost 30,000 per year from 1983 to 1988, and were approximately 65,000 in 1989 (Chris Pinney, COE, Walla Walla, personal communication).

2. Resident Fish

There is little difference in species composition of non-anadromous fish among the four reservoirs of the lower Snake River. Variations in relative abundance of each species are related to differences in availability of backwater and inshore habitats and of flowing waters in each reservoir (Wik *et al.*, 1993).

Occurrence of a fish species in a particular reservoir depends greatly on the time of year and specific needs of its life cycle. Many species of adult fish migrate from areas where they normally reside to specific habitats for spawning, where they can select deep or shallow water, slow or fast-moving water, or a particular type of substrate. Further, juveniles frequently move to a different habitat type after hatching, for feeding and growth during their first year of life.

In general, backwater areas of the lower Snake River have a greater abundance of fishes in all their life stages than offshore areas (COE, 1992b). Deep-water habitats support fewer fishes, the most common species including suckers (Catostomidae), cyprinids (Cyprinidae), and perches (Percidae). White sturgeon, a native sport fish of ancient ontogeny, spends a majority of time in relatively deep-water areas. Recent studies indicate that mid-depth habitats (*e.g.*, Lower Granite reservoir) may support a greater diversity and abundance of fish species than deep habitat (Bennett *et al.*, 1990, 1992). Beach seine collections indicate that the greatest numbers of juvenile fishes usually occur in shallow-water areas during most seasons.

As a group, native fish species (*e.g.*, cyprinids) spawn during spring and early summer when temperatures are still relatively low but increasing (Figure 2-4). One exception is the mountain whitefish, which spawns in late fall from October to December after water temperatures have declined. Introduced fish species, as a group, initiate spawning during spring and summer as soon as water temperatures become sufficiently warm (COE, 1992b). Many introduced game fishes (*e.g.*, centrarchids) initiate spawning in shallow backwaters where isolation first leads to spring warming, thus becoming vulnerable to water level changes from different rates of power generation at dams. Their eggs, when deposited in shallow shoreline areas of the reservoirs, are also susceptible to wave action from commercial and sport watercraft.

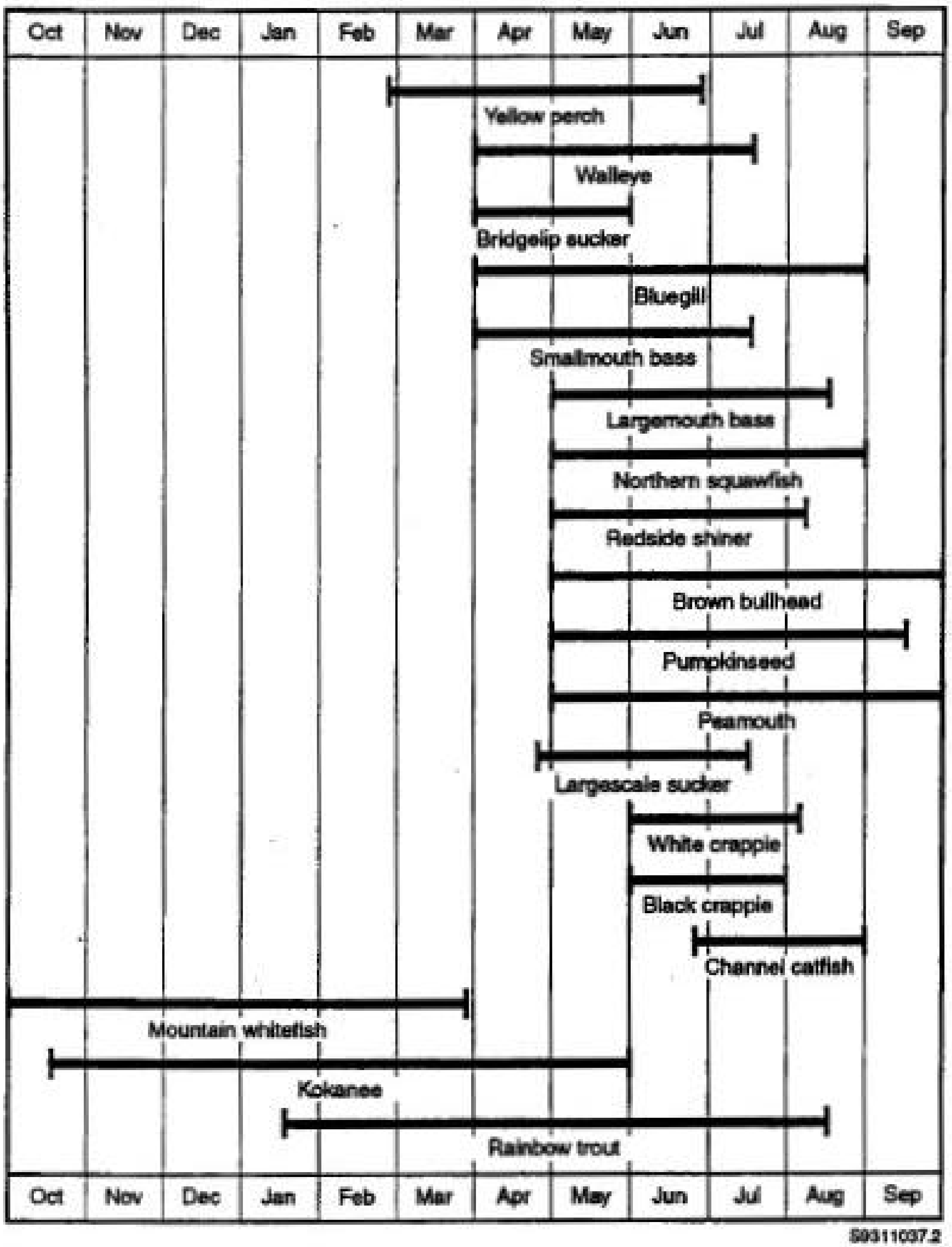

Figure 2-4. Spawning and Incubation Chronology of Resident Fish Species (From Bennett *et al.*, 1993; Stober *et al.*, 1979)

Predominant native fish species in lower Snake River reservoirs include rainbow trout, mountain whitefish, northern squawfish, redside shiner, chiselmouth, peamouth, bridgelip sucker, largescale sucker, and sculpins.

The most common introduced fish species in lower Snake River reservoirs include bluegill, pumpkinseed, smallmouth bass, largemouth bass, white crappie, black crappie, carp, channel catfish, brown bullhead, and yellow perch.

Many introduced sport fish (Centrarchidae) and native non-game fish (Cyprinidae) in lower Snake River reservoirs require shallow-water, inshore habitats, 6.5 feet deep or less, for successful spawning (Bennett and Shrier, 1986; Bennett *et al.*, 1983, 1990, 1991, 1992; Hjort *et al.*, 1981; Stober *et al.*, 1979). However, a few species (*e.g.*, channel catfish) will also spawn in deeper water areas of an impoundment. Shallow-water habitats also provide rearing areas for the young of non-anadromous game and non-game fishes, and foraging and rearing areas for juvenile anadromous salmonids. To ensure good reproductive success, water levels in inshore spawning areas should remain relatively stable during these periods.

a. Sturgeon (*Family Acipenseridae*)

i. White Sturgeon (*Acipenser transmontanus*)

White sturgeon are believed to require rock and gravel substrata in areas with at least some current for successful reproduction (Scott and Grossman, 1973; Wydoski and Whitney, 1979). Sturgeon populations were abundant below McNary Dam on the Columbia River until the area was inundated behind John Day Dam in 1968 (Stockley, 1981). Limited movement upstream past dams on the lower Columbia River is still achieved by fish that use navigation locks rather than fish ladders.

The white sturgeon is a relatively slow-growing, slow-maturing fish. In the Frazer River, British Columbia, female sturgeon do not reach sexual maturity until the age of 26 to 34 years, but some in the Columbia River become sexually mature at age 18 years. Adults survive spawning, but repeat only after increasing intervals of 2 to 11 years (Galbreath, 1979). Sexually mature sturgeon spawn from May to July at water temperatures between 48 and 63ºF (Wydoski and Whitney, 1979). Females do not build nests, but seek fast-flowing rocky areas of river at least 10 feet in depth to broadcast large numbers of eggs in large grayish masses. The eggs become sticky when exposed to water and adhere to any material contacted (Galbreath, 1979). Eggs can hatch in 1 to 2 weeks, and larvae are semipelagic a few days before dropping to the bottom.

Experimentally, white sturgeon fry released in aquaria first drop to the gravel surface or bury head-first (oriented "upstream") in the gravel and remain there for about 5 days. At 17 days, fry elicit diurnal swim-up activity. By the age of 20 days, fry do some swimming during the day (Brannon *et al.*, 1984).

From 1973 to 1975, an estimated 8,000 to 12,000 sturgeon lived in the Snake River from Lower Granite Dam upstream to Hells Canyon 0Dam (Coon *et al.*, 1977). About 86% were small fish <92 cm (3 feet long, presumably because the larger sturgeon were overharvested by anglers. Reproduction appeared to be adequate. There was some evidence of reduced growth after the three dams were constructed in Hells Canyon (years 1957 to 196), presumably because of reduced food availability (*e.g.*, lamprey and salmon carcasses, and lamprey larvae and molluscs).

Mature sturgeon in the middle Snake River probably spawn in the riverine section extending from Clarkston and Lewiston to below Hells Canyon Dam. Young sturgeon 60 to 92 cm (2 to 3 feet) long tended to move downstream between the end of August and the first of April (Coon *et al.*, 1977); in effect restocking reservoir areas below. Remnant adult sturgeon in lower Snake River reservoirs may spawn in tailraces below the dams. The Lower Granite reservoir appears to be a rearing and holding area for juvenile to subadult year-classes of sturgeon at midwater to bottom depths (Bennett and Shirer, 1986; Bennet *et al.*, 1988, 1990, 1991) with forays to other locations. Sturgeon in Lower Granite reservoir, as in the Hanford Reach (Haynes *et al.*, 1979), apparently concentrate in deep waters during the winter and become less active (Bennett *et al.*, 1991).

b. Trout and Whitefish (*Family Salmonidae*)

i. Rainbow Trout (*Oncorhynchus mykiss*)

Rainbow trout do not spawn in lower Snake River reservoirs. Sexually mature adults normally seek tributaries and other flowing-water areas to spawn in the spring. The spawning period may extend from January to August depending on the specific stock (resident or anadromous steelhead form), water temperature, and other conditions.

Mature rainbow trout spawn in cool waters of tributaries, such as the Tucannon River in Washington, the Clearwater and Salmon rivers in Idaho and the Imnaha and Grande Ronde Rivers in Oregon. Redds (nests) are excavated in gravel substrata for deposition of eggs, which are then covered by gravel similar to that removed during excavation. Successful incubation requires intergravel flow of cool, oxygen-bearing water through the gravel interspaces. Normal development time for eggs, before fry emerge, is 4 to 7 weeks. Young rainbow trout may enter inshore areas to feed in spring when water temperatures are favorable.

Many of the "rainbow trout" now found in Lower Granite reservoir (Bennett *et al.*, 1988, 1990, 1991) may be juvenile steelhead representing, for the most part, hatchery releases. Populations of resident trout in other reservoirs on the lower Snake River are low (Bennett *et al.*, 1983), and they subsist largely by hatchery augmentation. Large numbers of rainbow trout and other trouts (*e.g.*, cutthroat trout, brown trout, brook trout) are released from hatcheries in suitable tributaries and tributary lakes for the sport fishery as a result of the Snake River mitigation program.

ii. Cutthroat Trout (*Oncorhynchus clarki*)

Number of cutthroat trout in the lower Snake River reservoirs are low (*e.g.*, collections by Bennett *et al.*, 1988, 1990, 1991), but some may occasionally leave tributaries and appear in Lower Granite reservoir. The subspecies common in the Salmon River drainage and other major rivers north of the Salmon River is the westslope cutthroat (Simpson and Wallace, 1982). Spawning characteristics are similar to those of rainbow trout, but westslope cutthroat generally prefer waters that are clearer and colder, with temperatures <60ºF. The westslope subspecies normally spawns at 5 years of age, and post-spawning mortality is fairly heavy (Simpson and Wallace, 1982). Cutthroat trout in the Snake River system do not have an anadromous form. Populations in many tributaries of the lower Snake River are augmented by hatchery releases.

iii. Kokanee (*Oncorhynchus nerka*)

Kokanee salmon do not occur to any extent in lower Snake River reservoirs. This resident form of anadromous red salmon typically inhabit cool, clearwater lakes in headwater areas. Kokanee normally become sexually mature in 4 years, but may mature in 2 or 3 years under favorable conditions or in 5 years if food conditions are poor (Simpson and Wallace, 1982). To spawn, adult kokanee migrate to tributaries or outlet stream or use upwelling areas along shorelines (Foerster, 1968). In streams, adults excavate redds (nests) in gravel to deposit their eggs, then cover them. Shoreline spawners usually broadcast their eggs among larger cobble, where intergravel flow of cool, oxygen-bearing water bathes the eggs. Adult kokanee, like sockeye salmon, die after spawning. Young emerging from eggs deposited in tributaries or in outlet streams move either downstream or upstream to reach their lake or reservoir rearing areas.

Collection facilities at Lower Granite and Little Goose Dams on the lower Snake River often collect many "sockeye salmon," which are believed to be kokanee rather than the anadromous form. Small kokanee were collected inshore below Lower Granite Dam during the March 1992 drawdown test (Wik *et al.*, 1993; Dauble and Geist, 1992). Kokanee populations exist upriver in Dworshak reservoir on the Clearwater River (Maiolie, 1988) and in some lakes on the upper Salmon River (Chapman *et al.*, 1990; Waples *et al.*, 1991a) where they spawn primarily in the tributaries.

iv. Mountain Whitefish (*Prosopium williamsoni*)

Mountain whitefish spawn during winter (*e.g.*, November-February), usually over gravel in stream riffles but also over gravel shoals in lakes and reservoirs. Whitefish in Idaho waters mature sexually when 3 years old (Simpson and Wallace, 1982), and characteristically migrate upstream to suitable spawning areas (Daily, 1971). Eggs are broadcast and no redds (nests) are excavated. Fertilized eggs are adhesive and stick to the bottom substrate where eggs develop through hatching, which occurs after about 5 months. Mountain whitefish feed more actively when the water is cold during winter than when it is warm during summer (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

Mountain whitefish probably do not spawn to any extent in lower Snake River reservoirs, and they are not abundant there (Bennett *et al.*, 1983). Some mature whitefish may move upstream from Lower Granite Reservoir to spawn in the middle Snake River and in tributaries such as the Clearwater and Salmon Rivers in Idaho and the Grande Ronde and Imnaha Rivers in Oregon. Adult whitefish are known to migrate 55 miles upstream in the Clearwater River in correlation with increasing temperature and photoperiod of the late spring and early summer. Whitefish remain in the upper reaches of the Clearwater River until spawning in November, and move downstream to overwinter in deep pools (Pettit and Wallace, 1975). Currently, relatively few mountain whitefish reside in Lower Granite reservoir (Bennett *et al.*, 1988, 1990, 1991). Suitable temperatures may be marginal for incubation of whitefish eggs in mid-Columbia River reservoirs (Mullen *et al.*, 1986).

c. Minnows (*Family Cyprinidae*)

i. Northern Squawfish (*Ptychochellus oregonensis*)

Northern squawfish spawn during spring (*e.g.*, June to early August) in the lower Snake River (Bennett *et al.*, 1983). Females mature sexually at 4 to 5 years, and males at 3 to 4 years (Simpson and Wallace, 1982). Adults may migrate to select spawning areas in the spring, typically spawning over gravel in tributaries, in reservoirs, or in headwater areas of reservoirs with some current. Males often exhibit "swimming" behavior, with large groups attending a few females. Females broadcast small eggs that usually adhere to a gravel substrate. Eggs are not attended by adults and hatch within 7 days if water temperatures are constant at 65ºF. Young squawfish disperse in about 14 days (Beamesderfer, 1983; Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

The northern squawfish is abundant in the Lower Granite reservoir, where it moves upstream to spawn prior to spring outmigration of salmonid smolts. It is the primary predator on smolts in this reservoir (Bennett *et al.*, 1988, 1990, 1991); in fact, adult squawfish are the most common predator on outmigrating smolts in all four reservoirs along the lower Snake River (Bennett *et al.*, 1983). Adults migrate to the tailwaters of the Lower Granite Dam to feed on salmon smolts during their outmigration (Bennett *et al.*, 1983). On the other hand, juvenile fall chinook salmon are known to prey on larval squawfish. Adult squawfish are usually more common in deeper, flowing-water areas than elsewhere in these reservoirs. Juveniles are abundant during summer in shallow shoreline areas with gentle sloping, sandy substrata.

ii. Peamouth (*mylochellus caurinus*)

Adult peamouth spawn in reservoirs along the lower Snake River during spring, from May through September, when temperatures reach ~54ºF (Bennett *et al.*, 1983). They reach sexual maturity at 3 or 4 years of age (Simpson and Wallace, 1982). Adults spawn in groups over gravel or rubble substratum in shallow areas. Eggs are broadcast to settle and attach to bottom substratum. Eggs are unattended by adults and hatch rapidly (in 7 to 8 days) when water temperatures are ~54ºF. Young peamouth gather in schools and inhabit inshore areas where the water is warmed during spring, summer, and fall (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). Generally, peamouth are uncommon in all four reservoirs along the lower Snake River (Bennett *et al.*, 1983), including the Lower Granite Reservoir (Bennett *et al.*, 1990, 1991).

iii. Chiselmouth (*Acrochellus alutaceus*)

Adult chiselmouth spawn in the spring when temperatures warm to ~60ºF. Chiselmouth are assumed to mature sexually at age 3 or 4 years, and spawn primarily in streams over gravel or small rubble. It is likely that they do not build nests like other cyprinids, but cast eggs that adhere to the bottom substrata (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). There is no information on spawning of chiselmouth in the impoundments of the lower Snake River or their tributaries. Chiselmouth are present in Lower Granite reservoir (Bennett *et al.*, 1990, 1991), but they are more abundant in the three downstream reservoirs (Bennett *et al.*, 1983).

iv. Redside Shiner (*Richardsonius balteatus*)

Redside shiner mature sexually at age 2 or 3 years (Simpson and Wallace, 1982), and they spawn from July to early August in Snake River reservoirs (Bennett *et al.*, 1983). Although redside shiners appear to thrive in both warm and cold reservoir systems, they usually spawn at temperatures of 18 to 20.4ºC (Walburg *et al.*, 1981). Adults spawn along the shoreline in quiet waters, particularly in areas of submerged vegetation. Redside shiners typically assemble in small groups in shallow water (sometimes <6 inches) to broadcast and fertilize their eggs. Eggs are adhesive, settle to the bottom, and become attached to the substrate or to vegetation. Because only a few eggs are released at one time, spawning can continue for 3 to 4 days. Eggs hatch rapidly (*e.g.*, 8 to 12 days) under normal spawning temperatures.

Recently hatched fry move downstream to deeper areas with quiet water for rearing. Redside shiners probably remain in relatively deep-water areas from October to May (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). The redside shiner occurs in all reservoirs along the lower Snake River (Bennett *et al.*, 1983) and, because of its abundance and small size, may be important forage for larger predatory fish.

v. Carp (*Cyprinus carpio*)

The common carp is native to Asia. It was first introduced to the Columbia River in 1882 (Wydoski and Whitney, 1979). Carp usually mature sexually at age 2 or 3 years. Mature carp spawn during the spring and summer, at temperatures of 60 to 68ºF; they often move into shallow, weedy water <4 feet deep to spawn. In fact, carp will spawn with their backs exposed in shallows only 4 inches deep. Adult carp characteristically form highly active groups to spawn. Females broadcast eggs over a wide area and then leave, while the males linger. The number of eggs shed are relatively high, compared with the number shed by most native cyprinids, and they attach to vegetation, brush, debris, or stones. Hatching occurs rapidly in warm water, taking ~4 days at 71ºF. Carp fry stay in large schools in shallow water, and move into deeper water as they grow (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

Carp are common in all four reservoirs along the lower Snake River (Bennett *et al.*, 1983), but they are less abundant in Lower Granite reservoir (Bennett *et al.*, 1990, 1991), presumably because water temperatures are less than favorable (Mullen *et al.*, 1986). Carp are highly adaptable to different spawning conditions, and populations are capable of increasing rapidly when temperatures are favorable. This introduced highly prolific species has caused the reduction or disappearance of more desirable native species in some Idaho waters (Simpson and Wallace, 1982).

The nature of competitive interactions between introduced carp and native anadromous salmonids, if any, are not documented. Carp favor warmer temperatures and lower currents than native salmonids, and they spawn at different times and in different areas. Adult carp occur seasonally in fish ladders at dams but not the same extent as adult shad. Small carp have limited value as a forage species because they hide in aquatic vegetation until reaching 3 to 9 inches long, and their strong spines make them less desirable as prey (Sigler and Sigler, 1987).

d. Suckers (*Family Catostomidae*)

i. Bridgelip Sucker (*Catostomus columbianus*)

The bridgelip sucker spawns during the spring (*e.g.*, April through May) in lower Snake River reservoirs (Bennett *et al.*, 1983). Females mature sexually at age 5 years and males at 6 years (Dauble, 1980). Bridgelip suckers spawn at temperatures of 10 to 13ºC in lower Snake River reservoirs (Bennett *et al.*, 1983) and at 8 to 13ºC in the Hanford Reach of the Columbia River (Dauble, 1980). Suckers do not prepare nets, but broadcast eggs near the bottom over rock or cobble substratum. Young rear in shallow water areas near shorelines over mixed mud and rock bottom (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

The bridgelip sucker is typically a riverine fish, but many are found in reservoirs. Bridgelip sucker occur in all four lower Snake River reservoirs, but at lower levels of abundance than the largescale sucker (Bennett *et al.*, 1983). This species is much less abundant in the Lower Granite reservoir than the largescale sucker (Bennett *et al.*, 1990, 1991).

ii. Largescale Sucker (*Catostomus macrochellus*)

Largescale sucker spawn during the spring (*e.g.*, May to June) at temperatures of 12 to 16ºC (Bennett *et al.*, 1983). Males mature sexually at 4 years and females at 5 years (Simpson and Wallace, 1982). The species characteristically spawns in groups, and eggs are shed over gravel riffles where there is a current or in shallow-water areas along the shorelines of reservoirs. Ripe males occupy spawning areas for extended periods of time and fertilize eggs that adhere to bottom substrata and develop to hatching within 2 weeks. Fry are briefly pelagic, then move to shallow backwater areas for rearing (Sigler and Sigler, 187; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

The largescale sucker is highly adaptable and can reproduce successfully under a range of conditions. The species is both riverine and lacustrine. Populations are abundant in all four reservoirs on the lower Snake River (Bennett *et al.*, 1983). The largescale sucker is the predominant sucker species in the Lower Granite Reservoir (Bennett *et al.*, 1988, 1990, 1991). Largescale suckers spawn at 54 to 61ºF, compared with 46 to 55ºF in the bridgelip sucker (Bennett *et al.*, 1983; Hjort *et al.*, 1981; Dauble, 1980). Young suckers provide forage for many species of predatory fish, birds, and mammals.

e. Trout Perches (*Family Percopsidae*)

i. Sand Roller (*Percopsis transmontanus*)

The sand roller inhabits quiet backwaters characterized by undercut banks, submerged tree roots, and debris. This small, unique fish is an uncommon resident of the mid-Columbia River, but it occurred as far up as the Clearwater River in the Snake River system before the lower Snake River dams were built (Wydoski and Whitney, 1979). Its age at sexual maturity and spawning habits remain undetermined. The sand roller was not collected from the Snake River during recent surveys, but this may reflect a limitation of sampling gear (*e.g*., Bennett *et al*., 1983, 1988, 1990, 1991). The sandroller was not collected during the March 1992 retreat to deep water during winter and effectively avoid capture by most sampling methods. Sand rollers spawn in the Columbia River system (*i.e.*, Hanford Reach) during midsummer when water temperatures range from 14 to 16ºC (Gray and Dauble, 1979).

f. Bass and Sunfish (*Family Centrarchidae*)

i. Largemouth Bass (*Micropterus salmoides*)

The largemouth bass is a non-native fish that is uncommon in lower Snake River reservoirs except in some embayments. It matures sexually at 3 to 5 years in most Idaho waters (Simpson and Wallace, 1982). The largemouth requires slightly warmer spawning temperatures than the smallmouth bass, and more areas of aquatic vegetation to obtain high reproductive success. The largemouth bass may be more vulnerable to temperature declines, water level fluctuations, and wave action during spawning than smallmouth bass. The largemouth is less common than smallmouth bass in the lower Snake River, particularly in Lower Granite reservoir (Bennett *et al.*, 1988, 1990, 1991). Little Goose reservoir may contain a larger population of largemouth bass than the others (Bennett *et al.*, 1983).

Largemouth bass typically spawn in water 1 to 4 feet deep, but at times will spawn in water 7 or 8 feet deep. Largemouth bass typically deposit eggs over sand, gravel, or rubble substrata (Sigler and Sigler, 1987; Wydoski and Whitney, 1979). Largemouth bass spawn from May into August in lower Snake River reservoirs (COE, 1992b).

ii. Smallmouth Bass (*Micropterus dolomieu*)

The smallmouth bass usually matures when 3 or 4 years old (Wydoski and Whitney, 1979). It is a non-native fish that spawns from early June through July in lower Snake River reservoirs (Bennett *et al.*, 1991). Adults commonly enter embayments, or other areas warmed by insolation, to spawn. Nests, or indentations in the substrata, are constructed along low-gradient shorelines within sand or gravel substrata (<100 mm diameter) at depths of 2 to 20 feet. Piles of cobble or shell may be used as spawning sites. No current is required to incubate the eggs, but shoals exposed to some current and wave action may be used. Nests (cleared sites) are easily observed in shallow water. The male bass, in a characteristic similar to other species of centrarchids, clears the site and guards and fans the uncovered eggs until they hatch. At normal spawning temperatures, hatching occurs in 5 to 10 days and the yolksac is adsorbed in 10 to 14 days. Fry initially school, then disperse among rocks and vegetation along the shore when ~1 inch long. Temperature declines and wave action from wind may cause males to abandon nests (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). The smallmouth bass in Lower Granite Reservoir can be a significant predator on salmonid smolts, much like squawfish (Curet, 1993).

Smallmouth bass occur in all reservoirs on the lower Snake River, but are most common in Little Goose (Bennett *et al.*, 1983). They are the number two predator on salmon smolts in Lower Granite reservoir. Water level changes are known to expose nests and developing eggs to air and dehydration in lower Snake River reservoirs. During the heat of summer, adult smallmouth bass retreat to greater depths and cooler water. Stable water levels during the spawning and fry-rearing periods help produce a strong year-class (Sigler and Sigler, 1987). These conditions exist during MOP operation of the lower Snake River hydrosystem (Bennett, 1994).

iii. Bluegill (*Lepomis macrochirus*)

The bluegill is a non-native species in the lower Snake River that matures sexually at age 2 year (Simpson and Wallace, 1982). Bluegill in the lower Snake River spawn from July into August when temperatures are constant between 19.6 and 21.7ºC (Bennett *et al.*, 1983). Male bluegill generally form hollows or nests in sandy bottom substrata of shoreline areas in 1 to 5 feet of water. Shoal areas and particularly, embayments are also used for spawning. Several females may spawn at the same site, resulting in high numbers of eggs per nest. Bluegills practice colonial nesting, and several nests may be built close to one another. Eggs from several females may be fertilized by a single male. The male is pugnacious and protects the eggs during development, fanning with his fins to keep them aerated and clean of silt. Males also protect the fry for several days after they hatch. Eggs develop rapidly at ambient spawning temperatures and usually hatch within 5 days (Sigler and Sigler, 1987; Simpson and Wallace 1982; Wydoski and Whitney, 1979). The bluegill is present in all lower Snake River impoundments, and is most abundant in Little Goose reservoir (Bennett *et al.*, 1983).

iv. Pumpkinseed (*L. gibbosus*)

The pumpkinseed is a non-native fish that matures sexually in 2 to 3 years (Simpson and Wallace, 1982). It spawns from late June into early August in lower Snake River reservoirs (Bennett *et al.*, 1983). Males build a depression nest in shallow water, often between patches of vegetation, within sand, gravel, or mud substrata. The spawning behavior of the pumpkinseed is similar to that of the bluegill, but the pumpkinseed constructs its nest closer to the shore, in more shallow water, and is not a colonial nester. Fish spawn at 18.1 to 19.60ºC, and eggs hatch within3 days at ambient temperatures (*e.g.*, 82ºF). Males defend the nest aggressively. The pumpkinseed is present in all lower Snake River reservoirs, but is most abundant in Little Goose reservoir (Bennett *et al.*, 1983).

v. White Crappie (*Pomoxis annularis*)

The white crappie is a non-native fish that matures when 2 to 3 years old (Wydoski and Whitney, 1979). It spawns from June into early August in the lower Snake River reservoirs at 15.9 to 20.4ºC (Bennett *et al.*, 1983). Spawning takes place near such objects as rooted plants, brush piles, and stumps, or within protected rocky outcrops and cut banks. White crappie usually spawn in groups with nests placed 2 to 4 feet apart. Eggs are adhesive, and deposited on or near dead or living vegetation in selected nest areas of 5- to 7-inch diameter. Males guard the nests and fan the eggs. The tiny, transparent fry may leave nests as early as 4 days after hatching. They do not form schools that linger in shallow areas, as do bass fry (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

White crappie are most abundant in Little Goose reservoir, and populations usually pre-dominate over the black crappie (Bennett *et al.*, 1983). The white crappie appears to have greater tolerance than the black crappie for high turbidities, alkaline waters current high temperatures, and lack of aquatic vegetation or other such cover (Sigler and Sigler, 1987). It tends to concentrate around submerged brush, logs, or boulders in quiet water 6 to 13 feet deep during the day.

vi. Black Crappie (*Pomoxis nigromaculatus*)

The black crappie is a non-native fish that matures when 2 to 3 years old (Wydoski and Whitney, 1979). It spawns from June through July at 15.8 to 19.6ºC in lower Snake River reservoirs (Bennett *et al.*, 1983). Males excavate shallow depressions in soft mud bottoms, usually less than 3 feet deep, or near aquatic plants. Black crappie prefer quiet water with beds of aquatic vegetation for spawning more than do white crappie. Spawning fish form loose associations, but the males build nests 6 to 10 feet from the nearest neighbor. Males also guard the nest. Females may spawn with more than one male and produce eggs several times during the summer. At normal spawning temperatures, eggs hatch in 3 to 5 days. The tiny, transparent fry soon leave nests and drift in open water for a few weeks (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). Black crappie are most commonly found in areas of aquatic vegetation over sandy to muddy bottom substrata and, like the white crappie, often spend the day near submerged objects (Sigler and Sigler, 1987).

g. Catfish (*Family Ictaluridae*)

i. Brown Bulhead (*Amelurus nebulosus*)

The brown bulhead is a non-native fish that matures sexually at 3 years. It spawns from June through August in lower Snake River reservoirs (Bennett *et al.*, 1983), normally at temperatures of 69 to 71ºF (20.4 to 21.7ºC). Nests are circular depressions ~1 foot in diameter located in mud or sand, or among plants on the bottom. Nests are placed in shallow water from a few inches to several feet deep. The nest is guarded by the male, sometimes by both sexes, until young are several weeks old. Eggs are adhesive, laid in a mass, and hatch in 5 to 7 days, depending on temperature. When the yolksac is adsorbed (*e.g.*, 5 to 10 days), the young school, move about, and feed. Adults, or most often the male, continue to guard the young. Young disperse and move into deeper water as summer ends (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). A relative of the brown bullhead, the yellow bullhead (*Ameiurus natalis*) is also present in the lower Snake River, but the species is less abundant.

ii. Channel Catfish (*Ictalurus punctatus*)

The channel catfish is a non-native fish that reaches sexual maturity when about 3 years old. It spawns from July through August in lower Snake River reservoirs (Bennett *et al.*, 1983), usually at temperatures of 67 to 71ºF (18.1 to 21.7ºC). Both spawning time and temperature range are slightly lower than those reported elsewhere. Nests are placed in darkened, sheltered areas such as hollow logs, muskrat burrows, or under banks, often in relatively shallow water. Males select and clean the nest site, guard the nest, and keep the eggs clean and aerated with their pelvic fins. Eggs hatch in 6 to 10 days, at normal spawning temperatures. The young initiate swimming and feeding after they adsorb the yolksac in 2 to 5 days. If nests are disturbed, either the male or female may swallow the developing eggs (Sigler and Sigler, 1987; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

Channel catfish are more adapted for stream life than most other catfish in the Pacific Northwest, but it also prospers in lakes and reservoirs. The species occurs in all lower Snake River reservoirs and, like northern squawfish, may migrate to the tailraces of dams to feed on outmigrating salmon smolts (Bennett *et al.*, 1983).

h. Perch and Walleye (*Family Percidae*)

i. Yellow Perch (*Perca flavescens*)

The yellow perch usually reaches sexual maturity at 2 years. It is a non-native fish that spawns in Idaho from April to June when water temperatures reach 44 to 50ºF (Simpson and Wallace, 1982). Males arrive at the spawning grounds before females. Eggs are extruded in long, flat, ribbon-like masses usually near rooted vegetation, fallen trees, and brush, but over sand and gravel at times. Egg masses are semi-buoyant. Yellow perch usually spawn at night or during the early morning. Eggs swell and hatch after a 10- to 20-day period. Parents do not protect egg masses or young. Yellow perch larvae are initially photosensitive and pelagic, dropping to the bottom at lengths near 25 to 40 mm (Ney, 1978; Simpson and Wallace, 1982; Wydoski and Whitney, 1979). Larvae appear in plankton tows in the Columbia River.

Yellow perch prefer lakes of cool, clear water with abundant vegetation. However, perch are highly adaptable and reproduce successfully under a range of conditions. It is a schooling species, and individuals in crowed populations often become stunted to that adults never exceed 6-inch length. Yellow perch are abundant in all lower Snake River reservoirs (Bennett *et al.*, 1983, 1990, 1991).

ii. Walleye (*Sitzostedion vitreum*)

Adult walleye are a non-native species that spawns during the spring when the water warms to >40ºF. Sexual maturation varies widely with area, but females usually mature when 3 to 5 years old, a year later than males (Wydoski and Whitney, 1979). Males move first to spawning areas over shoals of rubble and coarse gravel in lakes or in reservoirs (when no stream with rocky riffles are available). Adult walleye may spawn over sand or silt bottoms, and usually spawn at night. Each female is usually attended by two or more males. Eggs are broadcast into crevices of the surrounding substratum and are adhesive when released, but soon harden. Eggs hatch into larvae ½-inch long in about 26 days at 40ºF, 21 days at 50 to 55ºF, and 7 days at 57ºF. Parents do not protect eggs or young (Ney, 1978; Simpson and Wallace, 1982; Wydoski and Whitney, 1979).

No walleye have been collected in lower Snake River reservoirs (Bennett *et al.*, 1983, 1988, 1990, 1991). Large walleye populations occur below McNary Dam on the Columbia River, and limited excursions to below Ice Harbor Dam, even further up the Snake River, may be expected. Spawning substrate and/or unsuitable temperature regimes may limit walleye production. Walleye apparently do not reproduce successfully in the middle Columbia River (Zook, 1983). In this species, spawning occurs at temperatures of 42 to 52ºF, but survival of larvae is poor at <50ºF.

Temperatures must rise to assure success for successive early life phases (Hokanson, 1977). Walleye spawn most successfully in the warmer Spokane Arm of Lake Roosevelt (Beckman *et al.*, 1985) and in warmer backwaters of the lower Columbia River (Hjort *et al.*, 1981). Adult walleye prey primarily in fish (Ney, 1978). If populations appear in lower Snake River reservoirs, they may include juvenile salmonids as their prey during the seasonal smolt outmigration. Walleye in John Day reservoir feed primarily (80% of diet) on non-game fish (Maule and Horton, 1983).

i. Sculpins (*Family Cottidae*)

i. Prickly Sculpin (*Cottus asper*)

Prickly sculpin, a native species, may mature sexually as early as 2 years, but many do not spawn until 4 years old (Wydoski and Whitney, 1979). They usually prefer areas with rock, cobble, or rubble bottom where they can hide. They depend on protective coloration for concealment when in open water over mud or sand bottom. Adult prickly sculpin commonly spawn in the spring during April, May, and early June. Eggs are adhesive, and deposited in rock crevices, under rocks, or on other support substrata, including debris from human activities. A male sculpin may spawn with several females at one nest site. Males usually fan the eggs with their pectoral fins and guard them during incubation. At normal spring temperatures (50ºF), eggs hatch in ~30 days. The larval stage is pelagic for 30 to 35 days, and larvae often appear in plankton tows in the Columbia River. Small sculpins often rear in shallow, vegetated waters (Wydoski and Whitney, 1979). The prickly sculpin does well in reservoir habitats. Sculpins are valuable as forage for predatory fish, mammals, and birds.

ii. Other Sculpins

Other species of sculpin, including the puite (*C. beldingi*) and mottled (*C. bairdi*) sculpins, occur in lower Snake River reservoirs (Bennett *et al.*, 1983), but little is known of their spawning and rearing requirements.

3. Terrestrial Ecology

a. Habitat

The lower Snake River and it's main tributaries, the Palouse (RM 59.5), Tucannon (RM 62), and Clearwater (RM 140) Rivers, pass through the xerophytic shrub-steppe, Ponderosa pine (*Pinus ponderosa*), and Idaho white pine (*P. monticola*) vegetation series (Franklin and Dyrness, 1973). The white pine assemblage consists of mixed stands of white pine, grand fir, Douglas fir, Engleman spruce (*Picea engelmanni*), and western red cedar (*Thuja plicata*) (Franklin and Dyrness, 1973). Although a large percentage of endemics comprise the vegetated component of the lower Snake River, the corridor serves as a major route of dispersal for a variety of plant and wildlife species. The cover types and representative species that occur within each type in the Snake River Basin are included in table 2-10.

Table 2-10
Cover Types and Representative Species of Each Type
Within the Lower Snake River Basin
(From COE, 1991)

Cover Type	Representative Features
Agricultural cropland	Grain crops; primarily winter wheat
Orchard	Fruit trees and grape vineyards
Forb land	Teasel (*Dipsacus sylvestris*) Prickly lettuce (*Lactuca serriloa*) Thistles (*Cirsium* spp.) Curly dock (*Rumex crispus*) Cheatgrass (*Bromus tectorum*) Bluebunch wheatgrass (*Agropyron spicatum*) Intermediate wheatgrass (*Agropyron intermedium*)
Pasture	Irrigated alfalfa Mowed or grazed forb land
Grassland	Cheatgrass Bluebunch wheatgrass
Shrub-steppe	Gray rabbitbrush (*Chrysothamnus nauseosus*) Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) Cheatgrass
Mesic shrubland	Hackberry (*Celtis reticulata*) Douglas hawthorn (*Crataegus douglasii*) Chokecherry (*Prunus virginiana*) Blackberry (*Rubus discolor*)
Riparian forest	Black cottonwood (*Populous trichocarpa*) Hackberry White alder (*Alnus rhombifolia*) Russian olive (*Elaeagnus angustifolia*)
Palustrine scrub-shrub	Coyote willow (*Salix exiqua*) Willow (*Salix* spp.)

Palustrine emergent	Cattail (*Typha latifolia*) Sedges (*Carex* spp.)
Palustrine open water	Ponds and backwater areas
Lacustrine	Reservoir
Riverine	Riverine channel
Unconsolidated levee	Sand and gravel bars
Rock talus	
Sand dune	
Residential/Industrial	
Recreational	
Quarry	
Railroad/Roads	

Artificial barren land predominates along the margin of the lower Snake River projects where the shoreline is marked by rock riprap, artificial structures, and roadfill. Riprap comprises over 40% of shoreline along the lower Snake River (COE, 1992b); and although its function as habitat is generally limited, it serves as the primary artificial habitat for wildlife. Because establishment of riparian vegetation is generally precluded where riprap, roadfill, and structures have been placed, their function as habitat is limited.

Riparian, as well as wetland and shallow water habitats along the Snake River, have become established under daily pool fluctuations of 3 to 5 feet. A general lack of riparian habitat along the lower Snake River is related to steep shorelines and undercut banks, extensive grazing, and expansion of rail facilities (COE, 1992b). Riparian vegetation is limited to production within a narrow corridor along backwaters, tributaries, and draws that have not been influenced by project inundation or development (COE, 1991). Areas of riparian and wetland habitat are included in table 2-11.

Table 2-11
Area (Acres) of Each Cover Type for the Lower Snake River Projects (COE, 1992b)

Cover Type	Ice Harbor Lower Monumental	Little Goose Lower Granite	Total
Agricultural cropland	58.5	157.5	216.0
Forbland	499.3	617.9	1117.2
Pasture	106.4	145.8	252.2
Riparian forest	49.6	79.6	129.2
Palustrine emergent	49.7	4.3	54.0
Palustrine scrub-shrub	126.2	155.0	281.2
Mesic shrubland	140.9	454.7	595.6
Grassland	3376.1	5665.1	9041.2
Shrub-steppe	3658.7	797.6	4456.3
Rock talus and exposed rock	1288.0	1392.0	2680.0
Palustrine open water	308.3	196.4	504.7

Collectively, the lower river is bordered by approximately 1000 acres of riparian vegetation that constitutes <1% of project lands of the four lower dams (COE, 1992b). Riparian habitat occurs in clustered distribution in association with Habitat Management Units (HMU).Quality of riparian habitat is generally low along the Ice Harbor and Lower Monumental projects, and is slightly increased along the Little Goose and Lower Granite projects (COE, 1992b). Reduced habitat quality is attributed to the young seral stage of vegetation, sparse canopy cover, and an overall lack of species diversity. A large proportion of the riparian understory is composed of young trees and shrubby species (*e.g.*, Russian olive, hackberry). Large areas of scrub-shrub are dominate by false indigo (*Amorpha fruiticosa*), a noxious shrub, and various willow species (*e.g., S. argophylla*) (COE, 1992b). Vegetation also includes black cottonwood, black locust, and white alder. Herbaceous vegetation includes dotted smartweed (*Polygonum punctatum*), cocklebur (*Xanthium* spp.), thistle (*Carduus* spp.), and mustard (*Brassica* spp.). Sand bars along the river support licorice-root (*Glycyrrhiza lepidota*), cocklebur, and willow.

Wetland and shallow-water habitat exists along the shoreline of the Snake River and around islands within the project pools. Emergent wetland habitat is more common along the Ice Harbor and Lower Monumental projects where small open-water areas, backwaters, embayments, and riverside channels occur more frequently (COE, 1992b). Emergent wetlands are of poor quality (COE, 192b) due to a reduced canopy cover and a lack of water. Although wetlands are not extensive, colonization by emergents has increased over time, in conjunction with increased sedimentation at the confluence of tributary streams and in backwater areas (COE 1992b). Wetlands are characterized by emergent cattail (*Typha* spp.) and bulrush (*Scirpus* spp.).

The shrub-steppe, grassland, and forbland types are characterize by relatively low herbaceous cover. This is due, in part, to historic livestock grazing, a condition of shallow soils, and a preponderance of cheatgrass as groundcover. On upstream project lands, where livestock grazing has been discontinued, species composition is greater and overall habitat quality is elevated (COE, 1992b).

A large proportion of land surrounding the lower Snake River projects has been developed as HMU's (table 2-12). Approximately 15,234 acres, including two Natural Areas, are managed for wildlife habitat (C. Christianson, COE, personal communication, 14 September 1992). Approximately 3,495 of these acres are maintained as irrigated HMU's. Irrigated HMU's received surface water from project reservoirs, and species demonstrate a dependence on irrigation. Without irrigation, the areas occupied by HMU's would be dominated by xeric species. Irrigated HMU's are planted with trees, shrubs, food plots, and herbaceous species to replace riparian vegetation that was altered as a result of project inundation. The majority of irrigated HMU's have been replanted within the previous 2 to 3 years (C. Christianson, COE, personal communication, 12 January 1993). These sites reflect lower habitat quality than other project lands (COE, 1992b).

Table 2-12
Habitat Management Units (HMU's)
Along the Lower Snake River Projects[1]

Management Unit	River Mile	Acreage[2]
Ice Harbor		
Big Flat	14 to 18	712.7[2]
Lost Island	22.2 to 24.5	161.8[2]
Hollebeke	24.1 to 25.9	246.8[2]
Rogers Reef	10 to 10.4	5.5
Lake Charlene	11.4 to 12	56.8
Charbonneau	11.5 to 12.5	107.8
Big Flat	13.9 to 15	87.6
Quarter Circle	15.7 to 16.2	82.6
Fishhook	17.1 to 19	240.3
Nineteen Mile	18.4 to 19.4	25.0
	20.1 to 21.6	37.0
	21.7 to 22.2	24.9
Snake River Junction	25.5 to 25.7	25.7
Couch Landing	28.9 to 34.1	93.2
Walker	29.9 to 31	116.6
Burr Canyon	35.9 to 38.2	185.6
Anchor Canyon		99.6
Lower Monumental		
Skookum	47 to 53	757.2[2]
Ayer	53 to 54.8	73.9
Fifty Five Mile	54.6 to 56	269.9[2]
Riparia/Alkali Creek	67	307.4
Joso	56 to 58.8	520.7
Tucannon River Area		226.0
	42.2 to 47	400.2
	53.1 to 54.6	124.2
	55 to 56	15.8
	56.1 to 57.6	118.0
Joso East	59	72.6
Sargent	61.7 to 66.8	69.5
Tucannon River		54.2
Little Goose Access Road		171.3
	63 to 66	211.1
	68 to 69.5	114.7
Palouse Canyon Road		1805.5

Little Goose		
Flagpole Gulch		63.8
Browns Gulch		36.4
Ridpath		80.2[2]
Purrington		71.6
Penawawa		104.4
Swift Bar		355.5[2]
Schultz Bar		130.9
Hanger/Dry Gulch		144.5
Phalen/New York		183.6
New York Island		49.6
New York Bar		219.1[2]
Deadman/Meadow Creek		218.6
Hastings Bar		154.6
Tucker Bar		35.6
Rice Bar		143.0
Beckwith Bar		111.0
Illia		375.6
	70.5 to 72	163.2
	72.5 to 75	92.4
	75.5 to 76	24.8
	77.5 to 78.5	20.8
	79.5 to 82	141.3
Cottonwood Canyon	87 to 88.8	85.6
Long Hollow	93.1 to 93.3	24.7
Stine Gulch	103.4	6.3
Almota Creek	103.8 to 105.1	39.8
	72.5 to 75.3	219.1
	76 to 77.3	52.6
	78 to 79	72.7
	81.6 to 83	78.4
	83.2 to 85.9	147.0
	88.7 to 91.2	113.1
	94 to 97.7	190.4
	99.4 to 101.5	110.5
	105.3 to 106.9	78.1
Willow Landing		60.0

Lower Granite		
Transmission Line HMU		63.0
	110 to 113	181.1
	109 to 110	54.2
	111 to 112	26.1
	113.5 Island	0.6
	114 to 116	172.4
	116 to 131	784.0
	118 to 119	42.2
	119	20.1
	120	28.7
	126	46.5
	128 to 130	49.6
	129 to 130.5	21.0
	131	24.4
Chief Timothy HMU		41.7[2]
Chief Timothy Cliffs		114.9
Wilma		83.4
	135	34.0
	136	13.3
	139	3.4
Hells Gate HMU		650.0[2,4]
Asotin Slough		49.2
	147	26.4
Lewiston Levee		2.3
Clearwater River		119.0
	107 to 109	87.5
	108	13.8
	112 to 118	189.8
	120 to 125	211.8
	127 to 128	55.1
	129	6.3
	130.5 to 132	75.8
	133 to 134	62.6
	138 to 139	15.5

[1] Project lands include Ice Harbor, Lower Monumental, Little Goose, and Lower Granite shorelines and adjacent areas.

[2] Irrigated HMU's

[3] Environmental Sensitive Natural Area

[4] Proposed for irrigation

b. Wildlife

Wildlife along the lower Snake River are concentrated in pockets of natural and/or managed habitats (*e.g.*, HMU's). Wildlife that occurs within wetland and riparian habitats include waterfowl, raptors, upland game birds aquatic furbearers, big game, small mammals, songbirds, reptiles, and amphibians. Of these, several are classified as state and/or Federal threatened and endangered species.

i. Waterfowl

Wintering waterfowl are the most abundant wildlife group occurring along the Snake River. Resident species are generally low in number, with the exception of lesser and greater Canada geese (*Brania canadensis*), found in association with most of the projects. Historically, Canada geese production has been limited to islands, with some production from cliff or bluff habitat (COE, 1983). The most productive island in the lower Snake River is New York Island (COE, 1983), which is covered with loamy soils, supports subirrigated vegetation, is a minimum of 0.5 miles from shore, and is not subject to seasonal inundation (COE, 1983). Other islands in the lower Snake River support only a minor proportion of the local geese population.

Non-island nesting geese use cliffs or artificial structures. Cliff nest sites vary from 10 to >200 feet above water on sheer cliffs and >200 yards inland on rock bluffs. A common feature of all cliff nest sites is overhead protection (COE, 1983). Historically, cliff nests and artificial structures accounted for a large percentage of geese production (Mudd *et al.*, 1980). Currently, cliff and artificial nesting structures accounted for 97 and 98% production at the Lower Monumental and Ice Harbor projects, respectively, during 1992 (L. Mettler, COE, personal communication, December 1992). Although cliff and artificial nest structures are of lesser importance in the Little Goose and Lower Granite pools, cliff nesting accounts for 45% of estimated gosling production for the Lower Granite project (L. Mettler, COE, personal communication, December 1992).

Historical estimates of 82,000 ducks and 29,000 geese have been reported for the four lower Snake River projects (COE, 1976). Estimated numbers of goslings hatched during 1992 were 131 for Ice Harbor, 143 for Lower Monumental, 458 for Little Goose, and 150 for Lower Granite (L. Mettler, COE, personal communication, December 1992). New York Island, within the Little Goose reservoir, accounted for 52% of estimated hatching.

Historically, HMU's in the lower Snake River have been planted with a grass-legume mixture and mowed to provide high-quality geese brooding habitat (COE, 1988). The quality and quantity of irrigated pasture along the lower Snake River is not limiting to brooding Canada geese unless access to these sites is limited by predation or competition. Lands not generally cultivated for Canada geese production are typified by sagebrush and rabbitbrush with minimal herbaceous groundcover (*e.g.*, subirrigated wheatgrass, annual rye) (COE, 1983).

Of the four projects along the lower Snake River, Little Goose supports the highest goose-nesting densities (*e.g.*, 90 nests producing 448 goslings in 1991). Densities for the remaining projects in 1991 are 34 nests and 88 goslings at Lower granite, 5 nests and 20 goslings at Lower Monumental, and 3 nests and 12 goslings at Ice Harbor (COE, 1992a).

ii. Raptors

Riparian forests and wetlands along the Snake River provide perching, nesting, and foraging habitat for raptors. Of these, only the osprey (*Pandion haliaetus*), northern harrier (*Circus cyaneus*), and bald eagle (*Haliaeetus leucocephalus*) occur in association with wetland or riparian areas.

Cliffs provide nest and roost sites for golden eagle (*Aquila chrysaetos*) and prairie falcons (*Falco mexicanus*) along the lower Snake River. Large cottonwoods and stands of Russian olive provide nesting habitat for American kestrel (*F. sparverius*), common barn owl (*Tyto alba*), western screen owl (*Otus kennicotti*), long-eared owl (*Asio otus*), short-eared owl (*A. flammeus*), and northern saw-whet owl (*Aegolius acadicus*). The majority of raptor species (including osprey) occur on the middle Snake River near the Dworshak Reservoir.

iii. Upland Game Birds

Riparian and wetland areas provide habitat for several species of upland game birds in the vicinity of the lower Snake River projects (COE, 1992a). Wild turkeys (*Meleagris gallpavo*) occur in small numbers along the Snake River during winter and spring (Tabor, 1976). Ring-necked pheasants (*Phasianus colchicus*) are associated with agricultural/riparian areas, and occur during breeding and wintering seasons within the HMU's along the lower Snake River (Lewke and Buss, 1977). Mourning doves (*Zenaida macroura*) are located throughout the riparian habitat which they use for nesting and roosting. Chukars (*Alectoris chukar*) are common throughout the fall within embayments seeps, and springs along the Snake River upstream of Central Ferry. Chukar occur in greater population densities in proximity to the Lower Granite project (COE, 1991). Moderate population densities have been reported at the Little Goose and Lower Monumental projects, and lower population estimates have been made for Ice Harbor (Mudd *et al.*, 1980). Distribution of chukar is dependent on topography and interspersion of mesic shrubland with other habitat types that support chukar foraging and thermoregulatory requirements (COE, 1991). Reduced chukar densities have been related to poor forage conditions, *e.g.*, drought (Mudd *et al.*, 1980); and, as McKern (1976) has noted, chukar will migrate to higher altitudes for forage in response to changes in vegetation moisture. California quail (*Callipepla californica*) are common in cropland, shrubsteppe, and palustrine and riparian habitats, and are large reliant upon a high degree of interspersion of these cover types (COE, 1991). Common snipe (*Gallinago gallinago*) occur inland at the Lower Granite and Lower Monumental projects (McKern, 1976).

iv. Songbirds

Distribution of songbirds along the lower Snake River projects is influenced by tree, shrub, grass, and legume cover. Mudd *et al.* (1980) recorded greater bird densities in trees, shrubs, and tall forb cover than in other cover types. In areas where cattle grazing has been eliminated, overall songbird densities have increased (Mudd *et al.*, 1980). Management of songbird habitat, which has restricted cattle grazing in certain areas, has resulted in increased species numbers and diversity (Mudd, 1980).

Habitat quality of songbirds is variable for up- and downstream projects. Riparian habitat quality for songbirds is low-to-moderate for the lower Snake River projects (COE, 1991), which can be attributed to young seral stage, sparse canopy cover, and lack of snags in forest habitat (COE, 1991). The understory component of riparian forests is not limiting in terms of stem density or canopy cover, but species composition (*e.g.*, hackberry, Russian olive) slightly reduces overall quality of understory vegetation for songbirds (COE, 1991). Conversely, the emergent scrub-shrub canopy component is limiting to songbirds (COE, 1991). Similarly, reduced canopy cover, in addition to low water levels, accounts for low habitat suitability of emergent wetland habitat for songbirds (COE, 1991). Production of emergent vegetation appears to be related to surface water elevation, and although emergent wetland habitat is increasing, it is not likely that habitat quality will vary significantly over time (COE, 1991) because species composition is not anticipated to change. Canopy cover of shrubs is the factor that would limit songbird distribution in mesic shrub habitat. Vegetation production in riparian shrublands is reliant on irrigation that ultimately affects patch success and determines habitat suitability for songbirds Grass and shrub-steppe habitats are suitable for songbirds, and are limiting only in the percent of herbaceous canopy cover (COE, 1991). Low herbaceous cover is likely a result of livestock grazing, shallow soils, and a preponderance of cheatgrass on disturbed sites (COE, 1991).

v. Aquatic Furbearers

Muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*), river otter (*Lutra canadensis*), and mink (*Mustela vison*) occur within embayments, tributaries, ponds, and riparian forests associated with project reservoirs. River otter use portions of rock riprap along project shorelines and densely vegetated draws at the confluence of major tributary streams. Beaver distribution is strongly associated with presence of cottonwood. Therefore, beaver are not widely distributed along the lower Snake River. Both mink and river otter use riprap areas along the banks of the lower Snake River as den sites (Sather-Blair *et al.*, 1991).

The majority of furbearers occurring in the lower Snake River breed between January and April, with parturition occurring between late April and July. Muskrats breed throughout the year, with March through June representing the peak breeding period; peaks and lulls in parturition occur at regular intervals between May and August (Chapman and Feldhamer, 1982). Similarly, river otter breed year-round, with parturition occurring at intervals between November and July (Chapman and Feldhamer, 1982) The presence of water around the entrance of den sites is essential for protection of young during parturition, and drawdown during this period may affect all furbearers within the lower Snake River. Data specific to aquatic furbearer reproduction in the lower Snake River are limited, and conclusions regarding specific impacts can only be considered conjecture.

vi. Mule and White-Tailed Deer

Mule and white-tailed deer use the lower Snake River canyon year-round and migrate throughout the canyon during the winter (COE, 1990). Mule and white-tailed deer are found along the lower Snake River reservoirs, in greater numbers upstream of the Lower Granite and along the upper Little Goose pools. Relatively few individuals occur along the Ice Harbor and Lower Monumental projects. In this area, the canyon is shallow, precipitation is reduced, and habitat consists of grasslands and basalt bluffs. Vegetation species diversity is significantly reduced. Conversely, upstream areas that support a greater number of mule and white-tailed deer are characterized by a variety of habitat types, including forest, scrub-shrub, grasslands, bluffs, and streams.

The limiting factor on the deer population in the lower Snake River appears to be a lack of water outside the vicinity of the mainstem (COE 1990) that reduces overall quantity and quality of available forage (Mudd *et al.*, 1980). In an attempt to compensate for this situation, irrigated HMU's that support an increased number of mule and white-tailed deer are maintained (COE, 1990). In an assessment of downstream habitat quality, it was determined that irrigated HMU's likely support deer densities in excess of numbers that could be accommodated under conditions of the bluebunch wheatgrass-Sandberg bluegrass (*Agropyron spicatum-Poa sandbergi*) zone. Grasses and forbs dominate this sere, with dominant shrub canopy of rabbitbrush and sagebrush. Uplands, adjacent to HMU's, are cultivated in dryland wheat (*Triticum* spp.) and barley (*Hordeum* spp.), or are grazed.

vii. Other Wildlife

Project reservoirs provide habitat for reptile, amphibian, small mammal, bat, shorebird, songbird, and colonial nesting species. Swallows construct nests within culverts that connect the mainstem with off-channel ponds containing emergent vegetation (COE, 1991). The majority of vertebrate species along the Snake River Canyon are dependent on tree-shrub riparian habitat associated with the project reservoirs (Lewke and Buss, 1977).

c. Threatened and Endangered Species

The bald eagle is a Federally-threatened species that occurs along the lower Snake River. Results of the Washington State midwinter bald eagle survey indicated that 10 bald eagles wintered along the lower Snake River in 1990. State-listed and candidate species occurring along the lower Snake River reservoirs in Washington are included in table 2-13.

Table 2-13
State and/or Federally Listed Threatened, Sensitive, Endangered, Candidate, And Monitor Species Occurring Within Aquatic and Terrestrial Habitats Along Reservoirs of the Lower Snake River in Washington

Species	Scientific Name	Status[1]
Plants		
Pygmy-weed	*Tillaea aquatica*	StS
Umatilla gooseberry	*Ribes oxyacanthoides*	StS
Idaho gooseberry	*River oxyacanthoides*	StS
Northwest raspberry	*Rubus nigerimus*	StT,FC
Piper's milk-vetch	*Astragalus riparius*	StS
Porcupine sedge	*Carex hystricina*	StS
Shining flat sedge	*Cyperus rivularis*	StS
Prairie cord grass	*Spartina pectinata*	StS
Giant helleborine	*Epipactis gigantea*	StS
Jessica's aster	*Aster jessicae*	FC
Broad-fruit mariposa	*Calochortus nitidus*	FC
Palouse goldenweed	*Haplopappus liatriformis*	FC
Cusick's lupine	*Lupinus cusicki*	FC
Spalding's silene	*Silene spaldingii*	FC
Insects		
Pale crescent	*Phyciodespallidus*	StM
Columbia River tiger beetle	*Cicindela columbica*	FC
Shepard's parnassian	*Parnassius clodius*	StC
Reptiles		
Tiger salamander	*Ambystoma tigrinum*	StM
Woodhouse's toad	*Bufo woodhousei*	StM
Ring-necked snake	*Diadophis punctatus*	StM

Birds		
Harlequin duck	*Histrionicus histrionicus*	FC
Loggerhead shrike	*Lanius ludovicianus*	FC
Western sage grouse	*Centrocercus urophasianus phaios*	FC
Black-crowned night heron	*Nycticorax nyticorax*	StM
Black tern	*Childonias niger*	FC
Great blue heron	*Ardea herodias*	StM
American white pelican	*Pelecanus erythrorhynchos*	StE
Bald eagle	*Haliaeetus leucocephalus*	FE,StT
Swainson's hawk	*Buteo swainsoni*	StC
Ferruginous hawk	*Buteo regalis*	FC,StT
Prairie falcon	*Falco mexicanus*	StM
Peregrine falcon	*Falco perigrinus*	FE,StE
Mammals		
Preble's shrew	*Sorex preblei*	FC
Fish		
Sand roller	*Percopsis transmontana*	StM
Piute sculpin	*Cottus beldingi*	StM
Bull trout	*Salvelinus confluentus*	FC
Chinook salmon, spring/summer	*Oncorhynchus tshawytscha*	FT
Chinook salmon, fall run	*Oncorhynchus tshawytscha*	FE
Sockeye salmon	*Oncorhynchus nerka*	FE
Molluscs		
Columbia pebblesnail	*Fluminicola columbiana*	FC
Shortface lanx	*Fisherola nuttalli*	FC
California floater	*Anodonta californiensis*	FC
Amphibians		
Spotted frog	*Rana pretiosa*	FC
[1]St = State; F = Federal; T = Threatened; S = Sensitive; E = Endangered; C = Candidate; M = Monitor		

4. Aquatic Ecology

Generally, the lower Snake River environment contains a mixture of native and introduced fish species (see section B.2. The construction of dams has altered the environment to favor fish species that prefer near-lentic (still-water) conditions rather than the lotic (moving water) conditions that existed prior to dam development. With the change from a riverine to lacustrine environment, there has been a shift in the trophic structure of the lower Snake River and, subsequently, a shift in the prey base for anadromous salmonids as well as resident lacustrine species. Prior to dam development, anadromous salmonids most likely foraged on benthic macroinvertebrates (Edwards *et al.*, 1974) from the substrate as they migrated downstream. Since dam construction, the prey base for anadromous and resident species has shifted to primarily a pelagic phytoplankton- and detritus-driven system. This supports a benthic invertebrate community consisting primarily of chironomids, oligochaetes, and amphipods, which are the preferred food items of the anadromous and resident fish species (Bennett *et al.*, 1990, 1991). This shift in the prey base for anadromous fish may have contributed to their decline. Additionally, this change to a lake-like environment has produced more favorable conditions for anadromous fish predators such as northern squawfish, smallmouth bass, and channel catfish.

a. Interrelationships Among Food Web Components

Figure 2-5 illustrates the food web for the Columbia River ecosystem (Cushing, 1992), and most likely applicable to the lower Snake River ecosystem as well. Certainly, all the major ecosystem components are included. The only component not specifically labeled in figure 2-4 is Fine Particulate Organic Matter (FPOM (<1 mm diameter). FPOM is an important organic source of energy, derived in part from the "death and feces" bracket shown at the right of the figure, as well as from the physical breakdown of all other ecosystem components, including organic matter from terrestrial photosynthesis entering the aquatic ecosystem.

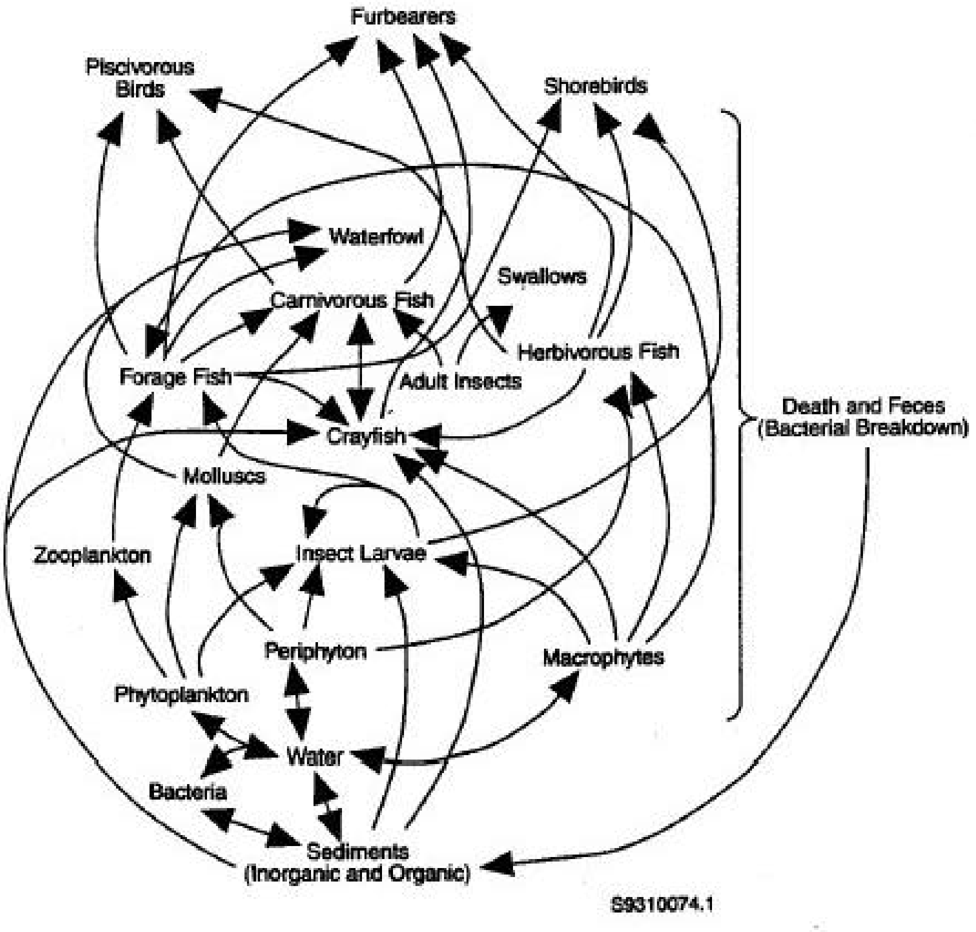

Figure 2-5. Interrelationships of Food Web Components for the Columbia River Ecosystem (from Cushing, 1992)

All components of the food web eventually perish. Their remains are eventually converted in FPOM or their mineral constituents by bacterial action and decomposition, and these are either deposited upon the bottom sediments where they are incorporated into this matrix or remain in the water column where they are utilized. It can be argued, of course, that all components shown in figure 2-4 are important in the functioning of the ecosystem. However, those components most related to anadromous fishes, and most likely to be impacted by reservoir drawdown, are discussed below. These include (upwards from the bottom of the food web) the sediments, bacteria, phytoplankton, periphyton, zooplankton, benthic invertebrates (shown as insect larvae and crayfish in figure 2-4), forage fish, and FPOM.

i. Sediments

Sediments, together with the water, form the main constituents of the physical setting of the aquatic ecosystem and its food-web components. The fine sediments are important in two ways: 1) they provide refuge and living space for chironomids and oligochaetes, both of which are important food items for fish in Lower Granite Reservoir (Bennett *et al.*, 1988); and 2) FPOM in the sediments is a food source for these organisms. Coarser sediments (rocks, riprap) provide a substratum supporting the attachment and growth of periphyton and several important invertebrates (*e.g.*, chironomids, caddisfly larvae, amphipods, and crayfish). Bennett *et al.* (1988) reported on the composition of the soft-bottom substrata in the Lower Granite Reservoir pool; they found varying percentages of sand, silt, clay, and volatile organics in several dredge and disposal sites, with sand and silt being the predominant components. Pinza *et al.* (1992c) reported the grain-size analyses of sediment samples collected between RM 119 and 127.4. They found that mean percentages of gravel (<2 µm), sand (2 to 62.5 µm), and clay (<3.9 µm) to be 0, 25.5, 61.8, and 12.7, respectively.

ii. Bacteria and Fungi

Bacteria and fungi are important in aquatic ecosystems in several ways. They "condition" Coarse Particulate Organic Matter (CPOM), converting poor-quality organic matter into a food source rich in protein and other nutrients. They are also important in breaking down and reducing dead organic matter into basic nutrients. Funk *et al.* (1979) reported on total coliforms, fecal coliforms, and fecal streptococci in the Clearwater River and lower Snake River, but these organisms are more important from a health than an ecological standpoint. No information on bacterial populations in relation to their function in ecosystems is available for the lower Snake River reservoirs or other comparable systems, to our knowledge.

iii. Fine Particulate Organic Matter (FPOM)

FPOM comprises a significant constituent of the energy base for lentic and lotic ecosystems. FPOM is the large pool of organic particles <1 mm in diameter, which are derived from many sources, including breakdown of larger organic particles; death and decay of macrophytes, phytoplankton, algae, and other organisms; and production of fecal pellets by zooplankton and insects. They from an integral part of the food web and are one of the main energy sources in streams and rivers. No specific data on the abundance or distribution of FPOM in these systems are available, although they are often included in biomass evaluations of phytoplankton. This is because much FPOM is in the same range as that of phytoplankton, and net samples usually are not separated prior to obtaining biomass measurements.

Sonntag *et al.* (1987) and Bennett *et al.* (1988) reported that organic matter content varied from 7 to 15% in soft-bottom substrate of the Lower Granite pool. Pinza *et al.* (1992c) reported mean percentages of total volatile solids (5.37) and total organic carbon (3.65) in sediment samples collected between RM 119 and 127.4.

iv. Phytoplankton, Periphyton, Macrophytes

The source of essentially all energy in aquatic food webs is primary production from photosynthesis by the primary producers. In lower Snake River reservoirs, thee are phytoplankton, periphyton, and aquatic macrophytes. These organisms, of course, must have a sufficient supply of the necessary inorganic nutrients to survive, and these come essential from two sources: 1) dissolution of inorganic substrates (sediments, rocks, soil) by the water; and 2) mobilization of nutrients by bacterial action in the water column and sediments. Given sufficient nutrients, suitable water temperatures, and proper habitat, the primary producers will produce biomass which, in turn, will be utilized by the secondary producers. Different secondary producers utilize the different primary producers to further elaborate organic matter for the higher trophic levels, and these are described later.

Phytoplankton, the free-floating algae, are used as food by zooplankton, molluscs, and insect larvae. Significant phytoplankton populations are known to develop in river-run impoundments like those of the lower Snake River (Funk *et al.*, 1979). These populations consist of algal cells broken free from periphytic growth on solid substrata, such as riprap rocks, and true lentic forms which develop in reservoirs or are flushed into reservoirs from off-channel lentic sites or upstream reservoirs (*e.g.*, Dworshak Reservoir). Neitzel *et al.* (1982a) reported on historical studies of phytoplankton in the Columbia River, and documented the increase over time related to the closure of dams upstream of the Hanford Reach. Phytoplankton populations would be expected to increase in the lower Snake River because lentic conditions there developed in closer proximity to a major supply of nutrient sources, such as those present in the Lewiston-Clarkston-Asotin area. Phytoplankton populations would also be expected to increase as more lentic forms becomes established in the reservoirs. Indeed, Falter *et al.* (1973) reported that cell counts did not exceed 2,000 cells or filaments/mL prior to closure of Little Goose Dam; these counts compare with those found in mesotrophic reservoirs in the northwestern United States, and also with those reported by Cushing (1963) from the Hanford Reach of the Columbia River. These populations consisted mainly of the diatom, *Asterionella formosa*, a free-floating alga.

Edwards *et al.* (1974) report that *Asterionella, Cyclotella, Melosira*, and other phyoplankters common in mesotrophic lakes and reservoirs in eastern Washington were found in the Snake River prior to impoundment by Lower Granite Dam. They further reported that common periphytic genera (*Cymbella, Gomphonema, Synedra*) were also present in the water column. Funk *et al.* (1979) present data on phytoplankton populations in the lower Clearwater and Snake Rivers during 1975 to 1977, and commonly report populations exceeding those reported by Falter *et al.* (1973). Common forms found by Funk included the genera *Cocsinodiscus, Cyclotella,* and *Melosira*, and frequent blooms of blue-green cyanobacteria. Beckman *et al.* (1985) report on extensive studies of phytoplankton production, abundance, and distribution in Lake Roosevelt, the impoundment behind Grand Coulee Dam on the Columbia River. They documented a similar species diversity, as reported for the lower Snake River, and found highest densities in June and July with mean densities of 13,000 to 25,00 x $10^4/m^3$.

Phytoplankton and FPOM are primary food items of the invertebrates in the lower Snake River ecosystem, both within the water column and following deposition and incorporation into the sediments. While suspended, they are ingested, along with bacteria, by zooplankton and by filter-feeding insect larvae such as *Hydropsyche* and *Brachycentrus*, both genera identified as members of the riprap-inhabiting community in lower Snake River reservoirs, and by filter-feeding molluscs. Following incorporation into the sediments, this organic matter is utilized by chironomids and oligochaetes, two important food sources for fish in this ecosystem. Amphipods use FPOM, which settle on or between riprap rocks.

Periphyton is another source of primary production, and hence energy, in the lower Snake River ecosystem. The mat-forming periphyton community is usually dominated by algae, although it is a complex mixture of autotrophic and heterotrophic organisms. It is grazed by a number of organisms including insect larvae (*e.g.*, chironomids, caddisfly larvae), snails, and amphipods. Following senescence, it usually breaks down into FPOM, contributing to this food source in the water column, as described above.

Data on periphyton growth and productivity in the lower Clearwater River and Lower Granite Reservoir are available in Funk *et al.* (1979). They reported significant growth of the filamentous green alga *Cladophora* in the lower Clearwater River, but significantly lower growth in the reservoir, probably related to fluctuating water depths, decreased current velocity, settling of detritus, and increased turbidity. *Cladophora* is a typical alga of oligotrophic streams and is often found in abundance in such places. Cushing (1967) reported on the productivity of periphyton in the Hanford Reach of the Columbia River, and found highest production in the spring and summer months, as would be expected. Net production rates were 0.005 to 0.0070 mg dry weight x cm^2/day.

Macrophytes, while living, function as a food source for some fish species and insects, but are more important as a food source after death and decomposition when their remains enter the CPOM-FPOM detrital pools. They are also important while living as a habitat for certain organisms. In addition to providing a food base for secondary producers, primary producers are also important in the production of oxygen as a byproduct of photosynthesis.

In the lower Snake River reservoirs, aquatic plant development is heaviest in the Little Goose pool, with *Elodea canadensis* and *Potamogeton nodosis* in heavy beds along calm, protected shores (Falter *et al*., 1974). In general, the lower Palouse and Snake River drainages are notable for their exceptionally heavy aquatic plant growths. Falter *et al.* (1974) report nine species of *Potamogeton* and seven other species of macrophytes as the dominant submerged macrophytes in this region.

v. Zooplankton

Zooplankton are usually not significant constituents of the food web in flowing waters, but may be important in semi-lentic environments such as the lower Snake River reservoirs, especially in the littoral and benthic regions. Zooplankton directly ingest certain, but not all, algal cells along with bacteria and FPOM.

Funk *et al.* (1979) report consistently low numbers of copepods and cladocerans in the free-flowing river above Lower Granite Reservoir (RM 154; <3 organisms/L). Numbers in Lower Granite Reservoir were also low, ranging from 1 to 46 organisms/L. They further state that zooplankton production at downstream river stations appears to have been sharply reduced. Ludden (1972) reported zooplankton numbers exceeding 200 organisms/L at Ice Harbor (RM 18) concomitant with the pre-impoundment studies. Post-impoundment counts of zooplankton from the same site by

COE limnologists have not exceeded 35 organisms/L. Zooplankton are food sources for small fish and juveniles of larger fish. Because of their paucity in the pelagic habitat of lower Snake River reservoirs, they are probably not important constituents of the food web in these regions. However, adequate investigations of this community have not been done for littoral or benthic zooplankton populations (M. Falter, University of Idaho, personal communication), and it is possible that they may be important food sources for young or small fish feeding in these areas.

Neitzel *et al.* (1982b) reported that crustacean zooplankters dominated most of their samples collected in the Hanford Reach of the Columbia River. The three dominant genera were *Bosmina, Diaptomus*, and *Cyclops*. Summer peak populations exceeded 4.5 organisms/L, while winter densities were generally <50 organisms/m^3. Beckman *et al.* (1985) found that cladocerans composed 44% of total zooplankton numbers in Lake Roosevelt, and that cyclopoids and calanoids accounted for 33 and 23%, respectively, of the total. Mean number from all stations was 15.5 organisms/L.

vi. Benthic Invertebrates

Benthic invertebrates are probably the most important organisms in the food web of these reservoirs in terms of their linkage between organic matter and algal food resources and forage and carnivorous fish. There is probably more information available about the populations of benthic invertebrates in the lower Snake River reservoirs than any other populations except fish.

Edwards *et al.* (1974) studied the benthic organisms of the Snake River in the future pool area of Lower Granite Reservoir, and reported finding typical lotic representatives of the orders Ephemeroptera, Trichoptera, and Diptera. In the developing pool behind Little Goose Dam, typical soft bottom-dwelling organisms were found. Brusven and Trihey (1978) present related data on the influence of fluctuating water levels on benthos of the lower Clearwater River; these data, however, are mainly relevant to typical lotic biota found in flowing streams rather than reservoir benthos.

Undoubtedly, the most complete data set available for the benthos of Lower Granite Reservoir is contained in Bennett *et al.* (1988, 1990, 1991). However, most studies prior to 1994 focused on characterization of soft substrate, with very limited sampling of hard substrate. Bennett *et al.* (1988) present data on reference populations of benthic invertebrates as part of a pre-investigation study to ascertain the impacts of dredge disposal and subsequent recolonization of these sites. They reported seasonal differences in the benthic communities, with highest numbers and standing stock during summer. Oligochaetes and chironomids made up 99% of the numbers present. There were no differences in standing stocks between deep and mid-depth stations, but diversity was greater at the mid-depth stations. The two subsequent publications, Bennett *et al.* (1990, 1991), present data on the results of dredge disposal recolonization, but there are data on shallow, mid-depth, and deep reference sites that could be used for basic information on this food web constituent. Although these data are the most complete available, and contain temporal information, they are not as comprehensive for the entire reservoir as is desirable for evaluating impacts of the drawdown alternative

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Beckman *et al.* (1985) studied the distribution and abundance of benthic invertebrates in Lake Roosevelt on the Columbia River. They found that oligochaeta were the most abundant taxon, comprising >75% of the total organisms collected at all stations. Chironomids were the only other taxon common at any of the stations, amounting to 17 to 23% of the benthos, with sphaeroid molluscs and nematodes accounting for the remainder. This indicates that benthic populations in the lower Snake River reservoirs appear typical for systems such as these, at least in this region.

The final constituent of this food web is the omnivorous crayfish. Crayfish feed mainly on a variety of food sources associated with the riprap and, in turn, are eaten by carnivorous fish species.

b. Predator-Prey Interactions

Extensive research on predator-prey relationships has been conducted in the John Day Reservoir on the lower Columbia River. John Day Reservoir, like Lower Granite Reservoir, is a run-of-river reservoir in the Columbia River Basin, and has predator-prey interactions similar to Lower Granite Reservoir. Therefore, results obtained from John Day may apply to Lower Granite Reservoir. Researchers have estimated that up to 3 million juvenile salmonids are preyed upon annually by northern squawfish, smallmouth bass, and walleye in John Day Reservoir (Rieman *et al.*, 1991). This represents ~14% of all juvenile salmonids entering the pool (Rieman *et al.*, 1991). Northern squawfish by far the most abundant predator in John Day Reservoir (Poe *et al.*, 1988), were responsible for 78% of the total loss, walleye accounted for 13%, and smallmouth bass accounted for 9% (Rieman *et al.*, 1991).

The main predators of juvenile salmonids in the lower Snake River are the northern squawfish (*Pychocheilus oregonensis*) and the introduced populations of smallmouth bass and channel catfish (Bennett *et al.*, 1988, 1990, 1991; Chandler, 1993; Curet, 1993). A crude population estimate of 33,600 piscivore predators was obtained by Thorne *et al.* (1992) for Lower Granite Reservoir by using hydroacoustic surveys supplemented with gillnet sampling. However, this study provided no information on the species or size composition of the predator population.

The combined predation on salmonid smolts by these three main predators may be the primary source of smolt mortality within the Snake River Basin (Poe and Rieman, 1988). An analysis of feeding patterns of the three main piscivore predators in Lower Granite Reservoir during the spring (April to June) of 1987 indicated that salmonids were found mostly in the stomachs of channel catfish (39% of the total), northern squawfish (22%), and smallmouth bass (3.6%). However, to determine the relative importance of salmonid smolts to the overall diet of northern squawfish, smallmouth bass, and channel catfish, an index of relative importance (IRI) was calculated. This method combines the frequency of occurrence, number, and weight frequencies of food categories obtained from piscivore stomachs into an index which ranges between 0 and 100%. Values near 100% indicate more importance than values near 0% (George and Hadley, 1979). The IRI indicated that during the spring of 1987 salmon smolts were important in the diet of northern squawfish and channel catfish. Salmon smolts did not constitute an important part of the diet of smallmouth bass during any season in 1987 (Bennett *et al.*, 1988).

Channel catfish stomachs contained mostly steelhead smolts, whereas northern squawfish and smallmouth bass contained chinook smolts. Most predation on juvenile salmonids is thought to occur in the tailrace section of the dams, the forebay of dams, and in the open shallow water zones (Bennett *et al.*, 1988). Further, predation on smolts in Lower Granite Reservoir was always highest during the spring period when smolt abundance was greatest (Bennett *et al.*, 1988). Chinook salmon juveniles were found in most of the stomachs during April, steelhead juveniles dominated the diet during May, and an equal number of chinook and steelhead were observed in predator stomachs during June (Chandler, 1993).

i. Northern Squawfish Diet

Chironomids were the most important prey item for northern squawfish, accounting for ~40% of all prey items during the spring, followed by fish (23%), insects (20%), and crayfish (17%). During the summer period, caldocera and crayfish accounted for 75% of their diet. In the fall and winter, chironomids, crayfish, and fish (non-salmonids) were the most important prey items (Bennett *et al.*, 1988).

Northern squawfish are generally opportunistic predators that prey on the most abundant food source available to them (Chandler, 1993). Thus, northern squawfish may rapidly adjust their feeding rate when a school of juvenile salmonids is encountered in order to take advantage of the abundant prey. Temporally-clustered prey captures by northern squawfish probably indicate that juvenile salmonids are encountered as temporal patches or schools (Peterson and DeAngelis, 1992).

Since little predator-prey research has been conducted on Lower Granite Reservoir, results from studies on John Day Reservoir provide insight into predator/prey dynamics within the Lower Snake River. Juvenile salmonids were found to constitute 73 to 99% of northern squawfish diet below McNary Dam (John Day Reservoir) in July 1988 (Peterson *et al.*, 1989). Larger squawfish (over 400 mm) were found to consume four to five times more salmonids than squawfish <400 mm (Gray *et al.*, 1984). The rate of predation of northern squawfish on smolts in the tailrace of McNary Dam was found to be highest during July and August, when high passage rates corresponded with increasing water temperatures. Mean consumption rates of northern squawfish below McNary Dam increased by four times (0.5 prey/predator to 2.0 prey/predator) as water temperature rose from 11.5ºC (May) to 19.0ºC (July) (Vigg *et al.*, 1991). Mortality was generally lower for yearling chinook and steelhead that migrate in April and May than for subyearling chinook salmon that migrate primarily in the summer (Rieman *et al.*, 1991).

A simulation model developed for John Day Reservoir determined that the major factor correlating with predation was temperature (Beamesderfer *et al.*, 1990). Further, over the course of the season, northern squawfish consumption rate of smolts was over five times greater in the tailrace than in the remainder of the John Day Reservoir (Vigg, 1988). Northern squawfish fed entirely on salmon smolts in the McNary Dam tailrace, while northern squawfish in the main reservoir fed on an equal number of salmonid and non-salmonid prey (Vigg,1988).

Within Lower Granite Reservoir, the consumption rate of salmonid smolts by northern squawfish was higher during the spring/summer period (0.06 to 0.17 smolts/predator/day) with large (>349 mm) northern squawfish having the greatest predation effect on juvenile salmonids. The highest consumption of juvenile salmonids, by all sizes of northern squawfish, occurred during the month of April (0.17 smolts/predator/day), decreased to 0.11 smolts/predator/day during May, and was down to 0.06 smolts/predator/day during June (based on an average consumption for 1987 to 1991) (Chandler, 1993).

During the 1987 to 1991 spring period, the average IRI for juvenile salmonids in northern squawfish 250 to 349 mm was 14%, compared with 54% in northern squawfish >349 mm (Chandler, 1993). This pattern of predation coincides with the peak outmigration of spring chinook salmon smolts in April, followed by juvenile steelhead peak outmigration in May and, lastly, by a weak outmigration of fall chinook salmon in June (Bennett *et al.*, 1988). Consumption of non-salmonid prey during these 3 months gradually increased as salmonid densities in the reservoir decreased.

Several researchers (Bennett *et al.*, 1983, 1988; Chandler, 1993) have reported a higher density of adult northern squawfish in the tailrace and the forebay of Lower Granite Reservoir during the spring than observed during any other season. Examination of the diel feeding patterns of northern squawfish indicated that feeding on juvenile salmonids peaked during the late morning and evening hours in Lower Granite Reservoir (Chandler, 1993).

ii. Smallmouth Bass Diet

During 1987, the diet of smallmouth bass consisted, for the most part, of chironomids, crayfish, and fish (Bennett *et al.*, 1983, 1988). In the spring, food items of smallmouth bass included chironomids (55%), crayfish (33%), and fish (9%). In the summer, smallmouth bass consumed fish (26%), crayfish (33%), and chironomids (30%), whereas in the fall, crayfish comprised >80% of their diet.

A consumption rate of 0.08 smolts/predator/day for smallmouth bass (<200 mm) and a population estimate of 100,000 smallmouth bass (>50 mm) were calculated by Curet (University of Idaho, personal communication) for the Lower Granite Reservoir. Smallmouth bass may have the greatest impact on age-0 fall chinook salmon outmigrants because their habitat use overlaps during the spring outmigration period. Smallmouth bass were more abundant in the low-velocity, shallow-water zones of the forebay and upper reaches of Lower Granite reservoir (Bennett *et al.*, 1983, 1988). Curet estimated that smallmouth bass predated ~5.3% of the 1992 fall chinook salmon outmigrants, whereas northern squawfish predation accounted for only 3.7% of the annual loss of juvenile salmonids in Lower Granite Reservoir. Northern squawfish enter the shallows to spawn in June, and during this time period, age-0 fall chinook salmon move out of the littoral zone and consequently are not available to northern squawfish. As Curet explains, yearling spring chinook salmon seem to travel more in open water and are thus subject to greater predation by northern squawfish than by smallmouth bass during April and May.

iii. Channel Catfish Diet

During 1987, the diet of channel catfish in Lower Granite Reservoir consisted for the most part of fish and chironomids (Bennett *et al.*, 1988). Predation of salmonid smolt sin the tailrace may be an artifact of the distribution pattern of channel catfish which tend to congregate in the tailrace each spring for mating purposes (Bennett *et al.*, 1988). In the spring, juvenile steelhead accounted for 39% of their diet (IRI) and juvenile chinook for 1% (IRI), whereas in the summer and fall period, salmonid smolts accounted for only 4% of their diet in the same tailrace area. Chironomids make up 30% of the diet in the spring and up to 86% in the fall (Bennett *et al.*, 1988).

III. Description of Alternatives

A. Drawdown

Drawdown alternatives that proposed modification to existing dam facilities and operations are discussed in this section.

The objective of drawdown is to lower pool elevations, thus increasing river velocities through the lower Snake River. It is anticipated that increasing river velocities may reduce the travel time of smolts through the river system to the ocean. However, each alternative will require modifications to the dam or spillways, existing facility operations, and adult fish passage facilities. All alternatives, with the exception of the Natural River Option, will require new, lower-level, juvenile fish bypass facilities. Current fish barging operations on the lower Snake River would cease during the drawdown period. Because hydraulic capacities would be reduced under drawdown conditions, hydropower production would also be reduced.

Analysis of the drawdown alternative assumes that all lower Snake River reservoirs will be operated at some lowered pool elevation (*i.e.*, minimum operating pool, spillway crest) during all or part of the juvenile fish outmigration period (15 April to 31 August). The analysis also assumes that, following drawdown, reservoirs would be returned to normal operating pool elevations.

Drawdown levels range from normal minimum operating pool to a complete river bypass of the dams. Drawdown could be achieved by passing water through the powerhouse, over the spillway, or both. Each alternative accommodates either constant or variable pool levels that would fluctuate with natural flows, once drawdown is achieved.

The types of alternatives that could be maintained once drawdown is achieved are broken down into five general categories.

Group 1 - Natural River Option. This alternative attempts to restore historic flows and relies on construction of an engineered channel around the existing dams.

Group 2 - Variable pool with existing powerhouse. These alternatives rely on operation of the existing powerhouses. "Variable pool" refers to allowing reservoir pool elevation to change relative to river discharge.

Group 3 - Variable pool with modified powerhouse operation. These alternatives rely on changes or modifications to turbines within the powerhouse or modifications to the powerhouse to allow more efficient operation at drawdown levels. "Variable pool" refers to allowing reservoir pool elevation to change relative to river discharge.

Group 4 - Constant pool with existing powerhouse operation. These alternatives rely on modifications to allow drawdown while maintaining existing operation. "Constant pool" refers to holding the reservoir pool elevation near constant.

Group 5 - Constant pool with modified powerhouse operation. These alternatives are similar to Group 4, except that turbine/generators would be modified to provide more efficient operation under drawdown operations. "Modified powerhouse" refers to replacing turbines in the existing powerhouse. "Constant pool" refers to holding the reservoir surface-water elevation near constant.

Variations of these five general groups have been described and include a total of nine drawdown operations. These nine options, including drawdown intervals and facility modifications, are the basis of this impact analysis. The schedule and general description of alternative configurations for an April 15 drawdown is summarized in table 3-1, while the range in average refill times for each alternative is summarized in table 3-2. These refill times will vary according to the length of the drawdown period (*i.e.*, refill period) and inflow into the reservoirs. These conditions are described for each alternative under operations.

Table 3-1
Schedule and Description of Alternative Configurations For April 15 Drawdown of Pool Elevation At Lower Snake River Dams. For Refill Period, Upper Range Encompasses Only Spring Outmigration Period Whereas a Lower Range Encompasses Summer Outmigration Periods As Well

		Alternative	Drafting Period	Refill Period	Juvenile Bypass	Adult Bypass	Powerhouse	Existing Spillway	New Spillway
Group 1	4a	Natural River/ Alternative 4A	February 16 to April 15	June 16 to 28/September 4 to October 21		Auxiliary exits; new adult ladders at Lower Granite and Little Goose		Drum gates at Lower Monumental, Lower Granite, Little Goose	
Group 2	5	Existing Powerhouse and Existing Spillway-Variable Pool	March 16 to April 15	June 16 to 24/September 4 to October 11	Collection channel; Vertical barrier screens; Transportation channel	New Adult Ladders at Lower Granite, Little Goose; Secondary ladder exits; Auxiliary exits		Drum gates at Lower Monumental, Lower Granite, Little Goose; Stilling Basin at Little Goose	
Group 3	9	Modified Powerhouse and Existing Spillway--Variable Pool	March 16 to April 15	June 16 to 24/September 4 to October 11	Collection channel; Vertical barrier screens; Transportation channel	Auxiliary exits; Secondary ladder exits; New adult ladders at Lower Granite/Little Goose	New turbine runners	Drum gates at Lower Monumental, Lower Granite, Little Goose; Stilling Basin at Little Goose	
Group 4	13	Existing Powerhouse and Existing Spillway - Constant Pool	March 29 to April 15	June 16 to 23/September 4 to October 5	Collection channel; Vertical barrier screens; Transportation channel	Auxiliary exits; Secondary ladder exits; New adult ladders at Lower Granite/Little Goose		Drum gates at Lower Monumental, Lower Granite, Little Goose; Stilling Basin at Little Goose	
Group 5	14	Existing Powerhouse and Modified Spillway - Constant Pool	March 24 to April 15	June 16 to 23/September 4 to October 5	Collection channel; Vertical barrier screens; Transportation channel	Auxiliary exits; Secondary ladder exits; New adult ladders at Lower Granite/Little Goose		Lower crest; Drum gates at Lower Monumental, Lower Granite, Little Goose; Stilling Basin at Little Goose	
Group 6	15	Existing Powerhouse and New Low-Level Spillway - Constant Pool	March 20 to April 15	June 16 to 24/September 4 to October 9	Collection channel; Vertical barrier screens; Transportation channel	Auxiliary exits; Secondary ladder exits; New adult ladders at all dams		Drum gates at Lower Monumental, Lower Granite, Little Goose; Stilling Basin at Little Goose	Six new bays with gates

Table 3-2
Range in Average Refill Time, in Days Per Project
For Each Alternative Under High-, Average-, and Low-Flow Scenarios.
Days Are Based On Either a 2- or 3.5-Month Drawdown Period

Alternative	June 16 Refill			September 1 Refill		
	190 kcfs	95 kcfs	20 kcfs	40 kcfs	30 kcfs	18 kcfs
Natural River Option		1	3	25	7	1232
Alts 5/9	1	2	20	6	9	26
Alts 13/17	1	2	12	4	6	14
Alts 14/18	1	2	15	5	8	19
Alts 15/19	1	2	17	6	9	21

1. Natural River Option (Alternative 4A

a. Description

This concept would produce the most extreme drawdown operation of any of the envisioned alternatives. For a river discharge of 20,000 cubic feet per second (cfs), the total drawdown below normal maximum pool levels would be approximately 115 feet at Lower Granite, 114 feet at Little Goose, 108 feet at Lower Monumental, and 97 feet at Ice Harbor Dam. The option consists of constructing river bypass structures and new river channels around each of the four lower Snake river dams. The structures will allow the pools to be lowered and the river diverted around each dam to achieve a near free-flow river condition during salmonid outmigration. Powerhouse, spillway, and navigation lock operations will cease during the drawdown period. The bypass structures will be designed so that both adult and juvenile fish can safely pass through the structure while remaining in the river. The new bypass structures will consist of ten concrete gravity monoliths forming 10 outlets. Each outlet will measure 45 feet tall x 50 feet wide. Submerged steel tainter gates will control flow through each outlet. The reservoir pools would be operated at a drawdown level during the juvenile fish outmigration, 15 April to 15 June, or 15 April to Labor Day. Pools would be returned to normal operating levels for the rest of the year.

b. Operation

The existing powerhouses and spillways will be used to lower upstream pool levels from maximum pool levels to near the existing spillway crest elevations (figure 3-1). Below spillway crest elevations, the powerhouses and existing spillways will be inoperable. To further lower the pools to near-natural river elevations, tainter gates on the new structures will be opened, throttling the flow to allow a controlled lowering of the upstream pool. As the pool reaches the natural river level, the tainter gates will be raised completely out of the water. Reservoir drafting will begin no later than 16 February to achieve the near-natural flow condition by 15 April each year. The total reservoir system storage which would be evacuated during the drawdown is estimated to be 1,663,500 acre-feet (AF). The drawdown time from full pool levels is limited only the rate of drawdown (2 feet per day), provided that average Lower Granite inflows are <210,000 cfs. Following the drawdown period, the tainter gates on the new bypass structures will be closed, allowing the reservoirs to be filled. If reservoirs are maintained at near-natural river elevations during the 15 April to 15 June time period, refill of the reservoirs will being on 16 June. Refill will take ~10 days, with average inflows of 95,000 cfs. If reservoirs are maintained at natural river elevations from 15 April to after Labor Day, refill of the reservoirs will begin around 5 September. Refill will take ~46 days, given average inflows of 30,000 cfs, but could take longer if flows are lower than average. Shorter refill times can be achieved by drafting upstream storage, but already a large portion of the September inflows into Lower Granite Reservoir generally come from drafts of Dworshak Reservoir.

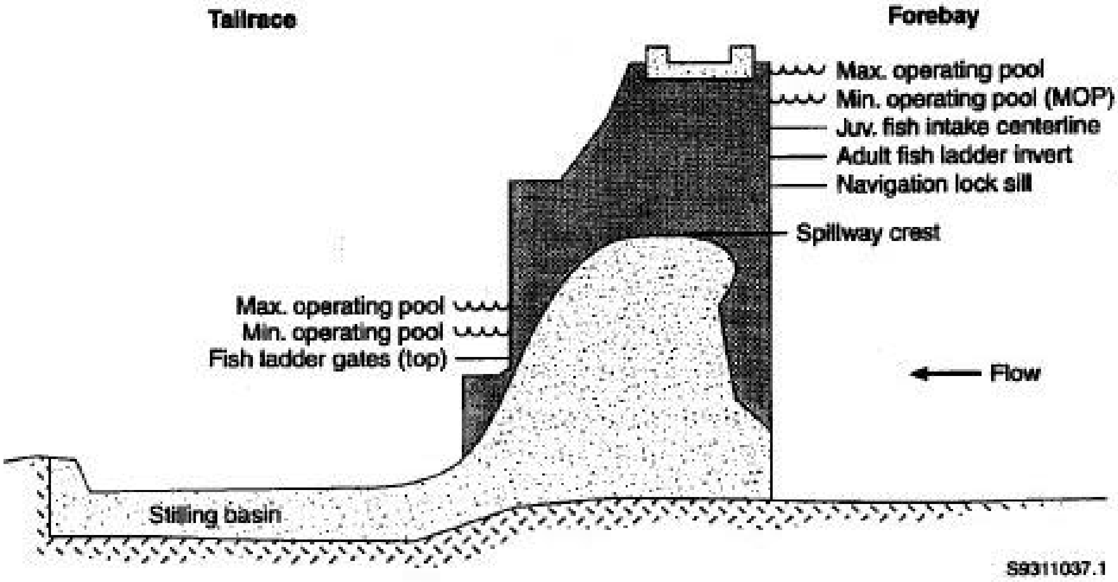

Figure 3-1. Relative Position of Surface-Water Elevations at Minimum and Maximum Operating Pool Relative to Structural Elevation of the Dam

c. Modifications

Project modifications in addition to the bypass structure, required to support drawdown operations include the following.

i. Juvenile Facilities

The period of transition between normal and drawdown operations will begin prior to the juvenile outmigration period. This will preclude the need for a low-level juvenile powerhouse bypass system. During the transitional refill period, juvenile bypass systems will be inoperable until normal pool levels are reached.

ii. Adult Facilities

Existing adult fish facilities will require modifications to allow movement of adult fish past the dams during the transition period between normal operation and drawdown/refill operations. These facilities will function only with pool levels between normal pool and spillway crest elevations, when powerhouses and spillways are operational. Adult passage through the new river bypass structure will be possible when the upstream pools are sufficiently lowered to allow the new tainter gates to be completely raised from the water.

iii. Existing Spillway/Stilling Basin Modifications

A hydraulic jump-type stilling basin, with end sill and training walls, will be constructed at Little Goose Dam downstream of the existing spillway rollerbucket. Drumgates will be installed downstream of the stilling-basin end sill at Lower Granite, Little Goose, and Lower Monumental Dams. The drumgates will be used to adjust stilling-basin tailwater elevations so that spillway flip-lips will be as effective as possible in reducing dissolved gas levels.

iv. Miscellaneous Modifications

Miscellaneous features at the dams and in, or adjacent to, associated reservoirs will require modification to allow operation or to prevent damage whenever pool levels are lowered below minimum operating levels. These features include the floating navigation lock guide walls, culvert and pipe outfalls, debris shear boom, water quality siphons (Lewiston Levees), and the adult fish ladder at Lyons Ferry Hatchery.

d. Water Travel Time

Minimum and maximum water travel times, from the confluence of the Snake and Clearwater Rivers to the mouth of the Snake River, are 62 and 27 hours for flows of 25,000 and 160,000 cfs, respectively.

2. Existing Powerhouse and Existing Spillway: Variable Pool (Alternative 5)

a. Description

This concept would produce variable pool operation with drawdown levels up to 57 feet at Lower Granite, Little Goose, and Lower Monumental Dams; and up to 49 feet at Ice Harbor Dam. The existing powerhouses will be operated to their hydraulic capacity, at pool levels not less than the corresponding existing spillway crest elevations. Flows in excess of powerplant capacity would pass uncontrolled (no gate control) over the spillway. The forebay water-surface elevations would fluctuate above the spillway crest, depending on river discharge and the flow split between the powerhouses and the spillways. The approximate total pool elevation change, as the river discharge changes from 62,000 to 225,000 cfs, is ~19 feet for Ice Harbor pool and 20 feet for the other three projects. The reservoir pools would be operated at a drawdown level during the juvenile fish outmigration during 15 April to 15 June or 15 April to Labor Day. Pools would be returned to normal operating levels for the rest of the year.

b. Operation

Reservoir drafting would begin no later than 16 March to achieve the target drawdown elevations by 15 April of each year. The total reservoir system storage which will be evacuated is estimated to be 1,313,300 AF. Reservoir drafting is limited to 2 feet per day to prevent embankment failure. This alternative proposes to operate the spillway without gate control, and allow flows in excess of powerhouse hydraulic capacities to pass over the spillways. Since the drawdown period will be occurring during the spring runoff months, it is likely that freshets will occur, increasing river discharges and raising the water level above the existing spillway crests by >2 feet. Depending on the hydrograph recession, it will probably be necessary to operate the spillway gate to prevent the reservoir pool from falling faster than 2 feet per day after the freshet. If reservoir elevations are maintained at their drawdown levels during the 15 April to 15 June period, refill of the reservoirs will take ~8 days with average inflows of 95,000 cfs. However, the refill time will increase dramatically in low-water years. If reservoirs are maintained at their drawdown levels from 15 April to after Labor Day, refill of the reservoirs will begin around 5 September and will take ~36 days, given average inflows of 30,000 cfs.

c. Modifications

This alternative will require the following physical changes to each of the four lower Snake River dams to accommodate this operation.

i. Juvenile Facilities

With the lowered pool levels, the existing juvenile bypass systems will be inoperable. A new lower-level juvenile bypass system will be required to collect and pass juvenile fish around operating turbines in the tailrace. Because of the magnitude of forebay fluctuation, the collection channel will be a pressurized system similar to that at John Day Dam. An 11-foot fluctuation range (from spillway crests to 11 feet above spillway crests), with full hydraulic capacity of powerhouses, would accommodate a river discharge up to ~136,000 cfs. If one or more powerhouse turbines were out of service, the river discharge (which would cause an 11-foot head on spillway crests) would be lower. The John Day juvenile bypass system operates acceptably with an 11-foot pool fluctuation, but the effect on juvenile fish passing through pressurized juvenile bypass systems operating over a greater pool range is unknown. Pressurized operation, for heads >11 feet, may not be desirable since the rapid pressure changes within the system may be harmful to juvenile fish. In addition, the higher the pool rises over orifices within gatewells, the less efficient the orifices may be in attracting juveniles into the collection channel. Juvenile fish transportation will not be possible since navigation will be suspended. Controlled reservoir drafting, along with the utilization of existing powerhouse and spillway operations to achieve the lower pool levels, will occur prior to the arrival of juvenile fish migrants. During the refill period, juvenile bypass systems will be inoperable until normal pool levels are achieved.

ii. Adult Facilities

When pool levels drop below minimum operating levels, existing adult fish ladder exits cease to function. To provide adult fish passage under this drawdown proposal, addition of secondary low-level adult ladder exits must be added. The existing ladder exits will also require installation of auxiliary exits consisting of a false weir, adult return flume, and water supply systems similar to the existing Lower Granite system. It will be necessary to modify the Lower Granite system to accommodate a wider pool fluctuation range. This will allow adult ladder operation during the period of transition from normal operating pool levels to drawdown pool levels. For extended drawdown operations, the false weir and return flume may not be biologically acceptable. A secondary low-level ladder exit, with a vertical slot control section similar to the John Day Dam adult ladders, could be used. The John Day system works under 11-foot pool fluctuation. An 11-foot fluctuation range would accommodate a river discharge up to 136,000 cfs. River flows above this would require the gravity feed system to be shut down, and the auxiliary ladder exits with fish return flumes to be used. With all four dams and reservoirs operating in the drawdown mode, the water surface elevations below the dams will be lower than original design (except at Ice Harbor). Therefore, adult ladder facilities, including entrances and auxiliary water supplies, will need to be modified. At all projects except Ice Harbor Dam, the existing adult collection system will be lowered to maintain adequate water depth for operation of adult fish ladder entrances. Adult ladder entrances and water supply systems at Ice Harbor will not need modification, because water surface elevations below Ice Harbor (McNary pool) will not change.

iii. Existing Spillway/Stilling Basin Modifications

At Little Goose Dam, a hydraulic jump-type stilling basin, with end sill and training walls, will be installed downstream of the existing spillway rollerbucket. At Lower Granite, Little Goose, and Lower Monumental Dams, drumgates will be installed downstream of the stilling basin end sill. Stilling basin training walls will also be extended, as required, for tailwater control by the drumgates. The drumgates will be used to adjust stilling basin tailwater elevations so that spillway flip-lips can be as effective as possible in reducing dissolved gas levels.

iv. Miscellaneous Modifications

Miscellaneous features at the dams and in, or adjacent to, associated reservoirs will require modification to allow operation, and to prevent damage when pool levels are lowered below minimum operating levels. These features include the floating navigation lock guide walls, culvert and pipe outfalls, debris shear boom, water quality siphons (Lewiston Levees), and the adult ladder at Lyons Ferry Hatchery. Embankments must be protected from erosion and failure for this alternative.

d. Water Travel Time

Minimum and maximum water travel times, from the confluence of the Snake and Clearwater Rivers to the mouth of the Snake River, are 229 and 60 hours for flows of 25,000 and 160,000 cfs, respectively. Travel time through the remaining pools, after drawdown, ranges from 211 to 51 hours for the above flow range.

3. Modified Powerhouse and Existing Spillway: Variable Pool (Alternative 9)

a. Description

This alternative is the same as Alternative 5, except for the powerhouse modifications described below.

b. Operation

The operation associated with this alternative is identified in Alternative 5.

c. Modifications

The physical changes required are identical to Alternative 5, except that turbine/generator sets at each of the lower Snake River dams would be replaced with new equipment designed to work more efficiently at the drawdown pool levels. Operating existing turbine-generator units at lower than design heads cause efficiency losses of ~5.3%. Low efficiency operation can be mitigated in various ways. For this study, installation of new turbine-runners was assumed. New turbine-runners can be designed to operate at peak efficiency at a lower head. However, a reduction in efficiency (less than existing turbines) may occur when operating new turbines at normal heads. Drawdown operations will also result in a decrease of power production due to the decreased head across the generating units.

d. Water Travel Time

See Alternative 5 description.

4. Existing Powerhouse and Existing Spillway: Constant Pool (Alternative 13)

a. Description

This alternative proposes a drawdown operation of 33 to 38 feet below normal maximum pools at Lower Granite, Little Goose, and Lower Monumental Dams, and a drawdown of 25 to 30 feet below normal maximum pools at Ice Harbor Dam. The powerhouses at each lower Snake River dm would be operated to their hydraulic capacity with excess water passing over the existing spillways. During the drawdown operating mode, the drawdown pool levels will be maintained at a near constant level (±5 feet). The reservoir pools would be operated at a drawdown level during the juvenile fish outmigration period, 15 April to 15 June or 15 April to Labor Day. Pools would be returned to normal operating levels for the rest of the year.

b. Operation

The four lower Snake River projects will begin drafting no later than 29 March in order to reach the target drawdown elevations by 15 April each year. The total reservoir system storage which will be evacuated, from full pool elevations to the drawdown elevations, is estimated to be 900,000 AF. If reservoir elevations are maintained at their drawdown levels during the 15 April to 15 June time period, refill of the reservoirs will take ~6 days with average inflows of 95,000 cfs. However, the refill time will increase dramatically in low-water years. Given the 192 inflows after mid-June averaging 21,000 cfs, refill of the reservoirs will take ~48 days. If reservoirs are maintained at their drawdown levels from 15 April to after Labor Day, refill of the reservoirs will begin around 5 September, and will take ~25 days provided average inflows of 30,000 cfs are achieved. The time for refill will vary, depending on inflows. During low-water years, when average inflows can drop to around 20,000 cfs, refill will take up to 54 days.

c. Modifications

This alternative will require physical changes to the four lower Snake River dams, as discussed below.

i. Juvenile Facilities

Existing juvenile bypass systems will be used during normal pool operations. However, during the drawdown operating mode proposed by this alternative, the existing juvenile bypass systems will be inoperable. A new lower-level juvenile bypass system will be required to collect and pass juvenile fish around operating turbines in the tailrace. Because of the restricted forebay fluctuation (±5 feet) during the drawdown operation, the new low-level juvenile bypass systems can be designed and operated similar to that currently in use at the lower Snake River dams. Fish will be guided by existing turbine intake screens into gatewells where they will pass through orifices (short 12-inch-diameter holes) into a collection channel. The collection channel will discharge into a transportation channel which will pass the fish and water to the river below the dam. Juvenile fish transportation will not be possible, since navigation will be suspended. A new set of vertical barrier screens will be required to achieve the highest levels of orifice passage efficiency. The new vertical barrier screens would be put in place prior to drawdown, and left in place during drawdown and refill. The older vertical barrier screens would then be put back into place for operation at the normal operating pool range. During the transition period between normal pool levels and target drawdown pool levels, both the normal and new low-level juvenile systems will be inoperable. Therefore, drawdown pools must be reached before the arrival of large numbers of outmigrating juvenile fish. Likewise, during refill, both low-level and existing juvenile bypass systems will be inoperable.

ii. Adult Facilities

When pool levels drop below minimum operating levels, existing adult fish ladder exits cease to function. To provide adult fish passage under this drawdown proposal, addition of secondary low-level adult ladder exits will be required. The existing ladder exits will also require installations of auxiliary exits consisting of a false weir, adult return flume, and water supply system similar to the existing Lower Granite system. This will allow adult ladder operation during the period of transition from normal operating pool levels to drawdown pool levels. Once down to the low-level (drawdown) operating pool, the low-level ladder exit can be utilized. With all four dams and reservoirs operating in the drawdown mode, the water-surface elevations below the dams will be lower than original design (except at Ice Harbor). Therefore, adult ladder facilities, including entrances and auxiliary water supplies, will need to be modified. At all projects except Ice Harbor Dam, the existing adult collection system will be lowered to maintain adequate water depth for operation of adult fish ladder entrances. Adult ladder entrances and water supply systems at Ice Harbor will not need modification, because water-surface elevations below Ice Harbor (McNary pool) will not change.

iii. Existing Spillway/Stilling Basin Modifications

At Little Goose Dam, a hydraulic jump-style stilling basin, with end sill and training walls, will be installed downstream of the existing spillway rollerbucket. At Lower Granite, Little Goose, and Lower Monumental Dams, drumgates will be installed downstream of the stilling basin end still. Stilling basin training walls will also be extended, as required, for tailwater control by the drumgates. The drumgates will be used to adjust stilling basin tailwater elevations so that spillway flip-lips will be as effective as possible in reducing resolved gas levels.

iv. Miscellaneous Modifications

Miscellaneous features at the dams and associated reservoirs will require modification to allow operation, or to prevent damage when pool levels are lowered below minimum operating levels. Features include the floating navigation lock guide walls, culvert and pipe outfalls, debris shear boom, water quality siphons (Lewiston Levees), and the adult ladder at Lyons Ferry Hatchery. Protection of embankment from erosion and failure will be required for this alternative.

d. Water Travel Time

Minimum and maximum water travel times, from the confluence of the Snake and Clearwater Rivers to the mouth of the Snake River, are 379 hours and 72 hours for flows of 25,000 and 160,000 cfs, respectively.

5. Existing Powerhouse and Modified Existing Spillway: Constant Pool (Alternative 14)

a. Description

This alternative proposes to operate the four lower Snake River dams and reservoirs at a level 43 to 48 feet below normal maximum pool levels at Lower Granite, Little Goose, and Lower Monumental Dams, and 35 to 40 feet below the normal maximum pool level at Ice Harbor Dam. To achieve this drawdown level, the existing spillways would be modified by lowering the crests 10 feet. The powerhouses at each lower Snake River dam would be operated to their hydraulic capacity with excess water passing over the modified existing spillways. During the drawdown operating mode, the drawdown pool levels will be maintained at near constant level ±5 feet). The reservoir pools would be operated at a drawdown level during the juvenile fish outmigration period, 15 April to 15 June or 15 April to Labor Day. Pools would be returned to normal operating levels for the rest of the year.

b. Operation

The four lower Snake River projects will begin drafting no later than 24 March in order to achieve target drawdown conditions by 15 April each year. The total reservoir system storage, which will be evacuated from full pool elevations to drawdown elevations, is estimated to be 1,110,000 AF. If reservoir elevations are maintained at their drawdown levels during the 15 April to 15 June time period, refill of the reservoirs would take ~7 days with average inflows of 95,000 cfs. However, the refill time will increase dramatically in low-water years. Given the 1992 inflows averaging 21,000 cfs, refill of the reservoirs will take ~59 days. If reservoirs are maintained at their drawdown levels from 15 April to after Labor Day, refill of the reservoirs will begin around 5 September, and will take ~31 days given average inflows of 30,000 cfs. The time for refill would vary, depending on flows.

c. Modifications

This alternative will require the following physical changes to each of the four lower Snake River dams to accommodate this operation.

i. Juvenile Facilities

Existing juvenile bypass systems will be used during normal pool operations. However, during the drawdown operating mode proposed by this alternative, the existing juvenile bypass systems will be inoperable. A new lower-level juvenile bypass system will be required to collect and pass juvenile fish around operating turbines to the tailrace. Because of the restricted forebay fluctuation (±5 feet) during the drawdown operation, the new low-level juvenile bypass system can be designed and operated similar to that currently in use at the lower Snake River dams. Fish will be guided by existing turbine intake screens into gatewells where the fish will pass through orifices (short 12-inch-diameter holes) into a collection channel. The collection channel will discharge into a transportation channel which will pass the fish and water to the river below the dam. Juvenile fish transportation will not be possible, since navigation will be suspended. A new set of vertical barrier screens will be required to achieve the highest levels of orifice passage efficiency. The new vertical barrier screens would be put in place prior to drawdown, and left in place during drawdown and refill. The older vertical barrier screens would then be put back into place for operation at the normal operating pool range. During the transition period between normal pool levels and target drawdown pool levels, both the normal and new low-level juvenile systems will be inoperable. Therefore, drawdown pools must be reached before the arrival of large numbers of outmigrating juvenile fish. Likewise, during refill, both low-level and existing juvenile bypass systems will be inoperable.

ii. Adult Facilities

When pool levels drop below minimum operating levels, existing adult fish ladder exits cease to function. To provide adult fish passage under this drawdown proposal, addition of secondary low-level adult ladder exits will be required. The existing ladder exits will also require installation of auxiliary exits consisting of a false weir, adult return flume, and water supply system similar to the existing Lower Granite system. This will allow adult ladder operation during the period of transition from normal operating pool levels to drawdown pool levels. Once down to the low-level (drawdown) operating pool, the low-level ladder exit can be utilized. With all four dams and reservoirs operating in the drawdown mode, the water-surface elevations below the dams will be lower than original design (except at Ice Harbor). Therefore, adult ladder facilities, including entrances and auxiliary water supplies, will need to be modified. At all projects except Ice Harbor Dam, the existing adult collection system will be lowered to maintain adequate water depth for operation of adult fish ladder entrances. Adult ladder entrances and water supply systems at Ice Harbor will not need modification, because water-surface elevations below Ice Harbor (McNary pool) will not change.

iii. Existing Stilling Basin Modifications

At Little Goose Dam, a hydraulic jump-type stilling basin, with end sill and training walls, will be installed downstream of the existing spillway rollerbucket. At Lower Granite, Little Goose, and Lower Monumental Dams, drumgates will be installed downstream of the stilling basin end sill. Stilling basin training walls will also be extended, as required, for tailwater control by the drumgates. The drumgates will be used to adjust stilling basin tailwater elevations so that spillway flip-lips will be as effective as possible in reducing dissolved gas levels.

iv. Lower Spillway Crests

Spillway crests on all lower Snake River dams will be lowered 10 feet below existing crest elevations. Because the spillway crests will be lowered and the pier widths increased under this modification, the existing tainter gates will not be usable. Therefore, they will be replaced with new steel tainter gates. In addition to the new gates, new seal beams, hoisting equipment, and side-seal heaters and additional stoplogs will be needed.

v. Miscellaneous Modifications

Miscellaneous features at the dams and in, or adjacent to, associated reservoirs will require modification to allow operation or to prevent damage when pool levels are lowered below minimum operating levels. The features include the floating navigation lock guide walls, culvert and pipe outfalls, debris shear boom, water quality siphons (Lewiston Levees), and the adult ladder at Lyons Ferry Hatchery. Protection of embankments from erosion and failure will be required for this alternative.

d. Water Travel Time

Minimum and maximum water travel times, from the confluence of the Snake and Clearwater Rivers to the mouth of the Snake River, are 293 and 59 hours for flows of 25,000 and 160,000 cfs, respectively. Travel time through the remaining pools, after drawdown, ranges from 283 to 54 hours for the above flow range.

6. Existing Powerhouse With New Low-Level Spillway: Constant Pool (Alternative 15)

a. Description

This alternative proposes a drawdown operation of 52 to 57 feet below maximum pools at Lower Granite, Little Goose, and Lower Monumental Dams; and a drawdown of 43 to 49 feet below normal maximum pool at Ice Harbor Dam. To achieve this drawdown level, the existing spillways would be modified by lowering the crests 10 feet. The powerhouses at each lower Snake River dam would be operated to their hydraulic capacity with excess water passing over the modified existing spillways. During the drawdown operating mode, the drawdown pool levels will be maintained at near constant level ±5 feet). The reservoir pools would be operated at a drawdown level during the juvenile fish outmigration period, 15 April to 15 June or 15 April to Labor Day. Pools would be returned to normal operating levels for the rest of the year.

b. Operation

The four lower Snake River projects will begin drafting no later than 20 March to achieve the target drawdown pool condition by 15 April of each year. The total reservoir system storage, which will be evacuated from full pool elevations to drawdown elevations, is estimated to be 1,250,000 AF. If reservoir elevations are maintained at their drawdown levels during the 15 April to 15 June time period, refill of the reservoirs would take ~8 days with average inflows of 95,000 cfs.

However, the refill time will increase dramatically in low-water years. Given the 1992 inflows averaging 21,000 cfs, refill of the reservoirs will take ~67 days. If reservoirs are maintained at their drawdown levels from 15 April to after Labor Day, refill of the reservoirs will begin around 5 September, and will take ~34 days given average inflows of 30,000 cfs. If refill takes place during a low-water year when average inflows can drop as low as 19,000 cfs, the refill period could take up to 84 days.

c. Modifications

In addition to the new low-level spillway required by this alternative, the following structural modifications to each of the four lower Snake River dams will be required to accommodate the proposed drawdown operation.

i. Juvenile Facilities

Existing juvenile bypass systems will be used during normal pool operations. A new lower-level juvenile bypass system will be required to collect and pass juvenile fish around operating turbines to the tailrace. Because of the restricted forebay fluctuation (±5 feet) during the drawdown operation, the new low-level juvenile bypass system can be designed and operated similar to that currently in use at the lower Snake River dams. Fish will be guided by existing turbine intake screens into gatewells where the fish will pass through orifices (short 12-inch-diameter holes) into a collection channel. The collection channel will discharge into a transportation channel which will pass the fish and water to the river below the dam. Juvenile fish transportation will not be possible, since navigation will be suspended. A new set of vertical barrier screens will be required to achieve the highest levels of orifice passage efficiency. The new vertical barrier screens would be put in place prior to drawdown, and left in place during drawdown and refill. The older vertical barrier screens would then be put back into place for operation at the normal operating pool range. During the transition period between normal pool levels and target drawdown pool levels, both the normal and new low-level juvenile systems will be inoperable. Therefore, drawdown pools must be reached before the arrival of large numbers of outmigrating juvenile fish. Likewise, during refill, both low-level and existing juvenile bypass systems will be inoperable.

ii. Adult Facilities

When pool levels drop below minimum operating levels, existing adult fish ladder exits cease to function. To provide adult fish passage under this drawdown proposal, addition of secondary low-level adult ladder exits will be required. The existing ladder exits will also require installation of auxiliary exits consisting of a false weir, adult return flume, and water supply system similar to the existing Lower Granite system. This will allow adult ladder operation during the period of transition from normal operating pool levels to drawdown pool levels. Once down to the low-level (drawdown) operating pool, the low-level ladder exit can be utilized. With all four dams and reservoirs operating in the drawdown mode, the water-surface elevations below the dams will be lower than original design (except at Ice Harbor). Therefore, adult ladder facilities, including entrances and auxiliary water supplies, will need to be modified. At all projects except Ice Harbor Dam, the existing adult collection system will be lowered to maintain adequate water depth for operation of adult fish ladder entrances. Adult ladder entrances and water supply systems at Ice Harbor will not need modification, because water-surface elevations below Ice Harbor (McNary pool) will not change.

iii. Existing Spillway/Stilling Basin Modifications

At Little Goose Dam, a hydraulic jump-type stilling basin, with end sill and training walls, will be installed downstream of the existing spillway rollerbucket. At Lower Granite, Little Goose, and Lower Monumental Dams, drumgates will be installed downstream of the stilling basin end sill. Stilling basin training walls will also be extended, as required, for tailwater control by the drumgates. The drumgates will be used to adjust stilling basin tailwater elevations so that spillway flip-lips will be as effective as possible in reducing dissolved gas levels.

iv. New Low-Level Spillway

This drawdown alternative proposes drawdown levels which are not achievable at existing lower Snake River dams. To accommodate this operation, a new low-level spillway will be required. The spillway will be constructed with six opening bays controlled by tainter gates. A new stilling basin will be required below the spillway to dissipate hydraulic energy caused by water flowing over the spillway. Non-overflow concrete monolith structures will be required to tie the new low-level spillway to the shoreline (dam abutment) and the adjacent existing concrete structure at the Lower Monumental and Ice Harbor projects. At the Lower Granite and Little Goose projects, an earthen fill will provide the tie into the adjacent existing structure. Wing walls will be used to hold the soil back from the spillway channel. During construction, the work site must be dewatered. At the Lower Granite and Little Goose projects, the existing earthen embankment will be utilized to hold back water upstream of the new spillways. Large cellular cofferdams will be used at the Lower Monumental and Ice Harbor projects to contain upstream waters. Smaller cofferdams will be used for each project to contain downstream waters. A new steel tainter gate with operator will be required for each spillway bay. Steel stoplogs will be provided upstream of the tainter gate to allow for dewatering of the spillway crest for maintenance. A new gantry crane will be required for setting stoplogs and tainter gate maintenance operations. Relocations of roads, railroads, visitor facilities, and other facilities will be required to construct the new low-level spillways.

v. Miscellaneous Modifications

Miscellaneous features at the dams and in, or adjacent to, associated reservoirs will require modification to allow operation or to prevent damage when pool levels are lowered below minimum operating levels. The features include the floating navigation lock guide walls, culvert and pipe outfalls, debris shear boom, water quality siphons (Lewiston Levees), and the adult ladder at Lyons Ferry Hatchery. Protection of embankments from erosion and failure will be required for this alternative.

d. Water Travel Time

Minimum and maximum water travel times, from the confluence of the Snake and Clearwater Rivers to the mouth of the Snake River, are 231 and 50 hours for flows of 25,000 and 160,000 cfs, respectively. Travel time through the remaining pools, after drawdown, ranges from 215 to 42 hours for the above flow range.

7. Modified Powerhouse and Existing Spillway: Constant Pool (Alternative 17)

a. Description

This alternative is the same as Alternative 13, except for the powerhouse modifications described below.

b. Operation

Project operation for this alternative is identical to Alternative 13.

c. Modifications

The physical changes required by this alternative are identical to Alternative 13, except that turbine/generator sets at each of the lower Snake River dams will be replaced with new equipment designed to work more efficiently at the drawdown pool levels. Operating existing turbine-generator units at lower than design heads causes efficiency losses of ~5.3%. Low-efficiency operation can be mitigated in various ways. For this study, installation of new turbine-runners was assumed. New turbine-runners can be designed to operate at peak efficiency at a lower head. However, a reduction in efficiency (less than existing turbines) may occur when operating new turbines at normal heads. Drawdown operations will also result in a decrease of power production due to the decreased head across the generating units.

d. Water Travel Time

See Alternative 13.

8. Modified Powerhouse and Modified Existing Spillway: Constant Pool (Alternative 18)

a. Description

This alternative is the same as Alternative 14, except for the powerhouse modifications described below.

b. Operation

Project operation for this alternative is identical to Alternative 14.

c. Modifications

The physical changes required by this alternative are identical to Alternative 14, except that turbine/generator sets at each of the lower Snake River dams would be replaced with new equipment designed to work more efficiently at the drawdown pool levels. Operating existing turbine-generator units at lower than design heads causes efficiency losses of ~5.3%. Low-efficiency operation can be mitigated in various ways. For this study, installation of new turbine-runners was assumed. New turbine-runners can be designed to operate at peak efficiency at a lower head. However, a reduction in efficiency (less than existing turbines) may occur when operating new turbines at normal heads. Drawdown operations will also result in a decrease of power production due to the decreased head across the generating units.

d. Water Travel Time

See Alternative 14.

9. Modified Powerhouse With New Low-Level Spillway: Constant Pool (Alternative 19)

a. Description

This alternative is the same as Alternative 15, except for the powerhouse modifications described below.

b. Operation

Project operation for this alternative is identical to Alternative 15.

c. Modifications

The physical changes required by this alternative are identical to Alternative 15, except that turbine/generator sets at each of the lower Snake River dams will be replaced with new equipment designed to work more efficiently at the drawdown pool levels. Operating existing turbine-generator units at lower than design heads causes efficiency losses of ~5.3%. Low-efficiency operation can be mitigated in various ways. For this study, installation of new turbine-runners was assumed. New turbine-runners can be designed to operate at peak efficiency at a lower head. However, a reduction in efficiency (less than existing turbines) may occur when operating new turbines at normal heads. Drawdown operations will also result in a decrease of power production due to the decreased head across the generating units.

d. Water Travel Time

See Alternative 15.

10. Other Facility Modifications

a. Downstream Weir

A downstream weir has been proposed as a method of controlling tailwater elevations. This would be designed as an alternative to modifying existing adult fish ladder entrances, and would provide for stilling basin energy dissipation, decreases in dissolved gases downstream of the dam, and minimization of flows impacting adult fish migration during drawdown operations. The following analysis was examined at Lower Granite Dam and assumes that Little Goose Dam is being operated at a pool allowing free-flowing river conditions at Lower Granite Dam.

The downstream weir would control tailwater levels below dams, allowing existing fishway entrances to function at lowered water levels. They would also the flip-lip at Lower Granite Dam to operate properly by keeping the tailwater elevation no lower than 633 fmsl and no higher than 642 fmsl. This is necessary to create a skimming flow during full powerhouse discharge and spill operations, which reduces the plunging action of water and minimizes nitrogen gas levels. The tailwater elevation range of 633 to 642 fmsl is also required for the adult fish entrances to function.

There are two possible locations for the weirs, the first (upper) being ~900 feet downstream of the powerhouse and the second (lower) ~1,750 feet downstream of the powerhouse. The upper location would be installed between the south shore and navigation lock, and would be in front of the powerhouse and spillway only. The lower location would have to span the entire river which is ~1,550 feet. Two types of weirs are examined: an adjustable crest weir and a fixed crest weir.

At the upper location, an 1,140-foot fixed crest weir could be installed that would span the front of the spillway and powerhouse. The difference in water surface head (DH) on either side of the weir would range from 8.1 to 11.5 feet with corresponding discharges ranging from 153,000 to 46,000 cfs. Adult fish have difficulty negotiating a water-surface differential >3 feet; therefore, construction of the fixed crest weir at location A would block all adult passage at the weir.

A fixed crest weir could be installed at the lower location and would span the entire river, which is ~1,550 feet. The DH at this location would range from 6.2 to 11.5 feet, with discharges ranging from 153,000 to 46,000 cfs. All adult passage would be blocked with a fixed weir at the lower location.

An adjustable weir has been suggested to minimize the difference in water-surface elevation across the weir while still maintaining the water-surface elevation between 633 and 642 fmsl. The DH for the two locations with an adjustable crest weir would range from 0.0 to 11.5 feet, with discharges ranging from 153,000 to 46,000 cfs. At 95,000 cfs the DH would be ~5.5 feet, which might be negotiable for adult salmon. Thus, even with the capability of adjusting the weir crest, a minimum discharge of 95,000 cfs would be necessary for good adult passage to occur at either location.

Vertical-slot fishways could be installed in the adjustable crest weir at the upper location. The weir would have ten 100-feet-wide drumgates. Between the drumgates, 14-foot piers could be installed which would contain 10-foot-wide vertical slot fish ladders, for a total of nine fish ladders. Flow at the fish ladders would range from 42 to 47 cfs with drawdown conditions previously described. Such ladder discharges are insignificant compared with flow levels past the drumgate. Adult fish would probably have a difficult time finding the ladder entrances, which would lead to substantial migration delays at the weir.

During spill, the powerhouse must also be operating along with proper tailwater elevations in order to achieve acceptable levels of dissolved gases. It is possible to achieve acceptable tailwater conditions with the downstream weir. However, the new obstacle would create additional migration delays for fish, which would be an unacceptable solution to the migration problems at Lower Granite Dam. A more acceptable solution to the migration problem at Lower Granite Dam during drawdown conditions would be to extend the range of the existing fish passageways at the dam through modifications.

b. Surface Flow Collection System

An alternate fish collection system located near the water surface in the dam forebay is also being considered as a means to improve juvenile fish passage around the lower Snake River dams. Water flowing into a forebay collection system, located above and in front of existing turbine intakes, would provide migrating juvenile fish another passage route around operating turbines. The forebay collection system could be operated independently of or in conjunction with the existing juvenile bypass systems. Operation of the forebay collection system in conjunction with the existing bypass collection system could result in increased fish guidance and may also reduce the time that juvenile fish spend in the forebay area.

Two general design concepts are currently being considered to improve juvenile fish collection and bypass at lower Snake River dams: 1) vertical juvenile fish entrance slots; and 2) shallow skimmer weirs or orifices. The first concept is based in part on a system presently used at Wells Dam on the mid-Columbia River. For application at Lower Granite Dam, vertical-slot fish entrances could be used to lead juvenile fish into a collection channel and related features. One entrance per generating unit (for a total of six) could be located across the face of the powerhouse. They would provide large entrances and create a flow in the upper portion of the forebay to attract downstream migrating fish into the fish collection and bypass system. The second concept is based on a system used at Ice Harbor Dam on the lower Snake River. The ice-and-trash sluiceway at Ice Harbor Dam is used as a surface weir system to attract and collect fish swimming in the upper portion of the water column. Fish entering the sluiceway pass into another sluiceway that discharges directly to the tailrace. At Lower Granite Dam, this system would be modified to skim juveniles into a collection channel leading to collection or bypass facilities.

B. Upstream Storage

Augmenting flows on the Snake and Columbia Rivers to facilitate spring migration of juvenile salmon and steelhead may be accomplished by modified operation of Dworshak Dam on the North Fork of the Clearwater River and Brownlee Dam on the Snake River. This action is also intended to increase water velocities and subsequently increase survival of juvenile fish by decreasing the time required to complete outward migration. On- and offstream storage sites in the Snake River Basin were evaluated as to suitability for augmenting lower Snake River flows. A total of 295 potential onstream storage sites and 119 offstream sites were identified in the Snake River Basin. Site indexes are included in appendix A (COE, 1992). A detailed description of the Galloway Site in the Weiser River Basin provides additional background on all aspects of site consideration.

1. Galloway Site

The Galloway site, located in the Weiser River Basin, is drained by the Weiser River that enters the Snake River above the city of Weiser. The site affords a maximum active storage volume of 715,000 AF. Outlet facilities accommodate flows for downstream maintenance, irrigation, and augmentation.

Operation of the Galloway site as an upstream storage facility would rely on a reservoir 18.2 miles long. Reservoir fluctuations would vary between 2,480 and 2,340 feet. Development of the Galloway site would require channel modification to increase capacity for flow augmentation. Operation of the Galloway site would accommodate elevated pool elevations in Brownlee Reservoir during April and May. Constraints on the volume of water released for augmentation would include the amount of active storage available at the start of augmentation, inflows during augmentation, channel capacity of the lower Weiser River (11,000 cfs), powerhouse capacity at the Hells Canyon projects (26,365 cfs), and target flows for survival at the Lower Granite Dam (140,000 cfs).

Operation of the site would assume that the volume of water necessary for fish passage would be withdrawn during May and June, and that no change in volume or surface elevation would occur during summer and fall. It is likely that stratification of the reservoir would not occur until after May, which could result in oxygen depletion within the system.

2. Other Snake River Storage Sites

Additional upstream storage alternatives are being considered on the Middle Snake, Clearwater Basin, Palouse Basin, and the Lost Valley Dam enlargement. As additional sites are reviewed for suitability, supporting documentation will be drafted.

C. Anadromous Fish Collection and Transport

Conveying fish by using a new collection system upstream of Lower Granite Dam, in conjunction with either canals, pipelines, or transport vessels, are some alternatives being considered for the Columbia River Salmon Mitigation Analysis (COE, 1994a). Alternatives would be developed

Alternatives that include barging would incorporate continuous water exchange to maintain ambient temperatures and gas saturation in the immediate environment and low-velocity rest areas.

1. Collection

Collection and conveyance of downstream-migrant salmonids from above Lower Granite Dam to below Bonneville Dam is being considered as a way to reduce fish mortality resulting from passage through hydropower turbines and from migration delay in reservoirs (COE, 1994a). Juvenile migrant salmonids collected under this plan would be transferred from collection facilities into a migrant system and released back into the Columbia River downstream of Bonneville Dam. The goal of an upstream collection system would be to improve upon present systems used to collect and transport juvenile salmonids. Most designs for current juvenile fish collection systems require major retrofits of existing hydroelectric projects, and are constrained by the unique physical and engineered features of each site. The upstream collection and transport concepts are intended to improve upon existing bypass and collection facilities and to increase the survival of migrating juvenile salmonids. These improvements are not expected to significantly impact the existing hydropower and navigation functions of the river systems.

Two options for collection of juvenile salmonids are currently being considered. The first option would collect juveniles at a large screen system, located about 7 miles downstream of the confluence of the Snake and Clearwater Rivers, at the former site of Silcott, Washington. The second option would involve a pair of collection facilities, one each located on the Snake and Clearwater Rivers. The Snake River and Clearwater River collectors would be located about 10 and 6 miles, respectively, upstream of Lewiston, Idaho. Both upstream collection options would include collection of juvenile salmonids at each of the downstream dams.

The Silcott collection option would be designed to capture 100% of all downstream migrant salmonids (figure 3-2). Total screen area required to pass the design discharge would be determined by the maximum allowable normal velocity at the screen surface to prevent impingement or injury. The facility would be configured to direct the juvenile migrant salmonids toward trapping systems at both banks of the river. Captured juveniles would then be passed into a barge loading facility. When the collection system was not in use, or when free flow of the river was required, the main screens would be removed and river flows would pass through the structure unimpeded.

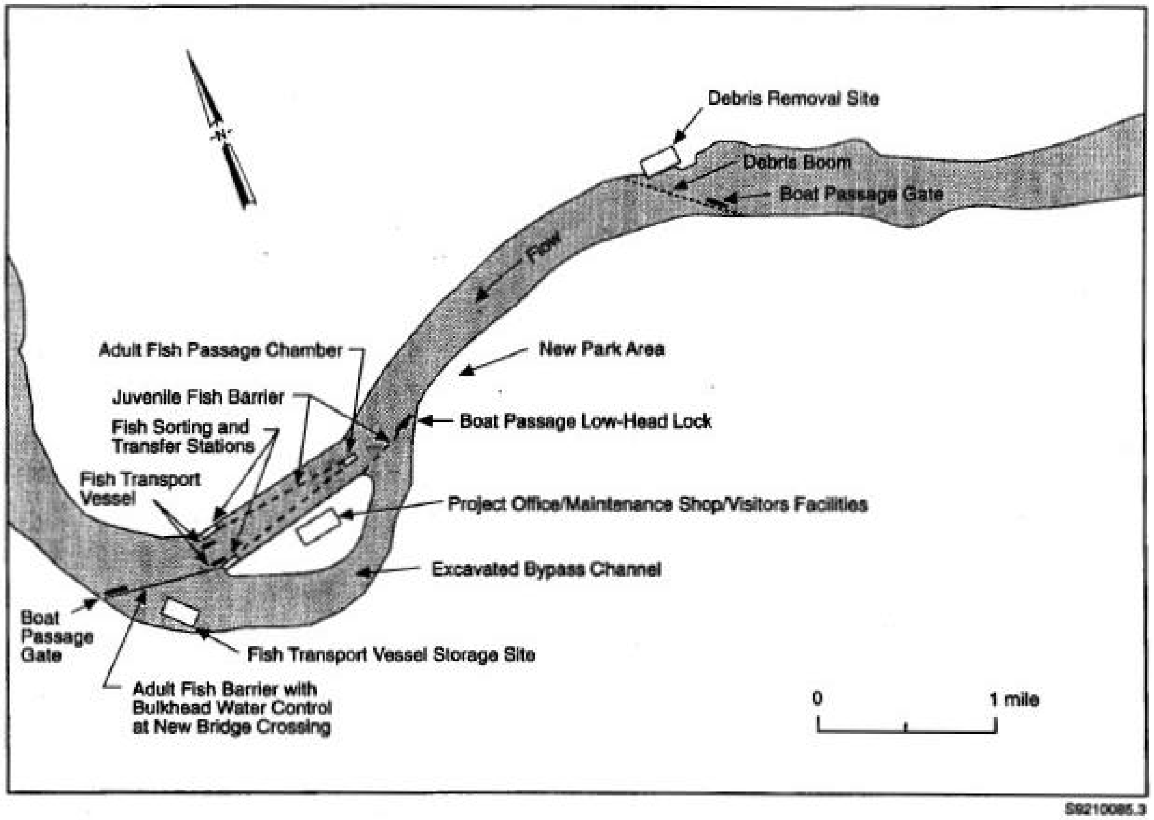

Figure 3-2. Schematic of Silcott Collector Facility and Proposed Upstream Passage

The second collection option, located further upstream on free-flowing sections of the Snake and Clearwater Rivers, would collect migrants upstream of Lower Granite Reservoir. These collector facilities would be scaled-down versions of the Silcott-site screen structure. Navigation locks would not be required, since commercial navigation does not extend above Lewiston, Idaho. These structures would be designed to withstand greater flow velocities than the Silcott-site structure.

2. Transportation

a. Canal

A migratory canal would carry downstream migrants to a point downstream of Bonneville Dam. The canal would begin at the collection facility at Silcott or alternately at the sites on the Snake and Clearwater Rivers. Fish that hatch and emerge downstream of the collection facility would be collected along the route from the screening bypass systems at the dams and pumped or mechanically lifted to the canal. No additional collection facilities would be included for tributary streams downstream of the collection site.

The migratory canal would consist of one of several types of channels, including a concrete-lined tunnel, elevated flume or enclosed pipe, concrete-lined channel, or cut-and-cover culvert sections.

The migratory canal design assumes an expected migrant passage rate of 2 million fish per day, a juvenile weight of 1/5 pound, and fish density of 1 fish per 7.5 gallons of water per minute. The average velocity would provide total water-particle travel time of 7 to 10 days from Lower Granite Dam to Bonneville Dam.

Resting ponds, where 25% of flow would be replaced with aerated water, would be provided at 10-mile intervals through the entire migratory canal system. Ponds would allow fish to rest or feed, because hatchery fish would depend largely on artificial feeding at pond sites. Ponds would also function to lower water temperature and to reduce gas saturation.

b. Pipeline

The pressure pipeline would consist of steel or concrete pipe section, instead of an open canal. The pipe would carry fish from the upstream juvenile collection facility and from each of the downstream dam's collection facilities. Resting ponds with 25% water exchange, would be provided every 10 miles.

The pressure pipe would consist of a steel or concrete pipe buried along the bank of the reservoir. The pipe would rise to free-surface open resting ponds located at 10-mile intervals. Water exchange, aeration, rest, and feeding would be provided in the resting ponds.

c. Idaho National Engineering Laboratory Flexible In-Reservoir Salmon Passage Conduit

The floating or neutrally-buoyant pipe or open-channel system would rely on a modular pump which would be used to move fish through a conduit. The conduit would pass through each dam, and flows would pass through the tailwater area of the dam. Fish from the juvenile sorting facilities would be discharged into the system downstream of the dam.

d. Barge System

Barges would be used at each collection facility to facilitate collection and transport fish to loading facilities. Barging operations would be similar to current operations that move fish from the Lower Granite Dam downstream to Bonneville Dam. However, the operation would require expansion to accommodate increased salmon volumes accumulated at upstream collection facilities.

3. Release

Fish transported throughout the system would be released through staggered discharge outfalls. Operation of release spillways would be random to reduce incidence of predation.

D. Existing System Improvements

This section includes a brief summary of existing systems and planned improvements for migrating losses of anadromous salmonids because of hydro operation.

1. Existing Systems

Systems which have been developed to compensate for anadromous fish losses on the lower Snake River include hatchery and corresponding satellite facilities used throughout the entire fish-rearing and acclimation process; juvenile collection and bypass facilities; juvenile transportation; and adult passage facilities.

Juvenile collection and bypass at Lower Granite, Little Goose, Lower Monumental, and McNary Dams are designed to bypass fish around the turbines for release or diversion to holding and/or loading facilities. A bypass system is currently being constructed at Ice Harbor Dam.

Juvenile transportation at Lower Granite, Little Goose, Lower Monumental, and McNary Dams involves varying combinations of trucks and/or barges during different stages of migration. Because of historic successes and no apparent impact to homing or survival, barge transportation has received extensive support in the Northwest. Collection and transportation facilities increased fish movement below Bonneville Dam in excess of that from in-river passage. The National Marine Fisheries Service advocated maximizing the program in normal and low-flow years to maximize survival of Snake River salmon and maximize protection of Snake River fall chinook.

Adult passage facilities at McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams consist of fish entrances, a collection channel, attraction pumps, and fish ladders.

2. Proposed System Improvements

Various improvements to the existing hydrosystem have been proposed to improve adult returns to the Snake River. These proposals include modifications to fish hatchery operations, juvenile collection and bypass systems, juvenile transportation, adult passage systems, and dam operations (COE 1994b, 1994c).

a. Fish Hatcheries

Expansion of existing facilities to accommodate supplementation strategies is largely unfeasible, due to a lack of adequate space at existing hatcheries and a lack of water resources (COE, 1992b). Therefore, reductions in fish production as well as improvement to existing facilities are considerations. Improvements to existing hatchery operations include elimination of fish pumps for planting or transportation operations, construction of additional containment facilities, and upgrade of the existing National Fish Hatchery at Dworshak.

b. Juvenile Collection and Bypass Systems

Improvements to juvenile bypass facilities are intended to reduce loss due to predation (*e.g.*, by providing dispersed release), improving fish guidance systems; improving bypass, loading, and holding facilities at Lower Granite Dam; reducing fish stress at holding facilities raceways and sample tanks; and screen intakes for adult fish ladder water at McNary to reduce juvenile fish loss. Surface-oriented forebay collector systems are also under development for dams on the Snake and Columbia Rivers.

c. Juvenile Transportation Systems

Improving juvenile transportation systems will involve providing net pens to supplement or replace barges; developing a means to reduce and control water temperatures in barges to improve barge condition; modifying barge release exits to reduce fish stress; and providing additional barges to the existing fleet. Short-haul barging (*i.e.*, transportation of juvenile salmonids collected in bypass systems downstream of the tailrace) will be evaluated in conjunction with existing practice at projects in both the lower Snake and Columbia Rivers.

d. Adult Passage Systems

Improvements to adult passage systems will include controlling fish-ladder water temperature to reduce stress; enhancing adult fish passage at Little Goose and Lower Granite Dams; improving system efficiency by enhancing entrance performance and attraction flow; improving hydraulic controls at McNary Dam; and eliminating low-velocity areas at McNary pool. Additionally, the potential to modify spill patterns to optimize adult passage and survival at John Day Dam will be evaluated.

e. Dams

Improvements to dams will include spillway and stilling-basin modification to reduce dissolved gases that result from spill. Portland District potential improvements include:

i. Extended Screens at John Day

Evaluate the benefits of installing extended screens to intercept a greater depth of water entering the turbine intake, thus improving FGE, and install if shown to be beneficial. This work will identify types of benefits to fish guidance efficiency. Included in this work is the identification and design of a test program, and determination and analysis of the biological benefits. There will be a need for a sectional model for this project.

ii. Juvenile Transportation at John Day

Evaluate possible transportation of downstream migrants to shorten in-river time and avoid bypass predation and reservoir mortality. This study will identify benefits and impacts to transportation. There will be a determination of scope and identification of test program(s). An analysis of biological benefits will be included.

iii. Bypass Outfalls Research at Bonneville

Evaluate existing outfalls and research possible improvements, alterations, and locations. This study includes documentation of existing data, and definition of various strategies/criteria. There will be an estimation and analysis of biological benefits. Formulation and analysis of research designs are needed.

iv. Bonneville I Fish Guidance Efficiency (FGE)

Model FGE to determine what improvements are necessary to improve FGE, construct test equipment, and conduct tests. Work out details of new tests and hydraulic model study plan, and the analysis of new or innovative procedures. This will include a determination and analysis of biological benefits.

v. Improvements to Turbine Passage Survival

Evaluate what improvements to turbines must/could be made to increase passage survival. This work would include an analysis of existing problems (to date). Define and outline research programs with assistance from turbine experts. The report will identify possible model and prototype studies that will provide hydraulic data on passage through turbines and turbine efficiency. The report will cover the steps necessary to determine how turbines and operational procedures can be modified to increase fish survival through the turbines and, at the same time, provide optimal turbine efficiency.

vi. Analysis of Spill Pattern

Research spill patterns at John Day to evaluate the best operations for adult and juvenile survival. The reconnaissance report will define a program for evaluating the spill schedule used during juvenile fish passage. The work is almost exclusively biological evaluation of hydraulic conditions and will required the construction and use of a hydraulic model during the next phase of study. Work in this phase is considered to be of a very limited nature. Effort should be directed at defining costs of a study and costs of the operational changes versus potential benefits of an improved spill program on both adult and juvenile migrants.

vii. Bonneville II Downstream Migrant System (DSM)

The study will identify measures to improve juvenile fish survival through the DSM system. The area of concern will include the collection channel, the weir, the energy dissipation region, the inclined screen, the downwell, and the DSM pipe. Engineering evaluations are necessary to determine potential improvements that could be made in the system to reduce mortality and descaling rates of juvenile migrants. The potential benefits of improved juvenile fish passage and the potential costs of implementing the program will be quantified. Two related studies will also be underway: 1) relocation of the outfall under the System Configuration Study; and 2) design of a smolt monitoring facility for the Bonneville Power Administration. Close coordination with these studies will be required to ensure proper consideration of all pertinent factors.

viii. Juvenile Bypass System Outfall Release Strategies (Short-Haul Barging)

Evaluate possible alternatives to the fixed-location juvenile bypass system outfall release site. Specifically, short-haul barging will be evaluated to increase survival of bypassed downstream migrant salmonids by: 1) eliminating fixed-location outfall release sites where predators may hold; 2) insuring migrants are released in mainstem (high-flow) areas away from slackwater, slowdown, and/or other areas likely to be predator infested; and 3) allowing for more fit/health migrants to be released by holding long enough to recover from stress/fatigue of bypass collection. Present collection/transportation practices will be evaluated to present positive aspects as well as negative aspects in need of improvements. Included in this work will be identification and design of a test program, and determination of biological benefits accrued to downstream migrants.

IV. Impacts of Proposed Drawdown Events and Other Mitigation Measures

A. Impacts From Drawdown Alternatives

1. Operations

For each alternative, drawdown would commence prior to outmigration of juvenile salmonids (*e.g.*, mid-April), and would extend through at least mid-June. Refill would begin immediately following the designated period of drawdown, with rates of refill varying relative to changes in inflow (see Section III for more details among alternatives). Refill time would vary with changes in inflows, and would increase in low-water years. Shorter refill times could be achieved by drafting upstream storage. Adult passage and juvenile collection facilities at dams would have to be modified to operate at lowered pool elevations. Engineered modifications to project facilities would be required for development of all options. Modifications specific to each of the Lower Granite, Lower Monumental, Little Goose, and Ice Harbor Dams are included within the System Configuration Study (SCS) analysis. Depending on the type and extent of modifications, implementation of the proposed drawdown options could decrease the operating efficiency of existing facilities and reduced hydropower production.

For each drawdown option, transition flows would not accommodated operation of juvenile bypass systems, and these systems would remain inoperable until planned pool elevations were resumed. Similarly, commercial navigation and existing methods for transportation of juvenile salmonids would cease during drawdown. Existing juvenile bypass facilities would also be inoperable below minimum operating pool (MOP). Unless new methods for transporting fish are employed, juvenile salmonids would pass through each dam (except under the Natural River Option) rather than being collected and transported around the turbines and generators. Increased spill during drawdown could reduce smolt mortality at each project compared to primary impacts to smolts that occur during turbine passage. However, other structures in the spillway basin (*e.g.*, drumgates) could cause substantial mortality to juveniles during passage. Additionally, turbine mortality is expected to increase during drawdown because of lowered head and resultant decreases in turbine efficiency with higher cantation at lowered pool elevations. Lowered head and increased screen velocities could also contribute to descaling of juveniles and affect operation of juvenile bypass barrier screens.

Existing adult bypass facilities could be modified to facilitate adult passage during drawdown. Assuming the modified facilities function as efficiently as existing systems, the primary impact to adults would result from construction during structural modification of the system. Modifications to adult facilities would include modifications to fishway entrances and the ladders, and construction of false weirs and return flumes on auxiliary exits. Limitations to these systems would only be realized under management of operations between spillway crest and near run-of-river (*e.g.*, Natural River Option), and during low flows when tailrace flow patterns become altered. In this case, adult passage will be impossible when the pool is between spillway crest and near run-of-river during both drawdown and refill.

2. Physical Conditions in Reservoirs

a. Changes in Water Velocities

Reservoir drawdown will create reaches of free-flowing river between each dam and the next downstream pool. However it is important to note that each drawdown alternative except the Natural River Option maintains a large pool, and that River velocities are not substantially changed through the pool areas.

Flow velocity calculations were computed at a variety of river stages for the lower Snake River. Flow was routed through cross-sections spaced approximately every quarter mile for pool elevations ranging from near free-flow to maximum pool operation level. Water-surface elevations, water velocities, and water travel times were then calibrated with known flow conditions. This approach provided a means to compare the lateral distribution of velocities across discrete cross-sections, and over a range of flow conditions for selected locations in the Lower Granite and Little Goose pools (tables 4-1 to 4-3, figures 4-1 to 4-5).

Table 4-1
Water Travel Times Between Dams and Under Various Drawdown Elevations
At 25,000 cfs From the Snake River-Clearwater River Confluence to the Mouth

Drawdown Option	Clearwater to Lower Granite Dam RM 139 to 107.5	Lower Granite Dam to Little Goose Dam RM 107.5 to 70.3	Little Goose Dam to Lower Monumental Dam RM 70.3 to 41.6	Lower Monumental Dam to Ice Harbor Dam RM 41.6 to 9.7	Ice Harbor Dam to Columbia River RM 9.7 to 0.0
No drawdown	207 hours	250 hours	167 hours	183 hours	10 hours
Alt. 13, 17	104 hours	127 hours	87 hours	101 hours	7 hours
Alt. 14, 18	71 hours	101 hours	73 hours	85 hours	5.7 hours
Alt. 15, 19	62.8 hours	79.6 hours	54.9 hours	58.5 hours	4.7 hours
Alt. 5, 9	55 hours	69 hours	48 hours	50 hours	5 hours
Natural River	12 hours	15 hours	10 hours	13 hours	5 hours

Table 4-2
Water Travel Times Between Dams and Under Various Drawdown Elevations At 60,000 cfs From the Snake River-Clearwater River Confluence to the Mouth

Drawdown Option	Clearwater to Lower Granite Dam RM 139 to 107.5	Lower Granite Dam to Little Goose Dam RM 107.5 to 70.3	Little Goose Dam to Lower Monumental Dam RM 70.3 to 41.6	Lower Monumental Dam to Ice Harbor Dam RM 41.6 to 9.7	Ice Harbor Dam to Columbia River RM 9.7 to 0.0
No drawdown	87 hours	104 hours	69 hours	79 hours	5 hours
Alt. 13, 17	44 hours	54 hours	37 hours	43 hours	4 hours
Alt. 14, 18	34.5 hours	43.5 hours	29.7 hours	36.3 hours	3.5 hours
Alt. 15, 19	27.2 hours	34.8 hours	24.1 hours	26.1 hours	3.5 hours
Alt. 5, 9	24 hours	31 hours	21 hours	22 hours	4 hours
Natural River	8 hours	11 hours	7 hours	9 hours	3 hours

Table 4-3
Water Travel Times Between Dams and Under Various Drawdown Elevations At 140,000 cfs From the Snake River-Clearwater River Confluence to the Mouth

Drawdown Option	Clearwater to Lower Granite Dam RM 139 to 107.5	Lower Granite Dam to Little Goose Dam RM 107.5 to 70.3	Little Goose Dam to Lower Monumental Dam RM 70.3 to 41.6	Lower Monumental Dam to Ice Harbor Dam RM 41.6 to 9.7	Ice Harbor Dam to Columbia River RM 9.7 to 0.0
No drawdown	37 hours	45 hours	30 hours	34 hours	3 hours
Alt. 13, 17	19.3 hours	24.2 hours	16.5 hours	19.5 hours	2.8 hours
Alt. 14, 18	11 hours	19.3 hours	13.1 hours	16.6 hours	2.8 hours
Alt. 15, 19	12.5 hours	16.6 hours	11.2 hours	12.8 hours	2.4 hours
Alt. 5, 9	11.5 hours	14.7 hours	10.2 hours	11.2 hours	2.4 hours
Natural River	6 hours	7 hours	5.4 hours	6.6 hours	2 hours

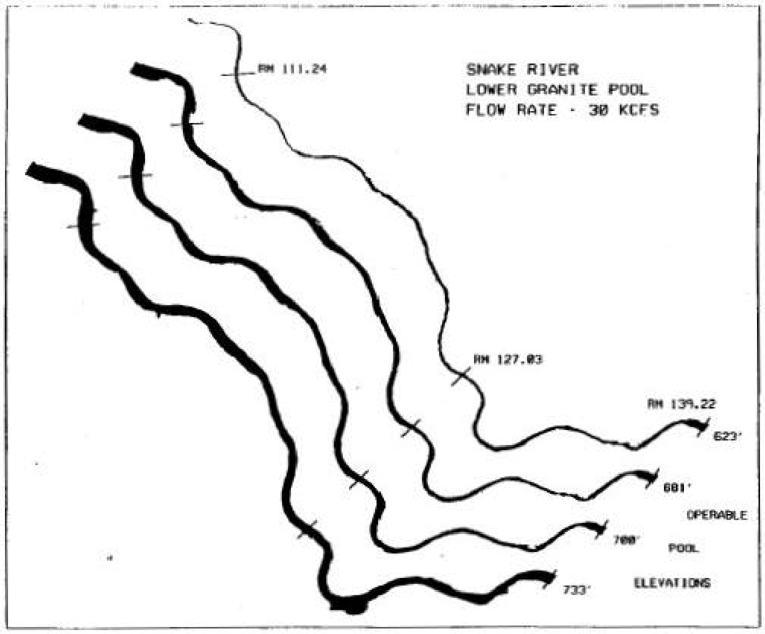

Figure 4-1. Location of Cross Sectional Area Used for Velocity Profiles Analyses Of Drawdown Scenarios on Lower Granite Reservoir

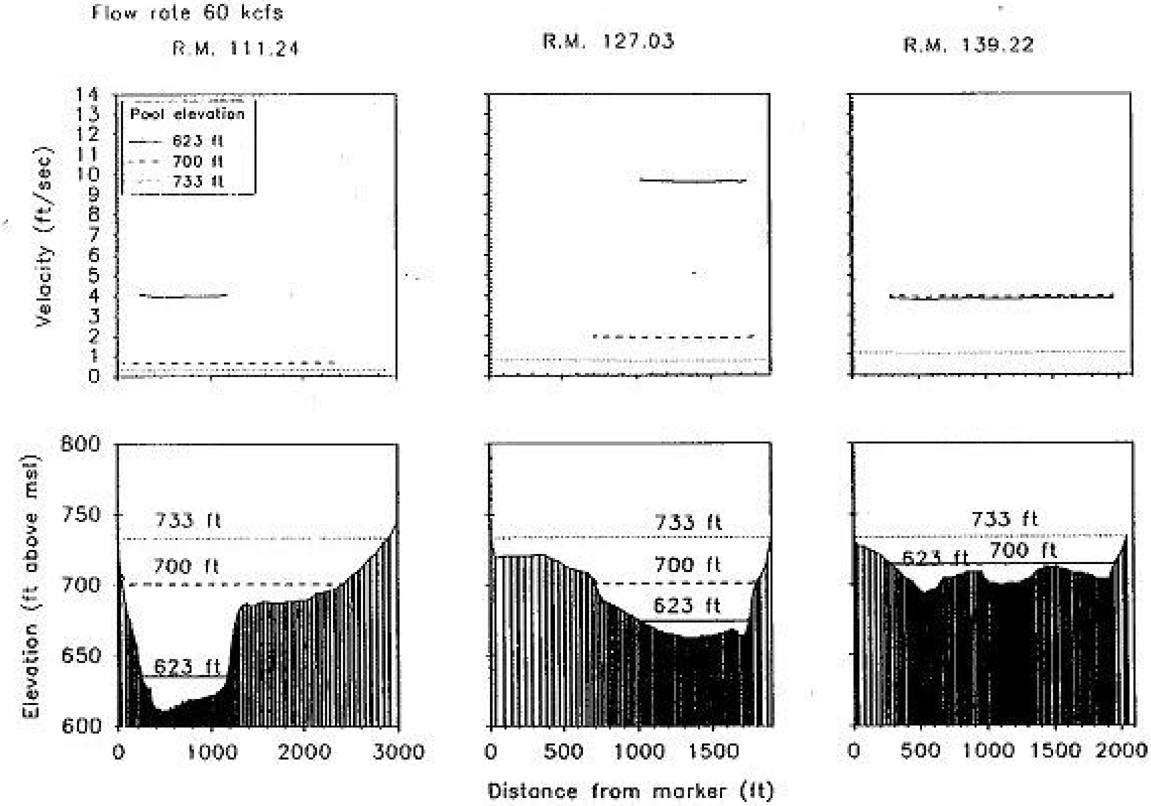

Figure 4-2. Comparison of Velocity Profiles for River Miles 111.24, 127.03, and 139.22 At a Flow Rate of 60 kcfs for 733, 700, and 623 Reservoir Surface Elevations

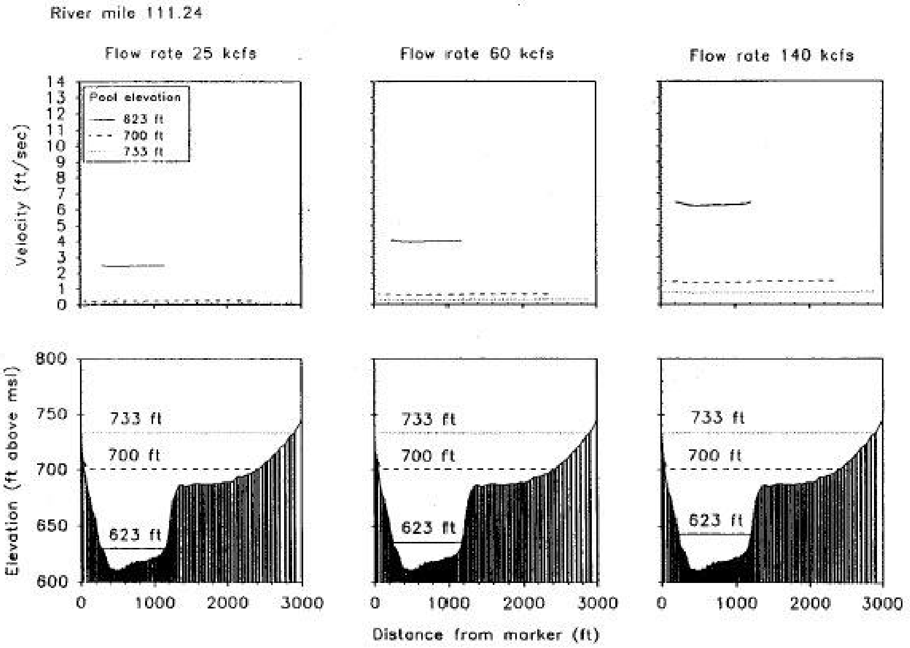

Figure 4-3. Velocity Profile Comparison of River Mile 111.24 for Flow Rates of 25, 60, and 140 kcfs

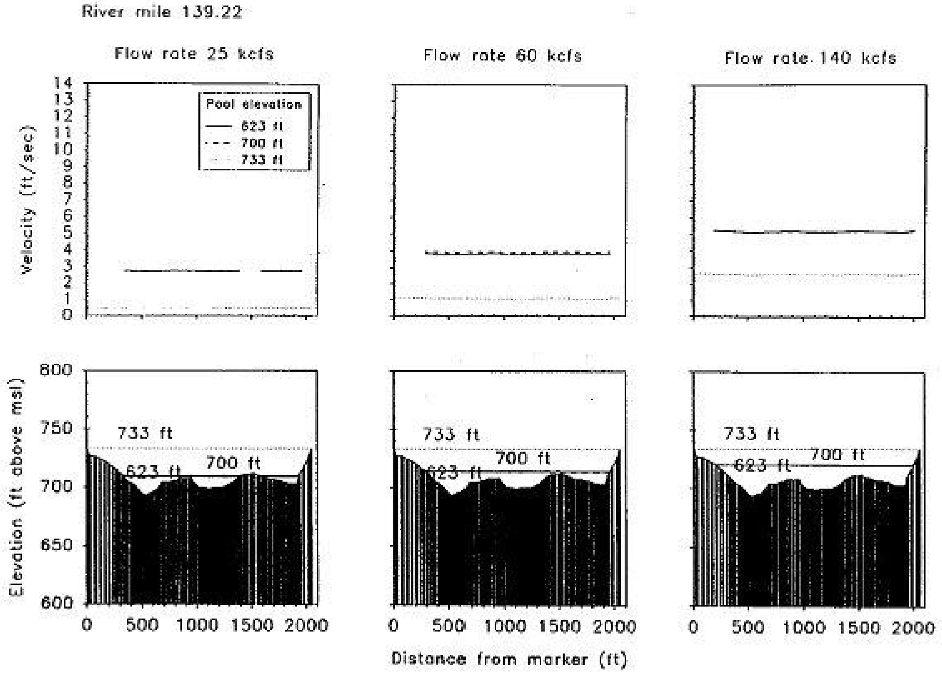

Figure 4-4. Velocity Profile Comparison of River Mile 139.22 for Flow Rates of 25, 60, and 140 kcfs

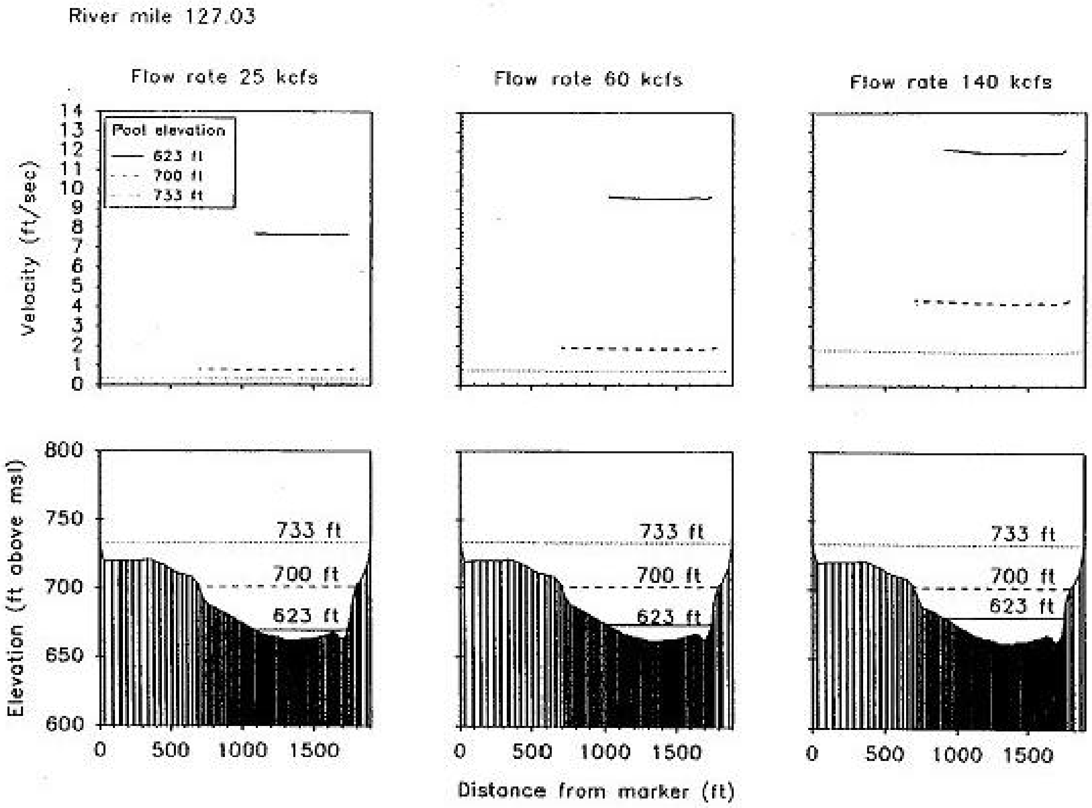

Figure 4-5. Velocity Profile Comparison of River Mile 127.03 for Flow Rates of 25, 60, and 140 kcfs

Water flow velocities were measured during the reservoir drawdown test conducted in March of 1992. The U.S. Geological Survey used an acoustic Doppler profiler to obtain flow velocity profiles through the Lower Granite Reservoir before drawdown, midway through the test, and at the lowest point. Dye tests were also performed in Lower Granite pool when the pool elevation level was 705 feet to measure the minimum and average water-particle travel time at this elevation. However, the discharge during these measurement periods was fairly unsteady, and recorded flow velocity patterns may not be directly comparable to modeled flow conditions; these data are currently being refined. Preliminary measurements and analyses are available in Appendix M of the *Lower Granite and Little Goose Projects 1992 Reservoir Drawdown Test Report* (Wik *et al.*, 1993).

Water travel times through the lower Snake River were estimated for a range of flow conditions (table 4-4) to show the relationship between discharge and transport rates. Average travel time from the Clearwater River confluence to the Columbia River (224 km) ranged from ~40 to 180 hours. This equals an average velocity of 1.2-5.5 km/hour, respectively. At the three flow regimes modeled, the drawdown alternatives resulted in a significant decrease in water travel time from existing conditions (no drawdown). Estimated travel times through the lower Snake River under existing conditions ranged from 147 hours at 160,000 cfs to 810 hours at 25,000 cfs. These times are reduced 43 to 52% for the lowest of the drawdown alternatives. Depending on the alternative selected, increases in flow (25,000 to 160,000 cfs) resulted in a two- to six-fold decrease in water travel time.

Table 4-4
Water Transport Time (Hours) For the Snake River
From the Clearwater River Confluence
To the Columbia River (224 km Distance)
Under Each Drawdown Alternative

Drawdown Alternative	Low Flow[1]	Moderate Flow&[2]	High Flow[3]
No drawdown	810	342	147
4A	61	40	27
5, 9	230	100	60
13, 17	430	180	72
14, 18	340	145	60
15, 19	265	115	50

[1] 25,000 cfs = 700 m^3/sec
[2] 60,000 cfs = 1700 m^3/sec
[3] 160,000 cfs = 4500 m^3/sec

Model estimates reflect a decrease in water travel time of around 45 to 75% under the Natural River Option, compare with other alternatives. The greatest different among drawdown alternatives occurs under low-flow conditions (range of particle transport time (61 to 430 hours). Changes in transport time through individual reaches are shown in tables 4-1 to 4-3.

b. Changes in Reservoir Volume and Surface Area

Physical characteristics of lower Granite Reservoir were mapped using Geographic Information System (GIS) methodology. There was no database available to do a similar analysis of other lower Snake River reservoirs. Modeled results indicated that reservoir volume decreased dramatically for the different drawdown scenarios. Changes in the amount of discharge did not change the relative proportion of reservoir volume when compared for each drawdown option (figure 4-6).

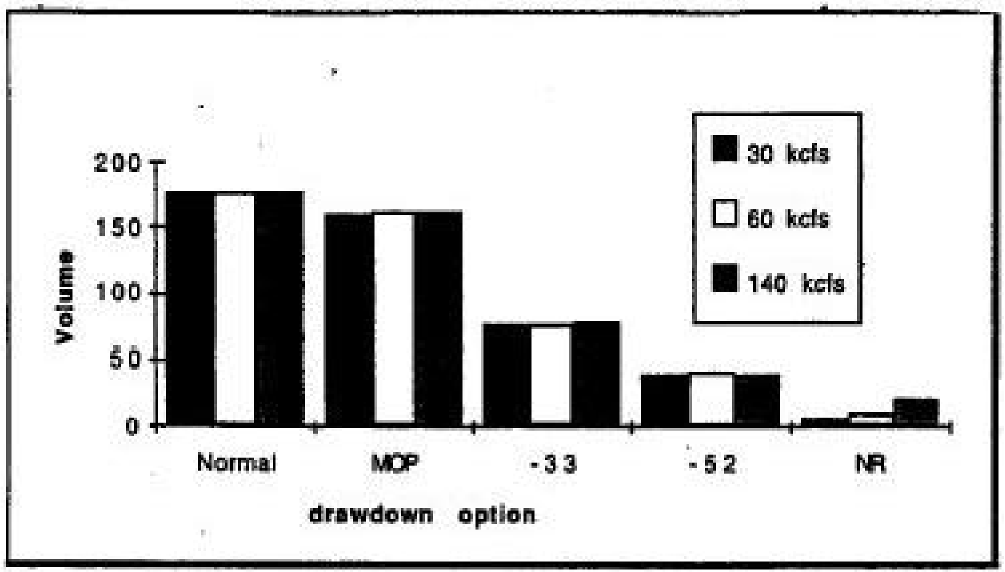

Figure 4-6. Lower Granite Reservoir Volumes (x10^8 feet^3)

Surface area of Lower Granite reservoir also decreased with lowered surface elevation, but changes were not as dramatic as those observed for volume. For example, the Natural River Option had nearly the same surface area as the 52-foot drawdown options. The Natural River Option showed the greatest relative change with increased discharge regimes. Relative amounts of reservoir surface area changed little with increased discharge for the other drawdown options (figure 4-7). In contrast, riverine surface area increased almost exponentially from normal pool to Natural River Option (figure 4-8).

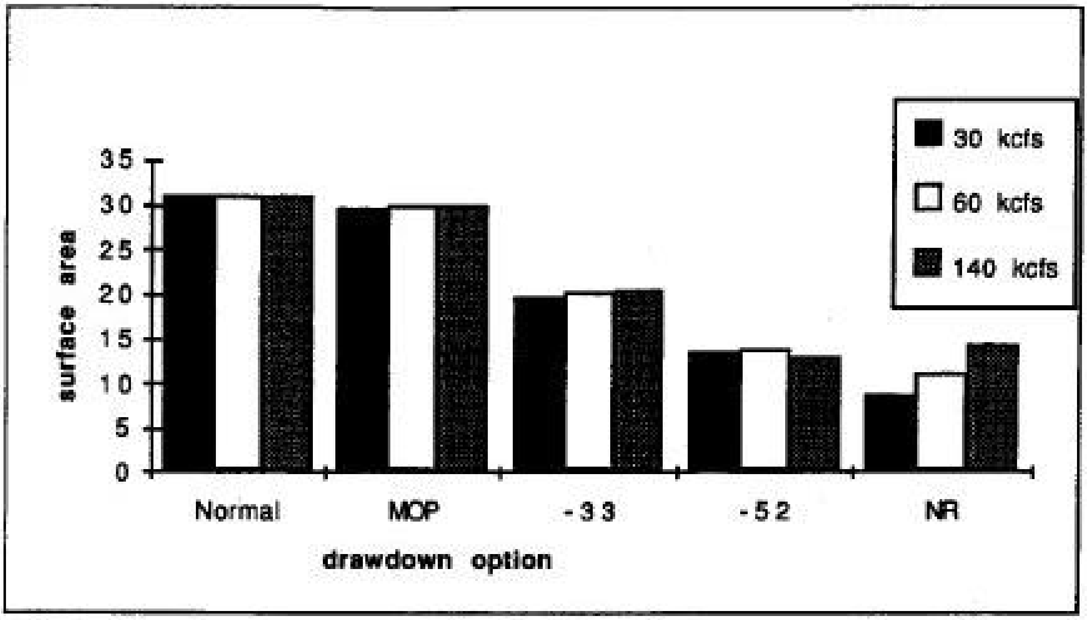

Figure 4-7. Lower Granite Reservoir Lentic Surface Areas (x10^7 feet^2)

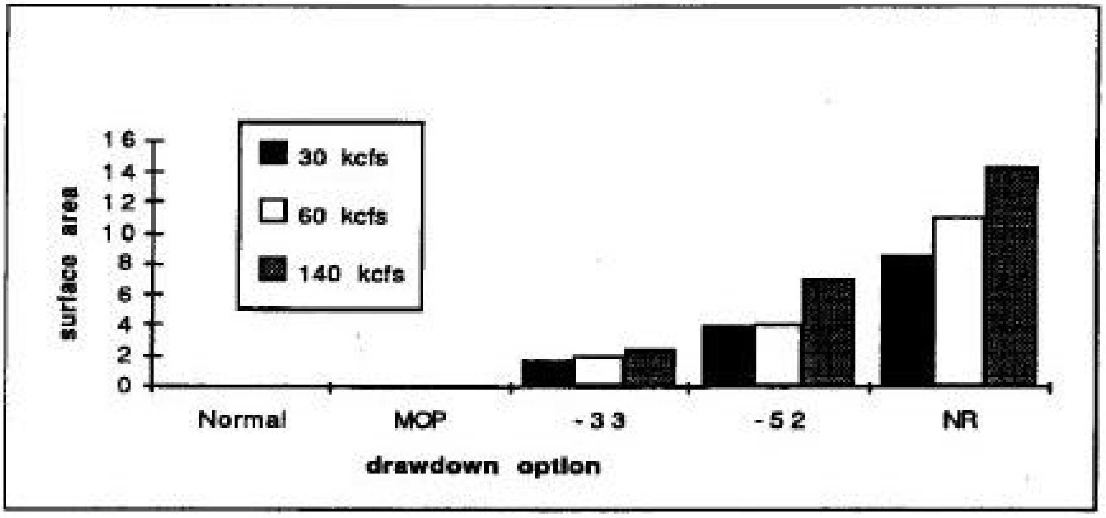

Figure 4-8. Lower Granite Reservoir Lotic Surface Areas (x10^7 feet^2)

c. Changes in Water Quality

To estimate the potential impacts of drawdown to water quality in the lower Snake River, this discussion focuses on the Natural River Option and the 33-foot drawdown with constant pool. The Natural River Option would involve installing bypass structures around each dam, and represents the most pronounced change in surface water elevation, because the option would essentially restore the lower Snake River to near pre-impoundment flow conditions. Alternative 13/17 would drawdown each reservoir to ~33 feet below MOP (25 feet for Ice Harbor) with pool elevations subsequently maintained at constant levels (±5 feet).l Lower surface-water elevations would be maintained during a portion (15 April to 15 June) or the entire (15 April to 31 August) juvenile outmigration period.

In the absence of data derived under flow conditions representative of the proposed drawdown scenarios, a qualitative discussion of water quality effects is presented. Hydrodynamic models used for predicting temperature and dissolved gas levels are similarly constrained by a lack of operating experience with pool levels below MOP. Results of the March 1992 Lower Granite/Little Goose Reservoir test drawdown are discussed where possible.

i. Temperatures

Water temperature plays a critical role in the successful rearing and migration of anadromous fish. However, following impoundment of the Columbia and Snake Rivers, factors such as gas-bubble disease, increased travel times, and passage through turbines have over-shadowed temperature effects as important causes of fish mortality. Temperature effects, however, may not always be direct. For instance, elevated temperatures may result in increased predation rates or increased susceptibility to disease.

Individual species and life stages of anadromous fish have different tolerances to extremes in temperature. Brett (1952) reports optimal temperatures for chinook salmon of 54 to 57ºF. Although fish were found to survive at higher temperatures, they avoided temperatures >59ºF. Bell (1986) reported a suitable temperature range for chinook salmon at 38 to 68ºF, with an optimal temperature range for migration of 49 to 58ºF. Optimal rearing temperatures for salmonids were shown to be 45 to 58ºF, with an upper lethal limit of 77ºF (Bell, 1986).

As a general rule, water temperatures rise markedly in impounded areas of the Columbia River during periods of low water and exceptionally warm weather. Historically, temperatures in the lower Snake River have always been a few degrees higher than those in the mid-Columbia River. Impoundments on the lower Snake River enhance isolation, which provides additional warming. Juvenile salmonids that move downstream late in the season face additional risk from elevated water temperatures, regardless of migration depth. Further, fish are not isolated from thermal extremes because thermal stratification does not normally occur in lower Snake River reservoirs (Falter and Funk, 1973). After July, Snake River reservoirs can reach temperatures in excess of 74ºF (COE, Walla Walla, District, unpublished data), which exceed levels considered optimal for anadromous fish (Chapman *et al.*, 1991). It has been shown that adult salmon migration can be blocked when temperatures exceed 70ºF (EPA, 1971). During certain years, elevated temperatures at the confluence of the Snake and Columbia Rivers (>70ºF) have been shown to impede migration of adult summer chinook salmon and steelhead into the lower Snake River (Lisom *et al.*, 1985; COE, 1992b).

The multi-agency Columbia River Thermal effects Study, initiated in 1968, led to three conclusions significant for salmonids spawning and rearing in the Snake River: 1) Any increase in temperature between 17 to 20&dec;C was considered detrimental to juvenile salmonids in the Columbia and Snake River systems; 2) 17ºC was the upper end of the optimum temperature range, and 20ºC or higher represented adverse conditions; and 3) the thermal resistance of young salmon was reduced 3 to 5ºC when the water was supersaturated with air (Ebel, 1982).

Drawdown operations could alter thermal regimes in the lower Snake River by changing the input, storage, and release of heat from project reservoirs. Inflow from upstream releases and direct inputs of solar radiation are the primary sources of heat to lower Snake River reservoirs. Drawdown operations will significantly alter the depth, surface area, and fetch of each of the reservoirs, which in turn, will alter the input-output and distribution of heat energy within the system.

The magnitude and direction of temperature change, however, will be difficult to predict because of competing mechanisms that result from drawdown. If the four lower Snake River reservoirs are drafted below MOP, solar heating would be reduced as a result of decreased pool surface areas. Reduced reservoir volumes would result in lowered heat buffering capacity which, in association with decreased hydraulic residence time, would act to lower overall average temperatures. In this case, as retention times within the reservoirs decrease, the temperature of inflowing waters will have a relatively greater affect on thermal regimes. Alternately, decreased buffering capacity and reduced reservoir mixing times could result in increased daily temperature maxima (COE, 1992b). It should be noted, however, that if increases in water velocity are sufficient to prevent thermal equilibrium with atmospheric temperatures, then a slight decrease in water temperature would again be predicted.

Temperature control studies (field and computer modeling) conducted in 1991 to measure the impact of upstream releases on water temperatures in the lower Snake River are still considered to be preliminary (COE, 1992b). Lower temperatures were recorded within the Lower Granite and Little Goose reservoirs following a limited release of cool water from Dworshak pool, although modeling results suggested that very large volumes (1 MAF) would be required to meet temperature objectives at the mouth of the river. Additional data from field studies and modeling exercises are clearly needed to better define the relationship between storage volumes, river flow, and water temperature.

ii. Dissolved Gases

Much has been written on the subject of dissolved gas supersaturation and gas-bubble disease. Weitkamp and Katz (1980) and Fidler and Miller (1993) provide excellent reviews of the gas supersaturation literature and a good source of general information on this topic. Many reports and articles have also appeared which address issues of gas supersaturation in the Columbia-Snake River system (EPA, 1971; Ebel *et al.*, 1975; Fickeisen and Schneider, 1976; Montgomery and Becker, 1980; Meekin, 1971; Rulifson and Abel, 1971; COE, 190).

Gas-bubble disease was described in the scientific literature as early as the late eighteenth century, and has been recognized as a serious problem in the Columbia River system since the mid-1960's (Weitkamp and Katz, 1980). Ebel (1969) and Meekin (1971) are generally recognized as providing the first reports that a serious supersaturation problem existed in the Columbia River system. Raymond (1968, 1969) noted that increases in migration time due to impoundment led to substantially greater exposure times for juvenile fish. Reports of mortalities and signs of gas-bubble disease in juvenile and adult salmonids from the Snake River appeared in the early 1970's (Ebel, 1971; Raymond, 1970).

Once exposed to elevated levels of dissolved gases, there are a number of ways in which fish may reduce or prevent the onset of bubble disease. For example, fish may increase the solubility of gas in their blood by sounding. A general rule of thumb is that for each meter of depth fish sound, the increase in pressure is sufficient to compensate for approximately 10% of saturation (Weitkamp and Katz, 1980). Because gas solubility is inversely related to temperature, sounding may provide an additional benefit if water temperature is lower at greater depths. The time required for emboli formation in blood, and eventual death, is substantially longer than the 60 to 90 minutes it takes for gas saturation to occur in critical tissues (Beyer *et al.*, 1976). Therefore, it is possible for fish to survive intermittent exposures to supersaturation if they are able to move into water with lower dissolved gas tension.

It has been shown, however, that even though many river channels are deep enough to permit sounding, not all fish are able to detect and/or avoid supersaturation. This ability appears to vary among species and individual life stages, and may be related to other factors (*e.g.*, light, temperature, pressure, prey density, and predation) that evoke depth-selective behavior (Fickeisen and Schneider, 1976). Therefore, any attempt to estimate fish mortality caused by supersaturation must take into account not only total dissolved gas (TDG) concentrations and the natural depth distribution within the area of concern, but also a host of complex and poorly understood physiological and behavioral factors that determine the length of exposure and vulnerability of individual species to gas bubble disease. For example, smolts may rise to tailrace surface waters during spill or the shallow sluiceway in the smolt bypass system.

Other variables that influence the levels of dissolved gases downstream of dams include powerhouse hydraulic capacity, tailwater conditions, and operational configuration. Existing water quality models are inadequate for predicting dissolved gas levels for drawdown scenarios where water levels are dropped below MOP. That is, there is no operating experience with reservoir levels below MOP with which to develop model inputs (COE, 1992b).

In order to better estimate the potential impacts of drawdown on water quality and key design and operational parameters of the lower Snake River reservoir system, the Corps of Engineers conducted a test drawdown of the Lower Granite-Little Goose reservoirs in March 1992 (Wik *et al.*, 1993). Tests were conducted to determine the effect of reduced hydraulic head and tailwater elevations on dissolved gas concentrations. Two spilling scenarios were used in the tests: 100% spill (no flow through the powerhouse), and combination spillway and powerhouse operation. Discharge rates for the 100% spill tests ranged from 28,500 to 114,000 cfs. Combination spill and powerhouse tests used spilling discharges of 23,000 to 81,400 cfs, with simultaneous flows of 23,000 to 84,000 cfs passing through the powerhouse.

Because of low inflows during the test (~30,000 cfs), special surge tests using reservoir storage were necessary to simulate the higher spill levels typically associated with spring runoff. However, average rates for mid-range flows during the test (~65,000 cfs) were low compared with spring runoff records collected over the past 50 years. Maximum flow values for the tests corresponded to average or slightly above-average rates compared with long-term spring runoff records.

A clear relationship between tailwater elevation and dissolved gas saturation was not apparent during the 1992 test drawdown of Lower Granite reservoir. One series of tests showed a slight increase in dissolved gas concentration with decreasing tailwater elevations (639 to 630 fmsl), although the volume of spill was increasing (*e.g.*, 26,300 to 35,300 cfs). The greatest increase in dissolved gas occurred when the tailwater elevation rose in response to increasing discharge (Wik *et al.*, 1993).

Reducing hydraulic head (*i.e.*, reducing forebay elevations), but maintaining similar tailwater elevations and spilling rates, produced little change in dissolved gas levels. However, dissolved gas levels generated by spill for tailwater conditions with no or minimal powerhouse operation were reported to be very sensitive to spilling rates. Increasing spilling rates resulted in substantially higher dissolved gas concentrations.

Mixing of discharge from combined powerhouse and spillway operations was negligible for at least the first few miles below the dam. This finding is particularly significant, as it questions previously held assumptions regarding the benefits of mixing powerhouse flow, which contains relatively lower levels of dissolved gases, with waters passing over the spillway that are enriched with dissolved gases. Therefore, for a considerable stretch of river below the dam, it seems unlikely that dilution from powerhouse discharge would be important in ameliorating high dissolved gas concentrations, unless powerhouse discharge comprised a majority of the total flow.

Dissolved gas levels as high as 135% saturation (with background levels of 100 to 104% saturation) were documented during the March 1992 test drawdown. This level is substantially higher than the 100% water-quality threshold established by the State of Washington. Therefore despite uncertainties connected with the drawdown tests, it is clear that potentially unacceptable concentrations of dissolved gases would result from alternatives which used spilling to pass juvenile fish at lowered pool elevation.

Each of the nine drawdown options would initially spill all flow in excess of powerhouse capacities in order to lower forebay levels. Therefore, during this initial lowering, dissolved gas levels would be increased an equal amount by each of the options. For the Natural River Option, spillway and powerhouse operations would cease once forebay levels are dropped below the spillway crest. Water would be diverted around the dams under the Natural River Option, with velocities regulated primarily by inflow rates. Once natural flow is restored, no further impacts due to dissolved gas supersaturation would be expected.

The remaining drawdown options would involve continued spilling of all flow in excess of powerhouse capacities. Estimates of the hydraulic capacities of the projects with water levels at spillway crest are 62,000 cfs for Ice Harbor and 86,000 cfs for Lower Monumental, Little Goose, and Lower Granite. Maximum recorded inflow to the lower Snake River is 245,000 cfs. Therefore, once the target forebay levels are reached under each option, continued impacts due to dissolved gases would largely be regulated by inflows in excess of rated powerhouse capacity. It is expected that impacts would vary from year to year with changes in spring and summer runoff. Estimated exposure to elevated dissolved gas levels, then, would be some function of spill volume and the number of days spilling occurred over the drawdown cycle.

Dissolved gas concentrations increased from around 105 to 135% as the tailwater elevation was decreased, and spill increased during the test drawdown of Lower Granite reservoir in March 1992 (COE, 1992a,b,c). This suggests that adult passage would be impacted during drawdown because of high gas concentration in the tailrace. The location of fish passage entrances relative to tailwater depth is of concern at high gas concentrations. For example, fish cannot experience bubble formation in their blood and tissues if total gas pressure is <130% saturation and they swim at depths < 3 meters. Supersaturation of the water below dams could have a detrimental effect on fish swimming near the surface and when approaching shallow fish ladders (Gray and Haynes, 1977). An additional concern is the potential for exposure to fall chinook fry that rear downstream of the lower Snake River dams following their emergence from tailrace spawning areas.

During the March 1992 drawdown test, about 1,600 fish were examined for symptoms of gas-bubble trauma. The majority of these fish were largescale sucker, smallmouth bass, and squawfish. Gas saturation values were 104 to 135%. No symptoms of gas-bubble trauma were observed, although fish most susceptible to gas trauma (*e.g.*, steelhead and chinook salmon smolts), were not sampled (Wik *et al.*, 1993). Because of the short duration, the possible effects to fish inhabiting the tailrace sections of the reservoirs for extended drawdown periods will need further monitoring. Projected gas saturation levels will range from 130 to 150% at spillway crest drawdown alternative (Wik *et al.*, 1993). These levels far exceed the 110% state standard. Resident fish species that are known to prefer the tailrace areas of dams include channel catfish and northern squawfish which are known to travel to the base of dams in the spring to feed on outmigrating salmon (Bennett *et al.*, 1983). Other resident fish that would be susceptible to the effects of gas supersaturation include channel catfish, chiselmouth, and walleye. Fish found to be most tolerant to high dissolved gas levels include largemouth bass, bullheads, and carp (Weitkamp and Katz, 1980).

A ranking of the drawdown options with respect to dissolved gas levels, from least to greatest potential impact is 1) Natural River Option; 2) options 13/17; 3) options 14/18; and 4) options 15/19. This ranking would be the same whether reservoirs are operated at lowered levels during a portion of (15 April to 15 June) or the total (15 April to 31 August) juvenile fish outmigration period, although a longer drawdown cycle would be expected to have a greater negative impact if spilling occurred beyond 15 June. The 43-foot (options 14/18) and 52-foot (options 15/19) drawdown options were ranked higher (*i.e.*, would have a greater negative impact) than the 33-foot option (option 13/17), if greater spill occurred in the process of dropping project pools to these lower levels. Once target pool levels are achieved, differences between the 33-, 43-, and 52-foot options would be negligible under conditions of no spill. With continued spilling, this ranking is less certain, and would depend on the actual spilling rates for each scenario. That is, hydrostatic head would be greatest at 33 feet, which might lead to higher dissolved gas concentrations, but powerhouse capacity would be reduced at the lower 43 and 52-foot pool levels, which could result in more spilling.

In response to emergency spill operations requested by the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS), an intensive 6-week compliance monitoring effort was carried out to measure TDG concentrations downstream of all spilling Walla Walla District projects in 1994. This monitoring resulted in timely reductions in spill discharge at some projects. The initial goal of the NMFS/USFWS request was to provide spill to achieve 80% fish passage efficiency (FPE) and not to exceed 120% of saturation in the next forebay downstream. Initial spill discharge caps were based on TDG monitoring and provided for a TDG ceiling of 120% in tailwaters. The States of Oregon and Washington then modified the total allowable TDG to 120% at point where it was highest (tailwaters). Monitoring of early warning signs of gas bubble trauma (GBT) in downstream migrating salmonids was conducted in 1994 at several locations monitored routinely by the Smolt Monitoring Program of the Fish Passage Center.

The original intent of the GBT monitoring program was to provide information that could be analyzed post-season. It was not designated to allow or justify the management of spill. Observations of bubbles in gill lamella averaged from 18 to 28% for the time period at Little Goose, Lower Monumental, and John Day Dams. At Little Goose and Lower Monumental Dams signs of GBT decreased over the time period addressed. At John Day Dam, the percent of fish affected with bubbles in the lamella increased to a maximum of 46.7% and then decreased somewhat after that. The highest percentage of fish with BGT were noted at Bonneville Dam on May 31, when 83.3% of the fish had signs of GBT. The states reduced the TDG limit to 115% based on mainly on this biological evidence.

The Columbia River Inter-Tribal Fish Commission monitored adult salmonids passing Bonneville Dam from May 20 to June 20, 1994, to determine if increased spill resulted in gas-bubble disease. No evidence of gas bubble disease was found on the 302 chinook salmon, 100 sockeye salmon, and 200 steelhead. These fish represented approximately 4% of the adult fish passing Bonneville Dam during that interval.

As a follow-up to the spring 1994 spill program, NMFS assembled a group of scientists on November 1 to 3, 1994, to identify 1) components of a monitoring program to determine the effects of high levels of total dissolved gas saturation (TDGS) on migrating salmonids and other biota; 2) short- and long-term information needs relative to those effects; and 3) research necessary to address these short- and long-term needs. The scientists produced a working document that outlined sites for TDGS and biological Monitoring, identified physical monitoring equipment and protocols for biological evaluations. They also recommended that standardized procedures for both physical and biological monitoring be implemented.

The NMFS and the U.S. Environmental Protection Agency (EPA) are currently developing a dissolved gas biological monitoring plan for Spring 1995. This plan will involve the states of Oregon, Washington, and Idaho, National Biological Survey, COE, FPC, Columbia Basin Indian tribes, EPA, and U.S. Geological Survey. Their effort will assess relative risks of management actions that expose fish to elevated dissolved gas levels in the Columbia and Snake Rivers. The intent of the agencies' monitoring and evaluation plan is to allow the use of spill to accomplish an 80% fish passage efficiency at COE projects while controlling TDG below some critical threshold of 115 to 120%; and to comply with provisions of Federal Energy Regulatory Commission orders at public utility district projects on the mid-Columbia River. This spill will include recommendations for physical and biological monitoring and TDG standards.

iii. Turbidity.

Some of the more visible effects of drafting reservoir pools to levels substantially below MOP include sediments being moved downstream from the present confluence area and an increase in streambank and beach erosion. As pool levels are lowered, groundwater from exposed areas begins to drain from bedrock and surface sediments. This drainage increases pore water pressure in areas where it exits from deposited materials, resulting in reduced slope stability. The extent of streambank and shoreline erosion would largely be dependent on the rate at which the water level is dropped. The maximum allowable drawdown rate estimated for Columbia and Snake River reservoirs is 2 feet per day (COE, 1992b).

Exposed embankment areas along most of the lower Snake River reservoirs are rock- and/or gravel-filled. The four reservoirs are bound by ~328 miles of shoreline (Lower Granite, 91;Little Goose, 92; Lower Monumental, 78; Ice Harbor, 67). Drawdown alternatives would require placement of substantial quantities of riprap for erosion control (COE, 1992b). The current plan calls for placement of erosion protection (*e.g.*, 3-foot layer of riprap) prior to initiation of drawdown, but only on engineered embankments. Thus, large areas of unprotected shoreline will be subject to erosion. It is also likely that increases in turbidity would occur during bank stabilization operations.

Results of the March 1992 Lower Granite to Little Goose drawdown test revealed measurable turbidity plumes where streams channeled through sediment deposits and along shorelines where bank storage was released following drawdown (Wik *et al.*, 1993). Increased turbidity due to mudflat erosion was not noted, although the absence of storm events during the test precluded this analysis. Although slight elevations in turbidity [7 to 12 nephelometric turbidity units (NTU)] were recorded at Lower Granite Dam during the third week of the test, levels decreased to baseline. As the pool was drafted, the scouring effect of increased velocities moved downstream and subsequently increased downstream turbidity. Coarser sediments (sands) deposited near the head of the pool were the first to be resuspended as pool levels were lowered, but settled out very quickly, resulting in a pattern of decreasing turbidity in the downstream direction.

Minimal increases in sediment transport were observed within the reservoir until maximum test drawdown levels were achieved. At this point, sediment transport increased to 39,000 to 68,000 tons/day (with 18,000 to 50,000 dons derived from the reach above the confluence with the Clearwater River). Slide activity caused by drawdown was primarily confined to slopes consisting of natural deposits of silts, sands, and gravel. Noticeable areas of extensive sliding were identified at the Port of Clarkston, Red Wolf Marina, Nisqually John Landing, Offield Landing, Port of Wilma, and at a number of locations along the south shore of both Lower Granite and Little Goose reservoirs (Wik *et al.*, 1993).

The effect of increasing turbidity on fish and other aquatic life following drawdown of the lower Snake River would depend on both the concentrations of suspended sediment to which organisms were exposed and the duration of exposure. There is ample evidence in the literature that increasing the suspended sediment load in a river has adverse impacts on fish communities. Potential impacts range from sublethal and chronic effects, including reduction in growth rates and resistance to disease, physiological stress, and impaired reproduction, to death.

Additional negative effects of increased turbidity on fish might include habitat degradation, reduction in prey resources, and behavioral changes. Many studies have documented that the deposition of fine sediment reduces available habitat for spawning and rearing (Cordone and Kelley, 1961; Smith, 1971; Muncy *et al.*, 1979; Berkman and Rabeni, 1987). Decreased survival of juvenile salmonids in cold streams has been attributed to the removal of substrate crevices, which has been shown to increase vulnerability to icy conditions (Hillman *et al.*, 1987). Changes in habitat features, such as overhead shading and substrate complexity, may lower foraging efficiency by impairing detection of prey (Ware, 1973; Wilzbach and Hall, 1985). Berkman and Rabeni (1987) noted that species feeding directly from the substrate were negatively impacted by habitat degraded by siltation. They suggested that species which are more opportunistic in their foraging behavior would be less likely to experience food limitation.

Turbidity causes light to be scattered and absorbed, which decreases the amount of light energy available for photosynthesis. This can result in reduced growth rates or losses of algae and aquatic macrophytes. Because the stems and leaves of aquatic plants dampen waves, this may accelerate erosion and further increase water column concentrations of suspended sediment. The loss of rooted plants would also result in decreased resistance of bottom sediments to erosion and disturbance by bottom-feeding fish. Reductions in macrophyte biomass would have a negative impact on snails and aquatic insects that graze on plants and provide food for juvenile fish. Filter-feeding zooplankton would be similarly affected by a reduction in phytoplankton productivity.

With only minor increases in turbidity, many effects are likely to be indirect and may be difficult to detect or measure in the absence of an established monitoring program. For example, behavioral effects, such as changes in alarm and avoidance reactions, impaired homing, and abandonment of cover, ma result in increased vulnerability to predation. Subtle changes in social organization and behavior may also occur following exposure to increased turbidity (Berg and Northcote, 1985). Changes in population size and/or community structure that might result from high levels of prolonged exposure to suspended sediment could have more serious ecological consequences. While it is clear that some fish can tolerate chronic exposures to low levels of suspended sediment, or even short exposures to higher levels, very few studies have reported threshold concentrations at which turbidity-related effects are expressed in different species or age-classes of fish.

Finally, it should be noted that while increasing turbidity is a likely outcome of each of the proposed reservoir drawdown options, it is not possible to accurately predict the range and magnitude of potential water-quality impacts that might be seen. This is primarily due to two factors: 1) there is insufficient information with which to develop models to accurately forecast the concentration and quality (*i.e.*, particle size and composition of suspended materials, presence of adsorbed contaminants) of suspended sediment that would be produced by each of the drawdown alternatives; and 2) the relationship between suspended sediment concentration, duration of exposure, and effects on biota is poorly understood. Moreover, the previous discussion considers turbidity as an isolated impact when, in fact, it is the cumulative effect of many factors, including dissolved gas concentrations and water travel time, that must be examined to fully evaluate effects on anadromous fish and other aquatic life.

iv. Contaminants

Changes in concentrations of contaminants present in the lower Snake River system during drawdown are not likely to occur because flow volume will not be altered. That is, the dilution capacity of the system is not likely to change, given the present rate of pollutant input from point and non-point sources. However, it is possible that some discharge systems (*e.g.*, domestic sewage, industrial effluent) could be located nearer to shorelines during drawdown, depending on their location and extent of drawdown. This shift could lead to reduced mixing and localized contaminant plumes of higher concentration than presently occur. One additional source of toxic chemicals in the water would be through the resuspension of contaminated sediments that are disturbed and transported downstream during drawdown. There is potential for contaminants to be desorbed from sediments after they are scoured into the water column during drawdown operations. This process could result in an exceedance of water quality standards in the water column (BPA *et al.*, 1993). However, it is unlikely that conditions would be much different from those occurring during high runoff years. Recent modeled results show that lead and DDT accumulated in Snake River sediments would be transported downstream with sediments during drawdown operations, and be deposited in partially drawn down pools. For the Natural River Option, lead and DDT would be deposited in the McNary Pool, downstream of the confluence of the Snake and Columbia Rivers (BPA *et al.*, 1993). Because concentrations of toxic dioxins and furans in Snake River sediments are barely above detection, there is no evidence that concentrations in the water column would be elevated during any of the drawdown alternatives.

v. Nutrients

It is likely that hydrological, chemical, and biological changes associated with drawdown will alter nutrient cycling, and in turn affect the trophic structure of lower Snake River reservoirs. In general, flow-through systems with short residence times have reduced rates of primary production. Uptake of nutrients by phytoplankton, and subsequent deposition within the reservoirs via sedimentation, would be reduced following drawdown of the lower Snake River. This would be especially true if drawdown was accompanied by increased turbidity and reduced light levels, which limit phytoplankton production. f follow then, that fewer nutrients would be retained within the reservoirs, and instead, would be flushed downstream into the Columbia River.

This may, however, be an oversimplification of the effect of water level changes on dissolved nutrients and uptake by aquatic plants. Many complex physical, chemical, and biological processes occur in natural waters which alter the form and availability of nutrients, as well as the major paths of nutrient cycling. A fraction of nutrients in Snake River reservoirs are likely adsorbed to suspended particulates or sediments, and are unavailable to biota. Aerobic sediments, in particular, have demonstrated a high affinity for phosphates. While erosion and resuspension of sediments have been shown to be an important source of nutrients for biota in many reservoirs, over many years erosion and sedimentation reduce the productive capacity of littoral areas through sediment removal, especially in steep-sided reservoirs (Ploskey, 1986).

Assimilation and subsequent release of shoreline nutrients by decomposing vegetation have been shown to be problems in reservoirs with fluctuating water levels (Ploskey, 1986). Algal blooms following reflooding commonly occur in association with reservoir drawdown. It is unlikely that plan colonization would occur along exposed shorelines in the Snake River during the relatively short drawdown period, especially if new riprap material is in place before drawdown. It is unknown whether aeration of exposed sediments during drawdown would enhance nutrient releases when water levels are raised. This would depend on the total surface area and composition of the sediments exposed during drawdown. However, it is likely that backwater areas would have a greater accumulation of organic matter than the steep, riprap-covered embankments that characterize most of the lower Snake River reservoir system. Anaerobic conditions are known to enhance rates of nutrient release, but anaerobic sediments do not appear to be prevalent within the Snake River system (Funk *et al.*, 1979).

Reduced water-column dissolved oxygen concentrations and development of anoxic bottom waters are additional concerns in nutrient-rich systems. Organic load and water temperature generally control oxygen demand at different depths, although basin morphometry and mixing determine whether oxygen demand will exceed supply (Ploskey, 1986). It is unlikely, however, with increases in river flow and reduced residence times, that depressed dissolved oxygen levels would be a concern in Snake River reservoirs following drawdown.

d. Summary of Impacts to Physical Conditions in Reservoirs

Water transport times will decrease markedly for each drawdown alternative, with greatest benefits achieved under the Natural River Option. The greatest difference among drawdown alternatives occurs under low-flow conditions. Reservoir surface are and volume decreased with lowered surface elevation. There was little change in the relative proportion of low velocity (lentic) habitat among the different alternatives, except under the Natural River Option. In contrast, the amount of free-flowing or lotic habitat relative to the total varied with discharge. Alterations in the physical characteristics of the reservoirs will, in turn, alter the input-output and distribution of heat energy within the system. However, the magnitude and direction of temperature change will be difficult to predict because of competing mechanisms from drawdown. Dissolved gas supersaturation from increased spilling is acknowledge to be one of the most significant adverse impacts of reservoir drawdown. Spilling potentially impacts resident and anadromous fish populations that reside downstream of the projects, including early life stages of fall chinook salmon. Resuspension and transport of sediments that occur during drawdown operations are not likely to increase concentrations of contaminants in the water column. However, turbidity and suspended solids could impact fish and other aquatic life by reducing primary and secondary production and nutrient flow. The relative magnitude of changes and net effects of alterations in water quality that result from drawdown operations remain uncertain. The lack of operating experience with project pools below MOP has hampered the development of computer models for predicting the effects of river flow on temperature and dissolved gas concentrations. The 1992 test drawdown of the Lower Granite/Little Goose reservoirs provided information indicating that spilling will result in increased dissolved gas concentrations, and for identifying areas along the lower Snake River system that are most vulnerable to erosion.

3. Anadromous Fish

Drawdown of lower Snake River reservoirs will affect anadromous fish populations mainly by causing changes to physical habitat. These changes may affect juvenile rearing and outmigration and adult migration and spawning. Changes in the habitat may occur within the reservoir as well as near confluences with tributaries.

Each of these changes may, in turn, impact the distribution and habitat use of anadromous salmonids and other fish species. For example, changes in flow will change velocity and depth profiles in the reservoir and spillway, characteristics which influence the distribution and migration rates of both juvenile and adult salmonids. Altered flow regimes may also result in changes in availability of substrate and cover. Finally, operational conditions at the dams may influence the behavior and survival of salmonids during downstream and upstream passage of hydroelectric facilities.

a. Changes in Physical Conditions

The greatest potential for impacts during drawdown will take place in inshore areas exposed by receding water levels which may result in stranding or entrapment. The extent of impact to these areas will depend, in large part, on the extent and duration of drawdown, the amount of shallow-water habitat exposed, physical features in the exposed area that contribute to entrapment of juvenile fish, and seasonal timing of the drawdown in relation to outmigration (figure 4-9).

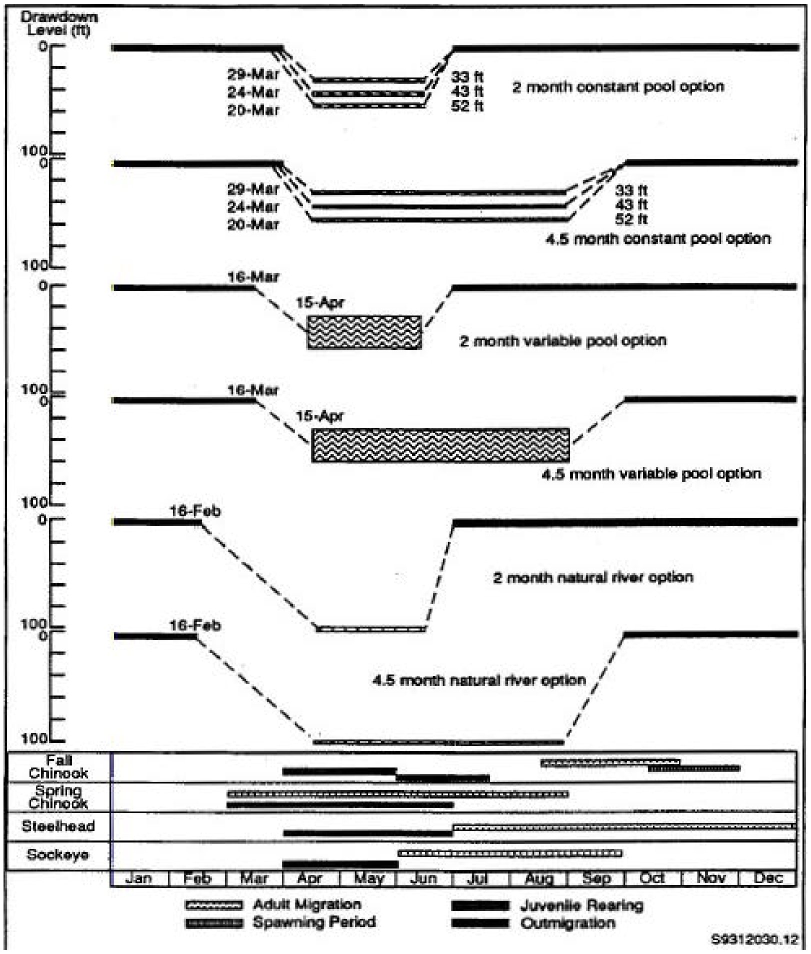

Figure 4-9. Visualization of Lower Granite Reservoir Drawdown Scenario Profiles In Reference to Critical Salmonid Life History Parameters

Much of the shoreline along lower Snake River reservoirs, particularly in the Lower Granite reservoir, now consists of steep canyon walls or riprapped roadways, railways, and shore lines (COE, 1976). At normal operational pool elevations, the water extends to the shoreline maintaining backwaters and embayments. At reduced pool elevations, shallow-water areas are exposed and embayments are reduced in size to an extent related to the stage of drawdown.

i. Staging Habitat

Staging areas, where salmonids gather before continuing outmigration as a group, are protected deep-water areas that are relatively unaffected by drawdown. The main staging areas in the lower Snake River system occur directly upstream of the forebay of Lower Granite Reservoir and mid-reservoir downstream of Silcott Island (Bennett *et al.*, 1988, 1990, 1991). The fish staging in Lower Granite Reservoir are a mixture of wild and hatchery fish.

Generally, smolts in the middle and lower Columbia River tend to migrate through reservoirs during the day and hold up in the forebays until dark (Sims *et al.*, 1978). There is insufficient evidence to quantify how long fall chinook salmon outmigrants "stage" in Lower Granite Reservoir before outmigrating. It may be a simple day-to-night phenomenon, but there is evidence to suggest that juvenile salmonids "stage" briefly in the forebay of each dam on the lower Snake River before continuing outmigration except during periods of high flow (*e.g.*, the spring spate).

Drawdown of Lower Granite Reservoir would probably have little effect on the time outmigrants spend in the Lower Granite staging area. Velocity increases in the dam forebays would be minimized during drawdown. Although hatchery and wild fish stage in the same location, staging response may differ between stocks. For example, Dauble *et al.* (1989) found that spatial distribution of juvenile salmonids in the Hanford Reach of the Columbia River was size-related (*e.g.*, larger outmigrants, spring chinook, sockeye, and steelhead occurred towards midchannel, while wild and hatchery 0-age fall chinook preferred in the shallower shoreline areas). Therefore, individuals would be affected differently by drawdown.

ii. Rearing Habitat

Juvenile fall chinook occur along low-gradient sandy shorelines in Lower Granite Reservoir during the spring (Bennett *et al.*, 1989; 1990; Buettner and Nelson, 1990). Presumably, many of these subyearlings pause in shallow-water areas to feed and grow prior to outmigration. The extent to which subyearling fall chinook salmon use shoreline ecosystems in other reservoirs of the lower Snake River is not well known.

Young chinook salmon in reservoirs are more susceptible to the effects of water-level fluctuation (*e.g*., power peaking), and thus effects of drawdown, than are those that rear in tributaries because they are more shore-oriented and usually pass downstream through reservoirs during low flows when the effects of water-level fluctuations are more exaggerated (Irving and Bjornn, 1981). Reservoir drafting at the rate of 2 feet per day is slow enough to reduce stranding and/or entrapment of juvenile fall chinook found in the main channel rearing areas. However, juvenile salmon rearing in embayments of backwater areas are highly susceptible to stranding. For example, Page (1976) reported that rapid reduction in flow through the Hanford Reach shortly after the emergency of fall chinook salmon from redds resulted in significant stranding in shallow shorelines and embayments that were isolated from the main river flow.

b. Smolt Survival in Reservoirs

In addition to changes to the physical habitat of anadromous salmonids, we assume drawdown will affect the survival of juvenile salmonids during migration and passage. A qualitative comparison of potential changes to the survival of juvenile salmonids during migration and passage has been developed. This analysis considers expected changes in physical habitat (*e.g.*, rearing, staging, migrating), other ecosystem components (*e.g*., predators), and operational conditions.

Mechanisms potentially affecting the survival of salmonid smolts through the lower Snake River may be separated into two general categories (Giorgi, 1991): 1) those affecting smolt performance in the environment; and 2) those influenced by migration rate. Implementation of drawdown alternatives is most likely to benefit mechanisms operating in the latter category.

Migration behavior of juvenile salmonids is determined by a complex set of interacting factors. These factors may include specific environmental conditions, physical variables, physiological attributes, and ecological variables (figure 4-10). Thus, no single factor can be singled out as a determinant. Physiological attributes related to migration behavior are largely influenced by environmental factors such as temperature and other seasonal conditions. Drawdown and associated flow regimes will affect the migration behavior and survival of juvenile salmonids, primarily because of changes in physical and ecological conditions of the environment. Drawdown of lower Snake River reservoirs will increase velocities through most of the affected reach and, thus, affect the migration rate of juvenile salmonids.

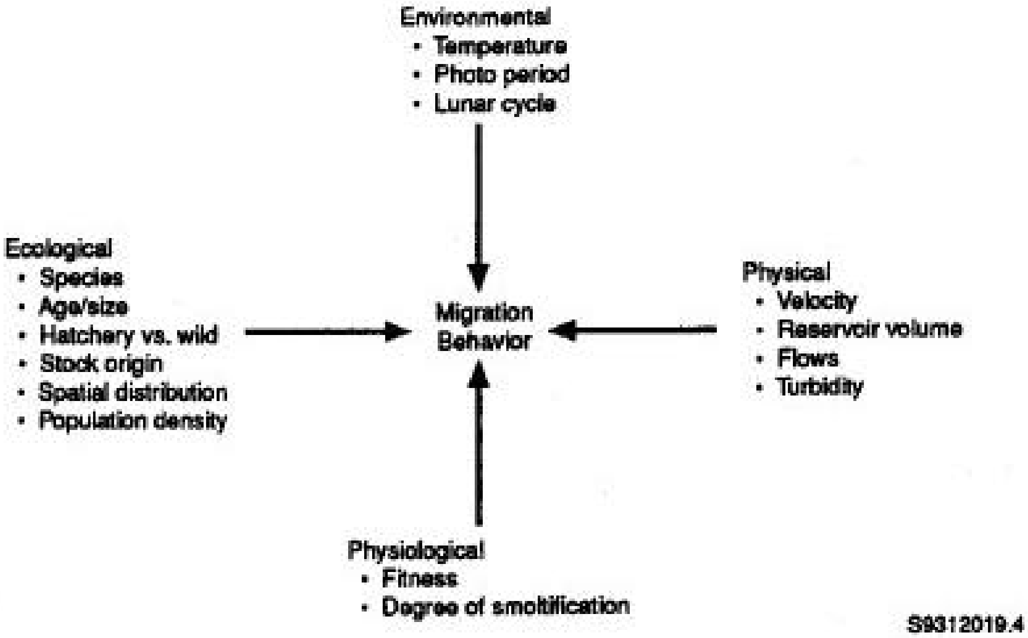

Figure 4-10. Factors that Can Influence Migration Behavior of Juvenile Salmonids

i. Travel Time

Within the matrix of conditions influencing successful migration to the ocean, flow or discharge rate during the outmigration period has been raised into relief. Numerous studies support the theory that increases in flows decrease the travel time of smolts in the Columbia River system. Following construction of several hydroelectric dams in the 1960's, early investigators were quick to identify the influence of flow conditions on migration rate of salmonid smolts. For example, Raymond (1968) compared migration rates of yearling chinook and salmon through free-flowing and impounded stretches of the Snake and Columbia Rivers. He found that the rate of migration was greatest through free-flowing sections and that travel time decreased through both free-flowing and impounded stretches when river discharge was increased from low to moderate levels. Migration rates from McNary Dam to the John Day Dam site increased from 24 to 40 km/day when discharge at McNary Dam was increased from 4,248 to 8,495 m3/second (150,000 to 300,000 ft3/second). Raymond (1969) reported that average migration rates of juvenile chinook salmon from Ice Harbor Dam to The Dalles Dam declined from 18 to 11 km/day after the formation of John Day Reservoir. The groups of fish compared were of the same size, age, and origin, and migrated during similar river discharges (~4,000 m3/sec). Bentley and Raymond (1976) estimated that construction of Lower Granite and Little Goose Dams delayed the migration of juvenile chinook salmon by 16 and 11 days during low and moderate river flows, respectively.

Recent studies conducted in the Snake River indicate that, within a given range of discharge conditions, a strong relationship exists between smolt travel time and discharge. For example, Buettner and Nelson (1989, 1990) reported that a two-fold increase in discharge (*i.e.*, ~1,100 to 2,200 m3/sec; 39,000 to 78,000 ft3/sec) resulted in an approximate two- to three-fold increase in migration rates of juvenile chinook and steelhead from the head of Lower Granite Reservoir to Lower Granite Dam. Movement of chinook and steelhead through Lower Granite Reservoirs was five times slower than in the free-flowing portion of the Snake River in 1986 (Buettner and Nelson, 1987). However, no clear relationship between discharge and migration rate was found for hatchery or wild steelhead and for chinook salmon migrating from the head of Lower Granite Reservoir to Little Goose Dam (Buettner and Nelson, 1987). Biological attributes influencing migration rates included origin of stock, fish size, and species. Additionally, differences in the degree of smoltification (*i.e.*, relative levels of ATPase) may have also accounted for some variation in migration rate. However, apparent faster travel times of wild steelhead smolt versus hatchery smolt could not be explained by differences in ATPase (Buettner and Nelson, 1990). The degree of smolt development may affect the performance of spring chinook salmon, in terms of both shorter travel time and detection during passage in hydroelectric dams (Giorgi, 1991).

Not all juvenile salmonids are expected to respond to increased flows in the same manner, principally because of differences in outmigration and rearing behavior. For example, numerous studies indicate no or little correlation between flow and migration rate of fall chinook (Sims and Miller, 1982; Miller and Sims, 1983, 1984; Giorgi, 1991). Thus, flow modification is not expected to influence the travel time and subsequent survival of fall chinook juveniles in the lower Snake River reservoirs (BPA *et al.*, 1994). Some benefits might be realized for fall chinook stocks that spawn higher up in the system and are actively migrating during later stages of drawdown. However, fall chinook populations spawning downstream of Lewiston will be rearing in the reservoir and are less likely to be influenced by increased flow regimes. It is also possible that fall chinook rearing in the reservoirs could be flushed out of the reservoir during the initial drawdown interval.

Estimates of the rate of migration for juvenile chinook salmon and steelhead in the Columbia and Snake Rivers vary depending on habitat and river discharge (table 4-5). Note that these smolt migration rates are ~25% of the transport rate estimated for the average water particle during flow conditions under the Natural River Option. Calculated migration rates of smolts through impounded reaches are ~35% of those modeled for the average water particle during the slowest flow scenario in the lower Snake River (see Tables 4-1 to 4-3).

Table 4-5
Migration Rates (km/hour) of Juvenile Chinook Salmon and Steelhead Through the Snake and Columbia Rivers
(From Raymond, 1979)

Type of Flow	Low[1]	Moderate[2]	High[3]
Free-flowing	1.0	1.7	2.3
Impounded	0.3	0.5	1.0

[1] Snake, 1,000 to 1,500 m3/sec; Columbia, 4,000 to 5,000 m^3/sec
[2] Snake, 2,000 to 3,000 m3 Columbia, 6,000 to 9,000 m^3/sec
[3] Snake, 3,000 to 5,000 m3/sec; Columbia, 10,000 to 14,000 m^3/sec

The differential migration rate observed between free-flowing and impounded reaches under similar river discharge scenarios suggests that increasing flows through impounded zones will not result in the same increase in migration rate as increasing flows through lotic or free-flowing zones. It is also likely that fish migration would be slowed in the dam forebay (*e.g.*, when fish approach the turbine/spill/bypass system) because of the physical barrier associated with the hydro facility. The physical presence of the dam and its barrier to fish movement may affect the migration rates of juvenile salmonids as much as conditions that exist upstream in the reservoir environment.

The reservoir environment can be separated into different hydrological zones that are characterized by general differences in depth, channel shape, and current velocity (table 4-6). Changes in hydrological conditions and in physical habitat variables occur as fish move downstream into Lower Granite Reservoir. Modeled results of average cross-section velocities (see section 4.2) show that large differences occur in the reservoir due to channel shape. Changes in existing flow and velocity patterns are likely to influence both migration rates and ecological interactions of juvenile salmon. Thus, drawdown of Lower Granite Reservoir could change any mortality factors associated within the reservoir environment. Most importantly, average water velocity in the dam forebay is not significantly increased during drawdown. Thus, if migration movement through the forebay-dam interface is a major determinant of total migration time between reservoirs, drawdown will do little to increase the overall migration rate of smolts.

Table 4-6
Changes in Hydrological Variables During Reservoir Drawdown For Existing Environmental Zones Near Lower Granite Dam

Habitat Zone	Surface Area		
	Volume	Velocity	Depth
Free-Flowing	Increase	no change	no change
Reservoir	decrease	increase	decrease
Forebay	decrease	no change	decrease
Tailrace	no change	no change[1]	no change[1]

[1] Unless water levels in Little Goose Reservoir are also drawn down.

The degree to which increased discharge (and velocity) will speed the rate of downstream movement of salmonids will be determined in part by species distribution and behavior during the rearing and outmigration interval. For example, Dauble *et al.* (1989) found that spatial distribution of juvenile salmonids in the Hanford Reach of the Columbia River was size-related (*e.g.*, larger outmigrants of spring chinook, sockeye, and steelhead occurred towards midchannel, while wild and hatchery 0-age fall chinook preferred the shallower shoreline areas). Changes in discharge may also influence species distribution. For example, Mains and Smith (1964) reported that fish density decreased near the banks and increased in the central portions of the river when discharge of the Snake River increased. They also concluded that shoreline preference, rather than velocity, was a major factor influencing distribution of juvenile chinook salmon. Additionally, Weitkamp and McEntee (1982) reported that migration rates of smolts through the Hanford Reach (56 km/day) were slower than expected from passive draft at average midchannel velocities. Behavioral activities that will influence migration rates are expected to differ by species and may include feeding, swimming rate, and habitat preference.

One noticeable effect of dams is that migration delays increase the tendency for salmonid outmigrants to hold-over for an extra season in one of the reservoirs before migrating to the ocean, or to residualize and spend their entire life in freshwater (Sims *et al.*, 1978). There is evidence to suggest that significant delays in migration during low-flo9w years may result in juvenile salmonids, especially steelhead, to hold-over in reservoirs for extended periods before completing migration (Raymond, 1979). Residualism rarely occurs among fall chinook salmon smolts, which characteristically outmigrate to the ocean as subyearlings. Increased migration rates that may result from drawdown could decrease the number of smolts that residualize increase the numbers of smolts migrating to the ocean, and result in higher adult returns.

ii. Survival Relative to Travel Time

Mechanisms potentially affecting the survival of salmonid smolts through the lower Snake River may be separated into two general categories: 1) those affecting smolt performance in the environment; and 2) those influenced by migration rate (Giorgi, 1991). Implementation of drawdown alternatives will most likely benefit survival mechanisms operating in the latter category.

A basic premise for the drawdown is that increased travel time will result in increased survival for salmonid smolts. However, factors other than travel time may affect survival of fish through the lower Snake River reservoir complex. For example, recent mark-recapture data indicate that survival indices for upriver stocks of yearling chinook salmon to Lower Granite Dam have decreased from 85 to 95% in the late 1960's were generated from wild stocks, while current estimates were derived from hatchery stocks. The poor survival of hatchery stocks could be attributable to inferior viability of hatchery fish, perhaps from increased incidence of disease or decreased physiological capacity to withstand environmental stressors. In addition, the habitat upstream of Lower Granite Dam may not be able to support the large numbers of fish being released from hatcheries (Giorgi, 1991). Reduced viability of hatchery stocks is indicated by relatively low rates of return (0.6%) when compared with wild stocks (1.6%) for the period 1975 to 1984 (Raymond, 1988).

Raymond (1979) contrasted survival between wild juvenile salmon from the Salmon River to Ice Harbor Dam before (1966 to 1968) and after (1970 to 1975) completion of Lower Monumental and Little Goose Dams. He reported that average survival declined from 89 to 33% during that interval. This analysis suggests that passage through the dam complex and/or the conditions created by the dams resulted in increased mortality to migrating smolts (Raymond, 1979). These mortality estimates may not be applicable today because of changes in the number of turbine units in operation, extent of spilling, and bypass screening, among other factors.

Many researchers believe that existing data on survival is inadequate to infer correlations between travel time and flow. Past analyses have often relied on general system mortality estimates as a measure of smolt survival, and have provided no assessment of bias or measures of precision (Dauble *et al.*, 1993). During the spring of 1993, researchers from NMFS and the University of Washington initiated studies in the lower Snake River to obtain estimates of travel time and survival for spring/summer chinook salmon and steelhead migrating through Lower Granite Reservoir and Lower Granite Dam (Iwamoto *et al.*, 1993). The purpose of the study was to determine the feasibility of obtaining more reliable and more precise estimates of survival for smolts passing hydroelectric facilities. The experimental design included estimates of both reach and project survival.

In 1993, fish were collected, marked, and released approximately 31 km upstream from Lower Granite Dam (Rkm 695) at the Nisqually John boat landing (Rkm 726). Seven groups of yearling hatchery spring/summer chinook salmon were released over a 7-day period (15 to 21 April; flows ranged from 60 to 70 kcfs at Lower Granite Dam, with a mean daily flow of 63 kcfs). Passive-integrated transponder (PIT)-tag systems at Lower Granite, Little Goose, and Lower Monumental Dams detected PIT-tagged fish passing each dam via the juvenile bypass system. The weighted average of individual survival estimates for all groups of yearling hatchery spring/summer chinook salmon passing through both Lower Granite Reservoir and Lower Granite Dam was 0.902 with a standard error of 0.008.

In 1994, fish were released approximately 7 km farther upstream at Silcott Island, near the head of Lower Granite Reservoir (approximately 50 km upstream of Lower Granite Dam). The research effort was expanded to include wild spring/summer chinook and steelhead, and releases were spread out over more of the spring outmigration period. Ten groups of yearling hatchery chinook salmon were released from 16 April to 10 May (flows ranged from 34 to 89 kcfs at Lower Granite Dam, with a mean daily flow of 68.7 kcfs), one group of yearling wild spring/summer chinook salmon was released on 17 May (flow was 78 kcfs at Lower Granite Dam), and nine groups of yearling hatchery steelhead were released from 23 April to 12 May (flows ranged from 65 to 93 kcfs at Lower Granite Dam, with a mean daily flow of 77 kcfs). The weighted averages of the individual survival estimates for yearling hatchery spring/summer chinook salmon was 0.933.

Assuming that 1) fish guidance efficiency (FGE) for yearling chinook salmon is 50%; 2) available passage routes are via turbines and the juvenile bypass system; and 3) bypass mortality is negligible, then mortality as a result of project passage for all yearling chinook salmon would range from 8.5 to 9.0% (17 or 18% turbine mortality multiplied by 0.5 or the number of fish passing through the turbines). If the assumptions hold, the system survival results for yearling hatchery chinook salmon in 1993 and 1994 indicate that reservoir survival was virtually 100%, with most mortality occurring as a result of Lower Granite Dam passage. If FGE of 75% is assumed for steelhead, mortality as a result of Lower Granite Dam passage would be approximately 4%, leaving approximately 5% mortality from reservoir passage. Thus, results of the 1993 and 1994 survival studies indicate that little or no improvement in survival of juvenile salmon through the Lower Granite Reservoir will result from drawdown of the reservoir.

The two deterministic models currently used to estimate the relationship between increased flows (*i.e.*, velocity) and survival of smolts contain key unknowns and required modification if they are to be used to estimate smolt mortality during drawdown conditions. See Section IV.f., *Application of Fisheries Models to the Risk Assessment Process*, for a more detailed discussion of these and other models.

c. Smolt Survival at Dams

Juvenile salmonids may pass a hydroelectric project through one of three main routes: turbines, spill, or bypass. The relative number of fish passing through any of these routes is likely to change during drawdown. For example, the swimming depth of migrating smolts affects the relative numbers of fish that are guided into the juvenile bypass system, pass through the turbines or are spilled. If the position of smolts in the water column is strongly correlated with depth, the relative distribution of smolts could shift when the forebay depth is lowered. Thus, the percentage of fish bypassed [fish guidance efficiency (FGE)] under reservoir drawdown could be different than those bypassed under current operating conditions. Additionally, juvenile bypass systems, as presently designed, would not be functional during the drafting and refill periods. Alternative strategies for bypassing smolts (*e.g.*, gatewell dipping) have been proposed for testing, but are not yet proven methods for safely collecting and transporting juvenile salmonids. Unless acceptable collection techniques are developed, certain activities directed at increasing the survival of smolts would cease during the period of drawdown. For example, barging of juvenile salmon and steelhead would cease for levels below MOP for all of the drawdown alternatives.

Flow patterns in the forebay region may also influence the distribution of fish stocks and subsequently affect passage location and route. Stuehrenberg and Johnson (1990) suggested that patterns of flow in the reservoir behind McNary Dam influenced passage routes of smolts originating from the Snake and Columbia Rivers. General patterns of flow in dam forebays will change markedly at the more severe drawdown conditions.

Smith (1974) reported that about 46% of chinook salmon and 29% of steelhead migrated between the surface and 6 foot depth at the forebay of Lower Monumental Dam. Other data suggested that steelhead tended to be uniformly distributed across the reservoir, but that chinook migrated in the central portion of the reservoir. Diel differences in migration depth were also observed. Catch data indicated that chinook favored the surface (upper 0 to 12 feet) at night, and steelhead were more surface-oriented throughout the day. Distribution of downstream-migrating chinook salmon was studied in free-flowing sections of the Snake River near Central Ferry by Mains and Smith (1964) and above Brownlee Dam by Monan *et al.* (1969). In both studies, fish were captured across the entire channel, with some preference apparent for the shoreline zone. It is important to note that the horizontal and vertical distribution of smolts changed under different flow regimes sampled in the Columbia River (Mains and Smith, 1964). Thus, alterations in flow during drawdown can be expected to alter the spatial distribution of smolts as they approach the dams. Since the survival rates of smolts during dam passage depend on their location in the water column, the lowered pool depth and changes in velocity profiles will affect the proportion of fish that pass through the turbines, and consequently affect their survival.

i. Turbine Passage

Mortality factors associated with turbine passage may be affected as a result of drawdown. For example, efficiency of existing operating facilities (*i.e.*, turbines) will be decreased if they are operated at the lower heads estimated for the drawdown period. Decreased turbine efficiency could decrease survival of fish passing through turbines (based on various studies indicating highest survival when units run at peak efficiency) (Ferguson, 1992). Bell (1981) reported that fish passage success generally follows turbine efficiency and that the best relationship of blade angle to a specific flow and head becomes critical for fish survival when plants are operated at less than designed heads. Replacing the turbine-runners should improve turbine efficiencies for lower head operation, and may allow survival to be increased when pools are operated at drawdown elevations. However, these are theoretical considerations, and unproven in actual practice.

Another major factor influencing turbine operation is the depth of the tailwater, a factor which contributes to cavitation. The extent to which cavitation affects fish survival is unknown.

ii. Bypass Systems

All alternatives, except the Natural River Option, would require that new lower-level juvenile fish bypass facilities be constructed. Two major benefits of bypass facilities include decreased numbers of fish passing through the turbines and the potential for alternative transportation options. Additionally, smolts can be examined and/or monitored for marks and tags to assess travel time and relative survival rates during downstream passage. One important assumption in designing and building new bypass facilities is that efficiency would not be significantly reduced when dams are operated at drawdown elevations. This assumption may not be met if design criteria are inadequate at the lowered water levels. For example, preliminary studies from the Lower Granite e-bay sectional FGE model indicates the FGE of existing submerged traveling screening will decrease. Additionally, changes in the size of and approach velocity for vertical barrier screens may also affect the extent of descaling and other injuries that lead to stress and mortality. The design of the vertical barrier screens will also affect flow up the gatewell slow which will, in turn, affect guidance efficiency.

Recent studies conducted at a new state-of-the-art fish bypass system for the second powerhouse at Bonneville Dam indicated that bypassed juvenile chinook salmon had lower survival rates than fish passing through turbines (Ledgerwood *et al.*, 1990). Thus both relative mortality rates and mortality factors within dam passage routs need to be examined before operational features are altered during drawdown. Mortalities for juvenile salmonids bypassed at Lower Granite and Little Goose dams ranged from <0.1 to 6.2% in 1989 and 1990. Benefits to each species differed according to the relative effectiveness of each bypass system. Sockeye and hatchery steelhead were apparently more susceptible to physical injury when guided into and passing through the McNary Dam bypass system (summarized in Ferguson, 1992). A recent summary of fish transportation studies by Matthews (1992) noted that the benefit of moving juvenile salmonids around turbines via bypass facilities may sometimes be nullified if heavy predation occurs at the bypass outfall. Thus, any new design would need to be field-tested to ensure that it functions according to specifications and to verify benefits to survival.

Collectively, data indicate that bypass mortality rates are site-specific. Further, mortality of run-of-river fish from bypass operations is likely to be different than estimates obtained for experimental releases. Experimental fish are usually selected on the basis of good condition and uniform size range, while non-experimental fish are from a wide range of sizes, conditions, and species. Changes in bypass efficiency during the drawdown interval will affect the number of fish that may be diverted from turbines. This issue needs to be addressed along with the condition of fish that impinge on vertical barrier screens. Juvenile bypass systems will be inoperable during the drafting and refill periods of all drawdown alternatives, including the Natural River Option. Consequently, increased numbers of juvenile salmonids will have to pass in the spill or through the turbines. Although drafting will occur prior to juvenile migration, lack of bypass during the refill period of the 2-month drawdown scenario will potentially affect large numbers of smolts.

iii. Spill

Schoeneman *et al.* (1961) reported that the overall mortality of smolts depends upon their distribution in the forebay (*i.e.*, passage route through the dam) and the time distribution of migrants over the dam. They derived estimates of 2% mortality over the spillways and 11% through the turbines for both fingerling and yearling chinook salmon for studies at McNary and Big Cliff dams. Numerous other studies indicate that juvenile fish passing through turbines have decreased survival rates than those passing through spillways (reviewed in Raymond, 1979). In light of this difference, Wilson *et al.* (1991) suggested measures to increase the spill effectiveness of juvenile salmon passing over spillways. Variations in spill appear to influence the passage route of juvenile salmonids. Kuehl (1986) obtained estimates of spill effectiveness at Lower Granite Dam using hydroacoustics. She found that 11, 19, and 35% of the total fish population passed over the spill when 4, 20, and 40%, respectively, of the river flow was discharged through the spillway. Giorgi *et al.* (1988) measured 41% passage at 20% spill, and 61% passage at 40% spill, for yearling chinook salmon using radio tags.

The efficiency of passage via spill for migrating smolts is likely to be different under a drawdown operation. For example, fish may be closer to the spillway crest and to the ceiling of the turbine intakes as the pool elevation is lowered (COE, 1994d). The net effect of this passage scenario on juvenile survival is unknown and would have to be tested.

If reservoir drawdown is implemented during below average flow years, dissolved gas supersaturation would be minimized. However, dissolved gas supersaturation is likely to exceed current maximum concentrations and durations if spill is used in lieu of a turbine bypass system to pass juvenile fish. Actual levels would depend on the total spill and the number of projects where drawdown (and spill) was occurring. Based on the results of the 1992 drawdown test (Wik *et al.*, 1993), it is unlikely that dissolved gas levels would be dissipated in the short section of free-flowing river created below each project. This could result in cumulate effects through each successive project with maximums expected in excess of 140% saturation (COE, 1994d).

The installation of drumgates, designed to maintain the effectiveness of flip-lips (*i.e.*, reduce dissolved gas levels) during drawdown, could create an obstacle for juvenile fish spilled past a project. Specific concerns during spill operations include the potential for increased injury and, also, the potential for increased disorientation of smolts caused by turbulence in the stilling basin.

d. Reservoir Ecology

The drawdown alternatives may affect the performance and subsequent survival of juvenile salmonids in ways other than those relating to travel time and passage. For example, changes in environmental conditions such as dissolved gas, turbidity, or velocity profiles (see Section II) may influence smolt performance by affecting their ability to exploit optimum habitats or to avoid predators. Indirect effects associated with changes in predation risk could also occur during drawdown. Small fish could take refuge in secondary habitat, even though open water habitat would be a more profitable area to forage. Individuals that take refuge from a predator may grow more slowly as a result. Competition and predation are two important factors that shape the fish community of the lower Snake River reservoirs, and ultimately affect the survival of migrating smolts.

i. Habitat Use

The greatest potential for impacts to habitat used by juvenile salmonids will likely occur in shallow inshore areas exposed by receding water levels. To assess these impacts, we modeled the extent of shallow-water habitat in Lower Granite Reservoir (*i.e*., areas with <15 feet of water depth) using GIS techniques, and found that the extent of shallow-water habitat varied throughout the reservoir (figures 4-11 and 4-12). For example, the 733 MOP scenario revealed extensive shallow-water habitat in the upper third of the reservoir upstream of Steptoe Canyon [river mile (RM) 128] with prominent shallows also occurring at Silcott Island (RM 131), and at the Port of Wilma (RM 134). The 33-foot draft scenario revealed shallow-water benches near Lower Granite Dam (RM 128). The deep drawdown option (52-foot draft) revealed significant shallow-water zones at RM 110, 120, and 127, respectively. Significant shallow-water zones were evident for each of the drawdown scenarios except the Natural River Option at RM 120. This indicates that this area could be an important rearing area for juvenile fish.

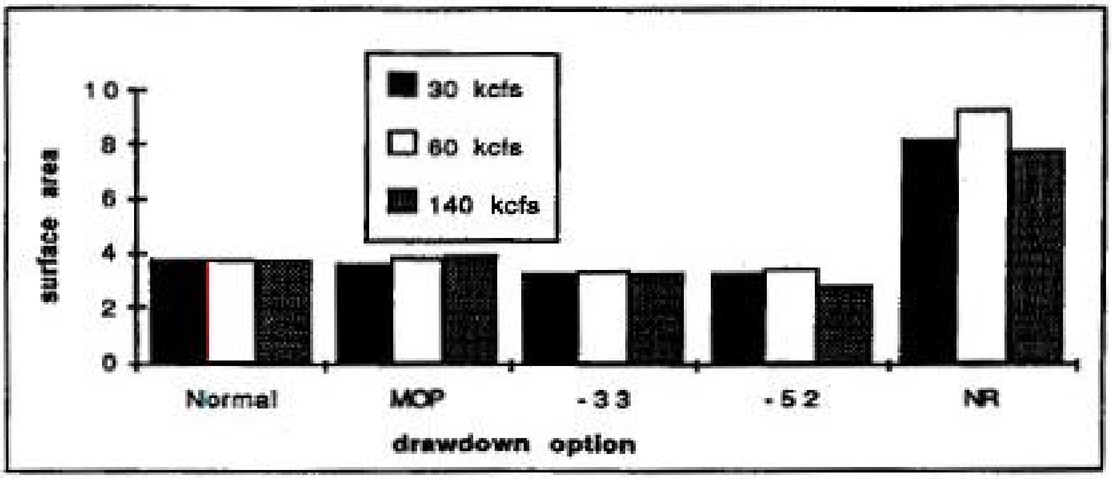

Figure 4-11 Shallow-Water Area (<15 feet) in Lower Granite Reservoir (x10^7 ft^2)

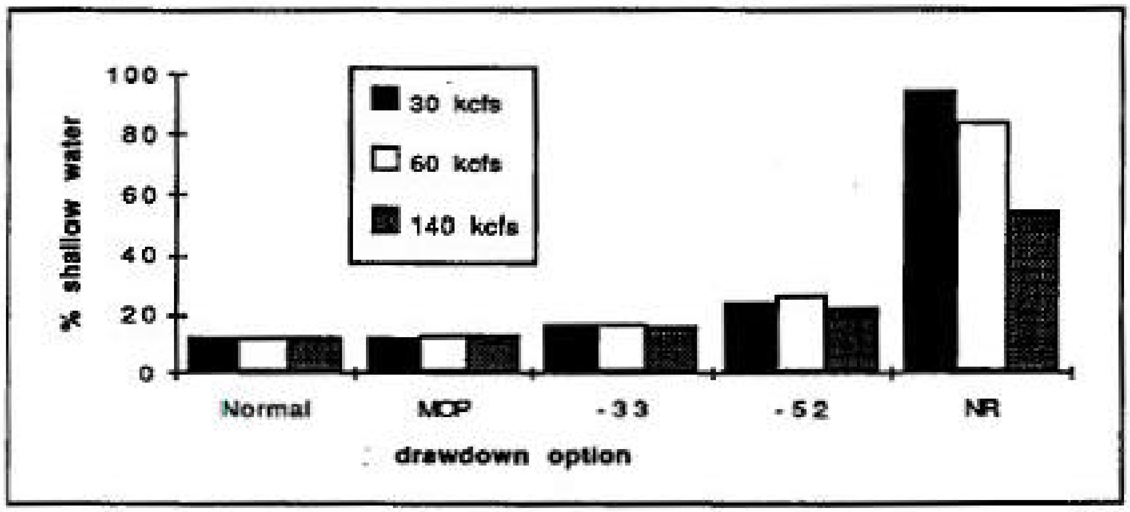

Figure 4-12 Relative Shallow-Water Area in Lower Granite Reservoir

Impacts of drawdown on habitat use by anadromous salmonids will be limited because of the low numbers of fish that rear in the shoreline areas. No 0-age chinook were observed along the shoreline downstream of Lower Granite Dam or found stranded during intensive surveys conducted from the April 1992 drawdown test (Dauble and Geist, 1992). However, NMFS and the Washington Department of Wildlife (WDW) found 22 juvenile salmonids, including subyearling chinook and sockeye salmon, stranded in Lower Granite Reservoir and tailrace areas (Dauble and Geist, 1992).

Low densities of 0-age fall chinook salmon were previously collected in Little Goose pool (Bennett *et al.*, 1983, 1993). This observation, along with recent sightings of fall chinook redds in the tailrace of Lower Granite and Little Goose Dams, indicates that low numbers of juvenile fall chinook could be present in lower Snake River reservoirs during drawdown. Presumably, many of these subyearlings pause in shallow water areas to feed and grow prior to outmigration. The extent to which subyearling fall chinook salmons use shoreline ecosystems in other reservoirs of the lower Snake River is not well known.

Juvenile fall chinook are particularly vulnerable to standing during the period when reservoirs are being drafted to drawdown condition. However, reservoir drafting at the rate of 2 feet per day is slow enough that stranding and/or entrapment of juvenile salmon would be limited to shallow areas or embayments with no access to the main channel. In addition, relative abundance of juvenile salmonids would be minimal during the initial drawdown interval. Drawdown alternatives 5/9 (variable pool options) are likely to result in wide fluctuations in pool elevation at the lowered pool level. This operational strategy would increase the likelihood of subyearling salmonids and other fish residing in nearshore areas to be stranded during the spring rearing and outmigration period.

ii. Species Interactions

Any benefits of increased migration rate on juvenile survival could be negated if predation rates on smolts were increased. Changes in predation rates due to any of the drawdown operations will vary by operation and by species of predators; reservoir length and configuration, water velocity, time of year (*i.e.* periods of prey availability to predators), and temperature all influence the overall rate of predation on juvenile salmonids.

The impoundments behind the Columbia and Snake River dams and the introduction of two predator species have increased the influence of large predatory fish on salmonid smolt survival (Gray and Rondorf, 1986; Prosser, 1986). Salmonid smolts are vulnerable to predation in reservoirs on the lower Snake River during the time they reside there and during their outmigration. Predation of salmonid smolts may be the primary cause of high smolt mortality in the Columbia River Basin (Poe and Rieman, 1988; Rieman *et al.*, 1991). Reservoir habitat generally favors populations of predatory fish, which remain there year-round feeding on resident forage species.

The main predators of salmonid smolts in the lower Snake River are northern squawfish, smallmouth bass, and channel catfish (Bennett *et al.*, 1988, 1990, 1991). Although there are data which document the prey preference of predatory fish, the mechanism by which predator fish consume juvenile salmonids, and how this mechanism might change under various drawdown operations, is not well understood.

Significant predation of salmonid smolts by northern squawfish appears to occur in the tailrace and directly at the dam face in the forebay of Lower Granite Dam during periods of increasing water temperature. High water temperatures, combined with life-history characteristics that increase the encounter rate between predators and smolts, result in high predation rates on juvenile salmonids. Juvenile salmonids that pass over the spillway, through the turbines, or bypassed back to the river are disoriented and easy prey for predators. It is not clear whether drawdown will affect overall water temperature, but drawdown of lower Columbia River reservoirs was expected to cause the water temperature to peak 2 weeks earlier (Flow Options Environmental Impact Statement). If this peak occurs during a major migration interval, one would assume that predation rates would increase above present conditions. In contrast, drawdown, combined with spill, could reduce predators in the vicinity of the projects if predators are displaced from the tailrace area (Faler *et al.*, 1987), or if turbidity is increased. As the freshwater residence time of smolts increases, the chance of an encounter with a predator also increases. Migration delays can increase exposure of juvenile salmonids to predators up to three times their original availability when compared with the pre-dam environment (Ebel, 1977). Studies have shown that subyearling chinook may be more vulnerable to predators because they move slowly through the reservoirs (Miller and Sims, 1984). Because they tend to remain nearshore, subyearling salmon would be less responsive to drawdown. In Lower Granite Reservoir, fall chinook spend an extended time (*i.e.*, 2 to 4 months) in the reservoir because they rear as they move downstream.

Yearling spring chinook salmon and steelhead appear to "stage" in Lower Granite Reservoir, which may increase their exposure to predation. Drawdown will increase the average water velocity through the upper reservoir, including the staging areas of spring chinook and steelhead smolts. If we assume an increase in water velocity equates to an increase in downstream smolt movement, these stocks would migrate through the upper reservoir faster than under present conditions. However, with the exception of the Natural River Option, drawdown is not expected to significantly increase the water transport time in the lower reservoir and in the immediate vicinity of the projects. Thus, all smolts could still be exposed to significant predation near the projects (*i.e.*, in the forebay and tailrace). Further, drawdown may tend to concentrate predators and prey in a smaller volume of water near the projects. This could increase chance encounters between predator and prey, resulting in a potential increase in predation or, conversely, saturate the predators with smolts and result in a decrease in predation since resident prey species will also be concentrated in the pool.

The Natural River Option is most likely to reduce predation on all species because smolts will not be disoriented or concentrated due to project operations; water velocities will be higher and temperatures most likely lower in the vicinity of the projects; and travel time will be increased over the entire length of the lower Snake River rather than only in the upper sections of each reservoir. The characteristics of the lower Snake River would be altered significantly to riverine habitat.

Predation of salmon smolts by northern squawfish seems to be less severe in riverine-type habitats (Buchanan *et al.*, 1981; Kim *et al.*, 1986). However, reductions in nearshore food bases (*i.e.*, crayfish, insect larvae, juvenile resident fish) will occur during all drawdown alternatives, and could cause many predators to shift their diet to juvenile salmonids.

Predation of juvenile smolts in John Day reservoirs by other piscivore predators indicated that smallmouth bass were less likely to feed on smolts than walleye and catfish (Poe *et al.*, 1988). Walleye and smallmouth bass were more likely to consume salmonids in late summer when juvenile salmonids are using the littoral areas of the reservoir for rearing (Dawley *et al.*, 1986). Poe *et al.* (1988) reported that channel catfish were the second most important predator on juvenile salmonids in the John Day Reservoir, with most predation occurring in the spring near the upper third of the John Day Reservoir. In Lower Granite Reservoir, smallmouth bass are major predators of age-0 fall chinook salmon because of similarities in habitat use during the spring outmigration pattern (Curet, 1994). Both species tend to be located in the shallow, low-velocity areas near the river margins. Drawdown of Lower Granite Reservoir may reduce predation of age-0 fall chinook salmon by smallmouth bass in the upper reservoir because shallow-water habitat would be reduced, potentially forcing juvenile fall chinook salmon into the open water or concentrating them in or around the shoreline margins (D.H. Bennett, University of Idaho, personal communication). However, because northern squawfish are open-water predators, the shift in habitat use may result in an increase in predation by northern squawfish on age-0 fall chinook salmon.

Predation of juvenile salmonids by birds, in particular the ring-billed gull, contributes to losses of outmigrating salmonids in the mainstem Columbia River (Ruggerone, 1986). In a study conducted at Wanapum Dam, gulls consumed ˜111,000 to 119,000 salmonids during a 25-day peak migrating period, or ˜2% of the spring outmigration and 5% of the daylight outmigration. Gulls were effective in consuming fish that had been traveling through the turbines and became disoriented or caught in the upwelling water below the turbines. Any drawdown scenario that increased turbine or spill passage would likely result in increased predation on juvenile salmonids by gulls.

The use of existing models to model predation rates during implementation of drawdown alternatives is questionable. For example, FLUSH models piscivore predation as a nonlinear function of water temperature. CRiSP is an improvement, in that it models predation as a function of predator density and water temperature. Thus, changes in predator density as a result of decreased reservoir volume may be accounted for when deriving estimates of smolt survival during downstream passage.

e. Returning Adult Salmon

Adult anadromous salmonids returning to the Snake River Basin must pass over as many as eight hydroelectric dams in the mainstem Columbia and Snake Rivers. Operation of these eight dams, and those at additional upstream facilities, influences the migration behavior of adult salmon and steelhead. Each of the mainstem dams has one or two fish ladders, with an entrance in the tailwater region designed to attract adult salmonids and pass them over the dam. There are also adult collection passageways at the base of the spillway and the powerhouse which lead adults into the fishways (Figure 4-13). Migrating adult salmon are attracted into the fish ladders by flows out of the fishways. Thus, the amount of spill and its distribution across the spillway can also affect passage.

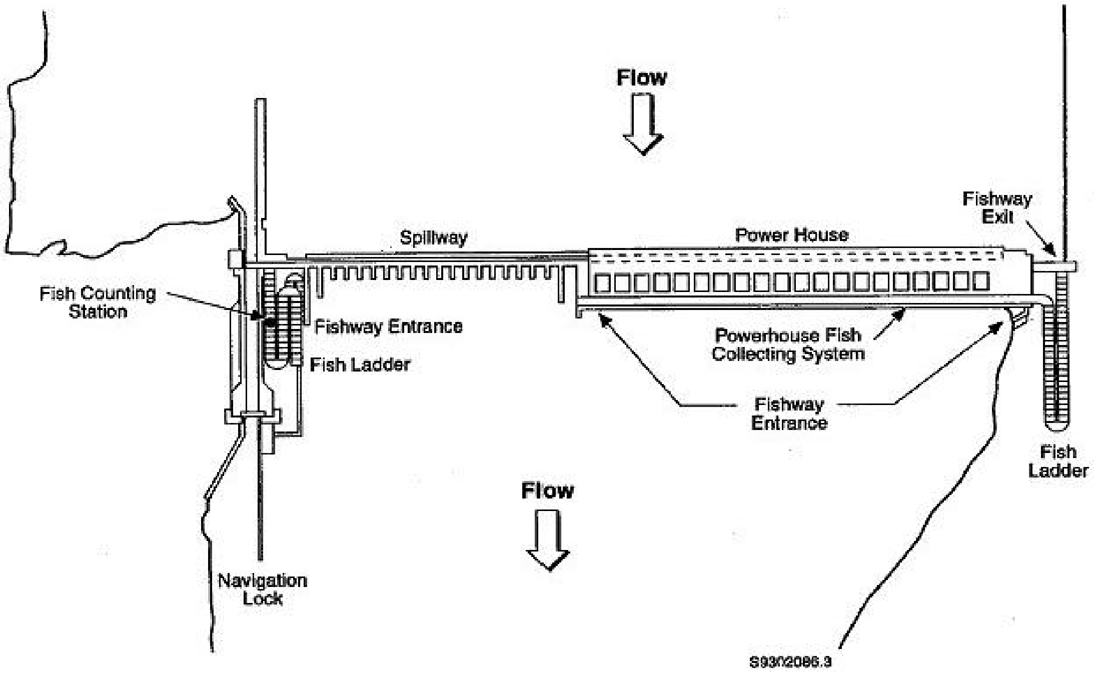

Figure 4-13. Generic Design of a Hydroelectric Facility in the Columbia River System, Including Location of Fishways

All drawdown alternatives, including Natural River Option, require that the present adult fish facilities be modified to operate during the period between normal operations and the drawdown/refill operations. Under the Natural River Option, the bypass structure and river channel around each dam would need to be designed so that velocities through the structures are suitable for adult passage (<9 feet/sec at river flows up to 225,000 cfs). Modeling studies are currently underway at the Corps' Waterways Experiment Station to design these bypass structures. Drawdown alternatives that utilize the existing spillway would require that adult fish ladders be modified to work under the forebay lower-level spillway alternatives require that existing fish ladder exits be modified and secondary low-level adult ladder units and vertical barrier gates be constructed. The Natural River Option would require that fish ladder exits be modified. These modifications would allow adult ladder operation fluctuation and lowered tailwater depths. For example, auxiliary exits with false weirs and return flumes will be required for adult passage during the transition drawdown and refill periods. The flumes will be required for adult passage during the transition drawdown and refill periods. At all projects except Ice Harbor Dam, the adult collection system would be lowered and adult ladder facilities, including entrances and auxiliary water supply, would have to be modified. All new facilities would be "state-of-the-art" and designed to fit passage criteria established by fisheries management agencies.

Even if fish ladders were functional, the proposed spill regime could influence fish migration (COE, 1992a). Each of the various drawdown alternatives will influence conditions at the fishway entrances, including maintenance of sufficient tailwater depth and proper hydraulics for adult attraction. These conditions may impact the ability of adult migrants to find and navigate the fishways. Additionally, instream flow conditions between mainstem dams may be changed during drawdown, thereby affecting the migration rate and behavior of adult salmonids.

i. Adult Migration Rates

Reported migration rates for adult salmonids in the Columbia and Snake Rivers vary according to discharge, velocities, and water quality. For example, Bjornn *et al.* (1992), recently reported that migration through the reservoirs was rapid (*i.e.*, 55 km/day or 1.4 to 1.8 days/reservoir), while the rate of migration in the free-flowing rivers ranged from 15 to 31 km/day. Adult chinook salmon have been known to migrate in free-flowing rivers at rates up to 24 km/day (15 miles/day) (Liscom and Monan, 1976). Migration rates in reservoirs range from 16 km/day for fall chinook salmon in Brownlee Reservoir, a large storage pool, to 56 km/day for spring chinook salmon in Ice Harbor and Little Goose reservoirs, both run-of-river pools (Bjornn and Perry, 1992). Studies conducted in the Snake River between Lower Granite and Little Goose Dams determined that summer chinook travel up to 39 km/day(Liscom *et al.*, 1976). Rates of travel for fish migrating from Ice Harbor to Little Goose Dams average 17 km/day (McMaster *et al.*, 1977).

Depending on the magnitude of increased velocities resulting from reservoir drawdown, drawdown could decrease the rate of migration for adult salmonids (*i.e.*, increase the amount of time they take to pass through each affected reach to the fishway entrance) (table 4-7). We estimated total travel time for adult salmon to migrate through the lower Snake River complex, using data on relative migration rates in reservoir and free-flowing environments, and passage delay at individual dams. Hydraulic modeling studies indicate that the Natural River Option would result in increased velocities through the entire Snake River complex. As a result, total travel time of migrating adults would be expected to increase when compared with travel time through impounded waters (existing conditions). However, adult salmon would not have to pass through fishways at the dams under the Natural River Option, thus eliminating or at least reducing the delay time associated with finding a passage route past the dam. We estimated that adult travel time would likely increase 10 to 30% above existing conditions during the other drawdown alternatives. The increased travel time would result from salmon encountering higher velocities through the newly created free-flowing section of the river. Actual delay at each dam would depend on operating conditions and the ability of fish to navigate the reconfigured fish ladder entrances.

Table 4-7
Estimated Travel Time (Days) for Adult Chinook Salmon to Migrate From the Confluence of the Snake and Columbia Rivers to the Clearwater River. Estimates are Based on Relative Migration Rates In Free-Flowing Versus Reservoir Environments[1] and Passage Delay[2] at Dams
(From Dauble and Mueller, 1993)

Operation	Flow Scenario		
	25 kcfs	60 kcfs	140 kcfs
Existing Conditions	15.1	20.8	29.6
Drawdown (Natural River Option)	9.3	9.3	9.3
Drawdown (Lowered)	16.2 to 17.3	23.3 to 26.1	29.6 to 33.6

[1] Assumed a migration rate of 56 km/day in Snake River reservoirs (Turner *et al*., 1983, 1984) and 24 km/day in free-flowing portions of the Snake River (OFC, 1960). Note: These rates are similar to those reported by Bjornn *et al*. (1991) for chinook salmon in 1991.

[2] The following passage delays were assumed: Ice Harbor, 4.9 days under all conditions (Turner *et al*., 1983, 1984); Lower Monumental, 1.8 days at 25 kcfs, 2.6 days at 60 kcfs, and 3.5 days at 140 kcfs (Monan and Liscom, 1974); Little Goose, 2.2 days at 25 and 60 kcfs (Turner *et al*., 1983); Lower Granite, 2.2 days at 25 kcfs and 8.2 days at 60 and 140 kcfs (Turner *et al*., 1983). It is likely that improvements made to current facilities have reduced these delay intervals.

Under the Natural River Option, adult passage would be effectively blocked during a portion of the transition interval when individual reservoirs are being lowered to achieve drawdown conditions and when the reservoirs are refilling after the drawdown period. Facilities would only function with pool levels between normal pool and spillway crest elevations when powerhouses and spillways are operational. Transitional facilities are planned to provide for adult passage for all other drawdown alternatives. The new fish ladder exits would be functional under the range of elevations planned for the drawdown interval. In addition, with all four projects operating in the drawdown mode, the tailwater elevations will be lower than originally designed (except Ice Harbor). Thus, adult ladder facilities, including entrances and auxiliary water supplies, would be modified. Because drafting of reservoirs to drawdown conditions would begin in mid- to late March, only the early spring chinook run would be expected to be impacted during the initial drafting period. However, depending on the length of the drawdown interval, upstream migration of summer and fall chinook salmon, sockeye salmon, and steelhead could be impacted during the refill period. The length of the refill period is estimated to take 7 to 32 days (see table 3-1), depending on upstream flows available and how low the reservoirs are drafted. Thus, drawdown could cause extended delays in passage of several stocks of adult salmonids.

There is no evidence that drawdown would alter present temperature regimes in the lower Snake River. Jaske and Goebel (1967) reported that the construction and operation of the five low-head dams on the mainstem Columbia River below Grand Coulee Dam produced no significant change in average river temperatures. Available literature suggests that water temperature during adult migration should range from 3.4 to 20.0ºC, depending on the stock and species of salmonid (NPPC, 1992b). These criteria generally reflect the conditions present during the normal migration interval in the Columbia and Snake Rivers.

ii. Fishway Use

The fishway used by adult chinook salmon and the rate of passage are influenced by the number and placement of entrances, current and water velocity, spill patterns, and effectiveness of the attraction flows at the entrance to the fishway (Bjornn and Perry, 1992). When there is little or no spill, few fish use the fishway entrances near the spillway. Small amounts of spill may increase use of entrances near spillways, but large spills can completely block a fishway for upriver passage of fish. Haynes and Gray(1980) concluded that passage delays at Little Goose Dam were related to heavy spilling, turbine operations, and trapping operations in the ladder. Passage delays at Little Goose were significantly higher than Lower Granite during the 2-year study. Generally, passage rates are lower when high flows and spills make it difficult for fish to find fishway entrances. However, low flows may also restrict passage of adult salmonids. For example, Liscom *et al.* (1985) reported that upstream migration of steelhead was delayed under "zero" flow conditions, or when only limited amounts of water (˜200 cfs) passed Little Goose Dam. As a result, extended periods of "zero" flow to allow water storage in reservoirs along the lower Snake River were not recommended during periods when adult salmonids were actively migrating.

During periods of power peaking, usually during daylight hours and on weekends, increased delays of adult salmonids due to turbulence have been documented (Gunsolus *et al*., 1975; Junge, 1966, 1971). The risk of passage delay due to increased turbulence would be increased at dams where fishway entrances are located near the spill (*e.g*., Lower Monumental Dam). Attraction of adult sockeye to fish ladders at Rock Island Dam on the Columbia River was dependent on both spill position and tailwater elevation at the ladder entrance (Leman and Paulik, 1966). Thus, additional studies may be required to define optimum conditions prior to design of new passage facilities and defining operation of dams during the drawdown.

Fallback or downstream passage of adult salmonids is an additional concern for drawdown or other operational scenarios. The rate of fallback o9f adult migrants over a dam varies with flow and spill, by dam, and by fish species. Horner and Bjornn (1981c) found that fallback rates are related to dam and fishway design and were positively correlated with increasing flows. Dauble and Mueller (1993) reported that fallback rates of adult salmon ranged from <1 to 70% at various projects in the Columbia and Snake Rivers. Fallback rates for spring/summer chinook were generally highest at the lower Columbia River projects, and fallback rates for fall chinook were generally higher at the Snake River projects. The high incidence of fallback for fall chinook salmon at the lower Snake River dams (up to 71% at Lower Granite Dam in 1991; Mendel *et al.*, 1992) is a cause for concern because of the potential for turbine mortality. Much of this fallback behavior appears to be the result of natural straying or wandering, rather than to project operations (Dauble and Mueller, 1993). Changes in the rate of adult mortality because of fallback would depend on the passage route, operational conditions, and ability of engineered structures to safely pass fish. Wagner and Ingram (1973) reported mortalities for adult steelhead passing through turbines at Foster and Green Peter dams on the Santiam River of 22 to 46%. Thus, conditions that increase the proportion of adults passing through the turbines could result in increased mortalities when compared with conditions resulting in downstream passage through bypass or spill routes. Extensive drawdown of forebay water level elevations will likely cause adult salmon and steelhead to migrate lower in the water column. This would decrease the percentage of adults diverted via juvenile passage screens, and increase mortality rates for adults that fall back through the turbine intakes.

Adult passage could be impacted by construction activities proposed for the Natural River Option, unless construction activities occurred during the winter when few anadromous salmonids migrate. Large increases in turbidity are expected during early periods of drawdown implementation (Wik *et al.*, 1993). These increases could result in decreases in migration rate (McMaster *et al.*, 1977).

It appears that all drawdown scenarios could have adverse impacts on passage of adult salmon and steelhead. A 2-month drawdown period could delay the migration and passage of spring and summer chinook salmon in the Snake River. However, reservoir refill and return to normal operations would occur prior to the major migration interval for sockeye and fall chinook salmon. Any drawdown alternative extending into September could impact the migration of adult fall chinook and steelhead, particularly during the refill period when upstream passage facilities may be inoperable.

Adult fish passage would be inhibited by the construction of rockfill weirs proposed for installation in the river channel downstream from lower Snake River projects. Three concepts have been suggested for additional evaluation as part of the SCS: two, three, or five rockfill weir installations (COE, 1994a). Construction of these weirs would provide adequate tailwater control for the adult fish system operation at the lowered pool levels occurring during drawdown. However, adult passage over the weirs themselves could be restricted because of the high water surface differentials (*e.g.*, up to 14 feet at 160,000 cfs for the two-weir system) and potentially high velocities (*e.g.*, up to 17.2 fps). Additionally, seven eddy conditions may be created above the weirs, which could cause delays in fish migration.

iii. Spawning Habitat

Drawdown could impact spawning and reproductive success of adult salmonids by reducing spawning habitat or by restricting access of fish to tributary spawning grounds. Fall chinook are known to have spawned in the area just downstream of Lower Granite, Little Goose, and Lower Monumental Dams. These spawning areas range in depth from about 12 to 28 feet below MOP. No other salmonids are known to spawn between the lower Snake River dams. Drawdown to near spillway crest would not directly affect the availability of spawning habitat in these areas, because the reservoirs would be back to MOP during the fall spawning and winter incubation periods (COE, 1992a). Construction of rockfill weirs would drastically alter substrate and velocity characteristics downstream of the lower Snake River dams. These changes could severely impact present spawning habitat for fall chinook salmon.

During the 1992 test drawdown of Lower Granite and Little Goose reservoirs, Dauble and Geist (1992) surveyed tributary streams to determine if access of adult steelhead was affected by the lowered pool levels. Their studies indicated that drawdown over an extended period could change resuspension of silt and form migration barriers to steelhead that use small streams for spawning. Additionally, steelhead would be impacted by a mid-February drafting period because they usually enter tributaries to spawn during January through March.

f. Application of Fisheries Models to the Risk Assessment Process

The objective of the ecological risk assessment is to provide quantitative estimates of the effects of systems operations alternatives on salmonid stocks. The results are expressed in terms of probabilities for a given outcome (ASTM, 1985), *e.g.*, for a given drawdown alternative, there is an X(Y|a) probability that spring chinook spawning escapement will increase by Y over the present baseline. Risk assessment is generally taken to describe the process of characterizing the potential adverse effects of environmental change by means of a probabilistic analysis (NRC, 1983). However, change may also be beneficial, as is the intent of the alternative systems operations plans for anadromous fish. The present risk assessment therefore addresses both positive and negative effects of operational alternatives.

The ecological risk assessment provides an element of the total information required by the decision-making agency to select a preferred course of action (figure 4-14). Other decision elements may include direct costs, effects on irrigation water supplies, or effects on other wildlife. There are six elements of the risk assessment process, derived from those identified by the EPA in their guidelines for ecological risk assessments (EPA, 1989);

1. Define stressors and ecosystem elements
2. Identify risk metrics and endpoints
3. Evaluate projection models
4. Calibrate for proposed conditions and evaluate sensitivity
5. Apply probabilistic simulation
6. Evaluate against baseline

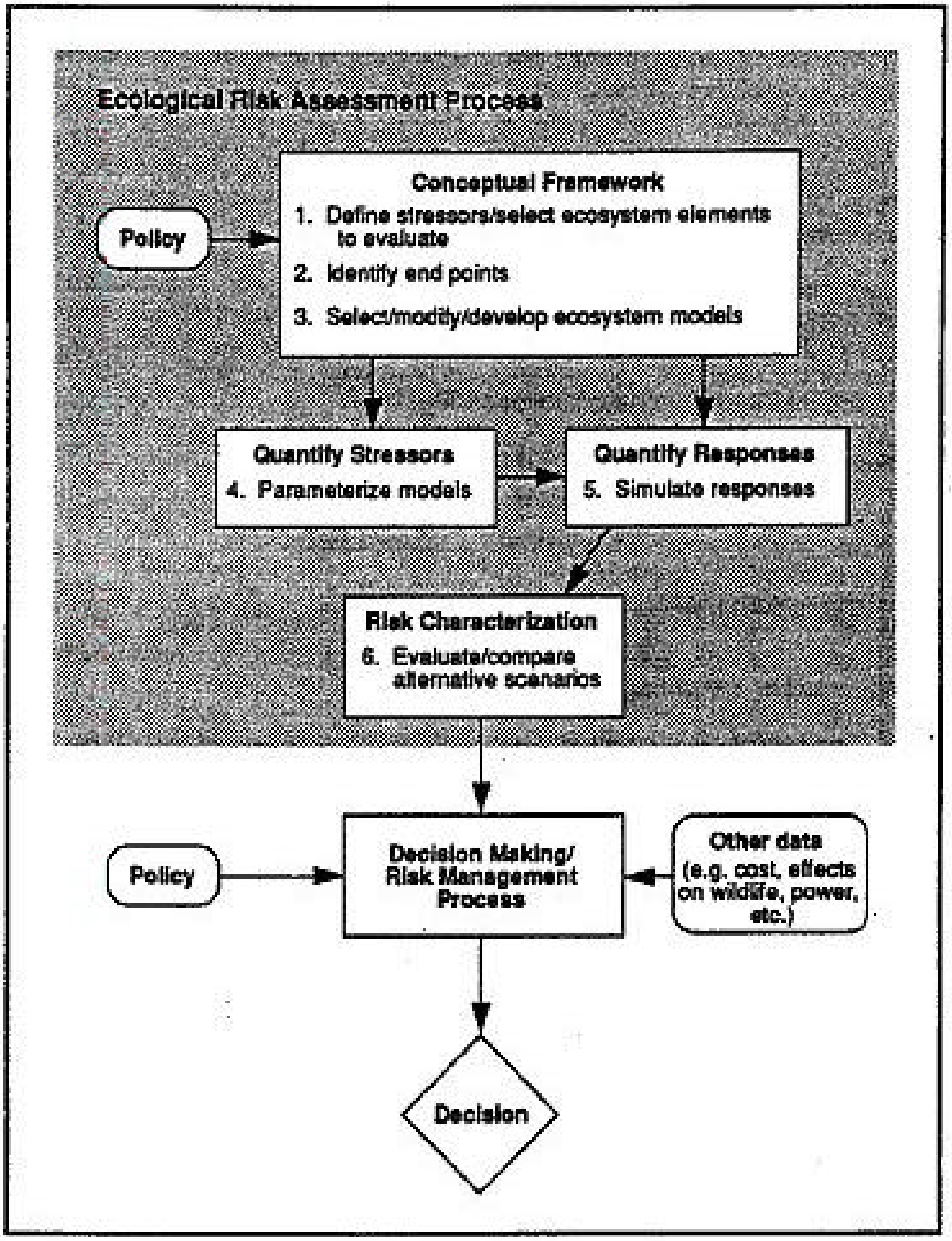

Figure 4-14. Ecological Risk Assessment in the Overall Systems Operations Decision Process

In this section, each of these steps is described and applied to the assessment of risks related to the proposed alternative system operational configurations.

Step 1: Define Stressors and Ecosystem Elements. Step 1 of the risk assessment process (*i.e.*, the selection of stressors and ecosystem elements to be explicitly evaluated) has been done for the present risk assessment. The stressors are defined as the proposed changes in the Snake River system operations alternatives, and the species to be evaluated are the Snake River sockeye and chinook salmon and steelhead. Specific stressors include modification to dam powerhouses, spillways, and pools. Stressor mechanisms include (but are not limited to) predation, dam mortality, and gas-bubble trauma. In the future, risk assessments could be performed for other ecosystem elements, including aquatic mammals and birds.

Step 2: Identify Risk Metrics and Endpoints. "Risk metrics" are the specific biological response variables of interest in the risk assessment. For salmon stocks, these could include the number of salmon smolts from the Snake River entering the Columbia River, the number of smolts entering the Columbia River estuary, or the adult escapement to the spawning area. "Endpoints" refer to the actual change in the endpoint measure that will be taken to signify a significant departure from baseline conditions. Endpoints may reflect an absolute value (*e.g.*, 107 smolts entering the Columbia River) or a relative value (*e.g.*, 10% of the average number of smolts over the period 1980 to 1990 entering the Columbia River).

Because drawdown alternatives focus on enhancing smolt migration, one appropriate risk metric is the percentage of smolts surviving to below Bonneville Dam. A corresponding endpoint is a specified percentage increase in smolt survival to below Bonneville Dam, as compared to current (baseline) conditions. However, the ultimate objective of these alternatives is to enhance stocks of wild salmonids. Because drawdown alternatives may affect upstream migration of adult salmonids directly through flow effects in reservoirs, by altering passage conditions and by construction activities, another critical risk metric will be adult spawning escapement. Endpoints for this metric will include extinction, decline from baseline, 10% or greater increase over baseline, and 50% or greater increase over baseline.

Other risk metrics have been used for salmonid modeling in the past, especially the maximum sustained yield or production (MSY or MSP). MSY/MSP is the maximum positive difference between replacement and actual population size. MSY/MSP has been espoused as a measure of population resiliency (MEG, 1988). This assertion is valid only if resiliency is defined as the maximum absolute number of individuals that can be harvested without depressing population size or viability. MSY/MSP otherwise indicates neither stability nor degree of fluctuation as a result of perturbation. Furthermore, because the objective of the drawdown alternatives is not to enhance harvest but to rebuild populations that are presently far below carrying capacity, the MSP/MSP is an inappropriate risk metric for the present analysis.

In addition to the endpoints, we must also define the time period over which the projection is to be made. Because of the stochastic nature of variation in population parameters, a change in equilibrium population levels may not be apparent for many generations. Also, a given set of conditions could lead to any of a number of outcomes, depending on the sequence of future events within the range of natural variations. Therefore, the risk assessment should present the range of possible endpoints for each metric, along with the corresponding probabilities that each of the endpoints could be realized within the specified time period.

Step 3: Evaluate Projection Models. The third step in the process is to identify and evaluate projection models that incorporate or account for the mechanisms by which drawdown alternatives could affect the risk metrics. Candidate models include the Columbia River Salmon Passage (CRiSP) model (BPA, 1992; Anderson *et al.*, 1993), the Fish Leaving Under Several Hypotheses (FLUSH) model (Weber and Petrosky, 992; Weber *et al.*, 1992), the Passage Analysis Model (PAM) (McConnaha, 1992), the Empirical Life Cycle Model (ELCM) (Schaller *et al.*, 1992), the Stochastic Life Cycle Model (SLCM) (Lee and Hyman, 1992), and the System Planning Model (SPM (MEG, 1992).

i. Model Distinctives

Life-Cycle vs. Passage Models. There are several ways of distinguishing among, or categorizing projection models. The first major distinction is in the scope of the models; intended application. Three of these models (ELCM, SLCM, and SPM) are life-cycle models which incorporate all stages of the salmonid life cycle, including ocean losses and upstream passage. The other three (CRiSP, FLUSH, and PAM) are downstream passage models that focus on a particular stage in the life cycle, specifically migration of smolts downstream through dams and reservoir systems. To simulate population changes from year to year, it is necessary to combine a downstream passage model with a life-cycle model in order to model the complete life cycle at an appropriate level of detail. The three most common model combinations are CRiSP/SLCM, FLUSH/ELCM, and PAM/SPM.

Deterministic vs. Stochastic Models. The second major distinction among these models is the means by which they incorporate the effects of parametric uncertainty and natural variability. Models which employ probabilistic methods to characterize natural variability among individuals and natural variations in ecosystem conditions (such as daily or hourly flow variations) are termed "stochastic" models. "Deterministic" models, on the other hand, predict the average (or expected) behavior of a group of individuals and represent conditions in the ecosystem only in an average sense, or for a specific time sequence of determined events. Stochastic models can provide a distribution of predictions by repeated execution, whereas deterministic models give a single prediction. Deterministic models require contiguously large population sizes and normally-distributed model variables to be valid; when population levels are density-dependent, natural variations will cause the average population to be below that predicted in a deterministic environment (Levins, 1969).

While a small population may appear to stabilize or increase in a deterministic simulation, a certain proportion of the possible outcomes from a comparable stochastic simulation may lead to extinction. It is, therefore, inadequate for populations at low density, such as the Snake River wild sockeye fall chinook, to establish whether the "average" population under a scenario stabilizes or recovers. Instead, the likelihood that chance events could determine recovery or extinction of a marginal population must be considered in such cases.

In addition to natural variability in a well-specified system, there is also the issue of parametric uncertainty in a natural system which is not fully characterized (*i.e.*, for which data limitations impact model predictions). A Monte Carlo approach is sometimes used to address parametric uncertainty, in which model parameters are drawn independently and at random from specified probabilistic distributions, and the model is executed for each set of model parameters. A variation of this method is known as Latin Hypercube, in which probabilistic relationships (*e.g.*, covariances) between parameters can also be specified (*i.e.*, parameters are no longer considered independent). In either the Monte Carlo or Latin Hypercube approach, the underlying model itself may still be essentially deterministic in that it will give a certain prediction for a particular set of parameters. However, the model parameters are allowed to vary randomly, either between runs or between steps within a single run, in order to assess the potential impacts of parameter uncertainty. The effects of parameter uncertainty in deterministic models such as CRiSP, PAM, and FLUSH can be assessed in this manner, although the degree to which this process is automated varies for each model.

Empirical vs. Mechanistic Models. A third distinction which is often drawn between different models is whether they are primarily empirical (based on simple relationships derived from observations) or mechanistic (attempting to mathematically represent the physics of underlying natural processes). Often PAM and FLUSH are referred to as being more empirical, while CRiSP is considered more mechanistic. However, this distinction is somewhat artificial since, in fact, all of these models attempt to represent some aspects of the physical system, and all contain significant empirical elements. Empirical models subsume a set of complex physical properties into a simple, less parameter-rich relationship. For example, PAM attempts to indirectly represent all processes contributing to reservoir mortality of smolts by a single relationship between mortality and water travel time. CRiSP, on the other hand, attempts to directly simulate specific elements contributing to reservoir mortality, including predator and prey density and behavior, as well as water flow velocity. In this sense, CRiSP is more mechanistic, and PAM more empirical. However, many of the relationships used in CRiSP to represent the specific processes are themselves empirical, with limited theoretical basis. Therefore, the key question in evaluating these models is not whether they are empirical or mechanistic but, rather, whether they adequately represent all significant (or potentially significant) processes occurring in the ecosystem, and whether available data support the representation used. For example, a complex mechanistic model may allow greater flexibility in representing detailed processes, but if there are few data to support parameterization of such a parameter-rich model, the advantage is minimal. A parameter-rich model can provide a false sense that physical processes are being appropriately represented if supporting data are insufficient. On the other hand, a parsimonious model (*i.e.*, one with few parameters) that does not account for all important processes, will only be applicable within the specific range of conditions under which it has been developed, and may not be used to extrapolate to conditions for which data are not directly available. Therefore, it is critical to understand and evaluate the data upon which a more empirical modeling approach is based, in order to know to which conditions it may be appropriately applied.

In the model selection process, and in evaluating outputs from the models, greater weight should be given to simpler models that include all critical components and processes (Barnthouse *et al.*, 1984). Critical components and processes are those that have the greatest influence on the model predictions (endpoint measures) under the simulated conditions. Complex models have an inherently large uncertainty associated with their output due to the large number of parameters that must be estimated and because of the greater number of stochastic processes and model functions that must be included (Rowe, 1977). Without knowledge of the correlations among parameters, risk analyses based on complex models will return estimates of endpoints with very large uncertainties (Suter *et al.*, 1985). Furthermore, models should be viewed as abstracts of reality, with the relative merit of each abstraction evaluated according to its ability to make reliable predictions under a given set of circumstances. The relative reliability of the models under unusual operating conditions is a central issue in model selection and in evaluation for the systems operations alternatives risk assessment.

Other Distinctions. In addition to the major categories described above, models can also be differentiated according to the specific salmonid stock for which they were developed, the data upon which they are calibrated, what methods are used to develop river flow sequences, and even which version of a specific model is used (since the models are continually under development, enhancement, and recalibration). These factors can make interpretation of model results difficult and confusing, since even a single model can lead to many different results, depending on how it is applied and what assumptions are employed.

ii. Model Overview - Downstream Passage Models

CRiSP [major versions are 1.0 (BPA, 1992a) and 1.4 (Anderson *et al.*, 1993); recent updates are versions 1.5.1 and 2.1.0] models smolt survival during downstream passage. It is based on two primary modules: smolt passage through reservoirs and through dams (Figure 4-15). The reservoir passage module estimates smolt migration numbers, predation rates, and gas-bubble mortality rates, which are combined to produce an overall smolt number passing through a given reservoir (Figure 4-16). The dam passage module estimates numbers of fish passing the am in a given time interval, the fractions moving through different pathways through the dam, and total mortalities associated with each pathway (Figure 4-17). The model estimates numbers of fish of all stocks on a project-by-project basis. Inputs to the model fall into five areas: 1) daily water flows through subbasin (project-specific); 2) water temperature (affects predator activity); 3) dam operations (project-specific); and 4) fish release timing and magnitude. It is mechanistically oriented, with most mechanisms being described by empirical relationships with calibrated parameters. CRiSP allows several parameters to be varied randomly during a run, including the predation activity coefficient, the supersaturation mortality coefficient, FGE's and mortality rates associated with various dam passage routes, spill efficiency, and reservoir migration rate variance. Most parameters are drawn from a broken-stick efficiency, and reservoir migration rate variance. Most parameters are drawn from a broken-stick distribution. In this manner, natural variations in system performance and fish behavior can be incorporated stochastically when running the model in Monte Carlo fashion, to estimate possible variations within a single year. Multiple years may be run, but the model does not operate sequentially, since there is no provision for estimating subsequent fry production from a given smolt run (that is, CRiSP must be paired with a life-cycle model to model multiple-year sequences).

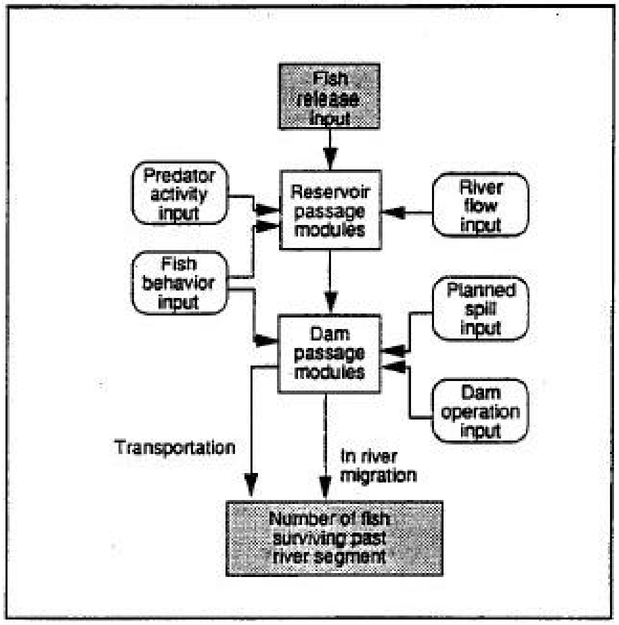

Figure 4-15. Columbia River Salmon Passage (CRiSP) Model

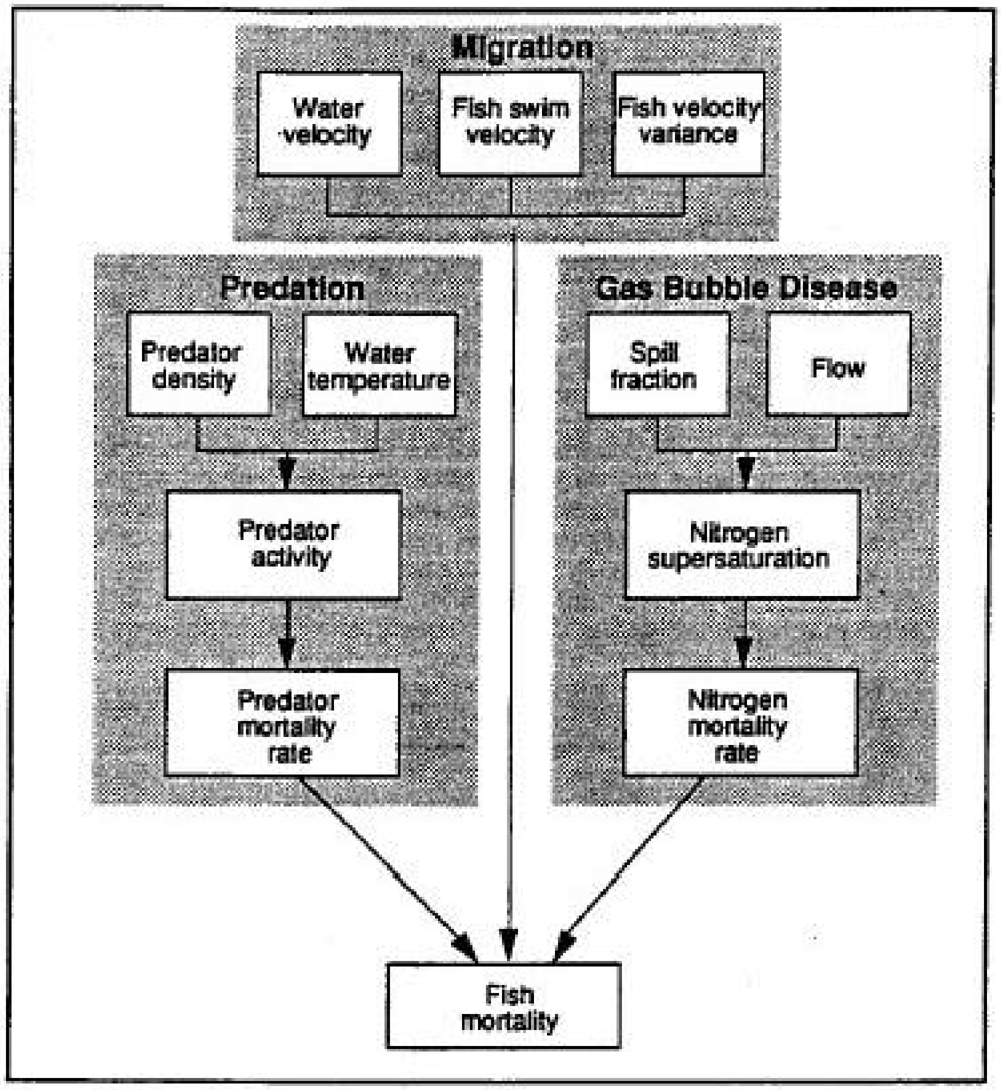

Figure 4-16. Reservoir Passage Module of CRiSP

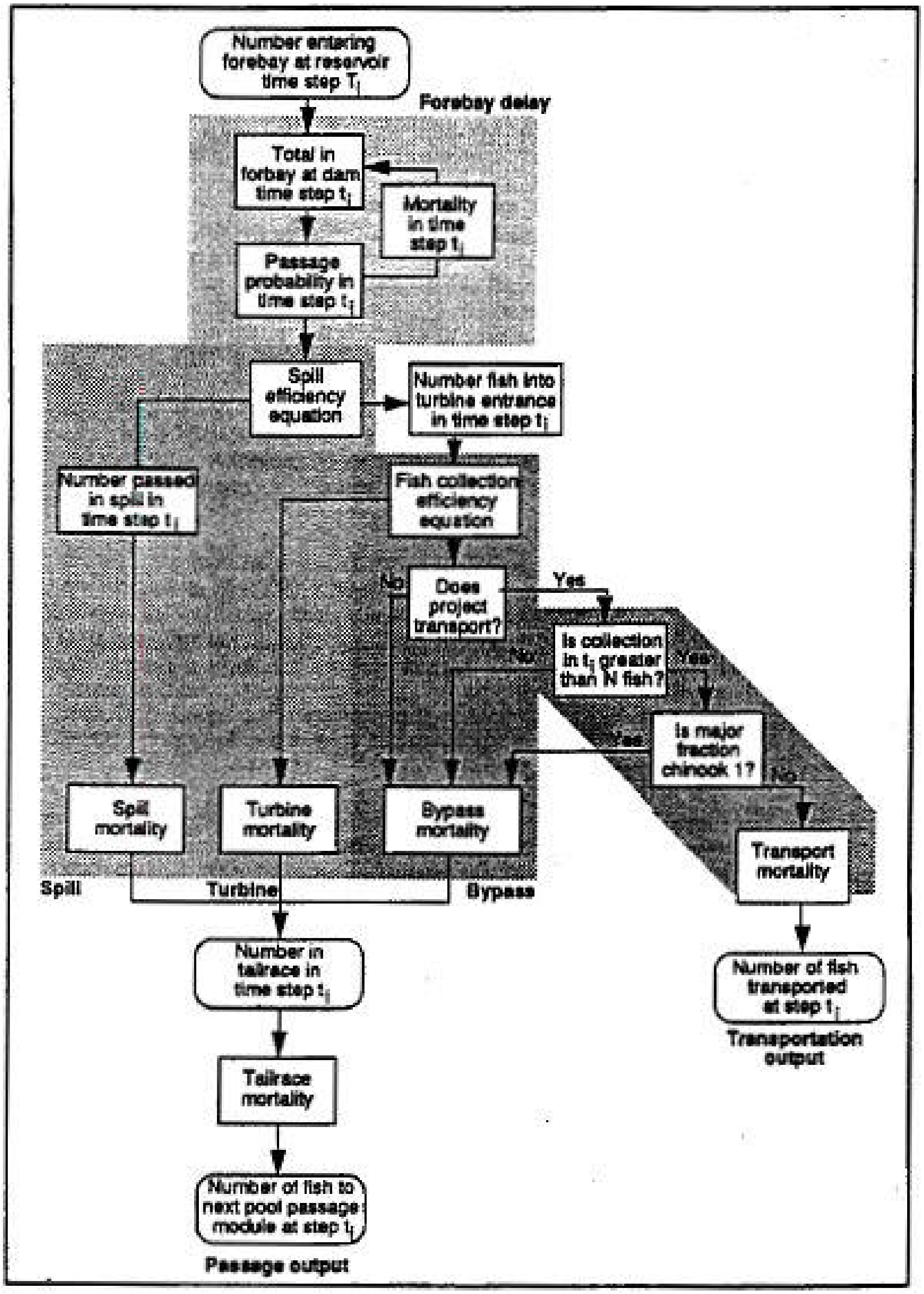

Figure 4-17. Dam Passage Module of CRiSP

FLUSH (Fish Leaving Under Several Hypotheses) models smolt survival during downstream passage. It depends primarily on an empirical relationship between reservoir travel time an flow, and on dam passage mortality rates derived from empirical studies. Different versions have been developed which incorporate different representations of reservoir mortality (FLUSH 3.2, Weber and Petrosky, 1992; FLUSH 4.0, Weber *et al.*, 1992). FLUSH 3.2 has been calibrated for, and applied to, the fall chinook smolt run in the Snake River; and FLUSH 4.0 is used to model downstream passage survival of spring and summer Snake River chinook. Inputs to the model include: 1) number and temporal distribution of smolts arriving at Lower Granite reservoir; 2) Snake River water flow rates (averaged over specific time periods); and 3) water temperature (FLUSH 3.2 only). Passage and survival through the system dams are evaluated in the FLUSH model using constants for survival rates at all dams, dam-specific values for FGE as coordinated from the standardized list of Fisher (1992), proportion of smolts through the spillway, and proportion of smolts transported.

PAM (McConnaha, 1992) is a spreadsheet model that utilizes hydraulic input data, powerhouse passage conditions, smolt transportation parameters, management of spill, and reservoir elevations to calculate the proportion of smolts successfully migrating downstream past Bonneville Dam. PAM uses the empirical Sims and Ossiander (1981) flow-versus-survival data to produce an estimate of mortality rate per mile as a function of flow. Flow, or water travel time, is derived from reservoir elevation, which is in turn derived from COE modeled backwater curves (HEC-2 model of the Waterways Experiment Station).

iii. Model Comparison - Downstream Passage Models

As discussed above, the distinctives which can be used to contrast the various models at a general level do not provide a clear basis for selecting any specific model. Each passage model contains some elements which are mechanistic, and elements which are empirical. Each model is based on some specific observations (data), and each is calibrated to reproduce historical observations. The key to evaluation of the various models is understanding the fundamental assumptions underlying each model approach, and how these may impact predictions made for conditions other than those under which the model has been developed and calibrated. Because the various models can give significantly different predictions of response to proposed operations (and especially reservoir drawdowns), such understanding is critical to the risk assessment process. Therefore, several comparative studies have tried to describe the model differences, evaluate model sensitivities, and determine causes of differing predictions (Barnthouse, 1993; SMCWG, 1993; ANCOOR, 1994; Barnthouse *et al.*, 1994).As these studies have progressed, a clearer picture of the fundamental differences between the models has begun to emerge. In this section, we review briefly the factors which are perceived to influence the success of various salmonid stocks in some fashion, and how each factor is treated in each model. Tables 4-8 to 4-10 provide tabular summaries of this review. Factors are discussed in terms of their potential impacts in each stage of the salmonid life cycle which is relevant to passage models:

Table 4-8
Factors Affecting Smolt Survival During Dam Passage And Their Treatment in Three Passage Models

Stage: Primary Factors	Dam Passage Secondary Factors	River Passage Model		
		CRiSP	FLUSH	PAM
Turbine Mortality	Guidance Efficiency	Drawn from broken-stick; can vary for day and night; project-dependent; can be age dependent	Specified constants project dependent	Specified constants project dependent
	Turbine Mortality	Drawn from broken-stick; can be project-dependent; 15% in SMCWG, 1993	Specified constants project dependent; 15% in SMCWG, 1993	Specified constants project dependent; 15% in SMCWG, 1993
Spillway Mortality	Spill Rate	Depend on river flow, power demands, and fish-related spill requests	Specified proportion or calculated to achieve specified fish passage	Depend on river flow, power demands, and specified spill caps
	Spill Mortality	Drawn from broken stick 0 to 7% (2% mean) in SMCWG, 1993	Specified constants; 2% in SMCWG, 1993	Specified constants; 2% in SMCWG, 1993
Bypass Mortality	Elevation	Can be drawn from broken stick; 2% constant in SMCWG, 1993	Specified constants - 2% in SMCWG, 1993	Specified constants - 2% in SMCWG, 1993
Tailrace and Forebay Predation	Predator concentration, smolt trauma and disorientation	Modeled similar to reservoir predation, but with increased rate constants to account for predator concentration	NDA1 - Assumed implicit in reservoir predation rates	NDA1 - Assumed implicit in reservoir predation rates
Cumulative Mortality	Nonfatal trauma leading to eventual death in combination	NDA1	NDA1	NDA1
Construction Impacts		NDA1	NDA1	NDA1
Changes in FGE and turbine efficiency		Changes in FGE may be addressed through depth-dependent FGE calculation; changes in turbine efficiency		

1NDA = Not directly addressed

Table 4-9
Factors Affecting Smolt Survival During Initiation of Migration
And Their Treatment in Three Passage Models

Stage: Primary Factors	Dam Passage Secondary Factors	River Passage Model		
		CRiSP	**FLUSH**	**PAM**
	Flow Rates	All factors are implicit		
Timing	Temperature			
Failure to Initiate	Entrapment Loss of anadromous instinct			
Migration in First	Flow rates in tributaries			

Table 4-10
Factors Affecting Smolt Survival During Reservoir Passage
And Their Treatment in Three Passage Models

Stage: Primary Factors	Dam Passage Secondary Factors	River Passage Model		
		CRiSP	**FLUSH**	**PAM**
Predation in Reservoir	Water velocity (Flow rate, reservoir elev.)	Water velocity increase toward centerline and with flow; affects fish migration velocity	Equivalent flow rate is the primary dependent variable	Equivalent flow rate is the primary dependent variable
	Predator density and behavior	Volume dependent; increases toward reservoir centerline	NDA1 - Assumed implicit	NDA1 - Assumed implicit
	Prey density and behavior	Fish behavior coefficient (age-dependent) mean and variance; location relative to centerline age-dependent	Dependence on smolt size above LGR only	NDA1 - Assumed implicit
	Availability of safe habitat	NDA1	NDA1	NDA1
Food Supply	Productivity in near-shore and riparian zones	NDA1	NDA1	NDA1
Disease	Turbidity	NDA1	NDA1	NDA1
Dissolved Gas	Explicit accounting	NDA1 - Assumed implicit	NDA1 - Assumed accounting	

1NDA = Not directly addressed

Initiation of migration. The beginning of downstream migration may be strongly correlated to in-river flow rates and water temperature, since it has been hypothesized that the migration instinct is initiated to some degree by spring freshet flows. In some cases, juvenile fish may either lose the anadromous instinct, or may be physically trapped, such that they do not migrate downstream and behave instead as resident fish (*e.g.*, kokanee). Migration from tributary spawning sites to the first reservoir pool in the Snake River system may be an important part of overall migration, but is not directly addressed in passage models. This aspect of downstream passage is, instead, handled through the distribution of fish (in terms of time and age/size) and river flow input to the models, and must, therefore, be specified prior to model execution.

Reservoir passage. It has been suggested that the most important factor determining success during reservoir passage is rates of in-reservoir mortality due to predation. This, in turn, has been viewed as being primarily a function of the amount of time juvenile salmon spend traversing the reservoir (travel time), which is influenced by water velocity through the reservoir. However, secondary factors which may also influence reservoir predation include predator activity (which depends on temperature), predator distribution, the availability of safe habitat near the edges of the reservoir in protected shallows, and the volume of the reservoir (which may impact predator and prey density). Travel time may also be influenced by the size and condition of migrating smolts, the degree of smoltification, and habitat preferences. For example, if smolts spend much time in shallow backwater areas of the reservoir, increasing flow velocities in the main channel will not significantly impact the fish travel times. Another factor that may influence passage survival is the availability of food, which could be influenced by fluctuations in reservoir level if such fluctuations were to disrupt the nutrient-productive riparian and near-shore zones. Food availability may also be impacted by water quality changes in the reservoir if those affect important links in the food chain. Fish in the reservoirs may be impacted by disease, which may be related, in turn, to water quality factors such as levels of dissolved gases and turbidity. These water quality factors are controlled to some degree by reservoir operations. Reservoir drawdown is expected to increase sediment load and turbidity because of increased erosion and instability of reservoir banks. Increased spill rates during drawdown may lead to elevated levels of dissolved gases, particularly in the upper reaches of the reservoirs.

CRiSP. Fish migration is described through an average downstream migration velocity which depends on the water flow velocity scaled by a fish behavior co-efficient (age- and species-dependent), and a variance in that average migration velocity which represents variability between individual fish. Water flow velocity depends on the location of the fish relative to the mid-channel (it is maximum at the mid-channel). As fish age, they are assumed to tend to move away from the shallow shore areas, and their downstream migration velocity therefore increases. Reservoir predation (expressed as mortality per unit time) is a function of predation activity (which is assumed to increase away from the shoreline and with temperature), and predator density (which is treated as a function of reservoir volume, and increases under drawdown scenarios). Fish migration behavior is incorporated through the age-dependent location of the fish relative to the mid-channel, which affects both the migration velocity and the predation activity.

FLUSH. Fish migration in FLUSH 3.2 is described through an empirical relationship between flow rates and travel time, which depends on smolt size. However, the smolt size dependence is limited to the reaches above Lower Granite Dam, thereby assuming that chinook are fully smolted and ready to migrate by the time they reach Lower Granite Dam. For all reservoirs, other than Lower Granite, fish travel time is an empirical function of water particle travel time. In FLUSH 4.0, fish travel time is an empirical function of water particle travel time. Reservoir predation (expressed as mortality per unit time) is a function of avian predation rates and piscivorous predation rates. Piscivore predation rate is modeled as a nonlinear function of water temperature and fish travel time through each reservoir using data from the John Day Reservoir (Beamesderfer *et al.*, 1990). A constant avian predation rate is applied to fish surviving dam passage if FLUSH 3.2, but is implicitly included in overall predation in FLUSH 4.0.

PAM. Reservoir predation (expressed as a fraction of migrants) is calculated for each reservoir from a direct empirical relationship between predation mortality and water travel time. The empirical relationship can be described by any of several types of curves. Three curves used in PAM are: 1) an exponential model which describes the relationship as a smoothly decreasing response with increasing flow; 2) a broken stick or spline model, in which a two step function produces diminishing mortality over a portion of the flow range, and no effect on mortality above a threshold flow; and 3) a polynomial model, which produces a decreasing mortality over a portion of the flow range and increasing mortality above a threshold flow. However, the polynomial in PAM is not allowed to produce an increase in mortality with increased flow, but is held constant. PAM does not explicitly incorporate any fish behavioral factors or effects of temperature on predation rates.

Dam Passage. Several possible in-river passage routes exist for smolts to move through dams: 1) specially designed juvenile fish bypass systems; 2) adult fish ladders; 3) spillways; 4) turbines; and 5) locks. In general, smolt passage through locks and adult passage facilities is considered insignificant. Collection and transportation by barge or truck are dealt with in a separate section. Each in-river dam passage route has associated mortality rates which may vary as a function of reservoir/dam operations, and the relative numbers of smolts using each route may also vary according to operations. The most important factors determining the fraction of fish following each route are rate of spill rate of powerhouse flow, FGE of turbine intake screens (which may vary as a function of powerhouse flow and reservoir level), and effectiveness of the design of fish passage systems. FGE may be impacted by changes in reservoir level, and would presumably decrease under drawdown configurations unless physical modifications were made. Fish passing through the turbines are subject to mortality rates which depend on the turbine efficiency (in turn impacted by powerhouse flow, and reservoir and tailrace elevations). Fish passing over the spillway are subject to mortality rates which depend on the rate of spill and spillway design. Fish passing through juvenile passage systems and/or adult fish ladders may be impacted by descaling at screens and other stresses, which can cause mortality or injury. All fish reaching the dam tailrace may be impacted by elevated levels of dissolved gases, which are, in turn, a function of rate of spill and spillway design. Finally, smolts may be impacted by enhanced predation rates due to concentration of predators in the tailrace and forebay areas and disorientation of smolts. Non-fatal injuries (such as descaling) may be cumulative. That is, they may eventually contribute to mortality at a downstream location. During dam modification under various operation scenarios, smolt passage may be impacted by construction operations.

CRiSP. Fish entering the forebay area are allocated to forebay predation, passage by spill, passage through the bypass facilities, collection and transportation, turbine passage, tailrace predation, and gas supersaturation mortality. Surviving fish continue into the next reservoir or estuary. Predation in the forebay and tailrace are modeled in a similar manner as reservoir predation, but the rate coefficients can be different to account for predator concentration in these areas. Spill rates depend on river flow rates, power demands, and requested fish-related spills. The fraction of fish spilled is modeled using one of several possible empirical relationships. A specified mortality rate is applied to spilled fish. Guidance of fish into dam bypass systems is modeled by an FGE which can be dependent on fish species, age, time (day or night), and dam configuration. FGE can be affected by drawdown through the relationship between screen depth and water surface elevation. A specified mortality rate is applied to bypassed fish, and some may be collected within the bypass system for transportation. Fish which are not spilled, transported, or bypassed must go through the turbines. A specified mortality rate is applied to fish passing through the turbines.

Although effects of nitrogen gas supersaturation on smolt behavior may impact predation rates, the model considers the two sources of mortality independently. An empirical relationship between gas supersaturation and mortality is employed, which uses a critical level of supersaturation below which mortality is zero, and a mortality coefficient which is species-dependent. This relationship is based primarily on laboratory experimental results, and does not account explicitly for depth-compensating fish behaviors which may reduce mortality. Nitrogen supersaturation can be computed using either empirical relationships between spill and supersaturation, or mechanistic relationships which account for physical processes involved in spill. Gas saturation is reduced over time through natural dissipation and mixing with other sources of less saturated water. The dam passage module of CRiSP is summarized in Figure 4-17.

FLUSH. Fish entering the forebay area are allocated to passage by spill, passage through bypass facilities, collection and transportation, and turbine passage. Surviving fish continue into the next reservoir or estuary. Forebay and tailrace predation mortalities are implicitly included in reservoir predation mortality estimates. The proportion of fish spilled is either a simple user-defined proportion, or can be based on a specified spill rate calculated to achieve a particular fish passage efficiency. In either case, spilled fish are subject to a constant specified rate of survival. Fish which are not spilled must pass through either the turbines or the fish bypass facilities. Guidance of fish into dam bypass systems is modeled by an FGE which is specified by the user for each project. Remaining fish pass through the turbines, and are subject to a specified turbine survival rate. Fish entering the bypass facility are subject to a specified bypass survival rate. Then they can be either collected for transportation, or passed into the next reservoir system. Nitrogen gas supersaturation effects are not explicitly considered in FLUSH. It is assumed that gas supersaturation can be controlled through imposition of spill caps, and that natural fish behavior (depth compensation) offsets gas supersaturation, such that it has a negligible effect on smolt mortality.

PAM. Fish entering the forebay area are allocated to passage by spill, passage through bypass facilities, collection and transportation and turbine passage. Surviving fish continue into the next reservoir or estuary. Forebay and tailrace predation mortalities are implicitly included in reservoir predation mortality estimates. PAM computes a daily spill for each project which depends on powerhouse capacity, in-river flow rate, a specified spillway cap, and a specified minimum fixed daily spill rate. It then allocates a proportional fraction of the fish currently in the forebay area to spill according to a fixed spill passage coefficient, and assumes a fixed spillway survival rate. Fish which are not spilled must pass through either the turbines or the fish bypass facilities. Guidance of fish into dam bypass systems is modeled by an FGE which is specified by the user for each project. Remaining fish pass through the turbines, and are subject to a specified survival rate. Fish entering the bypass facility are subject to a specified bypass mortality rate. Then they can be either collected for transportation, or passed into the next reservoir system. Nitrogen gas supersaturation effects are not explicitly considered in PAM. It is assumed that gas spersaturaturation can be controlled through imposition of spill caps, and that natural fish behavior (depth compensation) offsets gas supersaturation, such that it has a negligible effect on smolt mortality.

Mainstem passage. This report focuses on effects of various operation strategies of Snake River dams and reservoirs. However, smolts must also pass several dams in the mainstem Columbia River. Mainstem passage is influenced by many of the same issues discussed above (reservoir and dam passage). Operation of Snake River reservoirs will affect mainstem passage only through cumulative effects of smolt trauma (not addressed in models), smolt collection and transportation, and relative contribution of mainstem flow from the Snake River.

Estuary residence and passage. A controversial question is whether or not there exists a "biological window" of opportunity at the estuary in the salmonid life cycle. Such a window may involve physiological factors related to the timing of smolt adjustment from fresh to marine water conditions, as well as ecological factors such as food availability and predator density. If such a window exists, the survival of smolts in the estuary may be influenced by the timing of their arrival at the estuary, which in turn will be influenced by many factors in the river system, primarily rates of flow and fish migration through the system. River flow rates may also affect smolt survival in the estuary through their influence on water quality, food availability, and predation in the estuary and at the river mouth. These factors are not addressed directly in smolt passage models, although they may provide some motivation for decreased travel times through the reservoir system.

Transportation. A significant number of smolts may bypass one or more reservoirs and dams via smolt collection and transportation systems. Therefore, transportation can have significant impacts on smolt survival in many ways, although those impacts are not precisely defined. Smotls which are collected and transported are not subjected to mortality rates in any reservoirs or dams downstream of their collection point. However, there is a certain (typicall low, <5% rate) rate of mortality in the transport system (in the barge or truck, under conventional transport scenarios). Therefore, the apparent success of transportation (in terms of the smolt passage endpoint) depends on the relative rates of transport mortality to in-river migration mortality, and on the ratio of the number of transported fish to the number of in-river migrants. However, other factors may also be relevant; while survival ratios often measure only relative differences from collection to release points, transportation may have effects on other parts of the life cycle. For example, the ability of smolts to adapt to estuarine and eventually marine conditions may be impacted by transportation (adversely or positively). Also, it has been suggested that transportation may contribute to disorientation of fish upon their return as mature adults, and loss of homing ability.

The various passage models reflect fundamental differences in assumptions regarding the benefits of transportation. Return data have been studied to develop observed transportation benefit ratios (TBR's) that reflect the overall benefit of smolt transportation. While it is generally agreed that, in typical years, the TBR is greater than one, indicating that transportation has a beneficial effect, the way that information is used in calibration is quite different. CRiSP, which predicts relatively high in-river survival, assumes that the TBR simply reflects the difference between transport survival and in-river survival (*i.e.*, assumes no latent effects). For example, if transport survival (to the point of release below Bonneville Dam) is 0.95 and total in-river survival (past Bonneville) is 0.60, the apparent TBR is 0.95/0.6, or about 1.6. FLUSH, however, predicts lower in-river survival rates (say, for example, 0.2). Therefore, the apparent TBR (0.95/0.2 = 4.75) is too large when compared to available data. FLUSH accounts for this discrepancy by assuming that there are latent effects of transportation which cause mortality after the release of transported fish, not reflected in the raw transport survival fraction 0.95. Therefore, FLUSH adjusts the transport survival fraction downward such that the overall TBR is consistent with observations while maintaining low in-river survival. In our hypothetical example, where the target TBR is 1.6, FLUSH would use a transport survival rate of 0.32 (0.32/0.2 = 1.6), even though the apparent survival to the point of release is much larger. This reduction is assumed to reflect the latent effects of transportation.

iv. Comparative Summary - Passage Models

Factors Neglected by All Passage Models. Use of the passage models in a drawdown risk assessment is appropriate for the smolt-passage endpoint measure, but their use for adult escapement would require the assumptions that drawdown will have no effects on salmon stocks in the ocean, other than augmenting or decrementing their initial numbers, or an upstream migration of adults. The potential for drawdown to affect smolt survival below Bonneville, and the survival of smolts entering the Pacific Ocean, is real insofar as timing of the arrival at the estuary may affect the ecological conditions in the estuary as well as the physiological readiness of smolts for the transition to saline waters. This possibility is not directly evaluated in any of the models. Also, the various drawdown options may impact upstream migration of adults through impacts of construction activities, increased flow velocity in reservoirs and diminished effectiveness of adult passage facilities.

None of the models directly consider the potential effects of water quality changes other than temperature and gas supersaturation. One potential impact of drawdown may be increased sediment load and turbidity, which might have a negative impact on vitality and survival of fish.

All passage models neglect possible impacts of contingent mortality. Contingent mortality results from a concatenation of events that are not lethal when considered individually, but that act in concert to produce mortality. For example, smolt passage through turbine bypass systems and collection/transport systems causes both deaths and nonlethal injuries, including head and body damage and loss of scales. In a study of smolts collected from the Bonneville Dam bypass system at the first powerhouse, smolts with >10% descaling experienced an 18% mortality rate after 5 days versus 2% for all other smolts (Gessel *et al.*, 1987). Nonlethal injuries from dam passage may also increase susceptibility to predation. Screens may be expected to produce from 1 to 6% descaling; 10% descaled smolts have 10 times higher mortality rates in the reservoir than non-descaled fishes (Raymond, 1979). Passage through spillways and turbines may also produce descaling. It is obvious that the percentage of smolts with >10% descaling will increase as the number of dams passed increases. To account for such contingent histories, it would be necessary for the models to track subbasin specific stocks and accrue injury severity and probabilities at each stage of the model. Because the actual mechanism of mortality from dam passage (excluding predation) is usually injury, injury rather than mortality should be estimated and accrued over time on a population-specific basis. Probability of death would be commensurate with the severity of the injury, with death becoming certain above a certain threshold (Figure 4-18). Injuries may accrue or be repaired over time, resulting in a change in the injury probability distribution as injury events accumulate (Figure 4-18). Injury-causing events could be modeled as independent events, or may be more complex if correlations exist between injuries. Other sources of contingent mortality expressly excluded from the models include interactions between as-bubble state and predation in the tailrace. CRiSP models these as additive, and assumes that the result is conservative since predators preferentially attack already-weakened smolts. This assumption is valid only if smolts destined to die from gas-bubble trauma are eaten first. It is also possible that smolts suffering from non-fatal gas-bubble trauma are more likely to be preyed upon than smolts without gas-bubble trauma symptoms. This possibility has not been examined. Evidence in favor of this hypothesis includes the 12-fold greater prey consumption rate per predator found in the tailrace of John Day Dam relative to that in the reservoir (BPA, 1992a). The other models do not directly consider the impacts of gas-bubble disease, either direct or contingent.

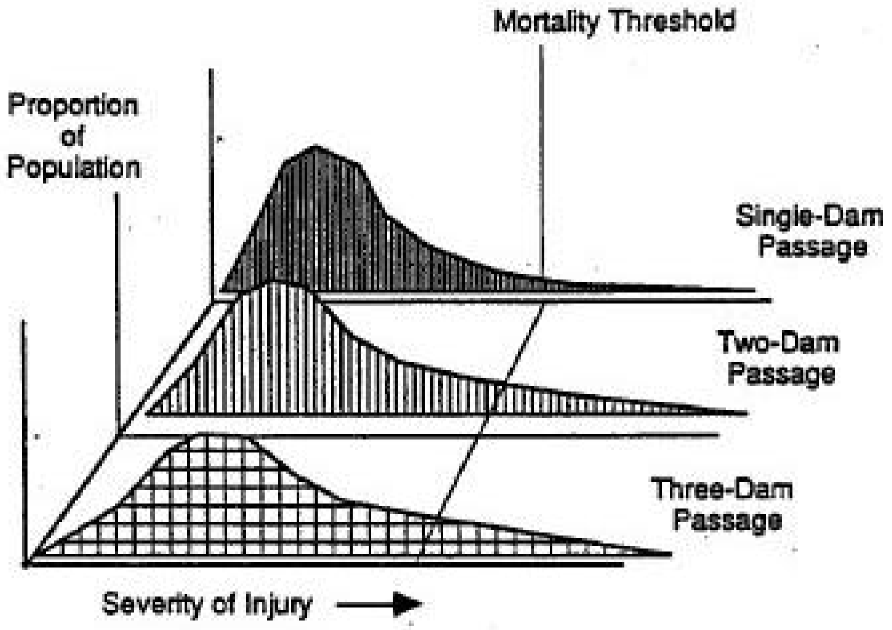

Figure 4-18. Hypothetical Relationship Between Probability of Injury and Sequential Dam Passage

All passage models neglect the potential effects of drawdown on the overall vitality of the reservoir ecosystem and any resulting impacts on smolts. In particular, yearling drawdown and refilling of reservoirs could affect survival of smolts through reduction in safe habitat (vegetation and shallows) and loss of food production capability.

None of the models account for potential changes in Fish Guidance Efficiencies (FGE) and turbine efficiencies, both of which may be altered under drawdown scenarios. In theory, the model parameters (FGE's and turbine mortality rates) could be adjusted to account for these changes. However, there is no means of determining (prior to drawdown) what the appropriate parameter changes might be.

Key Differences Among Passage Models. Differences among the three passage models reviewed here focus in three key arenas:

1) Flow/Survival Relationships

PAM and FLUSH rely heavily on empirical relationships between flow and reservoir mortality rates. These mortality rates are assumed to implicitly represent effects of several mechanisms including gas supersaturation, forebay and tailrace mortality, and smolt migration behavior, which are treated explicitly in CRiSP. Prediction of survival under conditions different than those under which data were collected and models were calibrated using a simple empirical approach can lead to failure of the models to account for significant changes in system structure. For example, PAM and FLUSH include forebay and tailrace predation in overall reservoir predation rates, which are modeled as primarily a function of flow. However, the rates of tailrace and forebay predictions are not driven by smolt residence time in the reservoir (a function of flow), but rather by concentration of predators in tailrace and forebay areas (not a function of flow). While the relationships used in PAM and FLUSH would indicate that tailrace and forebay predation decrease with increased flow under drawdown scenarios, in fact it is intuitively likely that most drawdown scenarios would not diminish (and may even increase) concentration of predator sin forebay and tailrace areas. Therefore, these portions of the overall predation mortality should be constant or possibly increase, rather than decrease. The only exception would be the Natural River option, under which there would no longer exist distinct tailrace and forebay areas. Similarly, changes in river operations may affect gas supersaturation rates in ways not adequately represented by implicit inclusion in a simplified flow/survival relationship.

Furthermore, the flow/survival relationships in PAM and FLUSH themselves rely heavily on data which are sparse and have been subject to strong criticism, specifically the data (and interpretation) of Sims and Ossiander (1981). Steward (1994) presents a critique of the methods, data, and assumptions underlying the flow/survival relationships. The data themselves are relatively few (seven data points for years 1973 to 1979) and sparse (one dam on the Snake and one dam on the Columbia, extrapolated to all dams). The experimental procedures used introduced potential uncertainty and errors, and likely underestimated survival rates, in part because of limited ability to resample marked fish. Unusual or changing conditions at the dams over the data collection period may have partially influenced the observed mortality rates. These changes included differences in debris accumulations between years, installation of spill deflectors to reduce gas supersaturation, and increases in fish guidance efficiencies. Finally, most of the apparent curvature in the relationship between flow and survival was caused by low observations of survival in two extreme low-flow years. Alternative interpretations of the data which would appear equally valid are:

- Mortality and flow are unrelated above some threshold low flow value, and that mortality increases with decreased flow only below that threshold;

- Changes in observed mortality rates were, although correlated to flow, not directly caused by changes in flow. Instead, they were caused by secondary factors such as trash accumulation which could be ameliorated by means other than increasing flow rates; or

- Changes in observed mortality rates were related to improvements in smolt guidance and passage systems at the dams over a period of several years (particularly if the 1970's data is combined with more recent information).

Accordingly, Steward (1994) recommended that the flow/survival relationship developed by Sims and Ossiander (1981), and implemented with some modifications in PAM and FLUSH, not be generalized to existing or proposed system conditions.

2) Treatment of Gas Supersaturation Effects

PAM and FLUSH do not explicitly quantify mortality due to nitrogen gas supersaturation, but instead assume that imposition of spill caps and natural fish behaviors will render the effects small or negligible. CRiSP does explicitly model gas supersaturation mortality, and the effects are important in overall survival predictions. While the effects of gas supersaturation on fish mortality and health have been studied in the laboratory, the corresponding effects under actual migration conditions may be different, and are not well quantified. Therefore, it is difficult to assess which model approach is most appropriate. Nevertheless, it is clear that this is a significant difference between the models, and tends to lead to enhanced estimates of benefits of drawdown and fish spill in PAM and FLUSH, and correspondingly diminished estimates in CRiSP.

3) Treatment of Transportation

The different means by which transportation is treated in the various passage models has been discussed above. It has been demonstrated (and is discussed below) that the passage model predictions are quite sensitive to assumptions regarding transportation, particularly in low-flow years. Again, there remains significant uncertainty regarding the actual benefit of transportation which needs resolution through further study, but it is clear that PAM and FLUSH results generally predict lower benefits of transportation relative to CRiSP, particularly when less optimistic assumptions are employed.

Adequacy for Risk Assessment. The various passage models reflect in their construction fundamental differences in assumptions among the various modeling teams (Barnthouse *et al.*, 1994). While all models agree that increasing water flow rates will generally reduce fish travel times, and accordingly reduce reservoir mortality, FLUSH and PAM treat this as the predominant factor affecting smolt survival. Conversely, CRiSP considers, in addition, many other possible factors, including gas supersaturation and fish migration behavior, and allows much more complex accounting of specific mechanisms. As a result, FLUSH and PAM can be expected a priori to treat the impacts of drawdown more favorably than CRiSP, since many of the factors which may offset the benefits of drawdown in CRiSP are not considered in PAM and FLUSH. It can, therefore, be argued that FLUSH and PAM, because of their basic assumptions, pre-specify that drawdown and spill will be beneficial, and do not adequately address the possible risks associated with these actions.

CRiSP, on the other hand, contains such a flexible and parameter-rich description of the river system that it can become difficult to objectively parameterize the model based on available information. One feature of complex, parameter-rich models which are subjected to calibration is that the solutions may be non-unique. That is, any number of possible model parameter combinations can give rise to the same overall predicted behavior, since there are so many interrelated factors which can be manipulated. Therefore, a good calibration (*i.e.*, good in terms of the model's ability to reproduce past observations) does not necessarily imply that subsequent future predictions will be accurate. It is necessary to somehow constrain the range of values that are possible for each parameter by specific observations, in order to reduce the problem of non-uniqueness. These activities are ongoing. For example, recent studies (Iwamoto *et al.*, 1994) have more tightly constrained overall smolt mortality rates at Lower Granite Reservoir, leading to reparameterization of the CRiSP model. It is also important that parameter sensitivity be evaluated, since model parameters are imperfectly known; sensitivity analysis is discussed in a following section. For these reasons, it is valuable to consider the passage models, and in particular CRiSP, more as a tool for testing various hypotheses, and for guiding study of a complex physical and biological system, than as a means of specifically predicting quantitative future response to system changes such as drawdown. Because CRiSP specifically incorporates some factors which may negatively impact survival under drawdown scenarios, it can be used to test the potential risks associated with specific actions. FLUSH and PAM, because they do not represent potentially negative effects, are restricted by their prior assumption that drawdown and spill will benefit fish populations, and cannot evaluate the potential sensitivity to that assumption.

An example of model use in hypothesis testing is the following. It has been stated (paraphrased from Barnthouse *et al.*, 1994) that the essential differences between CRiSP and FLUSH as they are currently being applied are captured in the following hypotheses:

- CRiSP - Survival of outmigrating smolts is high (whether transported or not), and marine survival is low. Declining marine survival is not a prior assumption, but is a result of calibration to a fixed total survival and assumed high in-river survival. In-river survival is dependent on flow, but also on many other factors which may offset the benefits of spill and drawdown.

- FLUSH - Survival of outmigrating smolts is low (whether transported or not), and marine survival is high. In-river survival is predominantly a function of water flow rates; offsetting factors are minor or non-existent.

Having identified these key model differences in philosophy, it may be possible to derive field studies and test which can evaluate the opposing hypotheses. For example, the response of key indicator stocks can be evaluated in light of the above hypotheses.

In summary, then, CRiSP is individually better suited to the purpose of risk assessment than PAM or FLUSH. This is not to say that PAM or FLUSH are necessarily inferior predictors of system behavior. Many individuals and groups are of the opinion that the assumptions and data on which these models are founded are sound and valid. However, in the context of a risk assessment, a model must allow consideration of the potential impacts of a wide variety of interrelated processes in terms of a range of possible outcomes of a future proposed action. CRiSP allows consideration and sensitivity testing of factors which may negatively impact smolt survival under drawdown configurations, whereas the other models implicitly assume those factors to be insignificant. FLUSH and PAM quantify one possible endpoint of possible system response, based on the assumptions that flow and survival are tightly linked and in-river survival is currently low. CRiSP provides an array of alternative possibilities, considering the potential for dispensating factors. While the models can be expected to give different predictions of the impacts of drawdown, taken jointly the define a wide range of possible outcomes that is useful in evaluating the potential risks and benefits of drawdown alternatives. Of course, any model must be used with the understanding that it is a simplified and imperfect representation of a complex system. All current passage models contain significant assumptions that require validation by further field study and hypothesis testing.

v. Model Overview - Life-Cycle Models

SCLM is a transition model that evaluates numbers of individuals surviving between states, such as number of smolts outmigrating versus the number of smolts reaching the ocean (figure 4-19). The numbers surviving between states are determined within the model by sampling from transition probabilities, which the model describes as being one of three distributions: the binomial, multinomial, and binomial-beta (Lee and Hyman, 1992). The binomial distribution is generated by a binary process in which the probability associated with the process is invariant. The binomial is approximated by the normal distribution when the number of cases (trials) becomes very large. Except for populations at very low densities, the normal distribution is probably sufficient. The multinomial is the generalization of the binomial when more than two outcomes are possible. This distribution is used specifically to generate probabilities for adult returns as harvested in-reach, subbasin escapement, or in-reach mortality. The bionomial-beta is a special case of the binomial in subbasin in which the binary probability is not constant. The net result in the many-sample case is a platykurtotic (wider) normal distribution. The SLCM incorporates three sources of uncertainty: variation among individuals, variation in parameters, and temporal variation in population structure and environmental conditions. Consequently, the outcome from a single simulation is of little interest; it does not necessarily indicate expected outcomes. Instead, the results from numerous simulations are used to define a probability distribution of outcomes. Alternatively, sequential (annual) results of series of simulations may be plotted against time to indicate potential time-courses of events. Although the SLCM has been termed a process model (Lee and Hyman, 1992), it is primarily an empirical model in which parameters for probability distributions are obtained from observation or approximations or else must be estimated using process models such as CRiSP (Lee and Hyman, 1992). The SLCSM is eminently suited to Monte Carlo simulations and risk analysis in that it relies on a minimum number of parameters; a weakness (as for all models reviewed here) lies in its failure to account for correlations between parameter values [*e.g.*, if mortality rates are high in the redd-to-smolt transition, they may be correspondingly lower (or as high) in the smolt-to-ocean transition]. The lack of information on correlations leads to uncertainties in assessment endpoints that are greater than would otherwise be the case. The SLCM does not account for subbasin- or project-specific effects specifically, but instead treats instream state variables and parameters as an aggregated average derived from smolt passage models. This constraint prevents the SLCM from being used as a standalone tool for evaluating systems operations risks. This limitation is tacitly acknowledged in that the CRiSP (or FLUSH or PAM) model must be used to generate smolt passage survival probabilities and coefficients of variation through the various subbasins and projects for each operations alternative (figure 4-20). However, there is no account made for project-specific or basin-specific effects on migration transitions or states for adult salmon, such as the ability of adults to locate fish ladder entrances under extreme flow conditions that would occur under drawdown. Where stocks, such as the Snake River sockeye, are limited in spawning to single subbasins, this limitation is less severe, but is still present. To overcome this limitation, subbasin state, variables must be defined where aggregate state variables exist in the present formulation of the SLCM, and between-subbasin transition probabilities must be incorporated and evaluated. The SLCM provides a necessary component of the overall risk assessment, in that it allows systems operations effects to be evaluated over time rather than as a set of passage runs without a system memory. Life-cycle models allow smolt output from a passage run to become and input to a subsequent passage run; consequently, the effects of the alternative may be examined over a specified time period.

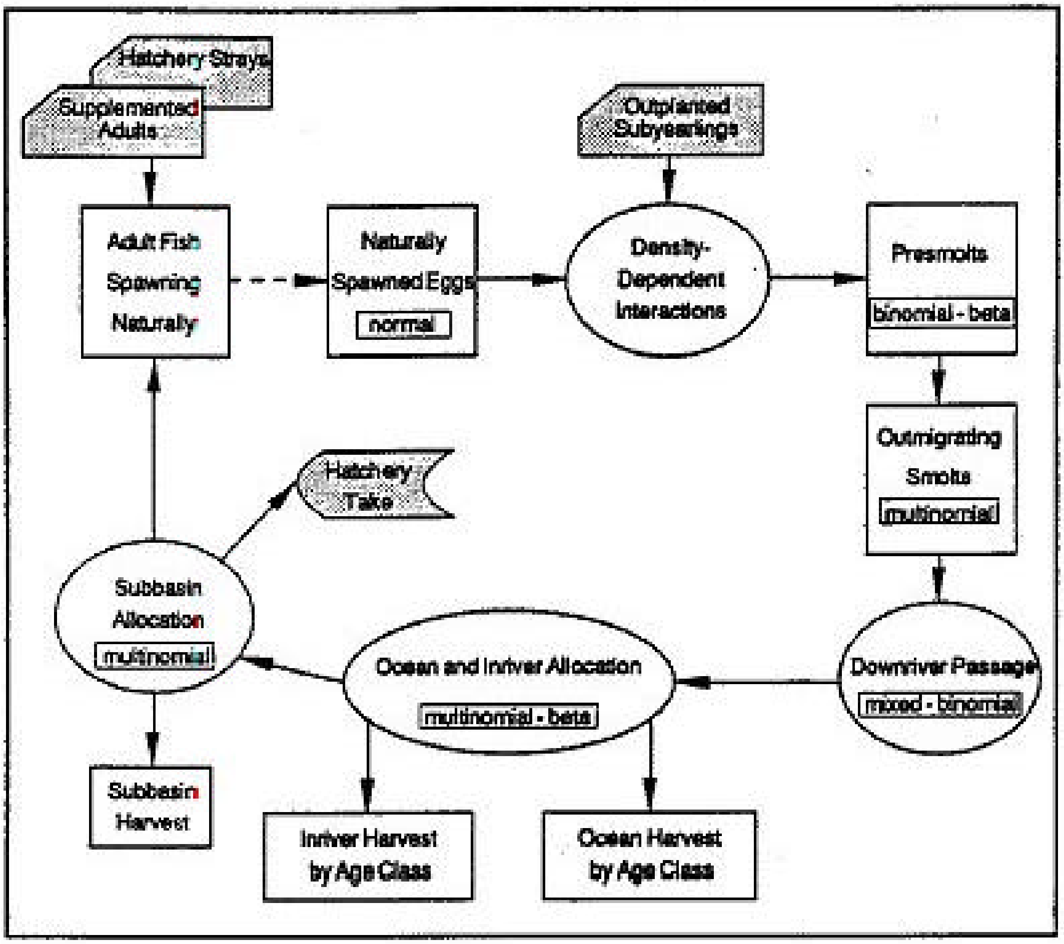

Figure 4-19. Flow Diagram for Naturally-Produced Smolts in the Stochastic Life-Cycle Model

The ELCM is an empirical model based on the Pacific Salmon Commission Chinook Model (PSC, 1989). The ELCM models numbers of fish moving between state variables much as does the SLCM, but relies on a modified historical time series approach to incorporate unknown but real sources of variations in to the model predictions. Initial stock productivity for fall chinook is estimated for years 1979 to 1990 (PSC, 1988). Transition probabilities are calibrated on the basis of past performance on the Hanford Reach for these years, yielding a series of year-specific survival probabilities (year interval), *e.g.*

s_{79-80}, s_{80-81}, s_{81-82}, *etc.*

These probabilities are then multiplied by a shear-specific scaling factor (year interval) to convert Hanford Reach survival to observed Snake River escapement, *e.g.*

$a_{79-80}s_{79-80}$, $a_{80-81}s_{79-80}$, $a_{81-82}s_{81-82}$, *etc.*

To simulate responses to future actions the time series of probabilities is again modified by computing a series of estimated juvenile responses to systems operations changes (byear interval), which are then multiplied by the corrected survival probabilities (above, yielding, *e.g.*

$b_{79\text{-}80}a_{79\text{-}80}s_{79\text{-}80}$, $b_{80\text{-}81}a_{80\text{-}81}s_{79\text{-}80}$, $b_{81\text{-}82}a_{81\text{-}82}s_{81\text{-}82}$, *etc*.

Simulations of responses are then performed using the 1981 to 1989 water year time series.

The ELCM is used in conjunction with FLUSH, which is used to derive the by weights (figure 4-20). Unknown sources of error in the ELCM include its reliance on the recent past as encompassing the rang eof variation in conditions to be expected in the future. The combinations of spatially-dependent causes that produced the flows and volumes in each water year are not likely to be repeated in the same temporal and spatial sequence in the future. Consequently, ELCM/FLUSH is not likely to encompass the range of conditions to be expected in the future. Such components are treated as independent random events in SLCM and CRiSP, although some degree of dependence among components is likely, total dependence would be unusual.

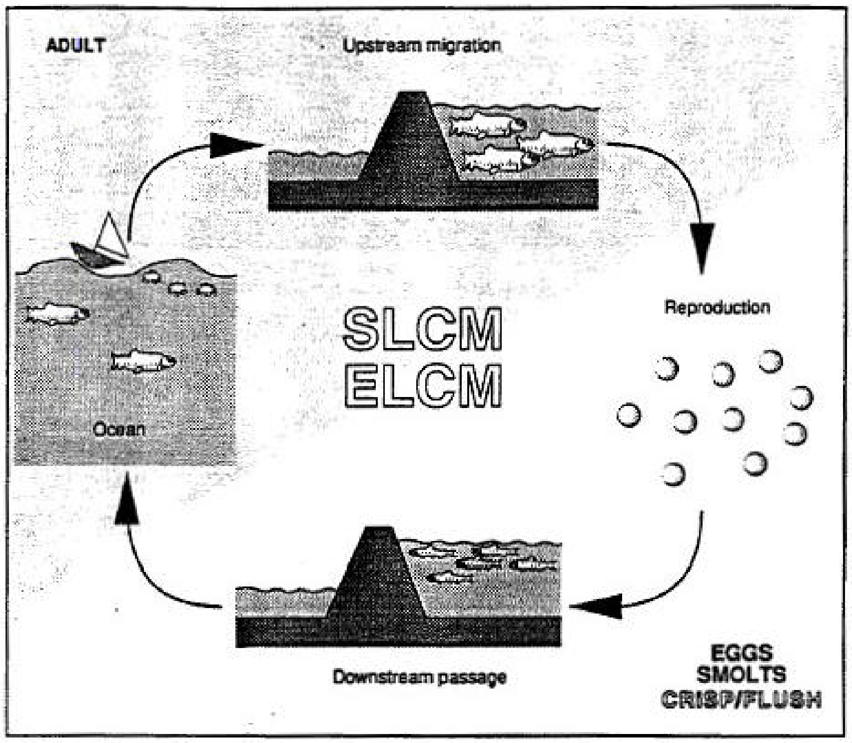

Figure 4-20. Use of Life-Cycle (SCLM and ELCM) in Conjunction with Smolt Passage Models (CRiSP and FLUSH)

SPM (MEG, 1992) is an empirical life-cycle model with stochastic variation in the estuary survival stage. It has three major modules: 1) tributary production modules; 2) mainstem passage module; and 2) adult survival and return module. A more detailed passage model such as PAM (or CRiSP or FLUSH) is typically used in lieu of the mainstem passage module.

vi. Model Comparison - Life-Cycle Models

In this section, we review briefly the factors which are perceived to influence success of anadromous salmonid stocks (in those stages which are relevant to the life-cycle models), and summarize how each factor is treated in each model. The models all start with a specified initial number of spawning adults, with a specified sex ration and fecundity, as input conditions.

Juvenile production.

The first step in a life-cycle model is estimating the number of spawned eggs. This depends on the availability of spawning habitat, number of returning spawners, ratio of male to female spawners (sex ratio), and number of eggs per female spawner (fecundity).

SLCM. The number of spawners is specified from the previous year's simulation results, or as an initial condition. The number of female spawners is generated from a binomial distribution parameterized by the total number of spawners and the probability of a given fish being female. This probability is specified during calibration. The number of eggs is generated from a normal distribution parameterized by the mean and standard deviation of number of eggs per female (multiplied by the number of female spawners).

ELCM incorporates egg production into an overall stock productivity function, modeled using a Ricker stock recruitment curve. This curve is parameterized by a fundamental stock productivity (estimated at 1.975 from Columbia River chinook data) and the number of spawners at replacement (estimated at 9,480 based on the number of spawners required to maintain the maximum sustainable yield of 3,430).

SPM accounts for habitat availability through a specified natural egg capacity. Number of returning spawners is provided from the previous year's simulation results, or as an initial condition. Sex ratio, fecundity, and natural egg capacity can be specified for each species and basin/subbasin.

Egg-to-Fry Stage

SLCM. The egg-to-fry stage includes the effects of density-dependence. The number of surviving pre-smolts are generated from a binomial-beta distribution parameterized by the number of eggs and the mean and coefficient of variation of egg-to-presmolt survival rates. The latter two parameters are generated based on a selected density-dependent stock recruitment function (such as Beverton-Holt or Ricker).

ELCM incorporate egg-to-fry survival into an overall stock productivity function, modeled using a Ricker stock recruitment curve, as discussed above.

SPM applies a simple function between number of eggs and an input egg-to-fry survival rat to determine the number of pre-smolts.

Fry-to-Smolt Stage

SLCM tracks up to four yearly classes of pre-smolts, with the number of pre-smolts remaining in a given year generated from a multinomial distribution parameterized by the number of pre-smolts in each class and a class-dependent probability of remaining in the pre-smolt stage for another year. The number of smolts in each class which stay are subjected to additional mortality and move into the next class of pre-smolts; the remainder begin downstream migration.

ELCM incorporates fry-to-smolt survival into an overall stock productivity function, modeled using a Ricker stock recruitment curve, as discussed above.

SPM models fry-to-smolt survival using the density-dependent Beverton-Holt production function to determining the number of in-basin surviving smolts. A simple survival rate is applied to in-basin smolts to generate the number of smolts migrating out of the subbasin. These numbers are used as input to the downstream passage model (typically PAM).

Downstream Passage Although some of the life-cycle models incorporate their own passage modules, it is common to use more detailed passage models (PAM, FLUSH, CRiSP) to generate downstream passage survival statistics or to directly compute the number of smolts surviving in a given year.

SLCM generates the number of smolts surviving downstream passage (to below Bonneville Dam) from a binomial-beta distribution, where the mean and coefficient of a variation of the survival probability are estimated from the results of executing a detailed passage model (typically CRiSP).

ELCM uses a detailed passage model (typically FLUSH) to estimate the passage survival rates and compute the number of fish entering the estuary.

SPM contains a mainstream passage module that can estimate passage mortality as a function of flow and other parameters. However, this module is typically replaced by survival rates estimated using PAM or another detailed passage model.

Spawning Recruitment. Ocean survival, various classes of harvest, upriver adult survival, and sub-basin allocation are treated in various levels of detail in the three models.

SLCM first generates the total number of smolts recovered as age-classed adults from a multinomial distribution with mean and coefficient of variation specified during calibration. These adults are then allocated to in-river and ocean harvest using a multinomial-beta distribution. Remaining recovered adults are allocated to the various subbasins through a multinomial distribution, with some subbasin harvest accounted for. Minimum targets for escapement and hatchery requirements can be specified, and take precedence over subbasin harvest, thereby loosely reflecting harvest management actions. Upriver migration mortality is not specifically modeled, but is implicitly included in the total adult recovery probability.

ELCM models age-specific exploitation and escapement using the PSC color analysis model, for Snake River fall chinook. The cohort size for each age class depends on the cohort size for the next younger class, escapement, ocean and terminal harvest, mortality due to commercial release of undersized fish, non-retention mortality, and the natural survival rate for each age class. These rates are estimated from a variety of data sources. For Snake River spring and summer chinook, a simplified approach is used since the age structure by return year can be estimated directly, and since limited ocean harvest does not warrant the use of a complex ocean management model.

SPM's Adult Survival and return module computes the final number of spawners, accounting for rates of harvest (ocean, estuary, in-river, and terminal), estuary, ocean and dam mortality, and pre-spawning mortality, through simple mortality rates which can be specified from available data and adjusted through calibration.

vii. Comparative Summary - Life-Cycle Models

Factors Neglected by All Life-Cycle Models. All of the life-cycle models employ a predominantly empirical approach with parameters describing survival rates or probabilities at each stage in the life cycle. These parameters are either estimated from available data or established through model calibration. Practically, parameter values are constrained using available data and adjusted within those constraints during calibration to match historical observations. Therefore, it is difficult for these models to adequately represent potential effects of modified river operations such as drawdown, since it is not known what the effects of the modified operations on the various stage transition probabilities will be. For example, changes in reservoir level may affect the ability of adult spawners to locate adult passage facility entrances, but no information is available on the magnitude of that potential impact since it is outside the rang eof conditions under which the models have been calibrated. Also, because of the limited range of conditions used in calibration, and since ocean and estuary survival are generally lumped, effects of river management (*i.e.*, flow rates and timing of smolt arrival) on estuary survival of outmigrating smolts cannot be accounted for.

Adequacy for Risk Assessment. Use of life-cycle models in an overall risk assessment of the impacts of drawdown alternatives requires the assumption that the effects of drawdown on life stages other than downstream passage are minor, and that the predominant effects of drawdown will be captured in the detailed passage models, which are to be linked to these life-cycle models. This restriction exists because the life-cycle models are calibrated to baseline conditions, and there are no means of objectively adjusting model parameters to directly account for the impacts of various management alternatives which are outside the rang eof calibration conditions. It would be possible to incorporate a range of values for transition probabilities based on professional judgment, thereby allowing the models to address possible drawdown effects on life stages other than downstream passage.

Step 4: Calibrate and Evaluate Sensitivity.

I. Model Calibration.

General Approach. The general approach to model calibration is the following:

1) Based on specific observations (for example, studies of turbine mortality rates), assign or constrain model parameters where possible.
2) Assign prior estimates for those parameters which are not directly estimable from data.
3) Execute the model with the estimated parameter values, and compare the predicted values of risk metrics (*e.g.*, adult escapements) to historical observations.
4) Adjust model parameters and repeat step 3 until the match between model results and historical observations is deemed adequately similar.

Issues. There are two key issues in calibration of predictive models for use in evaluating potential risks of operational alternatives. First, can the relationships which are derived to represent current and past conditions be extrapolated to future conditions, particularly if those future conditions are significantly outside the range of past conditions? This issue is particularly significant for models which emphasize empirical relationships with little mechanistic detail, since some mechanisms may be dormant under one set of conditions and active under another. For example, reservoir survival is calibrated to existing and past conditions, which raises some important questions with regard to future operational alternatives:

- Were there changes in conditions over time (such as general improvements in fish passage facilities, or unusual conditions in specific years) which bias or skew the data upon which the calibration is based?
- Will fundamental changes in the system response occur as a result of proposed alternatives (such as changes in efficiency and mortality associated with various bypass routes, hindrance to upstream migration, or disruption of food or habitat production) which cannot be captured in a relationship calibrated to current conditions?

- Second, are the model parameters determined through calibration actually representative of physical processes, or are they simply "tuning knobs" on a black box which can be manipulated to match observations in a variety of ways, depending on prior assumption? This issue is particularly significant for parameter-rich models, which allow great flexibility in calibration.
- Both issues point to the need for strategic gathering of information in a manner which will constrain key mechanisms and parameters as tightly as possible, and to the need for understanding the critical sensitivities of each model to underlying assumptions and parameterizations.

II. Sensitivity Analysis

One way to evaluate information needs is on the basis of their effects on the simulation endpoints. In general, for stochastic models, endpoint sensitivity is related to the degree of variance in the parameters, with less variable parameters holding the greatest sway over the model output. Also, parameters affecting later life stages hold greater sway than parameters affecting earlier life stages. Consequently, for life-cycle models, factors influencing adult returns to spawning grounds may be more important than factors influencing mortality on downstream migration of smolts.

Several studies of the sensitivity of model outputs to model parameter values have been performed for the downstream passage models. In this section, we review the conclusions of those studies.

Draft SOR 1992: Sensitivity analyses have been performed for spring and summer chinook using some of the passage models as part of the Columbia River System Operation Review (SOR) (BPA *et al.*, 1992). The models evaluated in this review were the CRiSP and PAM models. The FLUSH model was not evaluated, because it was still under development. The sensitivity analyses focused on downstream juvenile survival and travel time using spring chinook migrating downstream under summer flow conditions averaged for June and July at Priest Rapids and Lower Granite Dams, and the averaged mid-June through mid-August flows at The Dalles Dam. The sensitivity analyses were conducted by setting a baseline operation scenario with all parameters assigned the default or average values. Each parameter was then subsequently adjusted to a low or high setting while keeping the other parameters constant. The change in output was then recorded and parameters were ranked according to how much variation in output they produced. For the CRiSP model, the parameters with the greatest range of effects on smolt survival were related to gas supersaturation, predation activity in the reservoir, FGE, and turbine mortality. Of these parameters, predator density and activity, FGE, and turbine mortality are not known or estimable with little uncertainty under drawdown. Because of the high sensitivity of the model to these parameters, guesses as to their values during drawdown will introduce a potentially large and unquantified uncertainty in any estimates of survival obtained. Attention should be paid to quantifying these parameters under drawdown prior to estimating the effects of drawdown. For the PAM model, the factors with the greatest range of effects were flow and the relationship between predation and flow on the broken stick model. The effects on model output due to differences among the three predation/flow models (*i.e.*, exponential, polynomial, or broken stick) were small, due to the fact that flows for the baseline operation were within the range in which all three models produce the same output. A better test of the sensitivity of PAM to these predation/flow model alternatives would be to conduct the sensitivity runs under extreme flow conditions, rather than under baseline average conditions.

1993 CBFWA *et al.* FLUSH and PAM were used to evaluate the sensitivity of juvenile salmon survival estimates to eighteen operational scenarios. These scenarios were not necessarily intended to represent specific alternatives being considered for implementation, but instead were intended to provide general insight into impacts of a range of conditions on juvenile survival estimates. The scenarios fell into the following categories: 1) Base conditions with and without spill and transportation; 2) Base conditions with various flow augmentation and water budget assumptions; 3) Base conditions with various levels of predator control; 4) Drawdown test at Lower Granite with and without fish-related spill; 5) Drawdown to spillway at all Snake River reservoirs under various spill and transportation assumptions; 6) Drawdown to river level at all Snake River reservoirs with and without transportation; and 7) New upstream collector at Lewiston. Two transport assumptions (one more optimistic, the second less so) were tested. General results showed that the models considered (PAM and FLUSH) were most sensitive to the flow conditions and the transportation assumptions. Under the more optimistic transport assumption and at high flows, survival rates did not greatly change under the various scenarios. Predator control and drawdown scenarios increased survival at low flows, but did not greatly affect survival at high flows, under the optimistic transport assumption. Under the less optimistic transport assumption, the various scenarios had a greater impact on survival at both low and high flow rates. Survival estimates were actually increased from the base case at medium to high flow rates by eliminating transportation. Predator control increased survival estimates only slightly. Most drawdown scenarios provided significant improvement in survival estimates only under the less optimistic transportation assumption. The exception was the drawdown to river level (corresponding roughly to the Natural River Option), which increased survival estimates significantly, regardless of the transportation assumption used. Finally, the upstream collector led to the greatest overall improvement in survival estimates under the optimistic transportation assumption, but less improvement under the pessimistic transportation assumption. In all cases, except the drawdown to river level and upstream collector options, the maximum survival (under high flow and optimistic transport) was estimated at about 40%. The two exceptions led to maximum estimated survival of over 60%. The various options had greater impact on survivals at low flow rates, and under less optimistic transportation assumptions. Again, these results point out the strong sensitivity of FLUSH survival estimates to 1) flow; and 2) transportation assumptions. The authors note that they are "extremely sensitive" to these factors (page 10). This study did not vary survival rates through turbines, spillways, and passage facilities and, therefore, did not evaluate model sensitivity to these parameters.

1993 Workshop Proceedings: In 1993, a series of workshops of the Salmon Modeling Coordination Work Group were conducted. They provided overviews of three life-cycle models and three downstream passage models (with multiple versions of some models considered), and evaluated estimated spawning escapements and estimated downstream passage survival for a variety of hypothetical river operation scenarios. Again, these scenarios do not directly correspond to actual management alternatives, but are useful for general insight into model predictions of the impacts of various categories of actions. Separate comparisons were drawn for spring/summer chinook and fall chinook in the Snake River. Two reference scenarios were considered, based on the 1977 to 1988 flow sequence: 1) base case with no transportation, 10% spill, and FGE's from NMFS (1993) scenarios; and 2) base case with transportation with a variety of transport benefit ratios. In general, all passage models produced similar patterns of survival, although absolute survival percentages varied from model to model. All models predicted decreased survival at low flow and increased survival for more optimistic transport scenarios, but PAM and FLUSH results were more sensitive to these two conditions, leading to greatest differences between model predictions in very high and very low-flow years. Twenty-four alternative management scenarios were then analyzed for spring/summer chinook, and the downstream passage endpoint, with three transportation assumptions (none, optimistic, less optimistic), two predation assumptions (none, 25% reduction), two flow assumptions (actual flows, augmented flows), and two spill assumptions (fixed 10%, spill to achieve 80% FPE). Six of these scenarios were also modeled for the spawning recruitment endpoint, using a full life-cycle simulations. Twenty-four similar scenarios were modeled for fall chinook, with slightly different specification of the various assumptions. Again, six of these were subjected to full life-cycle analysis. Several general conclusions were drawn from the results of these simulations:

- FLUSH predicted largest changes from base survival in response to alternative management scenarios; CRiSP predicted smallest changes.
- Changes in estimated survival were greatest at low flows and diminished at high flows.
- Differences between the model predictions were greatest at low flows.

- FLUSH was most sensitive to flow and transportation assumptions, CRiSP was least sensitive.
- Flow augmentation increased estimated survival under all models, most in FLUSH, least in CRiSP.
- CRiSP was more sensitive to spill rates than PAM or FLUSH because of its direct incorporation of gas supersaturation mortality.
- Predation control increased estimated survival, but not as much as flow augmentation.
- Combined management actions led to general increases in survival estimates.

Other scientific reviews (*e.g.*, Barnthouse, 1993; Barnthouse *et al.*, 1994) support the general conclusions of these studies. In general, it is clear that the fundamental differences in the passage models give rise to different sensitivities to parametric representations and system configuration. The differences in predictions of future system behavior under drawdown scenarios are a direct result of these varying assumptions and model sensitivities.

- The sensitivity analyses point out several important gaps in existing data and information. Key areas of data needs are:
- validating of flow/survival relationships assumed by PAM and FLUSH,
- precise definition of various dam passage survival rates,
- in-river effects of gas supersaturation, and
- relative importance of reservoir morality versus dam mortality.

While the sensitivity of passage models to various assumptions, and the differences between these models, has been scrutinized, there has been relatively little study of the sensitivity of overall salmon survival to assumptions and parameterizations of life-cycle models. In general, the various life-cycle models (and in particular ELCM and SLCM) give similar results for given passage survival rates, and that downstream passage assumptions are predominantly responsible for the differences between CRiSP/SLCM and FLUSH/ELCM model predictions (Barnthouse *et al.*, 1994). However, the sensitivity of model predictions to parameters in the life-cycle models, and the potential impacts of system changes on these parameters are not well known. While this may not strongly impact assessment of risks due to a limited set of considered system modifications (*e.g*., drawdown configuration such as are considered here), the assumptions contained in the life-cycle models could significantly impact the perceived relative benefits of different approaches to restoration of salmon populations, such as spawning habitat restoration and protection versus improvement of passage survival versus ocean management.

Steps 5 and 6: Probabilistic Simulation/Compare to Baseline

I. Introduction

The fifth step in the process is to simulate each identified ecosystem element using the models identified in Step 3 with the parameterization and variable-probability distributional data collected in Step 4. Simulations have been run for several of the system operations alternatives. The result of this process should be presented (for the purpose of risk assessment) in terms of probability distributions for each risk metric under each systems alternative. In this section, we review and summarize the results of a number of comparative model studies which have been reported. For purpose of comparison, baseline model predictions (reflecting current operating conditions) are also included. Comparison of risk metrics between baseline and proposed scenarios provides quantitative estimates of the potential benefits/risks of the proposed alternatives.

II. Results of Specific Studies

Draft SOR 1992. An initial deterministic analysis of several drawdown alternatives was conducted during initial screening for the Systems Operation Review (SOR) (BPA *et al*., 1994), although the models were still under development to account for drawdown configurations. The analyses utilized the PAM and CRiSP models. No Monte Carlo runs were made, so the results are not complete in terms of the risk assessment. However, they do provide an indication of the average expected under the condition simulated, and under the assumptions of the two models (Table 7-3). Among the drawdown alternatives examined, the two most extreme were spilling the entire river at spillway crest (ANA-EM1) to drawing down the lower Snake River projects only while continuing to operate the turbines (AMG-DRAWC). Under these conditions, PAM and CRiSP produced quantitatively different results, although both models predicted enhanced survival of smolts through to below Bonneville Dam during extreme drawdown. Greater benefits were realized during low flows (1931 water year flows; upper portion of table 7-3) than the flows in the 1990 to 1991 water year (lower portion of table 7-3). PAM predicted much higher survival than did CRiSP over most of the system. PAM equated decreased travel time with increased survival, whereas CRiSP produced some increased survival due to decreased travel time that was offset by increased mortality from gas-bubble trauma and increased predator density due to the decrease in overall reservoir volume. Overall, PAM predicted an increase in survival of yearling chinook under all drawdown options. Under average water conditions, CRiSP.1 runs predicted a decrease in survival versus current baseline for most drawdown alternatives for the Lower Granite to below Bonneville and Wells to below Bonneville portions of the system. Both models predicted generally higher overall survival for salmon from below McNary to below Bonneville under average flow conditions. Predictions of survival from CRiSP.1 were similar to those from PAM for the sections of the river system below the Snake River dams. For those sections of the Snake where drawdown was implemented in the alternative, CRiSP.1 generally predicted lower survival than did PAM for the reasons outlined above.

1993 AFWG. The Anadromous Fish Working Group (AFWG) of the SOR selected three value measures (*i.e.*, risk metrics), and two flow conditions (critical and average), for determining impacts of the proposed operating strategies on salmonids: 1) average time (in days) that it takes for smolts to migrate downstream from their point of origin to below Bonneville Dam; 2) percentage of juveniles that survive from their point of origin to below Bonneville Dam; and 3) number of returning adults. For the first two value measures, the AFWG selected two juvenile passage models: PAM and CRiSP (version 1.4). SLCM was employed for the third value measure. Snake River indicator stocks evaluated by the CRiSP and SLCM models included natural Snake River spring chinook, natural Snake River summer chinook, natural Snake River fall chinook, and Dworshak Hatchery summer steelhead. Snake River stocks evaluated by PAM were spring chinook above Lower Granite Dam. Sockeye could not be modeled because measures of migrational characteristics (*e.g.*, dam passage parameters, travel time, and survival) were not available. Subyearling chinook (*e.g.*, Snake River fall chinook) could not be modeled using PAM since neither system nor reservoir survival estimates are available. However, the AFWG did model chinook using the mechanistically-based CRiSP model, since direct estimates of reach or reservoir survival are not required.

Model results indicated that travel times of all salmonid stocks would be decreased during drawdown, with greatest benefits (*i.e.*, shorter travel time) achieved under the Natural River Option (table 4-8). There was little apparent difference in benefits between the water conditions modeled. For example, predicted travel times decreased by about 10% under both average and critical water conditions. Travel time predictions also varied by model, with PAM indicating faster travel times for migrating spring chinook salmon than CRiSP. However, the relative amount of change in the predictions was consistent between the two passage models (AFWG, 1993). The four-pool drawdown scenario, with optimistic assumptions, increased in-river survival estimates over those produced for flow-control alternatives (AFWG, 1993). However, the four-pool drawdown did not increase survival estimates over flow-control alternatives with transportation. For all stocks except fall chinook, survival estimates for the Natural River Option were greater than for all other alternatives. Although the Natural River Option model conditions improved survival over current in-river conditions, it did not increase survival over current conditions with transportation.

The Stochastic Life Cycle Model (SLCM) was used to estimate the number of returning adults based upon the CRiSP juvenile survival rates calculated over the 50-year water record (AFWG, 1993). Flow-control alternatives that included transportation were able to increase the number of returning adults over that observed in the base level period for spring chinook and steelhead. However, none of the flow control alternatives were able to stop the downward trend in returning adults for Snake River summer and fall chinook. Four-pool drawdown with optimistic assumptions of juvenile migration characteristics for spring chinook was able to maintain a level of spawners equivalent to, or slightly above, those observed during the base period. This drawdown alternative resulted in decreased returns of adults for all other Snake River stocks. Lower Granite drawdown, including transportation at Lower Granite, had the greatest success of all drawdown alternatives and was the only alternative to result in greater adult returns than the current system with transportation. The Natural River Option was successful in exceeding the base period spawners for all Snake River stocks except fall chinook. However, it should be noted that SLCM predicted fewer than 10 fish returning to the spawning grounds without transportation (AFWG, 1993).

1993 ESA Section 7 Assessment. FLUSH and ELCM were employed in conjunction by the STFA Analytical Team to estimate the impacts of several management alternatives. Alternatives considered in addition to the base conditions (1990 SEIS) were operational configurations as specified by 1) BPA's Biological Assessment as approximated by the 1993 SEIS Alternative D; 2) the NMFS Operational sliding scale proposal; and 3) the CBFWA Detail Fishery Operating Plan (CBFWA, 1993). An amended version of the NMFS sliding scale option was considered briefly as well. A number of simulation runs were performed for each alternative, with different assumptions regarding transportation effectiveness, predation reductions, drawdown, and harvest. Five hundred (500) randomized flow sequences, each 28 years in length, were analyzed in terms of percent passage survival and adult escapement sequences; estimated passage survival was presented as a mean and standard deviation in percent. Two indicator stocks (Imnaha River and Marsh Creek) were considered in the life-cycle analyses.

Under the **base case scenario**, average FLUSH survival estimates ranged from 11 to 30%, depending on the transportation assumption used. Note, however, that the 30% survival estimate was based on a transport benefit ratio of 2.5:1, which was not used in any of the subsequent management alternative simulations; without this run, the maximum average survival was about 21%. Median base case escapements from ELCM were about 28% of MSP for both stocks. A "critical number of spawners" was (somewhat arbitrarily) defined as 200 (16% MSP for Imnaha and 23% MSP for Marsh Creek stocks). The estimated base escapements fell below this level in 30 to 50% of the simulations (depending on the stock and the time period considered).

For the **1994 Biological Assessment scenario,** average FLUSH survival estimates ranged from 11 to 33%. The highest survival was estimated for the optimistic transport assumption; predator control and Lower Granite drawdown led to only minor incremental improvements. Survival estimates were less variable (more stable from year to year) than for the base case, with standard deviations ranging from 3 to 6% (as compared to 6 to 9% in the base case). Estimated escapements improved somewhat over the base case, with median escapements near 41% of MSP for both stocks. The probability of dropping below the critical number of spawners decreased to 4 to 35%, depending on the stock, time period, and management option.

For the **NMFS sliding scale option,** FLUSH survival estimates ranged from 18 to 33%. Similar to the 1994 BA scenario, the highest survival was estimated for the optimistic transport assumption; predator control and Lower Granite drawdown led to only minor incremental improvements. Survival estimates were again more stable than the base case, with standard deviations ranging from 4 to 6%. The projected escapements were slightly higher than the 1994 BA scenario, with median escapements near 52% of MSP for both stocks. The Imnaha River stock dropped below the critical number of spawners in less than 2% of the runs, but the Marsh Creek stock escapements dropped below the critical number in 8 to 35% of the runs, depending on the management alternative and the time period considered.

For the **DFOP option,** FLUSH mean survival estimates ranged from 28 to 41%, with highest survival predicted for all Snake River reservoirs at spillway crest, and John Day drawn down to minimum operating pool. Under this scenario, the estimates were less sensitive to the transportation option, since estimated in-river survival was generally much higher than for other scenarios. Survival estimates were again less variable than the base case, with standard deviations ranging from 3 to 5%. Projected escapements were higher than the other options, with median escapements of 73% and 86% of MSP for the Imnaha River and Marsh Creek stocks, respectively, with drawdown of the Lower Granite pool only. For the simulated drawdown of all four pools, median escapements were 92% and 109% of MSP, respectively. The escapements dropped below critical level in 1 to 7% of the simulations, depending on the stock, time period, and predation control assumptions.

1995 Biological Opinion. FLUSH and ELCM were employed by the STFA Analytical Team to assess the impacts of three Federal Columbia River Power System (FCRPS) alternatives on five indicator stocks. The range of indicator stocks better represents the diversity within the Endangered Species Unit (ESU) than did the 1994 ESA Assessment described above. Three options considered were the 1995 Biological Opinion (BIOP) operating plan and two options of the DFOP (STFA Detailed Fisheries Operating Plan). Within each option, several cases were considered with differing assumptions regarding transportation, predation control, and depensation. The endpoints of the probabilistic analysis focused on the probability of achieving "recovery" (defined by the 8-year geometric mean escapement estimates exceeding a specific recovery escapement level) within specified timeframes, and on the probability of maintaining populations above threshold levels. Recovery level endpoints were defined as 50% of the 1962 to 1967 escapement levels. The geometric mean is biased toward low values relative to the standard arithmetic mean and, therefore, increases the influence of a single year of low escapement on the endpoint threshold. Endpoint thresholds were defined as 150 and 300 spawners for small and large populations, respectively. These thresholds were based on the Biological Requirements Work Group progress report (BRWG, 1994).

The **BIOP** alternative emphasizes transportation (two options) and includes no reservoir drawdown. Although surface collectors are considered in the BIOP, they were proposed late in the process and were not considered in these FLUSH simulations. For the BIOP, mean passage survival estimates ranged from 18 to 36%, and were more sensitive to the transportation assumption used. Probability of exceeding threshold endpoints in the near term (24 years) ranged from a low of 8% for the Sulphur Creek stock to a high of 83% for the Imnaha River stock, with some variability within each stock depending on specific modeling assumptions. Probability of exceeding the recovery endpoints ranged from 0% for the Sulphur Creek stock to a high of 73% for the Imnaha River stock, with significant variability within each stock as a function of transportation, predation, and depensation assumptions.

The first DFOP alternative (DFOP1) involves drawdown of all Snake River reservoirs to spillway crest and drawdown of John Day reservoir to MOP. It also specified flow augmentation targets, spill targets for 80% FPE, no transportation, and in-river migration improvements. Mean passage survival estimates under this option ranged from 38 to 44%, significantly higher than the BIOP results. Probability of exceeding threshold endpoints in the near term (24 years) range from a low of 17% for the Sulphur Creek stock to a high of 95% for the Imnaha River stock, with some variability within each stock depending on specific modeling assumptions. Variability was particularly large for the Sulphur Creek stock, for which threshold endpoints were exceeded in 17 to 78% of the simulations, depending on transport assumptions and depensation effects. Probability of exceeding the recovery endpoints ranged from 0% for the Sulphur Creek stock to a high of 100% for the Imnaha River stock, with significant variability within each stock as a function of transportation, predation, and depensation assumptions.

The second DFOP alternative (DFOP2) differs from the first primarily in that Snake River reservoirs would be drawn down to river level rather than spillway crest, and John Day reservoir would be drawn down to spillway crest rather than MOP. Mean passage survival estimates under this option ranged from 61 to 64%, significantly higher than either the BIOP or DFOPI results. Probability of exceeding threshold endpoints in the near term (24 years) ranged from a low of 46% for the Sulphur Creek stock to a high of 98% for the Imnaha River stock, with some variability within each stock depending on specific modeling assumptions. The lowest values occurred under optimistic transportation assumptions (since DFOP includes no transportation) and including depensation. Probability of exceeding the recovery endpoints was at least 83% for all stocks except Sulphur Creek; recovery of Sulphur Creek stocks ranged widely (3 to 75%), depending primarily on the transportation assumption.

g. Summary of Impacts to Anadromous Fish

Operation of Snake River reservoirs under the various drawdown scenarios can be expected to have potentially significant impacts on anadromous fish. These may be expected to be both beneficial (positive) and detrimental (negative), although the magnitude of the impacts of specific factors (and even whether they will positively or negatively impact anadromous fish) has not been precisely defined. Here, we summarize the expected impacts of drawdown on anadromous fish in a qualitative sense, and we summarize quantitative predictions (and uncertainties regarding those predictions) of the direction and magnitude of the impacts.

i. Perceived Beneficial Impacts

The various drawdown alternatives have been proposed specifically with the intention of facilitating the downstream migration of juvenile salmonids. It is expected that this will primarily be in the form of decreased travel time through reservoirs (because of increased water flow velocities), which is, in turn, expected to decrease reservoir predation rates. While it is generally agreed by all modeling teams that drawdown will decrease travel times, and accordingly decrease reservoir predation, the quantitative magnitude of that effect is disputed. Two widely used passage models (PAM and FLUSH) rely heavily on an assumption that water flow rate and smolt survival are tightly linked, based primarily on the survival data of Sims and Ossiander (1981). However, the validity of the underlying data, particularly under current or proposed operation conditions, is questionable (Steward, 1994). The other major passage model, CRiSP, employs a more mechanistic representation of the relationship between flow and fish migration. While it also predicts decreased travel times for smolts, the magnitude of the benefit is not as large as that predicted by PAM or FLUSH. Furthermore, CRiSP also employs empirical relationships describing fish migration behavior which are based on limited data or are parameterized during calibration, and these relationships are not yet well validated either. As a result, there is general consensus that drawdown will have a beneficial effect on smolt travel times, and resulting reservoir predation, but the magnitude of that effect is not well defined.

A secondary benefit of the drawdown scenarios is an increased fraction of fish passed through spill. Again, it is generally agreed that passage of fish via spill involves lower direct mortality rates than passage through turbines. However, the magnitude of the benefit of spilling fish is disputed. Two principal issues cloud the analysis: 1) would the spilled fish indeed have otherwise passed through the turbines, or are the increases in spill primarily due to spilling of fish which would have otherwise entered the bypass system?; and 2) do increases in spill cause increases in associated gas-bubble disease mortality? Because of the configurations of fish guidance screens, and the patterns of water flow in the dam forebay, increases in fish spill rates may not significantly reduce the number of fish passing through turbines, since spilled fish would tend to be those in the upper water column in the forebay, which would have been otherwise guided by screens into the bypass/collection system. This issue is not addressed well by the models, since fish guidance efficiencies and spill efficiencies have not been quantified under drawdown conditions. Gas-bubble mortality is also an issue of contention among the modeling groups. PAM and FLUSH modeling groups follow the assumptions that 1) gas-bubble morality is implicitly included in the Sims and Ossiander (1981) survival data; 2) imposition of spill caps can maintain dissolved nitrogen levels below acceptable limits; and 3) fish behaviors such as depth compensation will diminish the impacts of spill-induced dissolved gas levels. The CRiSP modeling team, conversely, assumes that laboratory-derived deep tank data regarding gas-bubble mortality is applicable to in-river migrants, and directly computes gas supersaturation mortalities which increase with higher levels of spill. There are indications that this approach may lead to overstimulation of actual gas supersaturation mortality, because in-river supersaturation levels are variable (not constant, as in the laboratory), and because fish behavior may compensate for supersaturation effects. Therefore, the benefits of increased fish spill and the impacts of spill during drawdown are currently disputed and ill-defined.

Effects of drawdown on dam mortality rates are not well known. However, in the Natural River Option case, downstream migrants will effectively bypass the dam, and dam mortality rates an be expected to decrease significantly.

ii. Perceived Detrimental Impacts

Species and life stages residing in shallow, nearshore habitats will be most susceptible to detrimental impacts of drawdown. Juvenile fall chinook that have emerged from redds downstream of the dams or smolts rearing in backwater embayments could get stranded during the initial drafting period. None of the current passage models are able to quantify this potential impact.

The spatial distribution of fish in the reservoir and forebay, and therefore the relative proportion of fish that pass a dam in the turbines, the spillway, or bypass, will change during drawdown. Decreases in forebay water level elevation may force a higher percentage of fish into lower depths, thus potentially increasing the number of fish passing through the turbines. Any fish passing through the turbines are also likely to experience a higher mortality rate than under current conditions because of lower head and reduced turbine efficiency. Therefore, it is expected that drawdown may lead to decreased FGE, and result in decreased survival in turbines. However, the magnitude of these decreases is unknown. Although the sensitivity of model predictions to these parameters could be tested, it would be difficult to identify actual parameter values to represent drawdown conditions. Direct modeling of changes in FGE's and turbine mortalities would require a much more mechanical representation of fluid flow patterns and fish behaviors than is currently possible; the alternative would require experimental studies under actual drawdown conditions to empirically determine parameter values. Many of the current model studies assume that physical changes in dam configurations would be implemented to offset these effects, but such changes cannot take place instantaneously, and typically require testing and modification over extended periods of time to achieve the optimal configurations.

Limiting impacts to adult upstream migrant salmonids during drawdown operations will depend largely on the success of new, lower-level fishway facilities. Spilling practices are likely to impact the ability of adult migrants to find and navigate the fishways, thus leading to migration delay. Drawdown may restrict the access of adult steelhead to tributary spawning grounds, and proposed construction activities could alter tailrace spawning areas presently used by fall chinook salmon. None of the life-cycle models are able to directly quantify these potential effects.

Drawdown will tend to concentrate the existing predators within a smaller volume of water through which salmonid outmigrants pass. However, drawdown will also increase the concentration of other prey fishes and not necessarily lead to higher predation on smolts. Smolts may also be more vulnerable to predators if they are restricted to pelagic, rather than littoral, zones during drawdown. PAM and FLUSH models do not account for changes in predator or prey density, and assume that fish behavior will compensate for changes in the predation regime. CRiSP does account for predator density, but does not directly account for fish behavior (such as the tendency of certain species to inhabit specific depths or zones of the reservoir), other than a general increase in predator density toward the reservoir centerline.

Drawdown may impact the general vitality of the ecosystem through periodic disruption of the littoral and nearshore environments (which are significant nutrient-production and habitat zones). However, the potential impacts on migrating salmonids are not well known, and have not been quantified.

The ability to collect and transport migrating smolts will be reduced under drawdown scenarios, although proposed enhancements such as collection curtains may offset or overcome this impact. Again, the impacts on fish survival are disputed. All of the passage models are highly sensitive to assumptions regarding the effectiveness of transportation, and those assumptions vary widely among various modeling teams.

iii. Conclusions

Drawdown is expected to result in decreased smolt travel time through the affected reservoirs. Decreased travel time is expected to increase survival of smolts through the reservoir mainly because of decreased contact with predators. All models agree qualitatively with these statements, but the magnitude of the predicted benefit varies significantly depending on model assumptions. If overall smolt survival is to be increased, passage mortality by other mechanisms must not be increased from current levels. Thus, smolt mortality during each route of dam passage (*i.e.*, bypass, turbine, and spill mortality) must not increased markedly during drawdown. Intuitively, the Natural River Option would 1) decrease travel time; and 2) decrease mortality from dam passage. The other drawdown alternatives may give rise to offsetting factors (including loss of transportation, increased gas supersaturation, decreased FGE, increased turbine mortality, decreased food and habitat availability, and negative impacts on adult migration), which could reduce the overall benefit to salmonid species. Models that assume these offsetting factors to be negligible predict significant positive benefits under drawdown scenarios. Models that directly incorporate some of these offsetting factors lead to diminished estimates of drawdown benefits and, in some cases, even overall negative impacts.

4. Resident Fish

The effects of various drawdown alternatives on resident fish will be dependent on species habitat preference, period and length of spawning, and location of rearing areas. The resident fish species most likely to be affected by drawdown include species that use the nearshore habitat for spawning, rearing, and adult feeding. Certain species use both nearshore and deepwater zones for rearing. Resident game fish currently using nearshore habitat include bluegill, pumpkinseed, sunfish, black and white crappie, smallmouth and largemouth bass, bullheads, and channel catfish.

The dewatering of shoreline areas during the spawning periods could have a significant negative impact on many resident fish species which rely to a large extent on these areas as critical habitat for survival. The existing impoundments, characterized by large, deep, slow-moving bodies of water, favor many of the introduced resident game fish now increasing and becoming firmly established in the four reservoirs. Resident fish least likely to be impacted by drawdown include species which prefer high flow rates and tend to inhabit mid-channel zones. These fish include the white sturgeon, mountain whitefish, bull trout, rainbow trout, northern squawfish, and chiselmouth.

The 1992 test drawdown of Lower Granite Reservoir provided an indication of impacts from lowered water levels on resident fish populations. Resident fish mortality associated with the March 1992 drawdown was estimated to be in excess of 35,000 game and non-game species. Most fish were stranded within the first 10 days of drawdown, when the pool was drawn down 23 feet (COE, 1993). Fish were typically trapped in embayments and off-channel pools, and were unable to follow receding water levels. Approximately 4,500 of the total mortality were game fish, and an additional 15,500 were mixed game and non-game species (Wik *et al.*, 1993). WDW personnel found over 15,000 dead fish during the drawdown, 67% of which were brown bullhead followed by crappie (13%). Because of the lack of personnel and coordination, estimates could not be verified. It was also not determined what percent of these numbers were juveniles or adults.

Although mortality figures from the test drawdown appear high, they may have bee insignificant relative to the total population of resident fish in the reservoir (Wik *et al.*, 1993). Additionally, many of them had little sport value. However, many more fish were probably not accounted for because they were either removed by predators or died in inaccessible areas. Additionally, impacts to the prey base or other ecosystem-level effects were not determined. Thus, the cumulative effects of stranding from annual drawdowns would be more severe than a one-time event.

a. Spawning and Rearing

Because most resident fish inhabiting the lower Snake River rely on the nearshore habitat for spawning, rearing, and feeding, the impact associated with these factors will depend on the period and extent of drawdown (figure 4-21). However, species could spawn during the stable low-flow period if suitable shallow-water habitat is present. The most severe impact pertaining to resident fish would occur under the extended (*i.e.*, 4.5-month) spillway crest drawdown alternative. Under this alternative, nearly all of the shallow-water habitat would be dewatered from 15 April to 15 August on all four reservoirs. Most resident fish spawning takes place during this time period. If drawdown is limited to MOP, stabilized water levels would tend to increase spawning success by keeping spawning areas from being dewatered. Little Goose Reservoir, with the most backwater and embankment habitats, would lose a greater percentage of these areas under the MOP alternative (Bennett *et al.*, 1992).

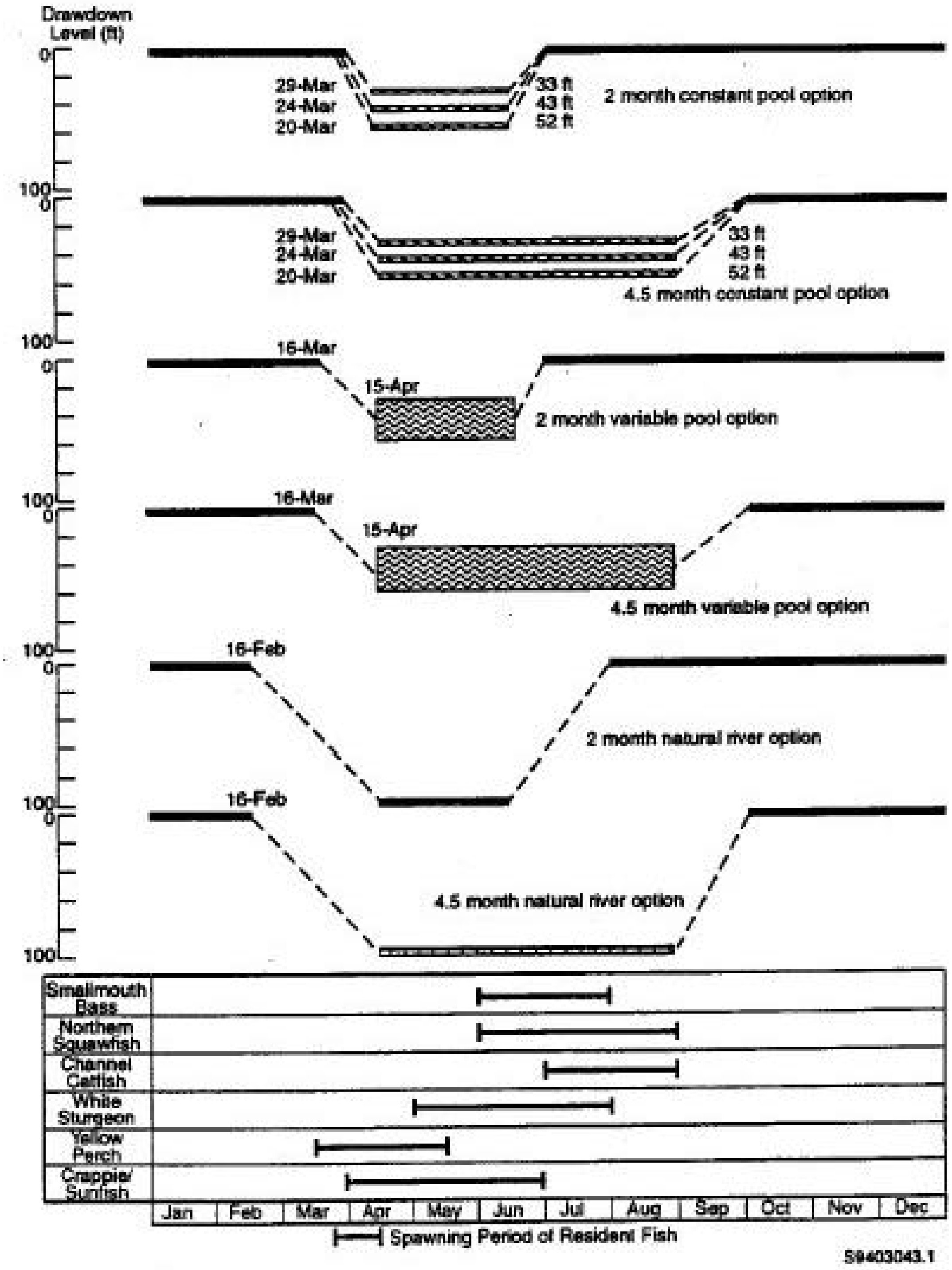

Figure 4-21. Visualization of Lower Granite Reservoir Drawdown Scenario Profiles In Relation to Critical Resident Fish Spawning Parameters

Of the four reservoirs, Little Goose appeared to be the most productive in terms of species diversity and species populations. The major sportfish established in the lower Snake River include the smallmouth bass, black and white crappies, channel catfish, yellow perch and sunfish (Bennett *et al.*, 1983). These species have similar spawning periods and habitat, and spawn in relatively shallow water (3 to 15 feet). Spawning is known to occur from June to July on low-gradient shorelines with sand or gravel substrate. Much of the preferred spawning habitat would be unavailable for utilization under the Natural River Option; although suitable spawning habitat may be available, the amount in terms of area would be less. Constant pool elevations (*i.e.*, MOP alternative) would be more beneficial than the variable pool option because shallow-water spawning habitat would be submerged over a longer period.

Crappies and sunfish prefer to spawn in the littoral zone near submerged vegetation from April to June. If spawning is initiated before drawdown, nests will become dewatered and dry up. Male sunfish and crappies which guard the nest during this period would be vulnerable to becoming stranded in pools and embayment areas.

Juvenile smallmouth bass utilize the nearshore riprap areas for rearing and protection from predators. Juvenile crappies and sunfish rear near shoreline habitats, feeding on insects and crustaceans (Bennett *et al.*, 1979). Hjort *et al.* (1981) found juvenile sunfish almost entirely in backwater areas of Lake Umatilla from June through September. Drawdown would impact rearing of these species by dewatering these important rearing areas. Predation on fry and yearling smallmouth bass could increase if emergent macrophytes and riprap was not available for cover and shelter.

Channel catfish, brown bullhead, and the yellow bullhead occur throughout the lower Snake River. Spawning for channel catfish has been reported from June through August in the lower Snake River. Suitable spawning habitat occurs, for the most part, near the shoreline in the littoral region of the reservoirs. Channel catfish would not be expected to be impacted by drawdown if spawning occurs after refill. In contrast, if the spawning period is near the end of the drawdown, refill would place nests in deep water and could reduce the viability of eggs. If spawning begins during drawdown, spawning habitat could be reduced and hatching success would be affected by increased velocities and sedimentation.

Brown bullhead spawn over an extended period, usually from May to September. Spawning habitat is similar to that of channel catfish. Rearing habitat includes the shallow-water zone for a short period, followed by dispersal to deeper water zones. Brown bullheads utilize embayment and shallow shoal habitats, feeding on plankton and midge larvae. Potential negative impacts of the 2-month drawdown to channel catfish and bullheads would be less severe than for spring spawners because they would be expected to spawn after reservoir refill. In addition, brown bullheads have the capacity to spawn again if their first attempt is unsuccessful (Bennett *et al.*, 1979). Potential negative impacts during the drawdown alternatives include loss of spawning habitat, loss of forage areas, and loss of prey items. Channel catfish are known to migrate to the base of dams in the spring to feed on outmigrating salmon. Drawdowns below a spillway crest could expose this species to prolonged elevated levels of supersaturated water, as a result of increased spill.

Yellow perch have become well established throughout the lower Snake River. The species is one of the most popular game fish in Little Goose Reservoir (Bennett *et al.*, 1983). Spawning occurs near rooted vegetation or near sand and gravel in mid-April to early May. Rearing takes place in the littoral zone, with fry feeding on zooplankton and insect larvae. If spawning is complete before rooted vegetation or near sand and gravel in mid-April to early May. Rearing takes place in the littoral zone, with fry feeding on zooplankton and insect larvae. If spawning is complete before drafting, there would be significant negative impacts to this species. Preferred habitat for fingerling yellow perch is clear water, near modest amounts of vegetation. Juvenile perch feed primarily on zooplankton in the shallow backwater regions of the reservoirs. These areas would not exist during the spillway crest or Natural River Option. Adult yellow perch are found in open-water zones of the reservoir, traveling in schools, and tend to prefer the dam forebay areas (Bennett *et al.*, 1979; Hjort *et al.*, 1981). The reduction of zooplankton production resulting from increased velocities and turbidity would severely impact the survivorship of juvenile yellow perch and decrease the feeding success of adult perch (COE, 1992b). During the March 1992 drawdown test, WDW counted 260 dead perch (Wik *et al.*, 1993).

Madtom tadpole and sculpins are numerous in Little Goose Reservoir. During the March 1992 drawdown test, adult sculpin and egg nests were found in recently dewatered shoreline areas of Little Goose Reservoir (Dauble and Geist, 1992). Most sculpin prefer cool, clear water with moderate-to-rapid current. They spawn in March and April in gravel and rocky bottoms. The male guards the nests until the eggs hatch. Sculpins are considered an important food item for salmonids and other warm-water fishes (Bennett *et al.*, 1983). The impact to these species will depend on the period and extent of drawdown. For example, sculpin that spawn during the drafting period would be highly vulnerable to stranding. Additionally, sculpin forced from riprap habitat into openwater areas would likely be subjected to greater predation. The 4.5-month versus 2-month period of drawdown would result in more severe impacts to these species.

Species that could benefit from drawdown include white sturgeon and mountain whitefish. Both species prefer swifter river sections and inhabit deepwater zones as well as shallow riffle areas. Increased water velocities could benefit sturgeon by providing more spawning habitat and helping to disperse their eggs. Both species have a wide and diverse forage base (Bennett *et al.*, 1983). During the experimental drawdown in March 1992, many mollusks (especially *Corbicula*) were found dead and drying out along mud, cobble, and riprap shoreline areas (Dauble and

Geist, 1992). Potential negative impacts to sturgeon would occur if there was a reduction of this important food item. Drawdown would not affect mountain whitefish spawning, since this species spawns in late fall and early winter (Bennett *et al.*, 1979). Late-hatching juvenile whitefish would be susceptible to dewatering since they would be utilizing the shallow riffle areas for feeding in early spring.

Other resident fish that may benefit from deep drawdown are members of the cyprinid family, including northern squawfish and redside shiner. Both species spawn in free-flowing waters (Bennett *et al.*, 1983). Northern squawfish and redside shiners are very numerous throughout the lower Snake River system. Northern squawfish could benefit from decreased competition for food items and from having food items confined to a smaller volume of water. Bennett *et al.* (1983) reported species having a high correlation to increased water velocity, including white sturgeon, chiselmouth, northern squawfish, and redside shiner. Hjort *et al.* (198) found that the distribution of bridgelip sucker, largescale sucker, and sculpin was positively correlated to current in Lake Umatilla.

Largescale and bridgelip sucker are the most abundant fish species throughout the entire lower Snake system, accounting for around 34% of the relative abundance (Bennett *et al.*, 1983). The impacts to adult largescale suckers from drawdown are expected to be less adverse than other fish species because of the high adaptability of this species. Adult largescale suckers have a diverse food base which changes throughout the year. Larval suckers have been observed utilizing the shallow-water nearshore areas, and are susceptible to becoming stranded during water-level fluctuations (Hjort *et al.*, 1981). Dauble and Geist (1992) found large numbers of juvenile catostomids stranded in shallow bays and nearshore habitats during the 1992 drawdown test. Larval bridgelip suckers are thought too be less vulnerable to stranding because this species spawn and rear in tributary streams away from the reservoir's influence (Hjort *et al.*, 1981). Adult bridgelip suckers feed mainly on periphyton and detritus during the summer. Reductions in cobble substrate and increased turbidities would reduce periphyton communities and, thus, provide fewer food items for bridgelip sucker.

b. Flow, Velocity, and Temperature Changes

Drawdown to spillway crest would significantly increase water velocities through a smaller water column. Increased water velocities may entrain juvenile resident fish, especially members of the centrarchid family, which prefer more lentic environments (COE, 1992b). Fish studied in Little Goose Reservoir that prefer more lentic environments include largemouth bass, black crappie, warmouth, and tadpole madtom (Bennett *et al.*, 1983). Entrainment could cause additional mortality if juvenile fish are exposed to high levels of supersaturated water during spilling.

Increased erosion and sloughing of the shoreline could adversely affect resident fish by depleting macrophyte beds, increasing sediment transport, depleting spawning areas, reducing benthic invertebrate populations, and increasing turbidities. Increased sedimentation associated with lowering of the reservoirs would severely impact the spawning success of smallmouth bass, white crappie, and pumpkinseed, which are susceptible to sedimentation of embayment areas (Bennett *et al.*, 1983). Species that are able to tolerate increased turbidities include the channel catfish and carp. Channel catfish have been known to inhabit muddy and turbid rivers and streams (Miller, 1966).

Important food sources for juvenile centrarchids, including zooplankton, are vulnerable to entrainment of the flushing action associated with reservoir drawdowns. Because productivity in the reservoir originates from the primary producers, including phytoplankton, extended drawdown periods may result in fewer food items available to juvenile fish during and after reservoir refill. Studies have found that zooplankton densities are reduced following drawdown of reservoirs. For example, May and Weaver (1987) reported up to 27% of the mean standing crop of zooplankton were sampled in the Flathead River below Hungry Horse Reservoir during deep drawdowns from May through December. They further reported that losses were greatest when the reservoir was not thermally stratified. The overall impacts to juvenile centrarchid growth rates will depend both on the periods fish will be utilizing this food group and the length of drawdown. Seasonal patterns of zooplankton abundance and factors affecting zooplankton densities are not well understood for lower Snake River reservoirs.

The impact of increased velocity on spawning success will depend on the type of habitat affected. Fish that tend to spawn in the upper reaches of the reservoirs will be more likely to be impacted by sedimentation and higher velocities. Velocities above 3 fps are considered unsuitable for successful precidae reproduction (McMahon *et al.*, 1984). Other species that would be affected by increasing water velocities during spawning include black and white crappie, pumpkinseed, bluegill, and brown bullhead (Bennett *et al.*, 1983). During the March drawdown test near Clarkston, the average velocity profiles increased from <1 fps at full pool to >5 fps during the drawdown. Velocities were generally greatest at mid-channel (Wik *et al.*, 1993).

Another important factor related to the 4.5-month drawdown is related to the potential for reduced water temperatures to occur as a result of late-summer flow augmentation at Dworshak Reservoir. Water temperature plays an important role in influencing the seasonal development of zooplankton production in reservoirs (Martin *et al.*, 1981). Losses of zooplankton from the system by the flushing action of drawdown has been shown to increase when the reservoirs are not thermally stratified (May and Weaver, 1987). Flow augmentation temperature models developed by the COE suggest water temperatures could become much cooler in Lower Granite and, to a lesser extent, in Little Goose during August and September. These lower temperatures could impact resident fish by limiting zooplankton production on which juvenile fish depend. Also, late-season spawners (*i.e.*, catfish and bullheads) may be impacted.

c. Summary

Resident fish species that use shallow-water habitat for spawning, rearing, and adult feeding (*e.g.*, smallmouth bass and channel catfish) will be affected by reservoir drawdown. Native species such as white sturgeon and northern squawfish prefer more lotic environments, and could benefit from increased flowing water habitat provided during drawdown. Although northern squawfish use shallow nearshore habitat for rearing, the increase in lotic habitat, preferred for spawning and adult habitat needs, could mitigate for loss of juvenile rearing habitat. Bennett *et al.* (1993) indicated that, at MOP, shallow-water habitat (0 to 15 feet) constitutes about 10% of the surface area of Lower Granite Reservoir, and that this habitat will be lost under drawdown. However, out GIS analysis of Lower Granite Reservoir indicate that the relative amount of shallow-water habitat (<8 feet) actually increased for the different drawdown scenarios. This shallow habitat is deemed important rearing habitat for smallmouth bass, northern squawfish, channel catfish, yearling chinook, and steelhead, as well as 0-age chinook. The substrate quality, or lack of, will be the limiting factor as to whether juvenile fish will utilize the "new" shallow habitat uncovered by drawdown. It is likely that must of this shallow water habitat has silt deposited from upstream areas. Thus, its value for spawning and/or rearing would be reduced.

Potential impacts of drawdown to resident fish will vary according to operating strategies. Expected impacts to major species of interest under various drawdown scenarios are summarized below.

Drawdown-General Impacts

- Available spawning habitat for white sturgeon will be higher for drawdown than under current conditions because of increased lotic habitat.
- Crayfish populations, which are a major food source for white sturgeon, smallmouth bass, and northern squawfish, will decrease because of stranding.
- Plankton will be entrained downstream, thus reducing food supply for juvenile centrarchids.

- Riprap habitat will not be available to smallmouth bass for rearing and cover, excepted where replaced near engineered embankments.

- Availability of less suitable nearshore habitat because of siltation effects.

- Predation on fry and yearling smallmouth bass could increase because of the lack of cover.

- All resident fish (young of year, YOY) and juveniles would be vulnerable to rapid lowering of water levels.

- Availability and complexity of specific habitat types will be altered for all resident fish YOY and juveniles.

- Physical flushing of YOY out of the reservoirs can be a serious problem with rapid drawdown.

- Nest-guarding species, such as channel catfish, sculpin, and smallmouth bass, will be vulnerable to stranding and desiccation if they spawn before drawdown.

- Resident catostomids and cyprinids (including northern squawfish) may benefit from an increase in potential spawning habitat formed by additional high-velocity habitat. This may result in additional recruitment of subyearling and offset the loss of rearing habitat.

2-Month Drawdown

- Smallmouth bass populations could be adversely affected.

- Smallmouth bass and channel catfish spawning success could be adversely affected if they were flooded off the nests during their spawning period. Depending on water temperatures, spawning could occur after drawdown refill with little or no adverse effect.

- For resident fish that have already spawned, stranding of fry and adults may occur because some species (*e.g.*, sculpin, channel catfish, and smallmouth bass) remain with their nests or fry for a period of time after hatching.

4.5-Month Drawdown

- Most species could still spawn during the stable low-flow period because suitable shallow water habitat could still be present.

- Extended drawdown may result in reducing the food items available to juvenile fish during and after reservoir refill.

- Zooplankton will likely decrease during an extended drawdown because less lentic area will be available during the productive season.

Constant Pool (maintains a constant pool level at the desired drawdown elevation, regardless of the river flow fluctuations):

- Constant pool would be more beneficial to smallmouth bass than variable pool because spawning habitat will be kept submerged over a longer period of time.
- Possible increase in the amount of production to the early-life-history stage, if elevations prior to and following spawning were held constant at 700 feet.
- The amount of deep-water habitat is reduced under this alternative from current operations. This may benefit white sturgeon because deep holes would be available for rearing and additional high-velocity habitat for spawning will be available.
- Because drawdown in this alternative is not as deep as the natural river option, severe impacts to the benthos and other food production components may not occur.
- Unavoidable impacts to northern squawfish and smallmouth bass will most likely occur under this alternative. Food production for these species may be reduced to some degree.

Variable Pool (once a specific drawdown level is reached, the pool is left to fluctuate around that level as river flow changes):

- Egg incubation success for smallmouth bass and channel catfish will be reduced substantially if the pool is fluctuated more than 2 to 3 feet during June and July.

Natural River (a free-flowing condition):

- Northern squawfish might benefit by having prey concentrated to a more confined water channel.
- The extreme (>115 foot) fluctuations on an annual basis would generally result in negative impacts to introduced resident fish in Lower Granite Reservoir.

Deleterious impacts to smallmouth bass would occur because of the rapid rise in pool elevations during the spawning period. Flooding of bass spawning nests would place already spawned eggs in over 100 feet of water, with little chance of successful egg incubation, or would force adult fish off the nests and prohibit spawning from occurring. This assessment also assumes that the substrate which exists at elevation 623 feet is suitable for spawning, and when the reservoir is refilled in September, a substantial change in the rearing environment will occur. This may strand YOY fry in deep, open water for a short period of time. If the YOY do not reorient to the rising water level, they will have difficulty finding food and might also be subjected to increased predation.

Increased water velocities and riverine habitat should benefit sturgeon and northern squawfish spawning.

Food production would be expected to decrease, primarily because of the loss of benthic production and crayfish, under reduced reservoir conditions. If the reservoir level were kept down, more riverine lotic type invertebrates may colonize and provide forage for the lost production from the dewatered benthos.

Current Operations

- Smallmouth bass populations will increase if water levels are kept stable during spawning and if favorable habitat is available in the nearshore riprap areas.

- Juvenile smallmouth bass use the near shore riprap areas for rearing and protection from predators, and they feed on benthic invertebrates and phytoplankton associated with this type of habitat structure.

- Impoundment has created favorable slackwater rearing environments for northern squawfish.

5. Terrestrial Resources

In general, impacts of the proposed alternatives would depend on timing and duration of drawdown, the extent of habitat removed or converted by construction, or the area affected by inundation or drawdown. Reductions in wildlife populations would occur as a result of direct mortality or indirectly through habitat loss or conversion. The effects to resources from implementation of any of the proposed alternatives could result from land bridging of islands, expansion of the drawdown zone, dewatering of riparian and wetland habitat, and reduced capacity for irrigation of Habitat Management Units (HMU's). Construction that would require excavation and disposal of fill material would also impact terrestrial resources. Drawdown would be most severe for run-of-river projects at spillway crest. Drawdown to MOP is not likely to affect projects where the proposed drawdown is within the lower limits of normal operating pool elevations. Fielder (1978) provides an assessment of impacts of both minimum and maximum water levels on wildlife within the Columbia and Snake Rivers, including waterfowl, upland game birds, big game, furbearers, colonial nesting birds, and fish. Impacts to fisheries resources are discussed within Section II. The minimum and maximum surface-water elevations and monthly surface-water fluctuations tolerable by wildlife in the lower Snake River projects are presented in Tables 4-11 and 4-12.

Table 4-11
Summary of Pertinent Project Data and Operating Limits

(Borrowed from Columbia River Basin - System Configuration Study.
Snake River Drawdown, Migratory Canal, Upstream Collector, Planning Aid Report, U.S. Fish and Wildlife Service)

Project	Elevation				
	Maximum Operating Pool	Upstream Minimum Operating Pool	Spillway Crest	Downstream Maximum Operating Pool	Minimum Operating Pool
Ice Harbor	440	437	391	346	340
Lower Monumental	540	537	483	442	439
Little Goose	638	633	581	541	538
Lower Granite	738	733	681	638	633

Table 4-12
Wetland and Riparian Habitats Along Lower Snake River Projects

(From COE, 1992)

	Scrub-Shrub	Habitat Forest Shrub	Emergent Wetland
Ice Harbor	50	98	15
Lower Monumental	126	84	87
Little Goose	123	131	9
Lower Granite	102	183	4

a. Habitat Changes

i. Terrestrial Habitat

Historically, upland habitat was typified by bluebunch wheatgrass and Idaho fescue. These areas, which have been degraded by overgrazing, are presently dominated by cheatgrass (Reed and Olney, 1994). A large percentage of project uplands are designated HMU's. These areas would be impacted by drawdown alternatives that limit existing pumping capabilities to the extent that irrigation is terminated (Reed and Olney, 1994). Resultant desiccation and heavy fuel loading may render vegetation susceptible to wildlife, due to the proximity of the railroad to most of these sites (Reed and Olney, 1994). Planting for wildlife crops would be discontinued that would subsequently impact upland species that are reliant on these sites for forage.

ii. Riparian Habitat

Woody riparian vegetation, including mesic shrub, totals approximately 1,006 acres along the lower Snake River projects (Reed and Olney, 1994). Local topography and unfavorable water regimes have limited the reproductive capability of riparian vegetation along the lower Snake River, where there is a distinct lack of tall trees.

In early seral development of riparian vegetation, plans that develop are tolerant of flow variations caused by natural flooding and dewatering. Although vegetation along the lower Snake River projects has developed in areas subject to daily fluctuations in surface-water elevation (*e.g.*, 3 to 5 feet), drawdown would be expected to affect riparian and emergent vegetation production. Rapid changes in flow may impact streamside habitat and the riparian community, the effect dependent on timing and length of the operational change. For example, a negative result could be realized if drawdown is timed with seedling dispersal, and seeds are distributed on dry substrates or on substrates that dry too rapidly, which would limit their viability. Conversely, drawdown could have an effect of enhancing vigor (Van der Valk and Davis, 1978a) that accommodates growth of competitively inferior or subdominant emergent and riparian species. This has been observed on the Hanford Reach of the Columbia River, where *Rorippa columbiae* is capable of persisting within a zone of extreme daily water level fluctuations (*i.e.*, 6 to 8 feet) (W.H. Rickard, PNL, personal communication).

Affects of drawdown could be augmented by site characteristics and age-related affects to vegetation. For example, soil permeability and drying time is dictated by soil substrate; and riparian vegetation in shallow soils would likely be less tolerant of effects of drought than vegetation in deeper soils (Walters *et al.*, 1980). However, in assessing net effects to individual plants, age-related characteristics of plants must be considered. For example, the USFWS (1992) observed that black cottonwood (*Populous deltoidei*), a shallow rooted species, improved under conditions of simulated groundwater drawdown of 0.4 cm/day when drawdown rates did not exceed average root growth.

Responses of species that are unable to persist and regenerate from seedbanks or rhizomes (Clayton, 1982) may include dormancy, destruction of the root system (Hosner and Boyce, 1962; Burrows and Carr, 1969; Williston, 1973) including decreased stem elongation, wilting, and chlorosis; or reduced capillary action of vegetation. It is speculated that reduced capillary action can hinder the colonization potential of vegetation. It is speculated that reduced capillary action can hinder the colonization potential of vegetation. Results of the March 1992 experimental drawdown would not support this conclusion and demonstrate that exposed gravel and mud substrates, between the ordinary high water line and minimum operating pool, were colonized by 156 species (Phillips, 1992). During March through July observations, Phillips (1992) also observed a notable change in species composition, but it was not demonstrated that the change in vegetative composition of the shoreline was not based on the species' annual productive cycle.

Drawdown may further affect riparian habitat by favoring production of undesirable or weed species, thus reducing habitat quality. Evidence suggests that reservoir drawdown zones are avenues for dispersal of weeds, and that drawdown may contribute to the spread of noxious weeds which outcompete native vegetation (Ebasco, 1992). In the northern Flathead Valley, *Butomus* spp. has a wide tolerance for water-level fluctuations and is an agressive colonizer. Although *Butomus* spp. is considered a favorable species for wildlife (*e.g.*, waterfowl), its character as a pioneer may serve to displace *Scirpus* and *Sparganium* spp. in a manner similar to that of a noxious invader (BPA, 1987). The experimental drawdown conducted during March 1992 accommodated establishment of indigo bush (*Amorpha fruticosa*), a Washington State Class B noxious weed; Russian thistle (*Salsoila kali*), which is not listed as a noxious weed in Washington; and reed canarygrass (*Phalaris arundinacea*), also not listed as a noxious weed in Washington downward of the ordinary high water line (Phillips, 1992).

Revegetation of exposed mudflats and gravel bars could potentially alleviate effects of invasion by noxious species. In areas exposed by the March 1992 experimental drawdown, shoreline vegetation (*e.g., Carex obnupta, Eleocharis* spp., *C. aperta, Scirpus* spp., *Deschampsia* spp.) that was transplanted to the site has become established (Phillips, 1992). Although it is expected that effects of drawdown would be exacerbated in riparian habitat during a drought year, results of the 1992 experimental drawdown, conducted during the hot and dry spring and summer, did not demonstrate affects of water deprivation (*e.g.*, leaves drying, curling, shriveling) (Phillips, 1992).

iii. Emergent Wetland

Wetland habitats is limited along the lower Snake River, and effects of drawdown would likely be similar to those discussed for riparian habitat. Effects to emergent and wetland habitat must be considered up- and downstream of each project. The Lower Monumental Reservoir supports the most extensive wetland community of any of the lower Snake River projects (*i.e.*, 87 acres). Therefore, the effects of drawdown would likely have the most significant impacts along this reach.

Water level fluctuations can favor regeneration of emergent wetland species; but species success is dependent on the frequency and intensity of water level change. The primary effect of drawdown downstream of each project would likely result from interruption of the hydrologic connection to the main channel. Groundwater flows that maintain suitable growing conditions outside the main river channel would be interrupted and result in reduced systems function (Kadlec, 1962). Rate of groundwater loss would further be affected by soil permeability, which would dictate the rate at which standing and nearsurface water was lost in wetland habitat. Fluctuations in surface water elevation in slackwaters may temporarily reduce emergent and submergent vegetation by altering habitat through erosion, desiccation, or siltation. However, water level fluctuations that enhance fragmentation and dispersal may have a positive effect on plant distribution (Clayton, 1982). In an analysis of water level fluctuation and affects on wetland communities in Lake Champlain, Countryman (1977) observed significant changes in all wetland communities between 29.0 and 30.0 meters, with effects noted initially for the grass/sedge component followed by a loss of emergents and riparian forest species.

iv. Submergent Habitat

In analyses of water level fluctuation in regulated systems. Wilcox and Meeker (1991) observed that extremes in disturbances (*e.g.*, high and low) or improperly timed disturbance, can result in reduced structural diversity of submergent vegetation. For example, in a system that was subject only to natural fluctuations in water level, plant species of diversity decreased when water level fluctuations were further minimized (Wilcox and Meeker, 1991). Further, in a system where winter water level fluctuations were increased, mat-forming submergent species dominated the drawdown zone.

Submergent habitat has not been quantified for the lower Snake River projects, but is assumed to be limited, correlated with the occurrence of shallow water habitat. Drawdown to MOP could increase submergent habitat as stable surface water elevations may enhance plant survival. Drawdown below MOP would effectively eliminate submergent habitat (BPA, 1994).

b. Wildlife

i. Waterfowl

Potential impacts to waterfowl nesting in the lower Snake River include 1) reduction in nesting habitat of inundation of nests during the breeding season; 2) increased rates of predation due to land bridging; and 3) decreased forage (*e.g.*, benthic invertebrates) in shallow-water areas (Cooke, 1980). In addition, water-level fluctuations an affect brood success through decreases in food availability or increases in energy demand caused by increased travel between feeding areas and cover. In the northern Flathead Valley, where reservoir drawdown coincided with nesting and brood rearing (late March through May), many habitats that were suitable for duck nesting were replaced by seasonally flooded mudflats and cattail stands that provide poor-quality duck nesting habitat (BPA, 1987). During the March 1992 experimental drawdown on the lower Snake River, loss of goose nesting habitat as a result of drawdown resulted in displacement of individuals to open-water areas distant from the drawdown zone. Displacement subsequently delayed nesting for individuals from both of these populations (BPA, 1987; COE, 1992a).

Loss of habitat is also realized when drawdown renders goose nesting structures ineffective. During the March 1992 experimental drawdown on the lower Snake River, goose nesting structures were dewatered and rendered useless to geese for nesting (COE, 1992b). In the northern Flathead Valley, loss of island and marsh nesting habitats increased the importance of these elevated nest structures. Many of the elevated nests that were occupied by displaced individuals were formerly occupied by osprey, bald eagles, or great blue herons (BPA, 1987).

Similar effects to ground nesters resultant from habitat loss or predation, realized as ground nesting that was initiated between 12 March and 2 May (peak 21 March to 15 April), coincide with power peaking drawdown (BPA, 1987). Results of 1984 and 1985 analyses of Canada goose loss in the northern Flathead Valley dictate current water-level management (*e.g.* up to 8-foot daily fluctuations) between the beginning of nest initiation and the end of hatching. Operational strategies are designed to protect goose nesting habitat and elude mammalian predators by supplementing flows (*e.g.*, maintain elevated surface water) early in the nesting period (BPA, 1987).

Fluctuating water levels and resultant land bridging in the lower Snake River (COE, 1992a) are primary causes of increased predation and nest failure. In the northern Flathead Valley, 64% of nest attempts during 1984 failed because of land bridging and subsequent predation. None of the sites that failed due to predation were used again in subsequent years (BPA, 1987). Although land bridging occurred at the Little Goose and Lower Granite pools during the March 1992 experimental drawdown, increased predation was not observed (COE, 1992b). It should be noted, however, that areas which were historically used by waterfowl during normal operations were used less frequently (COE, 1992a), and land bridges were exposed.

Operation of the system at MOP may encourage development of riparian vegetation providing nesting cover for Canada geese (BPA, 1994). Goose nesting along the shorelines is infrequent, but operation of the system at MOP may encourage nesting in the future (BPA, 1994). Vegetative growth within the drawdown may benefit brooding Canada geese, but operation at MOP may result in increased predation on goose broods because of increased distances between foraging areas and open water and land bridging (Reed and Olney, 1994). The USFWS (Unpublished data) concluded that predator access to island increases if water depth is less than 1.5 feet. Therefore, the range of effects would increase potential for land bridging at MOP on six islands in Lower Granite, and two each in Ice Harbor, Little Goose, and Lower Monumental (COE, 1992b). The Natural River Option would impart an affect on all islands within the project.

Effects to wintering Canada geese on the lower Snake River should be negligible since geese forage primarily within agricultural fields adjoining the project reservoirs (COE, 1976). Drawdown that increases the distance of shoreline vegetation to water may subsequently impact waterfowl foraging habitat. In addition to increased distance of shoreline vegetation to water, desiccation of backwater ponds as a result of drawdown will affect production of emergent vegetation and limit distribution of benthic invertebrates in exposed sediments. One benefit may result from stable pool elevations that could accommodate production of submerged aquatic vegetation used by mallards. Reduction in invertebrate availability can lead to termination of renesting, no nesting, reduced clutch size, or can affect timing of sexual maturation. Renesting species are reliant on high protein diets, and if invertebrate populations are affected by drawdown in areas where predation or nest destruction is high, duck nest attempts and/or success likely will be reduced.

In studies of areas characterized as deficient in moisture with unstable water levels, Swanson and Meyer (1977) concluded that the aquatic biota continually adjusted to changing water levels. During spring and early summer, wetlands were characterized by low water and seasonal wetlands dried. Although the amount of available surface water within the wetland was reduced and the species of invertebrates present varied, the proportion of animal food in the diet remained similar to that found during wetter years. Water conditions do, however, reflect major changes in the abundance and availability of species within temporary wetlands (Swanson and Meyer, 1977), and can be used as an indicator of waterfowl diet composition.

Although waterfowl adapt their diets to changes in invertebrate species composition, temporary losses of invertebrates in shallow feeding zones affect waterfowl ecology to a greater extent than an overall loss of seasonal water and associated invertebrate fauna. When sustained drawdown occurs (*i.e.*, >2 days), aquatic invertebrates are eliminated or greatly reduced in shallow nearshore areas and feeding conditions for breeding waterfowl deteriorate rapidly. As stated previously, most invertebrates associated with permanent water cannot adjust to short-term drawdowns that expose and inundate their habitat (Swanson and Meyer, 1977). This situation is remedied, to some extent, by maintaining constant water levels. Invertebrate fauna do not increase directly as a result of pioneering new habitats within the drawdown zone. However, species increase indirectly by thriving on decaying plant material that degrades as rising water levels inundate vegetation that has pioneered the drawdown zone. Invertebrates (*e.g.*, gastropods) may also respond to rising water levels by depositing large numbers of egg masses in flooded vegetation. Vegetation that develops in the drawdown zone and benefits waterfowl indirectly through invertebrate production may also benefit waterfowl directly by facilitating production of new species in foraging areas where succession has reduced species composition (Kadlec, 1962).

ii. Raptors

Impacts to raptors as a result of drawdown will depend on loss of riparian habitat and reduction in prey density as a result of upland and riparian habitat loss. Impacts to raptors are not anticipated to be severe because raptor species occurring in the lower Snake River generally use cliff and riparian habitat for nesting and perching, and forage in upland fields (*e.g.*, red-tailed hawk, Swainson's hawk, rough-legged hawk). Raptors that perch in riparian zones may benefit from drawdown initially as snags are created, but in the long-term the effect would be negative due to overall loss of perch and nest trees (Reed and Olney, 1994). Timing and duration of drawdown would have a greater impact on raptors due to lost production of prey species (*i.e.*, waterfowl).

iii. Upland Game Birds

Based on initial recommendations of the lower Snake River Fish and Wildlife Compensation Plan (1987), it is anticipated that upland game bird habitat may be impacted by drawdown. Enhancement measures within the original plan provided for and established contractual agreements with private land owners to retain irrigated alfalfa strips, dryland alfalfa, grass hay meadows, and/or unirrigated corners in circle-irrigated fields for buffer, roost, nest, and forage areas for upland game birds (COE, 1987). Effects to upland game bird habitat would be largely related to changes in riparian vegetation or changes in current land use on uplands adjoining the projects, and drawdown elevations that render existing pumping facilities unusable.

California quail, ring-necked pheasant, and mourning dove that commonly occur in the riparian corridor (COE, 1976) may be more severely impacted by direct effects of drawdown. Gray partridge, which are locally abundant above Lower Monumental Dam, are more reliant on agricultural uplands beyond the ordinary high-water mark(COE, 1976), and should not be affected by drawdown. Although chukar rely on moist areas for forage, they generally occur in association with rocklands, grasslands, and steep terrain; and are capable of shifting habitat use from riparian areas to higher altitudes during wet years (COE, 1976). Chukar rely on the springs and palustrine forested habitat of the Snake River. Chukar may be impacted by drawdown if riparian vegetation in this habitat is reduced. Common snipe, associated with mudflats or similar habitat from Lower Monumental through the Lower Granite reservoir (COE, 1976), may benefit from drawdown and increased exposure of sandbar, embayment, mudflat, and wetland sediments that have been observed during periods of power peaking (COE, 1976). Exposure of sandbars and mudflats, and increased travel distance to water may result in increased mortality from predation on upland game birds (USFWS, 1993).

iv. Furbearers

Impacts to furbearers as a result of drawdown will include exposure of muskrat, beaver, and river otter dens during breeding season, reduction in riparian and wetland habitat, and exposure of riprap den sites (COE, 1976). Species diversity of aquatic furbearers along the lower Snake River was drastically reduced as a result of original construction and inundation of riparian habitat (COE, 1976). During the March 1992 experimental drawdown, beavers were displaced from their lodges (COE, 1992b). Aquatic furbearers exhibit a preference for non-fluctuating river reaches, subimpoundments, or tributaries not affected by water-level fluctuation; and it has been postulated that on run-of-river reservoirs, aquatic furbearers compensate for effects of drawdown by extending their den entrances into the active channel (Mudd *et al*., 1980). The extent of drawdown below elevations that expose den entrances within natural and manmade habitats and predispose furbearers to predation during the breeding season may determine the extent of impact on the species.

In addition to exposure of furbearers along project shorelines, the change in spatial distribution of vegetation within riparian habitat may influence species-specific foraging efficiency (*e.g.*, beavers). Both stem density and stand homogeneity could be affected by drawdown. Although stem density and distance from the beaver den site to forage are not correlated, vegetative homogeneity and distance from the den site to forage have been established. In riparian areas where disturbance has altered vegetative species composition (*e.g.*, increased species diversity; COE, 1992b), beaver foraging efficiency may decline because of a lack of dominance of one or two selected forage species.

v. Mule Deer

Based on initial recommendations of the lower Snake River Fish and Wildlife Compensation Plan (1987), it is anticipated that mule deer habitat may be impacted by drawdown. The original compensation plan estimated that 1,800 deer wintered near the four lower Snake River projects prior to initial inundation. Subsequent to that study, 1,900 to 3,200 deer have been estimated to be on or near the four lower Snake River projects (COE, 1987). Upland grass and shrub communities and riparian tree, shrub, and marsh habitat are significant to mule deer in the lower Snake River (COE, 1976). The primary effects to mule deer would be associated with reduction in riparian habitat and increased distance from forage to cover.

vi. Small Mammals

Populations of small mammals would be impacted by sustained drawdown which supersedes 10 to 14 days (COE, 1992b). Although a majority of microtines are able to relocate temporarily, continued fluctuation of water levels would likely displace species permanently or result in reduced overall production potential.

vii. Colonial Nesting Birds

Ground nesters, beach nesters, and birds that nest on floating vegetation are susceptible to disruption of habitat by fluctuating water levels. Unstable and intermediate habitats, where water fluctuated frequently and rapidly or from year to year, are unsuitable for nesting either because habitat is frequently flooded or erosion reduces vegetation cover (McNicholl, 1985). Cortney and Blokpoel (1983) attributed changes in colony size of common terns (*Sterna hirundo*) to changes in vegetation (*e.g.*, colonizing vegetation on traditional nest sites) associated with fluctuating water levels. Colonies were affected not by fluctuating water levels, but by a lack of fluctuation which was necessary to eliminate early-succession vegetation.

Species may compensate, if disruption occurs early enough in the season, by renesting immediately following disruption or renesting later in the nest cycle. Species must be adaptable and will be influenced to the degree that site tenacity is decreased or system stability is restored. Other species may pioneer new habitats (Prince and D'Itri, 1985) as was evidenced in a case of extreme drawdown in the Flathead Valley were terns and gulls, displaced from historic sites, nested on elevated stumps (BPA, 1987).

c. Threatened and Endangered Species

i. Bald Eagle

Bald eagles tend to use the lower Snake River minimally and primarily during winter (*e.g.*, bald eagles usually disperse from wintering areas by late March), therefore impacts to bald eagles are anticipated to be minimal. Wintering bald eagles may derive short-term benefits from drawdown related to increased waterfowl densities and increased susceptibility of birds during winter months). Increased perch and roost sites may also benefit wintering bald eagles along the projects. The loss of anadromous fish rearing habitat has not been fully evaluated (Reed and Olney, 1994), but it would be assumed that reduced survival and spawner success would subsequently affect availability of prey base.

ii. Peregrine Falcon

Peregrine falcons may occur in the vicinity of the project although the species has not been reported for the area in recent years. Potential effects to peregrine falcons would result from reduced prey species abundance (*e.g.*, waterfowl), but it is not anticipated that this is a likely affect of the proposed activity.

iii. State Listed and Federal Candidate Species

Each of the listed plant and animal species typically occur in moist areas that have been established as a result of reservoir recharge. Drawdown may temporarily impact state sensitive prairie cordgrass, porcupine sedge, giant helleborine, and shining flatsedge. Drawdown elevations that vary from those of normal operation or drawdown during the reproductive season may result in irreversible impacts to these plant species. The critical period for many of these species is April to June.

Insects, reptiles, and amphibians (*e.g.*, Pacific tree frog) would benefit from stable pool elevations; the condition providing habitat for egg laying and larval development (BPA, 1994). However, because many of these species rely on microsites, impacts could be manifested in loss or permanent displacement of individual species.

During the March 1992 test drawdown of the Lower Granite reservoir, two mollusc species--the shortface lanx (*Fisherola nuttali*) and the California floater (*Anodonta califoniensis*) were exposed (Frest and Johannes, 1992). Further evaluation of habitat suitability and the potential effects of drawdown will be necessary to determine the extent of impact on the species.

d. Summary

The impact of drawdown alternatives on wildlife resources will be determined by both the timing and duration of drawdown and the extent of construction-related activities. Effects of inundation, dewatering, land bridging, and reduced capacity for irrigation will impart the most significant effects on populations. Additionally, loss or conversion of entire compliments of species by replacement may occur if aggressive competitors and noxious species become established in shoreline areas that are dewatered during drawdown.

Increased water level fluctuations, because of the extent of re-regulation throughout the entire system, would occur and impacts to these fluctuations would be greater than those occurring under existing operations. Specific impacts of drawdown to wildlife species may include increased predation on nesting and brooding rearing Canada geese, loss of foraging habitat to waterfowl, short-term increases in roosting area and perching habitat for raptors, conversion of foraging habitat for upland game bird species, and reduced forage potential for furbearers, big game, and small mammals.

Impacts of upstream storage or development of the migratory canal will involve specific conversion of habitat to another usable type or an area of non-habitat. Alteration of the side channel at Silcott Island to develop the migratory canal would be the most significant impact by converting a shallow water area to a deep water channel. Habitat loss or conversion and increased potential for predatory species would be the primary effect. Construction of the migratory canal would also impart on HMU's along the lower Snake River. Land conversion of HMU's to non-habitat will affect upland foraging bird and game species. Impacts to wetlands from alignment of the migratory canal may be the result along several high area tributaries.

Impacts of habitat loss from development of the migratory canal far exceed those of conversion as a result of inundation of water level. Removal of vegetation for construction or lay down areas creates an avenue for invasion of aggressive colonizers, which often are undesirable species. Although habitat loss resulting from inundation or water level imparts a negative effect on vegetation and wildlife distribution, the impact of negative or natural flora and fauna should be minimized. Displacement of species should be short-term and overall losses to the system should be negated as the system reestablishes some type of equilibrium.

6. Cumulative Impact to Aquatic Production

Drawdown of lower Snake River reservoirs may impact smolt-to-smolt survival through alterations to food web components of the ecosystem. Below are presented our predictions of which food web components will be impacted, the degree of impact, and the significance of these impacts to smolt-to-smolt survival.

Effects of drawdown on the photic zone (*i.e.*, <15 feet depth) of two sections of Lower Granite reservoir (figure 4-22) were modeled using GIS techniques. The reservoir was subdivided into these smaller sections because the entire reservoir could not be viewed at the scale required for analysis. The Centennial Island reach may be considered representative of the lower reservoir (*i.e.*, not subjected to lotic conditions in any of the drawdown options except the Natural River Option). The Silcott Island reach is located within the upper reservoir lotic/lentic transition zone for each of the drawdown scenarios. A pictorial representation of the change in photic zones for two different reaches of the reservoir (Centennial Island reach and Silcott Island reach) is presented to visualize the change in nearshore shallow zones (<15 feet deep) in two representative areas of Lower Granite Reservoir during differing drawdown scenarios and flow rates.

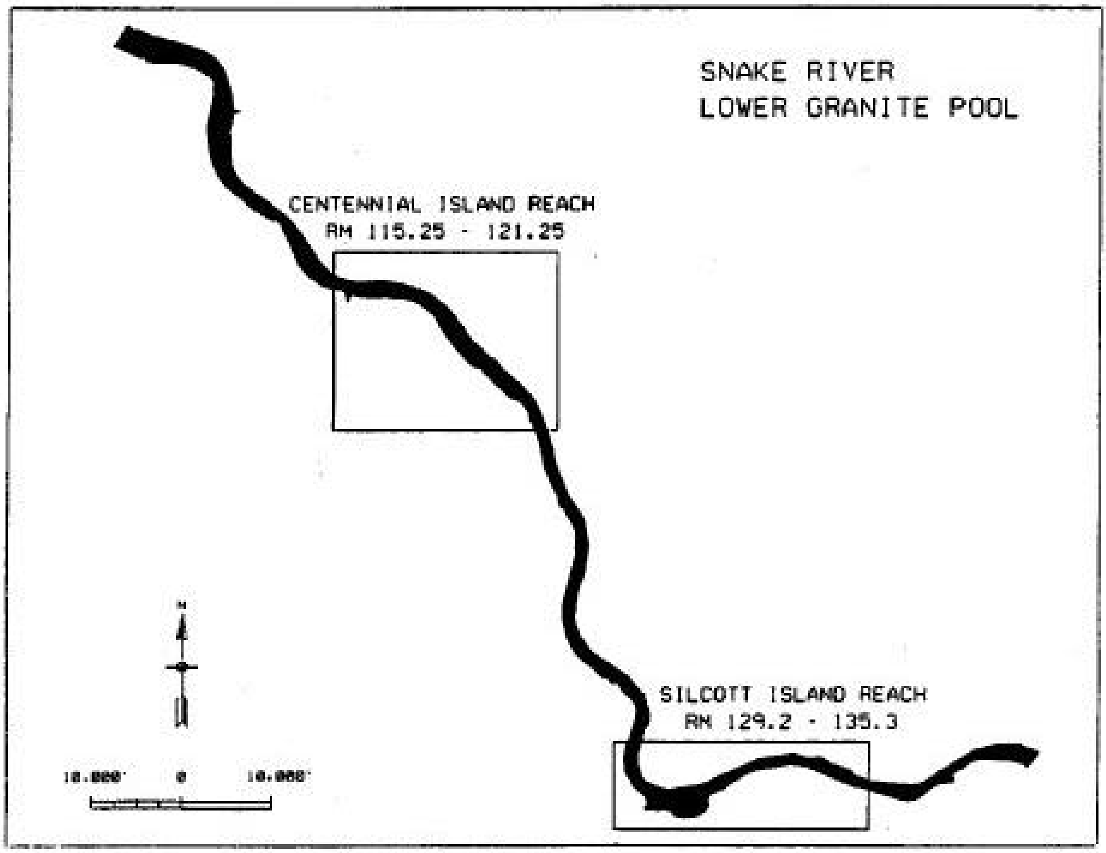

Figure 4-22. Location of Two Selected Reaches of Lower Granite Reservoir

a. Primary Production

Decreasing the water depth in the lower Snake River reservoirs could affect primary production either positively or negatively. For example, lowering water levels beyond the riprap zone would adversely impact periphytic communities attached to this substratum. However, periphyton will rapidly (3 weeks) reestablish once refilling has been completed, and the loss of this community as a food base for rock-dwelling invertebrates (*i.e.*, chironomids, caddisfly larvae) will be a short-term event.

Conversely, reduced water levels will allow sufficient light to penetrate to levels previously too deep to accommodate algal growth, thus promoting new growth (assuming suitable substrate are available) in these areas. However, dewatering that extends beyond the riprap rock zone, where periphyton can attach themselves, will preclude development of a new periphytic community.

Water quality changes (see Water Quality section for a full discussion) are inconclusive at the present, and it is difficult to do anything but conjecture here. It is unlikely that dissolved oxygen concentrations would be changed to a degree that would adversely impact primary, or secondary, producers. Whether or not the drawdown would mobilize nutrients such as nitrogen and phosphorus is also unknown. Funk *et al.* (1979) found nitrogen to be limiting in the lower Snake River reservoirs at various times; and Beckman *et al.* (1985) found nitrogen and phosphorus to be limiting at times in the main reservoir (Lake Roosevelt) and in some bays, respectively. Oxygen depletion, if it occurs in the deeper reaches, can result in the release of phosphorus from sediments. Funk *et al.* (1979) have reported the presence of a bloom of *Aphanizomenon flos-aquae*, a cyanobacterium, during late summer in Lwoer Granite Reservoir when phosphorus levels were elevated because of increased runoff. It is unlikely, however, that oxygen depletion will occur under drawdown conditions because of the increased circulation of water in the deep reaches and increased water velocities.

Beckman *et al.* (1985) also reported that an extensive reservoir drawdown of Lake Roosevelt behind Grand Coulee Dam resulted in a decrease in water retention time in the spring and a flushing of nutrients, sediments, and plankton through the reservoir. Mobilization of fine sediments could have two impacts on periphyton communities that are not dewatered: 1) increased turbidity might negate the penetration of light that could stimulate new production; and 2) the suspended sediments could act as scouring agents to remove periphytic growth from riprap substrate. Increased turbidity has been shown to scour periphyton communities in rivers (C.E. Cushing, PNL, personal observation, Salmon River, Idaho, Klickitat River, Washington).

Increased velocities are unlikely to have a significant direct impact on primary producers. Phytoplankton will be flushed through the reservoir system at a faster rate, but this should not decrease absolute populations or primary productivity. However if the drawdown period is extensive and residence times of phytoplankton are reduced, lentic forms may decrease as a result. Certainly, losses of this nature, although probably important to overall primary production in the system, would not contribute significantly to smolt-to-smolt survival.

Macrophyte beds may be significantly impacted by repeated drawdown, and the resulting effects may contribute to changes in their physical and temporal extent. This could significantly alter predator-prey relationships for those species dependent on macrophytes for cover or food. In systems where drawdown has been used to control nuisance growths of macrophytes, problems with subsequent algal blooms resulting from the release of nutrients has been encountered (Kadley, 1962; Cooke, 1980). However, it is unlikely that the macrophyte beds found in the lowe Snake River reservoirs are extensive enough to cause this, especially with the relatively rapid rate of turnover of the water column. Lantz *et al*. (1967) reported that 90% or more of the macrophytic vegetation was eliminated from the littoral zone by lake drawdown when drawdown lasted 3 or 4 months during a winter or summer period, but that neither a single short drawdown nor a spring drawdown eliminated the vegetation.

Our GIS analysis showed that the available photic zone increased with each drawdown scenario for the centennial Island reach (figures 4-23a, b, and c). The amount of photic area was not affected by an increase in flow rates except during the Natural River Option. A decrease in flow rate associated with a deep drawdown substantially increased the photic zone area at the Silcott Island Reach (Figures 4-24a,b,c).

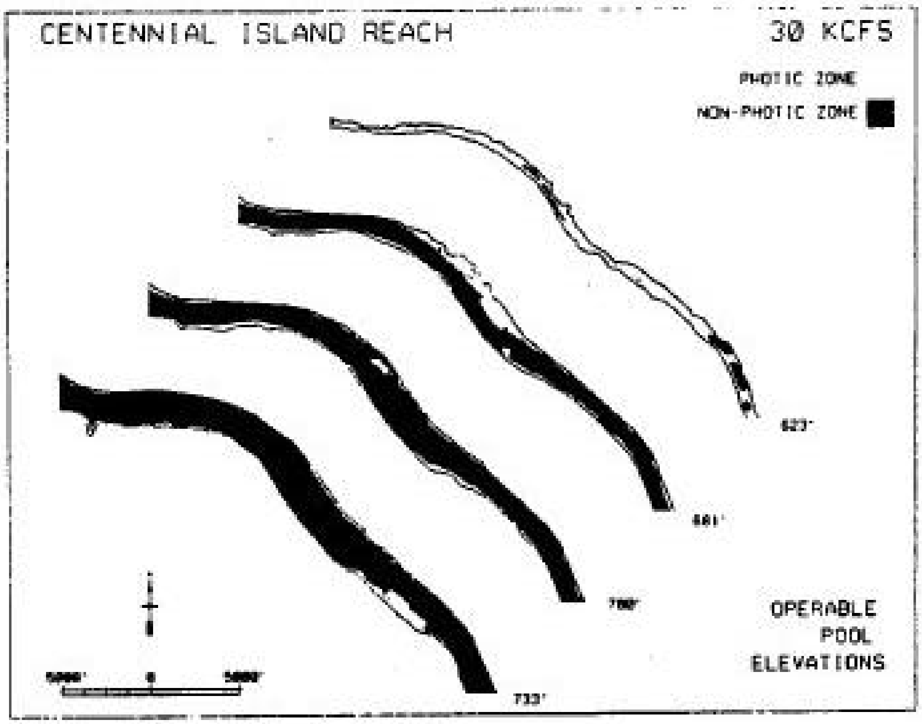

Figure 4-23a. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Centennial Island Reach at 30 kcfs Flow Rate

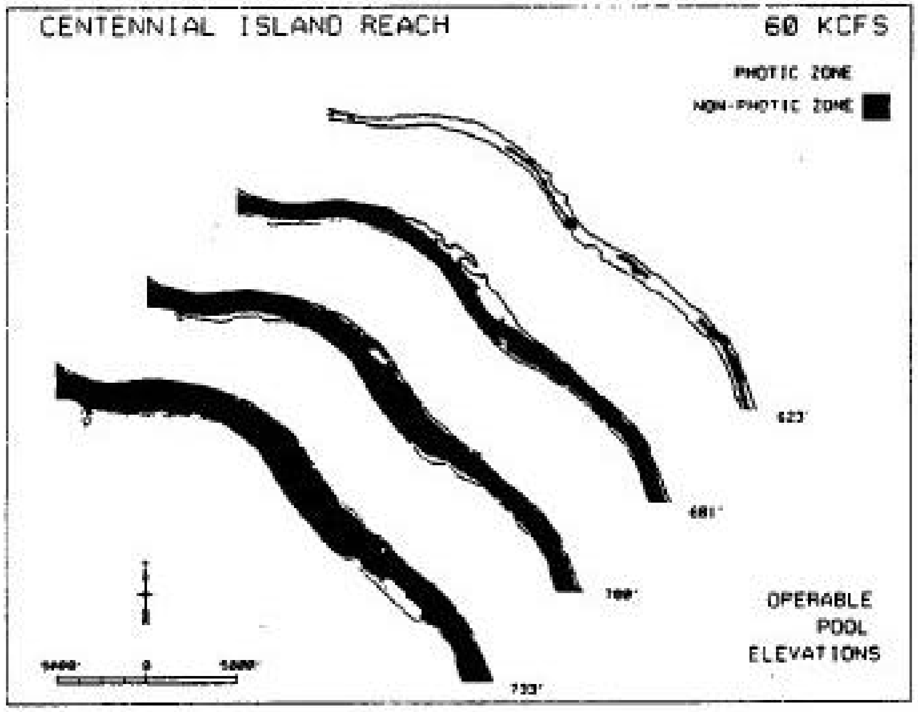

Figure 4-23a. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Centennial Island Reach at 60 kcfs Flow Rate

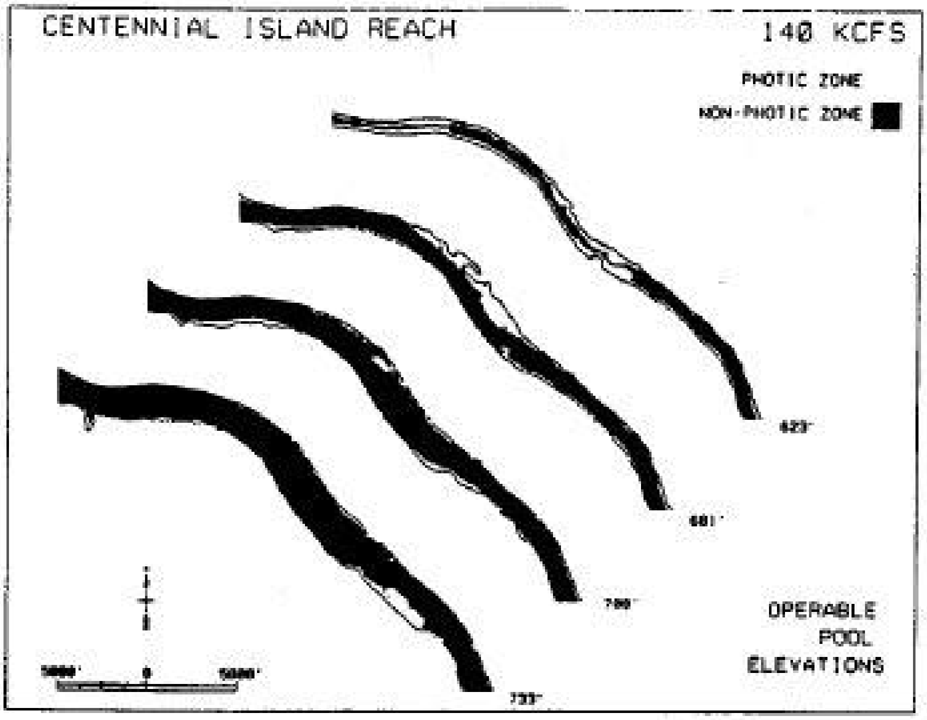

Figure 4-23c. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Centennial Island Reach at 140 kcfs Flow Rate

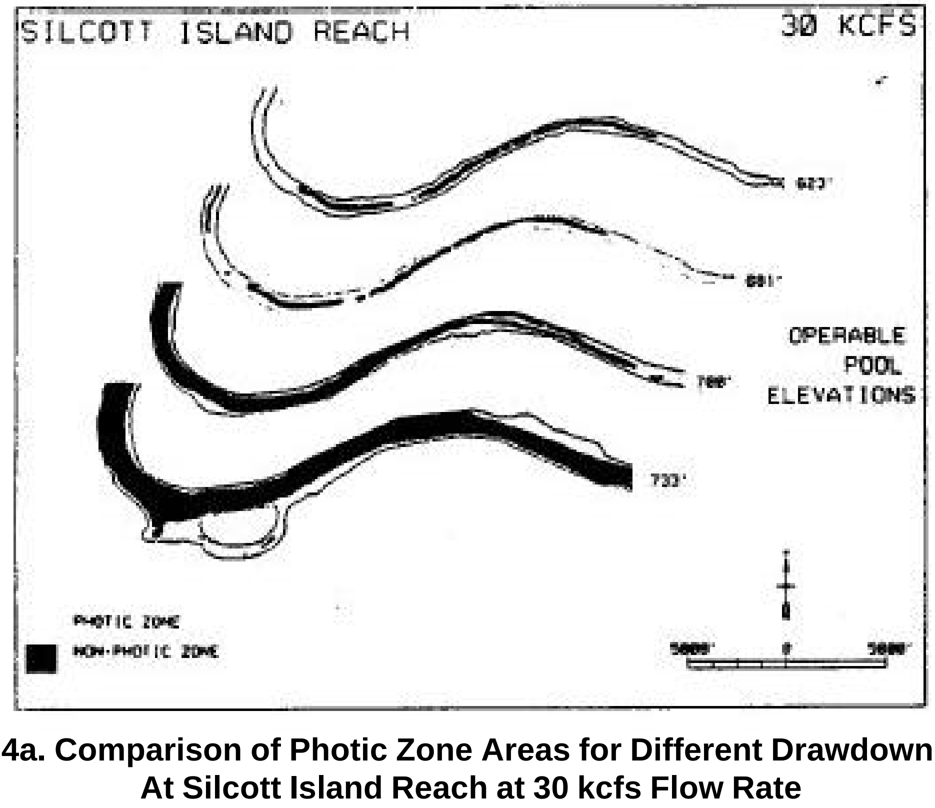

Figure 4-24a. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Silcott Island Reach at 30 kcfs Flow Rate

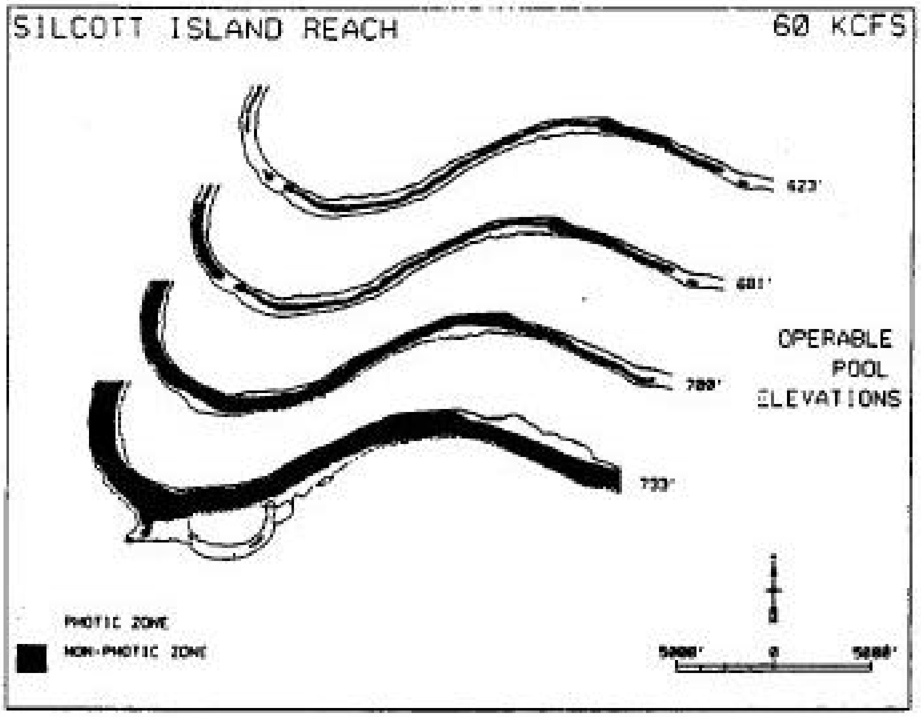

Figure 4-24b. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Silcott Island Reach at 60 kcfs Flow Rate

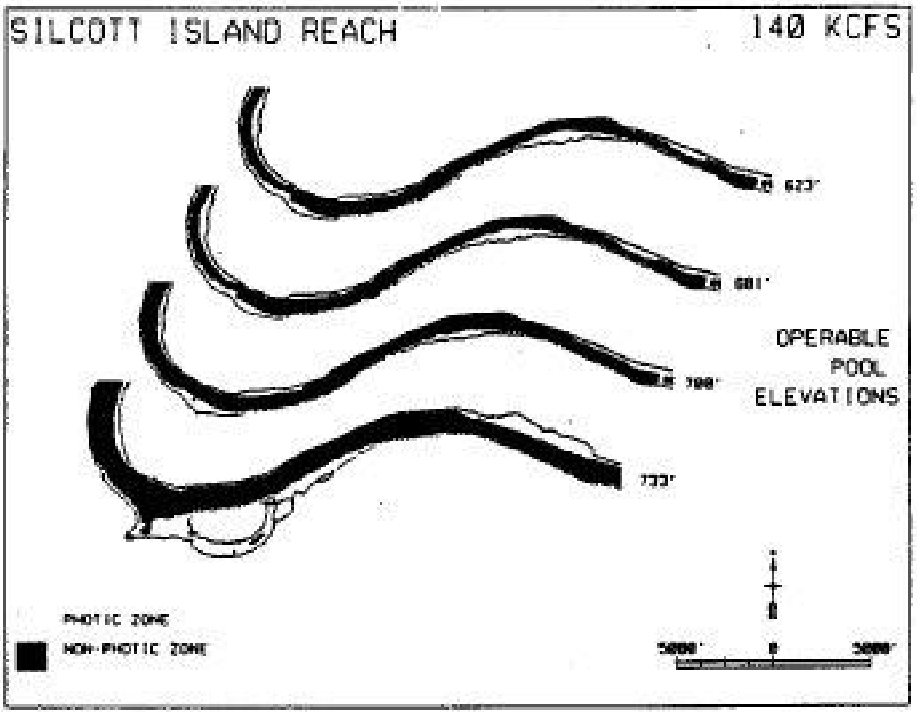

Figure 4-24c. Comparison of Photic Zone Areas for Different Drawdown Scenarios At Silcott Island Reach at 140 kcfs Flow Rate

Chironomids serve as a significant food item for young salmonids in the Columbia River (Becker, 1973) and some fish species in Lower Granite reservoir (Bennett *et al.*, 1988). However, it is unknown whether they inhabit riprap or soft sediments in the Snake River reservoirs. If the riprap chironomids are most important to the diet of fish, the combined effects of loss of food base (*e.g.*, periphyton, short term) and decimation of the invertebrate community may adversely affect salmonid growth and possibly survival.

b. Secondary Production

i. Zooplankton

One potentially important food web component for which limited data are available in lower Snake River reservoirs is zooplankton. Isom (1971) states that benthic invertebrates were of little importance as food items in storage impoundments because a truncated plankton-to-fish food chain was common. This, however, is contrary to findings of Bennett *et al.* (1988), who identified chironomids and oligochaetes as the main food items for some Snake River species. Published data for zooplankton in lower Snake River reservoirs reveal extremely low population numbers which could suggest that they are not important (Funk *et al.*, 1979). However, discussions with M. Falter (University of Idaho, Moscow, Idaho), who collected the data for the Funk *et al.* (1979) analysis, reveal that zooplankton data were collected only in the pelagic regions of the reservoirs and that zooplankton populations in littoral and benthic regions (harpaticoids) were not examined. He agrees that these populations could exceed those in the pelagic regions, and constitute a primary forage constituent, along with larval insects, for young fish. It is highly likely that dewatering would severely impact the littoral and benthic zooplankters (harpaticoids), but these populations would likely recover following rewatering because they can reproduce parthenogenetically, or have resting stages, or both (Pennak, 1953). Beckman *et al.* (1985) found that increased retention times of water in Lake Roosevelt during all months resulted in increased densities of zooplankton. The converse would indicate that increased flushing times resulting from drawdown would decrease zooplankton densities. If it can be shown that zooplankton are an important food resource for young fish, then temporal considerations would be of importance if dewatering occurs at time when this food resource is important in the fishes' life-cycle.

ii. Benthic Invertebrates

Depending upon the length of drawdown and the final operational surface elevation, benthic invertebrates may or may not be significantly affected by drawdown. Drawdown scenarios presented in this report are of sufficient duration to cause adverse impacts to those populations existing in areas above the final pool elevation. Adverse impacts would be recognizable among organisms that are exposed and that cannot follow the receding water levels or burrow into substrates to survive. Particularly susceptible are the riprap-inhabiting insects (*e.g.*, chironomids, caddisfly larvae), amphipods, crayfish which get trapped above the water level, and molluscs. Organisms not exposed should not suffer adverse impacts except as described below under velocity changes and mobilization of sediments. Drawdown is unlikely to have a significant impact on benthic organisms through changes in water quality unless toxics (*e.g*., dioxins, furans) are liberated in the system in sufficient concentrations to be deleterious (refer to Water Quality section).

For mobile organisms such as crayfish, that can change position with fluctuating water levels, the greatest potential for impact would be associated with crowding. In addition, because the preferred location is among riprap, dewatering the shoreline and forcing survivors into less suitable habitat, such as sandy bottoms or to embayments, may adversely affect these organisms. Indeed, numerous losses of crayfish were recorded during the experimental drawdown of the Lower Granite Reservoir in March 1992, although many crayfish appeared to be following the receding water levels (Wik *et al*., 1993). Some molluscs may be mobile enough to follow receding water levels or burrow into moist sediments to escape desiccation. Despite this, there was a significant loss of molluscs, mainly *Corbicula*, during the experimental drawdown of the Lower Granite Reservoir in March 1992. Amphipods may also have a limited ability to follow receding water levels, but we observed many desiccated amphipods on riprap stones during the experimental drawdown in March 1992.

Increased velocities and mobilization of fine sediments can have an adverse impact on some benthic invertebrates. Increased suspended sediment loads can adversely impact filter-feeding invertebrates such as *Brachycentrus* and Hydropsychidae larvae, both of which are present in lower Snake River reservoirs and which occur below the dewatered zone. We observed heavy losses of the filter-feeding organisms that inhabit riprap habitats from desiccation during the experimental dewatering. Increased mobilization of sediments was documented during the experimental drawdown in March 1992 (refer to Water Quality section). This will obviously impact sediment-dwelling benthic organisms in these reservoirs by transport to new sections of the reservoirs, or by death if they cannot withstand the actual suspension, transport, or deposition on unsuitable substrata. Beckman *et al.* (1985) reported that the extensive reservoir drawdown of Lake Roosevelt greatly reduced bottom fauna habitat.

Impacts of drawdown on the soft-bottom benthos is undetermined. Cursory studies conducted by PNL during the experimental dewatering suggested that organisms occurring within this substrate burrow to deeper depths to avoid desiccation, or perish. However, quantitative samples collected from the Little Goose Reservoir showed no decrease in benthic populations following dewatering and subsequent filling; it was dewatered for only brief periods. In fact, increases of many forms were found, although it is highly likely that these increases were not related to the experimental drawdown, but rather to the inadequacy and timing of the sampling program. Hildebrand *et al.* (1980) state that the organisms best able to survive or take advantage of water-level fluctuations are chironomids and oligochaetes, the most prevalent organisms in the soft-bottom habitat of the lower Snake River reservoirs. Kaster and Jacobi (1978) reported that larvae of *Chironomus plumosus* were active at a depth of 8 cm in substrates exposed to air for 21 days. *Limnodrilus* specimens were also found burrowing deeper in air-exposed sediments, with smaller individuals being more successful. These authors further stated that the rate of survival of these organisms, when exposed to air, was greater in organically rich sediments than in sand and silt. Bechman *et al.* (1985) compared benthos populations in dewatered zones of Lake Roosevelt with those in non-dewatered zones. They found that mean density of benthos was lowest in the dewatered zones in all season samples. Further, densities were lowest immediately after drawdown, and then increased gradually through the year.

c. Resident Fish Populations

Unless extensive entrainment or migration takes place, lowering the Snake River reservoirs during drawdown would concentrate a predators and prey and increase predator-prey interactions. The predator food base could decrease as a result of impacts to large invertebrates, particularly crayfish, that reside in nearshore habitat. Decreased water levels would force some fish into more open water habitat and increase the magnitude of species interactions. Thus, juvenile resident and anadromous fish are likely to become more important to the diet of large predatory fish such as bass and squawfish. Other ecological characteristics expected to be impacted by drawdown include decreased reproductive success due to siltation effects and lowered water level (*i.e.*, loss of riprap) on spawning areas, decreased growth from loss of primary and secondary production, and increased species interactions.

d. Summary of Cumulative Impacts to Aquatic Production

Periphyton or attached algae and macrophyte beds will be adversely impacted during drawdown. Their ability to reestablish will depend on the length of the drawdown and availability of suitable substrate. Dewatering of nearshore areas would severely impact the littoral and benthic zooplankters, and densities would further decrease if they are entrained during drawdown. Impacts to benthic invertebrates will depend upon the length of drawdown and operational surface level. Substantial loss of benthos that inhabit the riprap will occur. Large invertebrates, including crayfish and molluscs, will be desiccated unless they can reach suitable habitat. Juvenile fish will be more vulnerable to predation during drawdown because of higher densities of predators, decreases in shallow water habitat, and potential for prey switching.

B. Impacts From Upstream Storage Requirements

The environmental effects described in the following paragraphs are a summary of the more significant effects identified in the Galloway terminated feasibility study (Wik *et al.*, 1993).

1. Water Quality

Operation of Galloway Dam, especially the potentially high-volume discharges for downstream fish passage during the spring, will significantly affect and determine reservoir water-quality conditions. It is assumed, in the general discussion that follows, that the filling of the pool during the winter and early spring will result in a full pool by the end of April. Projected reservoir elevations based on the previous 50-year record indicate this will occur roughly every other year. It is also assumed that the entire volume of water necessary for fish passage (715,000 acre feet) will be withdrawn during May and June, that the ensuing flows (July through November) will equal reservoir releases, and that no net change in the volume or elevation will occur during the summer and fall. All other analyses included in this document are based on exposed pool elevations derived from the analysis of 50 years of hydrologic data.

During the release of water for anadromous fish, it is unlikely that stratification of the reservoir would occur. After May, stratification would occur with much higher temperatures in the bottom water (hypolimnion). This could result in severe dissolved-oxygen depletion. The ability of the reservoir to clarify inflows is suspect. Most of the inflowing sediment is presently composed of fine silts and clays, thus settling rates are slow. With a bottom discharge, much of the suspended solids could pass downstream.

Loading of nutrients would be high, with probably 80% of the phosphorus load coming from streambank erosion (Weiser River Soil Conservation District). Most of this phosphorus is probably in the particulate phase and strongly bonded to sediments, making it unavailable to the water column. However, a high amount of dissolved phosphorus would still exist to allow algal production and not be a limiting factor.

The land area to be inundated and drained by Galloway Reservoir contains numerous mercury deposits and a formerly active mercury mine. An investigation to predict the levels of mercury to be expected in Galloway Reservoir fish (Buhler *et al.*, 1984) indicated that the average mercury concentration will fall within the range of 0.17 and 1.32 mg/kg wet weight. The Food and Drug Administration's (FDA) present action level for methylmercury is 1.0 mg/kg. Mercury uptake by fish will occur in the initial years of impoundment, and eventually the mercury levels in fish will drop within levels acceptable for human consumption. Following the initial filling of the reservoir, fishing will be prohibited for a period of 2 to 5 years, during which time fish tissue analysis will be conducted to ascertain levels of mercury in the resident fish. The fishery will open only when concentrations are found to be below those determined to be safe (FDA action level of 1.0 mg/kg dry weight).

Water-quality conditions within Galloway Reservoir, as with most reservoirs, will be at their worst during the first 3 to 4 years after filling. During this time, decomposition of vegetative material and organic sediment occurs, reducing dissolved oxygen concentrations and increasing the levels of ironically-reduced constituents (*i.e.*, iron and manganese). Because of the small amount of vegetation in the watershed, these adverse conditions will probably not be as severe as noted in other reservoirs. Following this initial period, water-quality conditions will improve and stabilize.

Downstream impacts will depend on reservoir water-quality conditions and discharge operations (*i.e.*, use of selector gates). Of utmost concern to the lower Weiser River will be the temperature and dissolved oxygen levels, with turbidity and nutrients of lesser concern. During most summers, hypolimnion dissolved-oxygen concentrations will be low, possible inadequate for downstream use by fish species. Because of the relatively high gradient of the lower river (8 feet/mile) and the presence of riffles, progressive reaeration will occur as the water flows downstream.

Impacts to the Snake River from Weiser River impoundments will be minimal. The Weiser River accounts for ˜9% of the total flow to the Snake River, and little difference in water quality or sediment loading is expected due to impoundment of the Weiser River upstream. During flow augmentation with 11,000 cfs, the Weiser River will be 30 to 50% of the total flow in the Snake River at Weiser. Water quality changes downstream can be adequately evaluated by detailed modeling of reservoir and discharge water quality.

2. Anadromous Fish

The environmental effects of the Galloway project are being prepared, but are not available at this time.

Because there is no remaining stock of anadromous fish above Hells Canyon Dam on the Snake River, there are not likely to be any negative impacts as a result of construction of new storage projects above this location, such as Galloway. One of the screening criteria used for potential new storage was that a project have no known negative effects to anadromous fish stocks.

It is conceivable, given the present climate, that upstream and downstream fish passage through the Hells Canyon projects may be restored. In that event, fish passage facilities may be required for the Galloway project, or else the losses to the anadromous fishery will require mitigation.

3. Resident Fish

Project impacts to resident fish resources will occur in three locations: 1) in the reservoir area; 2) in the lower Weiser River; and 3) potentially in the Snake River below the mouth of the Weiser River. Existing stream fisheries for rainbow trout and smallmouth bass will be eliminated in the permanent inundation area. Stream fisheries in the upper reservoir area will also be degraded, due to annual inundation as the reservoir refills after the previous year's drawdown. Indirect impacts may occur from stream habitat deterioration above the reservoir, and from proliferation of nuisance fish species. Stream habitat may be adversely affected by silt accumulation in the streambed just above the reservoir. Although no data are available to estimate this effect, it is likely to be a minor loss. Nuisance fish, such as squawfish, may thrive in the reservoir and migrate above the reservoir to spawn. They could compete with, and feed on, populations of more desirable nongame and game species. However, the effect may be minor if existing squawfish populations in the river are fully using spawning habitat.

The reservoir may possibly provide suitable conditions for game fish populations. However, extensive annual drawdown, and potentially unsuitable temperature and turbidity conditions, severely limit fishery potentials. Model studies indicate that habitat suitability will be low-to-moderate for black crappie, yellow perch, smallmouth bass, and rainbow trout, provided these species could even survive the large-volume water releases.

Below the project, fish populations in the Weiser River will be affected by changes in flow regimes and temperature and by potential changes in stream substrate. Model studies indicate that warm-water species use will be reduced because of decreased flows and habitat during the winter months. Habitat suitability for cold-water species will remain similar, or slightly increase. However, with probable channel degradation and loss of suitable spawning areas, it is assumed that the spawning run of rainbow trout entering from the Snake River will decline.

4. Wildlife

The long-billed curlew is recognized by state and Federal agencies, as well as private organizations, as an important species (declining species of special concern) whose habitat losses should be minimized. A project goal is to recover unavoidable curlew habitat losses in-kind or with out-of-kind resources. The Columbian sharp-tailed grouse, a species with a limited, dwindling range and declining population (identified as a sensitive species in Idaho), was identified as a potential out-of-kind resource to offset curlew habitat losses.

The Idaho ground squirrel, an Idaho state sensitive and Federal candidate species, occurs within the project area. A project goal is to minimize habitat losses and, if possible, encourage establishment of new colonies in a suitable habitat.

A project goal is to compensate for upland game bird (*i.e.*, pheasant, quail, chukar) habitat loss by improving management on compensation lands adjacent to the reservoir, and/or adjacent to the lower river. Chukar losses should also be offset with improved management on compensation lands.

Development of upstream storage would result in big game habitat loss. A project goal is to select and manage areas for compensating other species (*i.e.*, meadowlark) and/or habitat losses to provide winter range improvements for big game.

Wetland habitats (*i.e.*, wetland, riparian, palustrine) were identified as areas where other habitat losses could be recovered. These habitats are considered Resource Category 2 under the USFWS Mitigation Policy and, as such, the USFWS goal is not net loss of in-kind value. Other cover types are considered Category 3 and 4 resources and, as such, the goal is to fully compensate their losses.

5. Vegetation

The obvious impact to vegetation is the loss from inundation by the reservoir. More subtle impacts are land-use changes and consequent impact to vegetation in the lower Weiser River below the project. In the reservoir area, nearly 6,900 acres of riparian and upland vegetation will be inundated. The project will likely induce change in cover types along the Weiser River below the dam site. Because channel excavation and bank protection will be required for site development, landowners bordering the river will have the opportunity to convert riparian and wetland acres to crop and pasture. Acquisition or subsequent development of these areas for habitat management would be the proposed action for these sites.

6. Cultural Resources

Cultural resource conditions within the project area will greatly change with the construction of Galloway Dam. Cultural sites located at lower elevations within the proposed reservoir area will be totally inundated and lost to further study. Other sites may be partially inundated and subjected to loss from erosion and deterioration. Actual project construction could destroy or impact cultural sites. An increased human presence in the area will increase the chances of human activity impacting cultural properties. Additional cultural resources studies will be needed to identify the location of sites, and to determine their significance. Data recovery may also be required in some instances.

7. Summary of Impact from Upstream Storage

Water quality changes to the Snake River from an impoundment in the Weiser River will be minimal. One concern following the Galloway terminated feasibility study was the presence of mercury deposits in the watershed. There is little potential impacts for water storage operations to impact anadromous and resident fish populations that occur downstream in the Snake River. Impacts to vegetation, wildlife, and cultural resources will occur because of inundation by the reservoir. Some compensation to terrestrial resources is possible through mitigation projects and relocation.

C. Impacts From Collecting and Transporting Anadromous Fish

Collection and conveyance of downstream-migrant salmonids from above Lower Granite Dam to below Bonneville Dam is being considered as a method of reducing fish mortality resulting from passage through turbines and from migration delay in reservoirs. The upstream collection and transport concepts are intended to improve upon existing bypass and collection facilities. Operation of the fish conveyance system is anticipated to be seasonal, with full operation occurring from March through October of each year. Two general options for collection of juvenile salmonids are being considered. The first option would collect juveniles at a large screen system in a low velocity area located about 7 miles downstream of the confluence of the Snake and Clearwater Rivers. The second option would collect fish upstream of Lower Granite reservoir in the free-flowing portions of the Snake and Clearwater Rivers. These structures would be designed to withstand greater flow velocities than the reservoir site.

1. Water Quality

It may be easier to control potential problems with decreased dissolved oxygen, nitrogenous waste buildup and waterborne pathogens when transporting fish via the barge alternative compared with migratory canal alternatives. Turbidity, elevated temperatures, and potential algae buildup are other areas of concern. Chemicals that will be used to maintain this artificial environment must be closely examined to ensure that they are not toxic or that they do not result in sublethal effects such as those that suppress the immune systems of juvenile salmon or interfere with smoltification. Applicable laws, depending on which chemicals would be needed for maintenance, would be the Federal Insecticide, Fungicide, and Rodenticide Act and Toxic Substances Act. There is also potential for water-quality degradation from fuel and oil spills caused by construction equipment and in storage areas.

Debris and sediments would be major problems with a facility of this size. Existing screening systems passing a few thousand cfs in protected situations have severe debris problems. Even with the upstream removal of large debris, smaller debris would concentrate in the collector/separator due to the 0.125-inch wedgewire mesh. This debris accumulation would be channeled into the collection facilities, resulting in probable fish handling stress and survival concerns. Current fish separator technology may be unusable under these kinds of debris loads. There is evidence of these problems at some existing fish separators during high debris-load periods.

Sediment in the vicinity of the proposed downstream facility site could be a major problem during periods of higher flows. Current information from the recent reservoir drawdown test shows areas of sediment deposit and sediment erosion near the site. The alterations of flow patterns at the facility would probably cause sediment deposition.

2. Anadromous Fish

The success of any upstream collection concept would be highly dependent on the biological success of the fish transport program currently operated for all Snake River salmonid stocks. For the upstream collector concept to be effective in rebuilding stocks of anadromous salmonids, there must be no adverse effects greater than those caused by current collection and bypass systems in place at Snake River dams. A surface-oriented collector could be a beneficial alternative to current turbine intake collectors. A low velocity guidance/collection facility has several potential advantages over turbine intake collectors, including 1) collection of smolts before they get disoriented and/or delayed in the Lower Granite reservoir; 2) the removal of smolts prior to exposure to predators; and 3) a reduced need for flow augmentation. However, these benefits assume that reservoir mortality due to predator activity is high and that in-river passage conditions are suboptimal.

Additional research and site monitoring is still required to determine the most appropriate location for constructing an upstream collector facility. Potential impacts to salmonids from construction include the conversion of limited fall chinook salmon shallow water rearing habitat to deep water full pool operations as a result of dredging and increased and/or prolonged resuspension of fine sediments. Construction impacts, including their modification of flow patterns, could be substantial if not adequately managed with biological criteria. Additionally, construction of a guidance/collection facility could partially block access of steelhead to spawning habitat in Alpowa Creek.

Although the structure may act efficiently in removing subyearling fall chinook salmon, they could be removed before they are physiologically ready to migrate from the Lower granite Reservoir rearing area. In order to optimize conditions for Snake River fall chinook salmon, the collector systems at Lower Granite and Little Goose Dams would need to be fully operational at the time of initiation for subyearling outmigration. Further, adequate in-river passage conditions through the Lower Granite and Little Goose reservoirs would need to be determined and maintained.

The CRiSP 1.4 model results for the upstream collector indicated that, assuming an 95% FGE, highest benefits were achieved for juvenile fall chinook salmon. For example, it yielded increased benefits of 78% for high flow years to 181% during low-flow years for fall chinook salmon from upper Lower Granite reservoir to the Columbia River estuary. Estimated juvenile survival benefits (increase) for spring chinook salmon were lower and ranged from 19% for high flow years to 31% for low flow years. A sensitivity analysis performed for the single and dual upstream collector options suggested that an FGE of 75% and bypass mortalities of <5% should be achieved before such a collector should be considered for fish passage.

3. Resident Fish

One concern of the upstream collection system is that operational conditions designed for collection of juvenile salmonids may adversely impact populations of resident fish. Potential impacts of the screening system on resident fish include 1) fish impingement on the screens; 2) mortality during collection and transport of salmonids; and 3) delay and/or barrier to fish movement. It is not possible to quantify potential impacts to resident fish inhabiting or migrating near the proposed facility sites because the specific design and operational criteria for the upstream collection system have not been specified. Additionally, the low and high velocity barrier concepts proposed for the Snake River system are dramatically different with respect to hydrologic conditions created near the screen structure. These conditions will influence the behavior of fish approaching the facility, both upstream and downstream directions.

Current screening design and operating criteria have been established to enhance the safe passage of salmonids. These criteria will likely protect resident fish species of similar size and swimming behavior. For example, studies have shown that chinook salmon fry 32 to 40 mm in length would not be entrained through a 4-mm perforated plate (Fisher, 1978). Most juvenile catostomids and cyprinids of the same size would not pass through these openings because their body shape is similar. Other fish species commonly found in the lower Snake River reservoirs (*i.e.*, centrarchids, cottids, and ictalurids) generally have a deeper body depth or larger head diameter to length ratio, and also would not pass this opening. However, resident fish must be able to swim at a speed equal to or greater than the screen approach velocity to avoid becoming impinged on the screen.

Impacts to resident fish would likely be greatest for populations that migrate throughout the reservoir to-and-from spawning sites and for early life history forms that passively drift during larval development. For example, weakly swimming species or life stages would be most vulnerable to mortality from impingement. Abundant species that associate with juvenile salmonids (*i.e.*, juvenile catostomids and cyprinids) would be vulnerable to mortality during collection, sorting, and transport. Success in upriver movement through the facility by resident fish would be dependent on hydraulic characteristics of the fishway, the sensory-response behavior of resident fish life phases, and their swimming performance.

4. Terrestrial Ecology

The most obvious and among the most important effects of the migratory canal alternatives is the potential damage to various wildlife species and associated habitat along the route of the canal. The barge alternative would be unlikely to impact wildlife habitat. Damage from construction of the canal alternatives could come from a variety of project-related mortality factors (poaching, drowning, blasts, *etc.*), soil erosion and associated habitat reduction, direct habitat destruction, primary and cumulative interruption of migratory pathways, and invasion of competing species and/or disease. Other particularly important areas of concern include dams to wetlands, water quality, and aesthetics.

Impacts from excavation or disposal of fill associated with construction of the migratory canal would be realized at agricultural sites and in adjacent habitats. The right-of-way for the migratory canal would pass through several HMU's along the lower Snake River (Reed and Olney, 1994) and this, in addition to resting ponds which are proposed at 10-mile intervals, will remove mesic shrub habitat from these areas.

a. Wildlife and Habitat

The migratory canal alternative would 1) replace existing natural habitat with artificial structures; 2) could constitute a trapping hazard to some wildlife populations; and 3) would impose a migratory barrier to terrestrial and aquatic species. Staging areas and borrow pits would convert habitat to unusable areas for some species. Several aspects of the canal alternative raise concerns relative to migration. The canal project may cause a new barrier where there is none, and it may have a cumulative effect in an area where impediments currently exist (road/railroad). Effects may differ according to time of day and season. Even where the canal does not constitute an impassable barrier, it may have a directing or channeling effect that may make some species more vulnerable to predation.

The upstream collection facility will impact emergent habitat at Silcott Island by converting a shallow water area to deep water habitat (Reed and Olney, 1994), and subsequently affect Canada goose breeds. Additionally as a result of dredging, forage potential for colonial nesting species and raptors may be reduced. Conversion of shallow water habitat to a deep water channel will limit habitat potential for fish and waterfowl, primary forage species of these two groups.

Conversely, construction of the migratory canal may result in short-term increases in prey species abundant to raptors that forage in upland habitats. Overall, the canal should not significantly affect raptor species, however habitat conversion in riparian areas may reduce nest/perch opportunities.

Habitat conversion will affect 1,150 acres (Reed and Olney, 1994), including agricultural lands and HMU's along the projects. Development of this alternative should not impact upland game bird production, unless a significant number of acres are taken out of game bird habitat production.

b. Endangered Species

Several bald eagle and peregrine falcon nests occur along the route of the channel for the migratory canal. There is no conclusive evidence that any species of concern would be adversely impacted, but biological consultations and assessments pursuant to the Endangered Species Act would be required.

Construction of the migratory canal would convert riparian habitat and may reduce perching opportunities for bald eagles. Dredging the side channel at Silcott Island for development of the upstream collection facility will convert potential spawning and rearing habitat to deep water channel that may affect prey species abundance to bald eagles.

c. Wetlands

The alignment of the canal would impact wetlands within the Columbia River floodplain and will also likely cross numerous high order tributaries to the Columbia River. Primary, secondary, and cumulative impacts are likely to be significant. Many wetlands are situated adjacent to the river and are hydrologically connected to the Columbia and Snake Rivers. These sites provide breeding habitat for wildlife, escape cover for fish, and play a major part in nutrient cycling.

The migratory canal should not impact emergent habitat. Resting ponds that will be located every 10 miles may be designed to accommodate several emergent wetland species. New habitat that will be created can be designed to accommodate a variety of species, particularly small mammals and birds. Adequate planning and direction is the desired spinoff of this project. Diversity of habitat could be increased, but detailed and specialized study and designs will be requisite.

The upstream collection facility will impact emergent habitat at Silcott Island by converting a shallow water area to deep water habitat (Reed and Olney, 1994). The relevance of this impact is related to the proximity of the proposed activity to riparian vegetation of the Chief Timothy HMU and cumulative effects of the operation on adjoining riparian habitat. Development of these facilities will also eliminate any submergent vegetation that persists at the site currently.

d. Invasive Vegetation

The migratory canal will provide a transportation corridor for invasive plant species (*e.g.*, purple loosestrife, Russian olive, yellow flag). A vigorous invasive-species monitoring and corrective-action program should be incorporated into the proposed project.

5. Cultural Resources

All construction activity for fish collection facilities, barge loading facilities, elevated flumes, excavated canals, and fish resting ponds have the potential to affect significant prehistoric cultural resource sites or historic properties related to early Euroamerican exploration and settlement. Most sites that would be impacted are not now known because the fish migratory-canal alignment lies predominantly outside existing pool areas that have been covered by prior cultural resource inventory studies. Whereas the total inventory of sites is estimated to be substantially fewer than recorded for the floodplain bars, some kinds of sites, especially burials, are highly sensitive to regional Native American groups, and are estimated to be common for this project. A Programmatic Agreement for cultural resources would have to include several complex and costly elements, such as a methodology for complete archaeological and historic survey of the project area, evaluation of identified finds based on their potential eligibility for the National Register of Historic Places, appropriate mitigation for unavoidable adverse impacts, and the curatorial disposition and location for all finds made. The high potential for disclosing still more unmarked ancestral graves of local Native American groups also dictates a prearranged plan of action, for these finds that has been coordinated with the tribes. Since the extent and kinds of mitigation for cultural resources are the result of a consultative process (36 CFR Part 800), and lacking specific information regarding the numbers, types, and locations of affected cultural resource sites, it is not appropriate to attempt to address potential project effects on cultural resources until inventory surveys and site evaluations have been completed.

6. Construction

Much of the construction of the open channel and cut-and-cover channel will be performed along or near the banks of the Columbia and Snake Rivers. Some minor degradation of water quality in the rivers could occur from construction site water run-off.

7. Summary of Impacts From Collecting and Transporting Anadromous Fish

Upstream collector facilities and migratory canal alternatives present many unproven technological ideas. While current approach-velocity criteria were used in the initial design, these criteria were established for much smaller screening devices (2,000 cfs maximum) with short exposure times for fish. Given the estimated screen length, current approach-velocity criteria may be unsuitable. The ability to maintain desired water velocities through the screen with changes in river flow, wind/wave action, and debris-sediment load are also major concerns when scaling up current technology. If the upstream collector is to be considered further, design concepts addressing these concerns would need to be developed.

Modeling results indicate that benefits to anadromous salmons, above those currently achieved with turbine intake systems, could be realized with collection/transport systems. However, these benefits assume unrealistically high FGE (*e.g.*, 95%). Additionally, fall chinook salmon would tend to be collected before their normal rearing is completed. An upstream collection facility would be a barrier to upstream movement of resident fish--white sturgeon, in particular--which move up the Snake River from Lower Granite Reservoir to spawn. Downstream movement of fish entering the reservoir for rearing would also be affected, although resident fish could presumably be sorted and returned to the river.

The side channel at Silcott Island is currently excellent habitat for aquatic furbearers, waterfowl, and wading birds, because shallow-water emergent wetland and riparian habitats are present, and because of its proximity to the Chief Timothy HMU. Shallow water and emergent wetlands would be lost if the side channel was dredged, with a concurrent loss of wildlife value. Also, disturbance from human activity at the site would likely increase, further reducing wildlife value. Losses of wildlife habitat at the other proposed sites, beyond losses directly resulting from facility construction, are likely to be minimal. These facilities may also block furbearer movement, particularly river otter, in the river. The concentration of fish at these facilities may also attract river otters, which may then have to be trapped to reduce predation. This area is the primary goose nesting area for Lower Granite Reservoir. The displacement of habitat and the high activity levels in this area will have an adverse impact on the mitigated nesting population of Canada geese.

V. Uncertainty and Risk Analysis

A. Introduction

This chapter presents an analysis1 of the uncertainties and risks associated with the proposed drawdown of the Snake River, intended to increase survival of listed Snake River salmon stocks as they migrate from Lewiston, Idaho, to Bonneville Dam. The analysis is based on a systematic method that considers: 1) the smolt survival objective; 2) drawdown as a strategy to achieve this objective; 3) the operating assumptions needed to accept drawdown as a feasible strategy; 4) uncertainties associated with these assumptions; 5) the risk of drawdown not being a feasible strategy or of underlying assumptions turning out to be false; and 6) the need to monitor/manage the uncertainty and risk associated with drawdown of lower Snake River reservoirs.

Decision makers must weigh perceived risks and benefits through a variety of complex processes, which typically include intuitive and values-driven considerations. The process we used to identify the uncertainties and risks is illustrated in figure 5-1.

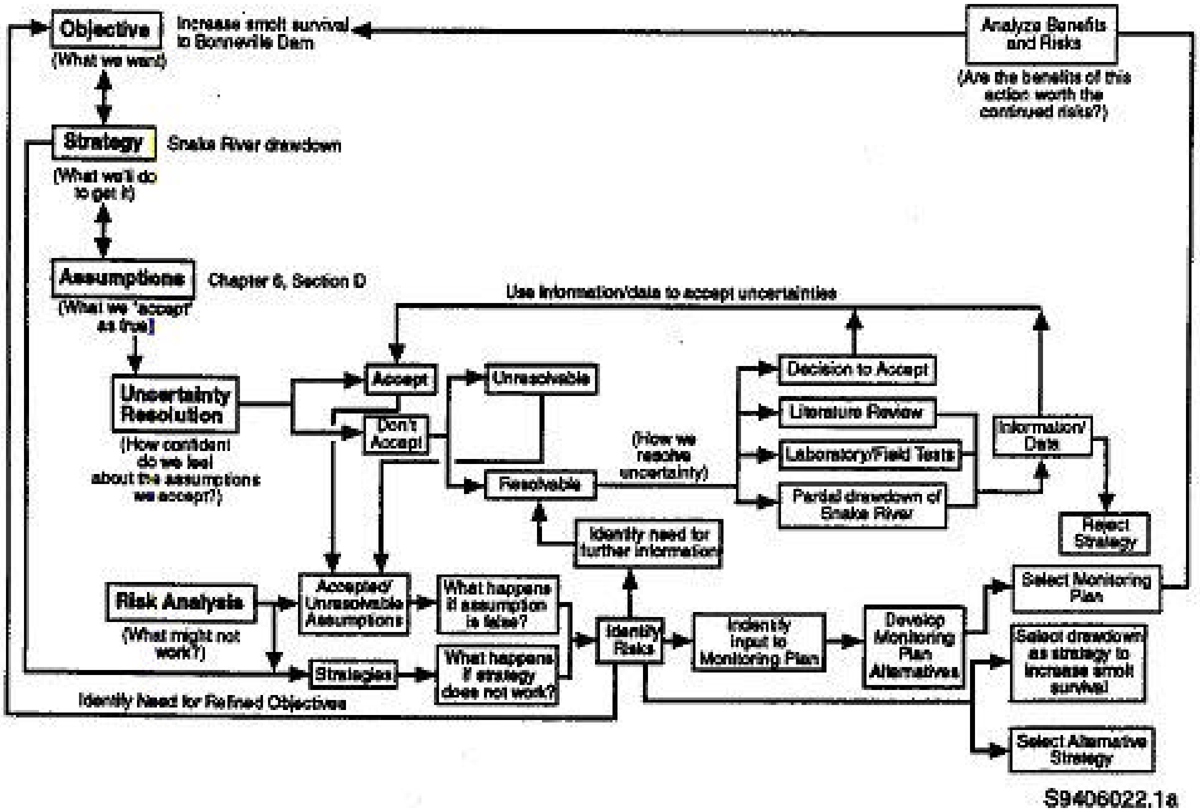

Figure 5-1. Schemata of the Process Used to Identify and Resolve Uncertainties and Identify and Monitor Risks

1. The Objective

The proponents of drawing down the Snake River from Lewiston, Idaho, to Ice Harbor Dam have stated the objective is to increase survival of downstream migrating smolts in the Lewiston-to-Bonneville-Dam reach of the Snake and Columbia Rivers (NPPC, 1993; Wik *et al.*, 1993). This objective is the basis for drawing down reservoirs in the lower Snake River even though survival through this reach has not been quantified. In addition to increased survival, smolts are expected to experience increased fitness for estuarine and early ocean survival without offsetting impacts to other salmonid life stages (*i.e.*, eggs, fry, adults). Increased survival will be accomplished while minimizing adverse impacts to non-target species of interest and to other uses of the river system (*e.g.*, for hydroelectric power generation, irrigation, navigation, recreation).

The U.S. Army Corps of Engineers was asked by the Northwest Power Planning Council (NPPC) to evaluate the effectiveness of drawdowns to meet the objective of decreasing travel time for migrating smolts and to determine if it was possible to increase their survival. Decreasing time for migrating smolts is not a new idea. The U.S. Army Corps of Engineers (COE) has been increasing river flows to speed salmon migrations since the Council's first fish and wildlife program.

Increasing smolt survival to Bonneville Dam does not guarantee that more adult salmon will return to the Snake River Basin. The problems with correlating smolt production and adult returns are a concern of NPPC (NPPC, 1987, 1994), COE, and Bonneville Power Administration. This is especially true where there are weak stocks competing with hatchery stocks for limited resources. This risk analysis follows from the objective to increase smolt survival, although this objective should be reevaluated before reservoir drawdown or any other strategy is implemented.

2. The Strategy (Drawdown)

The strategy under consideration is drawdown of lower Snake River reservoirs during smolt outmigration to decrease their travel time from Lewiston to Bonneville Dam. The various alternatives are described in greater detail in section III of this document.

B. Underlying Assumptions

The defined objective of drawdown and other operational alternatives focuses on increasing the survival rate of smolts migrating out of the Snake River and through the Columbia River to the estuary. The implied problem statement is: the survival rate of smolts migrating from the Snake River at Lewiston, Idaho, to the Columbia River at Bonneville Dam is low. The strategy (drawdown) is then proposed to increase survival of smolts from Lewiston to Bonneville Dam. Proponents of drawdown assume that 1) increased velocity of water in the reservoirs during outmigration will decrease travel time for smolts; and 2) that this decreased travel time will increase smolt survival.

Following is a list of critical assumptions related to implementation of drawdown as a strategy for increasing smolt survival. Acceptance implies a range of actions. Here we mean that an individual or agency 1) agrees or consents; 2) accommodates or reconciles; and, most importantly, 3) regards the assumption as true, valid, normal, or usual. If one or more of the following statements are not accepted as true, it may be necessary to find an alternative strategy to drawdown or, at a minimum, to monitor the results of implementing the strategy.

The following assumptions underline background activities of major life-cycle variables influencing experimental objectives.

1. Baseline information is adequate to evaluate effects of Snake River drawdown on smolt survival.

2. Construction activities needed for drawdown of Snake River reservoirs will not adversely affect survival of Snake River smolts.

3. Other environmental factors do not limit the smolt population; that is, increasing the number of smolts at Bonneville Dam by improving survival rtes will increase the numbers of all stocks of interest.

4. Habitat (*e.g.*, spawning, rearing, estuarine, ocean) will support increased adult returns and increased juvenile production.

5. Smolt fitness for adapting to estuarine and early ocean conditions depends on the time they arrive in the estuary.

It is further assumed that smolt survival from Lewiston, Idaho, to Bonneville Dam is an appropriate response variable to measure the success of drawdown. The following list of assumptions underlie selection of smolt survival was the response variable. No similar response variables have been developed to monitor impacts on non-target species and other river uses.

6. Smolt survival can be measured from point of origin to Bonneville Dam. An experiment can be designed and implemented to estimate survival rates. (This assumption implies that this measurement is the best measure of the potential benefits of drawdown. The experimental design has to be resolved; how many PIT-tagged fish are required to measure survival to Bonneville? What if estuarine or early ocean survival are the limiting factors? This survival cannot be measured.)

7. Smolt survival from the point of origin to Bonneville Dam can be estimated with a sufficiently low variance to permit smolt survival during drawdown to be compared with smolt survival during non-drawdown periods.

8. Survival rates for smolts are correlated with ling-term fitness and reproductive success of the population.

The decision to use drawdown to increase smolt survival during migration is based on the assumption that travel time for smolts will be decreased and that survival is independent of flow. The following list of assumptions underlie using drawdown as the means to decrease travel time.

9. Smolt survival through the affected reach is related to faster migration time. (Smolt mortality is directly related to migration time.)

10. Smolt behavior (*i.e.*, distribution, activity) does not change in a way that delays migration under drawdown conditions.

11. Mortality rates in reservoirs are related to travel time, not to location of exposure to the threat.

12. Mean water velocity increases in reservoirs from tailrace to forebay during drawdown.

13. Mean smolt travel time is proportional to mean water particle travel time.

The decision to use drawdown to increase smolt survival is based on the assumption that other behavioral and physiological characteristics of smolts will not be adversely affected. One can infer from the following list of assumptions that drawdown will not adversely affect smolt behavior or health.

14. Smolt distribution through the water column is similar under full-pool and drawdown conditions.

15. Drawdown does not offset increases in smolt mortality rates resulting from incidence of gas-bubble trauma.

16. Stranding and entrapment of smolts will be minimal during drawdown.

17. Drawdown does not increase pre-spawning mortality caused by delaying adult migration.

18. Stranding and entrapment of adult fish will be minimal.

19. Returning adults will not be adversely impacted by changing their homing and straying rates.

20. Genetic integrity of stocks will be maintained.

21. Relative survival of hatchery- and naturally-produced fish is unchanged and does not change the survival potential of wild fish.

22. Ocean survival will remain unchanged or increase if drawdown is used to increases smolt-to-smolt survival.

The decision to use drawdown to increase smolt survival during migration is based on the assumption that there are no adverse ecological interactions. The following assumptions relate to ecological interactions of smolts with both the abiotic and biotic environment expected during drawdown.

23. Drawdown does not cause offsetting increases in smolt mortality rates from predation (*e.g.*, due to crowding of smolts or predators).

24. Drawdown does not cause offsetting increases in smolt mortality rates from disease pathogens.

25. Productivity of food organisms remains sufficiently high to meet smolt needs during outmigration.

26. The availability, quality, and quantity of spawning-habitat will not be adversely impacted.

27. Adult access to tributary streams will not be impaired.

The decision to use drawdown to increase smolt survival during migration assumes that the dams and reservoirs can and will be operated to achieve benefits associated with decreased travel time. The following assumptions relate to dam and reservoir operation in the lower Snake River.

28. Drawdown does not offset increases in smolt mortality rates by changing passage conditions through the turbines or following passage through the turbines.

29. Drawdown does not offset increases in smolt mortality rates by changing passage conditions over the spillways.

30. Drawdown does not offset increases in smolt mortality rates by changing passage conditions through the juvenile bypass system.

31. Fish guidance efficient at the dams is not decreased during drawdown.

32. Diversion mortalities and impingement rates on barrier screens are not increased.

33. Bypass facilities can be modified to mitigate potential problems associated with drawdown.

34. Gatewell operations, relative to bypass facilities, at the dams will not be affected with regard to smolt survival.

35. Gatewell operations at the dams, relative to bypass facilities, will not be affected with regard to predation on smolts.

36. Adult fish passage facilities can be modified to mitigate reduced efficiency/increased mortality, if any.

37. Survival and upstream migration success will not be adversely affected (*e.g.*, by difficulties with passage facilities).

38. Sufficient attraction water can be provided to guide adults to fish ladder entrances.

39. Spillways can be modified to mitigate potential problems associated with drawdown (*i.e.*, drumgates can be made to not substantially increase juvenile mortality).

The decision to use drawdown to increase smolt survival is based on the assumption that non-target species will not be adversely affected. The following assumptions relate to potential impacts to non-target species in the reservoirs that will be drawn down in the lower Snake River.

40. Habitat availability and habitat quality, or habitat quantity for resident species and non-listed stocks will not be significantly impacted by lowered water levels.

41. Food production (*e.g.*, aquatic invertebrates and benthic organisms) for resident species and non-listed stocks will be adequate during drawdown.

42. Disease incidence and mortality for resident species and non-listed stocks will not be significantly increased.

43. Predation mortality for resident species and non-listed stocks will not be significantly increased.

44. Water quality and temperature changes will not significantly impact non-target species.

45. Eggs and juveniles of resident and non-listed stocks will not be significantly impacted by exposure or stranding.

The decision to use drawdown to increase smolt survival is based on the assumption that management of harvest, habitat, hatcheries, and fisheries-related institutions will not be adversely affected. The following list of assumptions relate to potential changes to harvest, habitat, hatchery, and other fisheries-related institutions that may result from drawdown.

46. Harvest management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt-to-smolt survival in the lower Snake River.

47. Habitat management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt-to-smolt survival in the lower Snake River.

48. Hatchery management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt-to-smolt survival in the lower Snake River.

In summary, for drawdown to be considered a viable option, all the above assumptions must be either: 1) accepted as true; or 2) their uncertainties resolved until acceptable; or 3) their uncertainties accepted as unresolvable. The associated risk can be monitored if it is important to understanding or resolving the strategy. The process for dealing with the uncertainties is discussed in the following section.

C. Uncertainties Associated with Assumptions

Any statement of an assumption implies some degree of uncertainty. For example, drawdown may not be achieveable within a planned timeframe or for a given quantity or frequency of occurrence. How conditions we are in these assumptions is important. These assumptions are the basis for selecting drawdown to increase smolt survival. If drawdown is the wrong strategy, it might seriously damage anadromous fish populations in the Snake River or it could result in the fruitless expenditure of monies.

Before implementing drawdown as the strategy to increase smolt survival, we need to examine and analyze these assumptions. Which assumptions can we accept without any further information? Which assumptions cannot be accepted on the basis of existing information or perceived risk? That is, do we need more information before we make a decision? Some of the uncertainty associated with assumptions about the proposed strategy can be resolved. However, the decision makers will want more information before accepting these assumptions. More information usually comes through research. The method used to conduct this research (*i.e.*, literature review, field studies, modeling) depends on what information is needed, how long it might take to get the information, and the cost of getting the information (figure 5-2). Some critical assumptions may prove to be unresolvable. That is, no matter how long we study the issue, we could never hope to have all the answers.

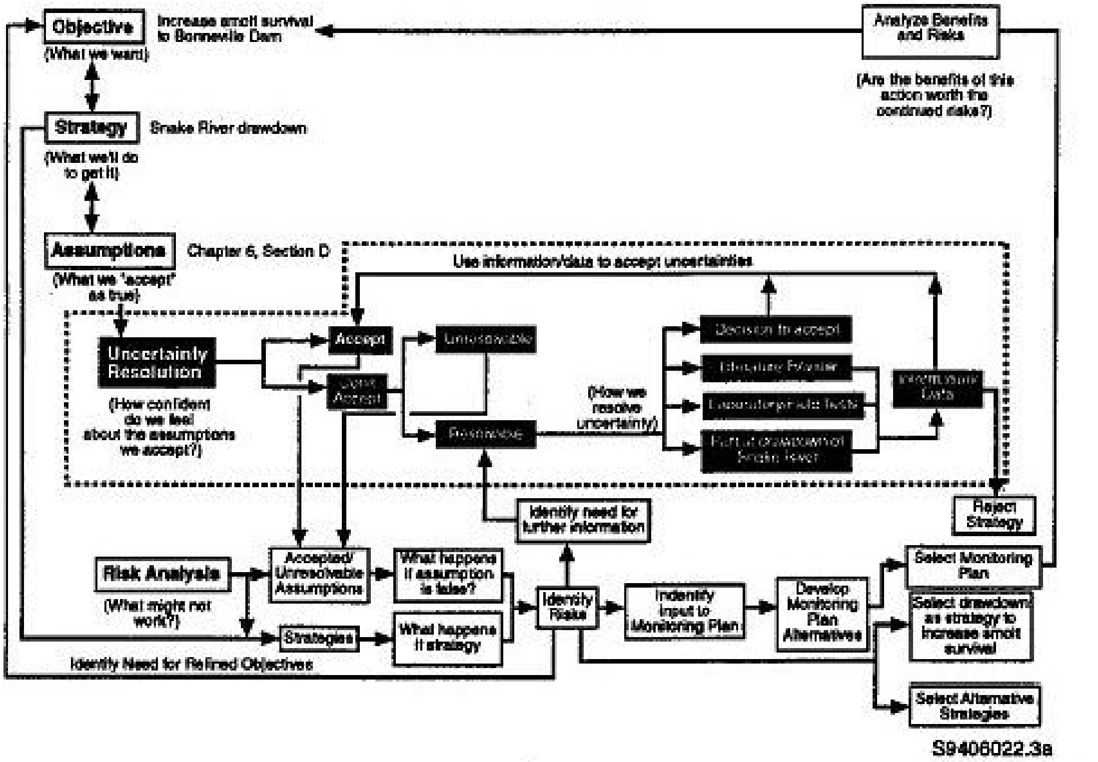

Figure 5-2. Schematic of Uncertainty-Resolution Process

1. Acceptable Uncertainties

Some assumptions related to drawdown are "accepted" on the basis of existing knowledge and information, pending documentation. Acceptance of an assumption implies that 1) the uncertainty associated with a given assumption has little potential of adversely affecting the accomplishment of the objective (increased smolt-to-smolt survival); or 2) so much is known about this particular biological/ecological/engineering relationship that further study is not justified in the context of drawing down the Snake River.

The following assumptions can be accepted, with the understanding that an assumption found to be false will not adversely affect the objective of increased smolt survival between Lewiston, Idaho, and Bonneville Dam. For example, in assumption #41, a less-than-adequate food supply for redside shiners during drawdown would probably not affect smolt survival. Other assumptions may be perceived as being high risk to the population during drawdown (*i.e.*, #17. Drawdown does not result in increased pre-spawning mortality caused by delays in adult migration), but would not affect the objective of increasing smolt survival. Assumptions that are not accepted, based on the criteria established include:

8. Survival rates for smolts are correlated with long-term fitness and reproductive success.

The underlying basis for increasing smolt survival is dependent on increased return of reproductively successful adults that are fit and able to withstand unpredictable and uncontrollable changes in the environment. It would make no sense if those agencies and individuals that advocate drawdown to increase smolt survival believed that increasing the number of smolts could adversely impact the survival of the species. Included in this statement is the assumed resolution of the potential conflicts between short-term gains (more juveniles) and long-range benefits (a reproductively fit population).

12. Mean water velocity increases in reservoirs from tailrace to forebay.

Based on the hydrological data presented in sections 3 and 4, we assume that the mean water velocity from tailrace to forebay will increase when the reservoirs are drawn down, compared to water velocities present during current operations.

17. Drawdown does not result in increased pre-spawning mortality caused by delays in adult migration.

This assumption relates to the long-term fitness of adults. The objective for drawdown is to increase juvenile survival to Bonneville Dam. When the decision is made to select drawdown as a strategy, increased pre-spawning mortality is not considered a high risk. Thus, any pre-spawning mortality that occurs because of drawdown must be accepted.

18. Stranding and entrapment of adult fish will be minimal.

This assumption relates to the long-term fitness of adults. The objective for drawdown is to increase juvenile survival to Bonneville Dam. When the decision is made to select drawdown as a strategy, stranding and entrapment of adults is not considered a high risk. Thus, any stranding and entrapment of adults that occurs because of drawdown must be accepted.

19. Returning adults will not be adversely impacted through changes in homing and straying rates.

This assumption relates to the long-term fitness of adults. The objective for drawdown is to increase juvenile survival to Bonneville Dam. When the decision is made to select drawdown as a strategy, straying rates of adults is not considered a high risk. Thus, any straying of adults that occurs because of drawdown must be accepted.

26. Spawning-habitat availability, quality, and quantity will not be adversely impacted.

This assumption relates to the long-term fitness of adults. The objective for drawdown is to increase juvenile survival to Bonneville Dam. When the decision is made to select drawdown as a strategy, impacts to the quality and quantity of spawning areas are not considered a high risk. Thus, any adverse change in the quality and quantity of spawning habitat that occurs because of drawdown must be accepted.

27. Adult access to tributary streams will not be impaired.

This assumption relates to the long-term fitness of adults. The objective for drawdown is to increase juvenile survival to Bonneville Dam. When the decision is made to select drawdown as a strategy, lack of adult access to tributary streams is not considered a high risk. Thus, any adverse impacts from adults not being able to access tributary streams because of drawdown must be accepted.

40. Habitat availability, habitat quality, or habitat quantity for non-target fish (resident species and non-listed stocks) will not be adversely impacted by reduced water levels.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River. When the decision is made to select drawdown as a strategy, impacts to the habitat availability, habitat quality, and habitat quantity for non-target fish are not considered a high risk. Thus, any reduction of adverse change in the habitat of non-target fish that occurs because of drawdown must be accepted.

41. Food production (*e.g.*, aquatic invertebrates and benthic organisms) for resident species and non-listed stocks will be adequate during drawdown.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River. When the decision is made to select drawdown as a strategy, impacts to food of non-target species is not considered a high risk. Thus, any reduction or adverse change in the food production for non-target fish that occurs because of drawdown must be accepted.

42. Disease incidence and mortality for resident species and non-listed stocks will not be significantly increased.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River. When the decision is made to select drawdown as a strategy, increased incidence of disease and mortality for non-target fish is not considered a high risk. Thus, any increase in disease or mortality of non-target fish that occurs because of drawdown must be accepted.

43. Predation mortality for non-target fish (resident species and non-listed stocks) is not increased.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River. When the decision is made to select drawdown as a strategy, predation on non-target species is not considered a high risk. Thus, any predation on non-target fish that occurs because of drawdown must be accepted.

44. Water quality and temperature changes do not impact non-target species.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River. When the decision is made to select drawdown as a strategy, the potential changes in the water quality for non-target species is not considered a high risk. Thus, any changes in the water quality that may impact non-target fish occurring because of drawdown must be accepted.

45. Eggs and juveniles of resident and non-listed stocks will not be significantly impacted by exposure or stranding.

This assumption relates to the potential impacts to all fish, other than the anadromous salmonids that outmigrate through the lower Snake River. The objective for drawdown is to increase juvenile survival for the anadromous salmonids that outmigrate through the lower Snake River.. When the decision is made to select drawdown as a strategy, dewatering or stranding of resident fish is not considered a high risk. Thus, any impacts to non-target fish that occur because of drawdown must be accepted.

2. Unacceptable Uncertainties

Some uncertainties have been resolved as a result of this analysis and other recent studies (*e.g.*, SOR process, model studies at WES). However, there are many other uncertainties that must be resolved before a decision to initiate drawdown of lower Snake River reservoirs. There are also different categories of uncertainties (*i.e.*, each with different degrees of risk). Four methods are listed here as means of generating information to resolve those uncertainties that cannot be accepted based on existing information: 1) review of new scientific information; 2) examine data from outside the Snake River Basin; 3) conduct small-scale short-term studies (*i.e.*, in the field and laboratory, with modeling exercises and engineering analyses); and 4) learn from a partial (one- or two-reservoir) drawdown of the Snake River (figure 5-5).

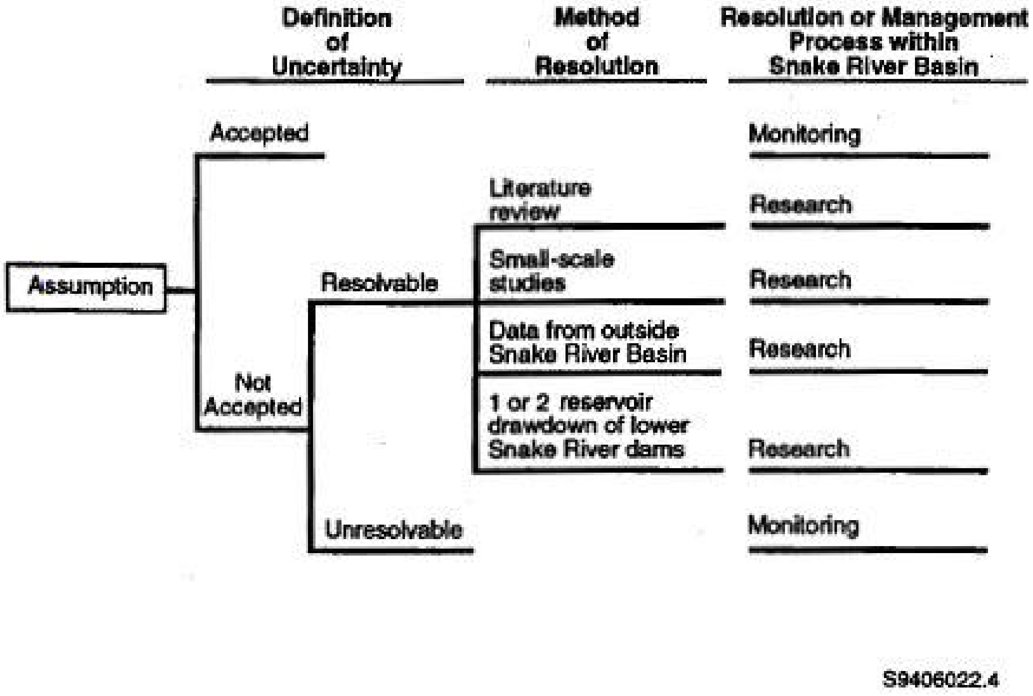

Figure 5-3. Schematic of Uncertainty Resolution/Management Process

a. Resolvable Uncertainties

Resolvable uncertainties are uncertainties that we believe can be resolved with additional information. Following are critical resolvable assumptions. The cost and time required to conduct an engineering study and accomplish and test a facility modification should provide information sufficient to resolve the uncertainty associated with these assumptions. This information is necessary to make a decision about drawing down the Snake River. If one or more of the assumptions later prove false, then drawdown will not increase smolt survival.

1. Baseline information is adequate to evaluate effects of Snake River drawdown on smolt survival.

There are some baseline data that are needed to adequately evaluate smolt survival. For example, what is the current intrareach survival? How does survival vary among species and with changing environmental conditions? Many of the baseline information assumptions based on Sims and Ossiander (1981) have been used for setting parameters in the passage models used to assess baseline conditions. However, Steward (1994) recommended that this flow-survival relationship not be generalized to existing populations and conditions. Thus, additional information should be collected from field studies conducted in the Snake River before another drawdown test is conducted.

Iwamoto *et al.* (1994) recently conducted a pilot study to estimate survival of hatchery-reared chinook salmon through lower Snake River dams and reservoirs. They reported that accurate estimates of juvenile salmon passage survival through individual reaches and projects could be obtained. Studies are ongoing to obtain additional baseline information needed to evaluate the effectiveness of drawdown for increasing smolt survival. The challenge will be to isolate causal factors contributing to any change in survival during drawdown or other change in operations strategy (see Section IV.A.3.b-c for additional discussion).

4. Habitat (*e.g.*, spawning, rearing, estuarine, ocean) will support increased adult returns and increased juvenile production.

Spawning and rearing habitat inventories are currently being conducted in the Snake River Basin. Habitat quality has declined historically in the Snake River Basin (Chapman and Witty, 1993) and current conditions do not permit maximum smolt production based on escapements over Lower Granite Dam. The consequences of this freshwater habitat degradation, combined with changes in ocean productivity are difficult to discern (Lichatowich, 1993). The adequacy of the habitat to support increased salmon production can also be assessed using life-cycle models, but the adequacy of estuarine and ocean habitat is probably unresolvable. Some of these issues are address by the life-cycle models used to assess the potential results of drawdown. For example, SCLM has a density dependent term that accounts for spawning habitat. Rearing habitat is assumed to be unlimited. The portion of this assumption that deals with estuarine and ocean survival is included in the unresolvable section of this plan (see Section IV.A.d for additional discussion on model application and limitations.

5. Smolt fitness for adapting to estuarine and early ocean survival depends on the time they arrive in the estuary.

More information is needed on the relationship between arrival time in the estuary and smolt-to-smolt survival, especially as related to the timing differences among species and runs. Limited information suggest that changes in estuarine conditions (*i.e.*, nutrient supplies have occurred during the last century (Weitkamp, 1993). Whether these changes, superimposed upon changes in the timing and composition of salmonid populations has affected the carrying capacity of the Columbia River estuary is unknown. This information may be obtainable through a combination of field and laboratory research. However, the life-cycle and passage models do not address this issue (see Section IV.A.3.b for additional discussion).

6. Smolt survival can be measured; an experiment can be designed and implemented to estimate survival.

The experimental design, sampling schedules, sample size, and specific hypothesis to be analyzed can all be examined with models. This should be completed before selecting a strategy to increase smolt survival. Additionally, inriver investigations of smolt survival could be improved by installing deflectors and diversion systems at lower Columbia River dams, including Bonneville (Iwamoto, 1994).

7. Smolt survival can be estimated with a sufficiently low variance to permit comparison of smolt survival during drawdown with smolt survival during non-drawdown periods.

Dauble *et al.* (1993) recently reviewed various methods used for estimating smolt survival through the Columbia River system and concluded that these methods failed to provide either an assessment of bias or any measure of precision. Recently, Iwamoto (1994) reported that the Single-Release and Paired-Release models described in Dauble *et al.* (1993) and Burnham *et al.* (1987), respectively, could provide estimate of juvenile passage survival. However, basic facilities (*i.e.*, detectors and bypass systems) do not exist throughout the Columbia River, downstream to Bonneville Dam. Thus, this information will have to be examined using existing passage models (see Section IV.A.3.f. for additional discussion on model application and limitations).

15. Drawdown does not cause offsetting increases in smolt mortality rates resulting from gas bubble disease incidence.

The questions related to gas-bubble trauma can be addressed with additional laboratory studies, some of which are currently underway at different research groups. Additional information on the relationship between drawdown and dissolved gas levels is discussed in Sections 3 and 4 of this plan. However, the issue of predation susceptibility during or following gas bubble trauma needs to be addressed. Mortality from gas bubble trauma is a major component of total fish mortality during migration in CRiSP, one of the passage models used to assess potential impacts of drawdown. CRiSP output assumes a lower net survival than PAM or FLUSH (two other passage models), because PAM accounts for differences in water quality during drawdown. PAM and FLUSH assume the conditions described by Sims and Ossiander (1981), however, the conditions in these models are different than those expected during drawdown.

25. Production of food organisms remains sufficiently high to meet smolt needs during outmigration.

Current passage and life-cycle models do not address this issue. Currently, the only sources of mortality in the models are gas bubble trauma and predation. However, this concern may be resolved by field studies that are in progress on the Snake River. There is limited information on the feeding habits of juvenile salmonids and the abundance of prey species under current conditions (Bennett *et al.*, 1988, 1992). Additional studies of reservoir limnology and productivity may yield baseline data useful for assessing the impacts of reservoir drawdown on secondary production.

If one or more of the following assumptions later prove false, then drawdown will not increase smolt survival. The cost and time required to conduct an engineering study and a drawdown of one or two reservoirs[2] should provide the information needed to resolve the uncertainty related to these assumptions. This information is necessary to make a decision about drawing down the Snake River as a long-term solution to increasing smolt survival from Lewiston, Idaho, through Bonneville Dam.

9. Smolt survival through the affected reach is related to faster migration time. (Smolt mortality is directly related to delayed migration time.)

The relationship between smolt survival and migration time through the lower Snake River reservoirs will probably only be resolved by drawing down two reservoir pools during smolt migration.

10. Smolt behavior (*i.e.*, distribution activity) does not change in a way that delays migration under drawdown conditions.

The scientific literature addresses many of these smolt behavior issues. Some of this information is discussed in Sections 3 and 4 of this plan. There are some issues that will only be resolved when fish are observed during an actual drawdown. A well designed experimental approach to these issues could be addressed during one reservoir drawdown.

13. Mean smolt travel time is proportional to mean water particle travel time.

The relationship between smolt survival and migration time through the lower Snake River reservoirs will probably only be resolved by drawing down two reservoir pools during smolt migration.

21. Relative survival of hatchery- and naturally-produced fish is unchanged and does not change the survival potential of wild fish.

The relationship between smolt survival and migration time through the lower Snake River reservoirs will probably only be resolved by drawing down two reservoir pools during smolt migration.

28. Drawdown does not offset increases in smolt mortality rates by changing passage conditions through the turbines or following passage through the turbines.

30. Drawdown does not offset increases in smolt mortality rates by changing passage conditions through the juvenile bypass system.

The relationship between smolt survival and migration time through the lower Snake River reservoirs will probably only be resolved by drawing down two reservoir pools during smolt migration.

31. Fish guidance efficiency at the dams is not decreased during drawdown.

The fish guidance efficiency at each dam will only be known from observations and measurements taken during drawdown conditions.

32. Diversion mortalities and impingement rates on barrier screens are not increased.

The impingement on the barrier screens at each dam will only be known from observations and measurements taken during drawdown conditions.

33. Bypass facilities can be modified to mitigate potential problems associated with drawdown.

The impingement on the barrier screens at each dam will only be known from observations and measurements taken during drawdown conditions.

34. Gatewell operations at the dams, related to bypass facilities, will not be affected with regard to smolt survival.

The performance of the gatewells during drawdown will only be known from observations and measurements taken during drawdown conditions.

36. Adult fish passage facilities can be modified to mitigate reduced efficiency increased mortality, if any.

The performance of the adult passage facilities during drawdown will only be known from observations and measurements taken during drawdown conditions.

37. Survival and upstream migration success will not be adversely affected (*e.g.*, by difficulties with passage facilities).

The performance of the passage facilities during drawdown will only be known from observations and measurements taken during drawdown conditions.

38. Sufficient attraction water can be provided to guide adults to fish ladder entrances.

The performance of the attraction during drawdown will only be known from observations and measurements taken during drawdown conditions.

39. Spillways can be modified to mitigate potential problems associated with drawdown.

The impacts of drumgates on juvenile passage mortality will only be known from observations and measurements taken during drawdown conditions.

Resolvable uncertainties are a high priority in the near term, because they affect the ability to select drawdown as a viable strategy for increasing smolt survival for a long time into the future. The outcomes of literature reviews, small-scale tests, or one- or two-reservoir drawdowns can modify details of the selected strategy to increase smolt survival in the Snake River. However, short-term results are not expected to fundamentally change the objective, but to help ensure its success. The purpose of small-scale studies and planning is to "set up" the selected strategy. Consequently, it is important to define a selected strategy in sufficient detail to sharply focus planning on the stated objective.

b. Unresolvable Uncertainties

Some critical uncertainties are not expected to be resolved before a decision on Snake River drawdown is made. Even if the uncertainty is studied during an actual test drawdown of the river, these uncertainties could still take many years to resolve. For most, resolution is not feasible, and all extend beyond the experimental/testing scope of Snake River drawdown. However, the risk that any of these assumptions are false should be assessed and the risks managed through monitoring. While these uncertainties cannot be resolved, the health and condition of the Snake River anadromous fisheries can be monitored for signs of unexpected change. On the basis of new information and other evidence, drawdown or any other strategy to increase smolt-to-smolt survival will need to be reevaluated.

Following are critical assumptions that are unresolvable within the timeframe for decision making. The cost and time required to quantify every causal relationship to smolt survival are prohibitive. Many other factors that limit the recovery of Snake River salmonids, besides "smolt survival," have not been defined or quantified, and may not be before a decision on drawdown is implemented.

2. Construction activities needed for drawdown of Snake River reservoirs will not adversely affect survival of Snake River smolts.

3. Other environmental factors do not limit the smolt population; that is, increasing the number of smolts at Bonneville Dam by improving survival rates will increase the number of all stocks of interest.

4. Habitat (*e.g.*, spawning, rearing estuarine, ocean) will support increased adult returns and increased juvenile production.

11. Mortality rates in reservoirs are related to travel tie, not to location of exposure to the threat.

20. Genetic integrity of stocks will be maintained.

22. Ocean survival will remain unchanged or increase if drawdown is used to increase smolt survival.

23. Drawdown does not cause offsetting increases in smolt mortality rates from predation (*e.g.*, due to crowding of smolts or predators).

24. Drawdown does not cause offsetting increases in smolt mortality rates from disease pathogens.

34. Gatewell operations, relative to bypass facilities, at the dams will not be affected with regard to smolt survival.

46. Harvest management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt survival in the lower Snake River.

47. Habitat management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt survival in the lower Snake River.

48. Hatchery management will either remain unchanged or will not change in such a way as to adversely impact benefits of drawdown to increase smolt survival in the lower Snake River.

In review, the required steps in the uncertainty process are: 1) quantitatively state the objective (increased smolt survival)3; 2) clearly define the strategy (draw down the Snake River) and its underlying assumptions to defend the selection of the strategy; and 3) examine the associated uncertainties to determine those uncertainties that require resolution before implementing the strategy. Next, we must identify the risk associated with 1) having selected the wrong strategy; and/or 2) accepting assumptions that later prove false.

D. Risk Analysis

The risks involved in drawing down the Snake River to increase smolt survival from Lewiston, Idaho, to Bonneville Dam lie both in the selected strategy and its underlying assumptions. If the strategy proves unfeasible or does not perform as expected, survival will not increase (unless for other reasons than drawdown). Additionally, if any assumptions later proved false, this could mean that smolt survival may not increase and, perhaps further, that survival may decrease or some other unwanted result may occur.

The technical staff for each decision maker will need to determine which risks apply to 1) the possibility that the overall strategy of drawdown simply does not work; or 2) that one or all of the underlying assumptions prove false. The decision maker should then weigh the risks relative to the potential benefits and decide how to proceed in the face of inevitable uncertainty. A decision to implement drawdown must, therefore, be preceded by a systematic risk evaluation to detect and permit correction of unforeseen errors (figure 5-4). The following questions related to feasibility, uncertainty, risk monitoring, and alternative strategies from the structure of an evaluation process for Snake River drawdown.

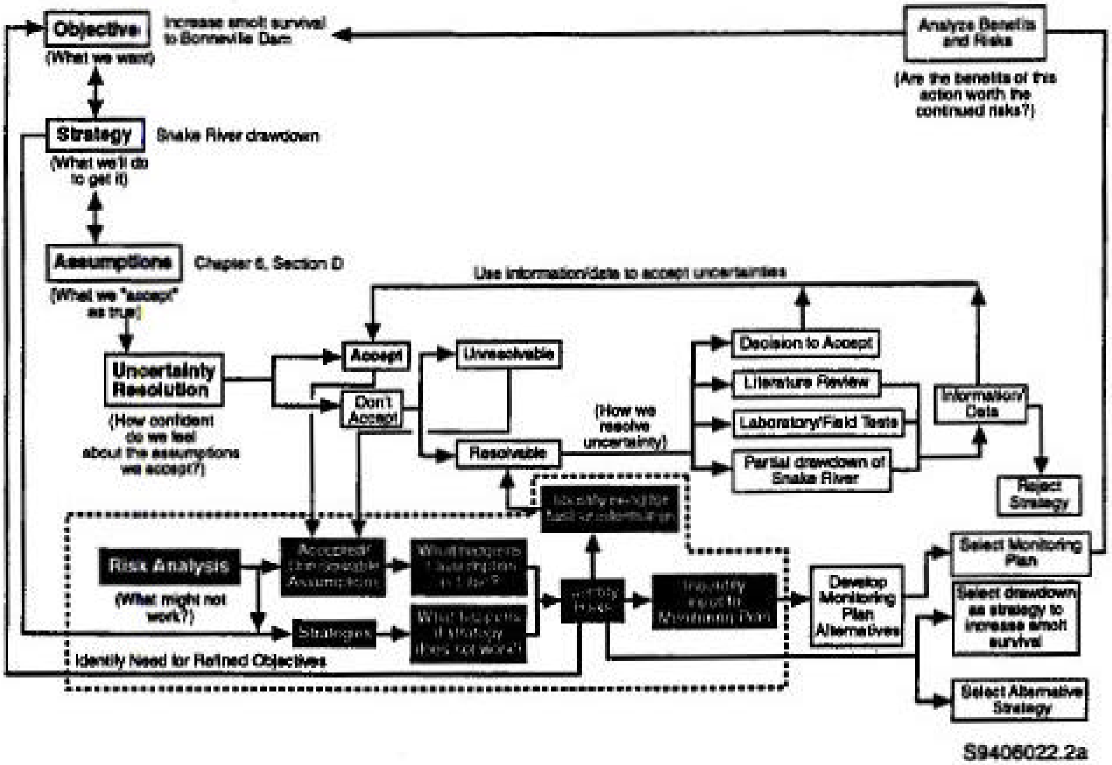

Figure 5-4. Schematic of Risk Analysis and Monitoring Process

1. **Are the strategies sufficiently well defined and are they feasible? If not, why not? What is missing? Are assumptions related to feasibility of facilities and operations (including monitoring) accepted? (If accepted; reports, documents, or study results that address the specifics are available.)**

   a. **Is drawdown well defined?** No. A wide range of options is being considered. This risk analysis, along with other assessments in this Phase I Biological Plan, assumes "that all lower Snake River reservoirs will be operated at some lowered pool elevation (*i.e.*, MOP, spill crest) during all or part of the juvenile fish outmigration period (15 April-31 August)." The risk analysis also assumes that "reservoirs would be returned to normal operating pool elevations" following drawdown (see Section III).

b. **If drawdown is not well defined, why not?** There are five categories of alternatives that describe or define drawdown and a total of nine specific alternatives, each requiring modification to the dams or spillways, existing facility operations, and adult passage facilities. All alternatives, with the exception of the Natural River Option, will require new lower-level juvenile fish bypass facilities. Fish barging on the lower Snake River would cease during drawdown.

c. **What is missing?** A decision to proceed with one of the options.

d. **Are the assumptions accepted?** No. There are many critical assumptions that could be tested before a decision to draw down the Snake River is used to increase smolt survival.

2. **What are the risks associated with accepted and unresolvable uncertainties? (Risk refers to the likelihood of failing to meet the stated objective of drawing down the Snake River during smolt outmigration.) What are the implications of increasing smolt survival by drawdown if the underlying assumptions prove false? And what is the likelihood that some accepted assumptions *do* prove false?**

The risks of drawdown are defined by 1) the possibility that the strategy of drawdown will not work; or 2) the probability that one or all underlying assumptions prove false, with the result of not increasing smolt survival and/or perhaps realizing some unwanted result. Six types of risk requiring analysis relate to Snake River drawdown:

a. **Extinction.** Productivity of the target species (Snake River salmonids) is reduced to a level from which it cannot recover, and eventually the species or stock no longer exists.

b. **Loss of access to or availability of abiotic habitat.** The physical or chemical component of the habitat becomes limiting (*e.g.*, no spawning gravel, loss of wetlands, pollution) and the benefits of increased smolt survival are realized.

c. **Loss of access to or availability of biotic habitat.** The biological component of the habitat becomes limiting (*e.g.*, predation, disease, loss of food organisms) and the benefits of increased smolt survival are not realized.

d. **Change in behavior or physiology of the target species.** Long-term fitness, reproductive success, or early-life-history survival of the target species is adversely affected.

e. **Adverse ecological interactions.** Productivity and survival of non-target species in the Snake River are adversely affected.

f. **Unresolvable engineering or management issues.** Management or engineering problems cannot be accomplished to realize the benefits of increased smolt survival (*e.g.*, no fish passage facilities at the dams, harvest management not regulated to protect Snake River salmonids).

3. **What are the implications to the stated objective, if an assumption proves false?**

The implication lies in specifically associating one or all of the above defined risks with the accepted and unresolvable assumptions (tables 5-1 and 5-2).

Table 5-1
Risks Associated With Each Accepted Assumption Underlying Drawdown of the Lower Snake River

The question one must ask about each accepted assumption underlying drawdown to increase smolt survival		Risk to Snake River salmonids and non-target species if assumption is false
8.	What if smolts traveling from Lewiston, Idaho, to Bonneville Dam are not as fit and their reproductive success is decreased because of drawdown?	Change in the behavior or physiology of the target species.
12.	What if mean water velocity does not increase in reservoirs from tailrace to forebay?	Change in the behavior or physiology of the target species. Loss of access to or availability of abiotic habitat.
17.	What if drawdown causes increased prespawning mortality from delaying adult migration?	Loss of access to or availability of abiotic habitat. Unresolvable engineering or management issues.
19.	What if returning fish are adversely impacted through changes in homing and straying runs?	Change in the behavior or physiology of the target species.
26.	What if spawning habitat availability, quality, and quantity are impacted?	Loss of access to or availability of abiotic habitat.
27.	What if adult access to tributary streams is impaired?	Loss of access to or availability of abiotic habitat.
40.	What if habitat availability, habitat quality, or habitat quantity of non-target (resident species and non-listed stocks) are impacted by lowered water levels?	Adverse ecological interactions.
41.	What if food production is not adequate for non-target (resident species and non-listed stocks) are impacted by lower water levels?	Adverse ecological interactions.
42.	What if disease incidence and mortality for non-target (resident species and non-listed stocks) increase?	Adverse ecological interactions.
43.	What if predation mortality for non-target (resident species and non-listed stocks) increases?	Adverse ecological interactions.
44.	What if water quality and temperature changes impact non-target species?	Adverse ecological interactions. Loss of access to or availability of abiotic habitat.

Table 5-2
Risks Associated With Each Unresolvable Assumption Underlying Drawdown of the Lower Snake River

	Unresolvable assumption underlying reservoir drawdown as feasible to increase smolt survival	Risk to Snake River salmonids and non-target species if assumption is false
2.	What if construction activities needed to draw down the reservoirs adversely affects survival of smolts?	Loss of access to or availability of abiotic habitat.
3.	What if other environmental factors limit the population; that is, an increase in the number of smolts reaching Bonneville Dam does not increase production for all stocks of interest?	Loss of access to or availability of abiotic habitat.
11.	What if rates of mortality are not related to migration time, but to location of exposure to a threat?	Loss of access to or availability of abiotic habitat.
14.	What if smolt distribution through the water column is such that smolts do not realize the benefits of drawdown?	Loss of access to or availability of abiotic habitat. Change in the behavior or physiology of the target species.
20.	What if genetic integrity of stocks is not maintained?	Change in the behavior or physiology of the target species.
22.	What if ocean survival for smolts decreases from drawdown?	Loss of access to or availability of abiotic habitat.
23.	What if drawdown causes offsetting increases in smolt mortality rates from predation due to crowding of smolts or predators?	Loss of access to or availability of abiotic habitat.
24.	What if drawdown causes offsetting increases in smolt mortality from disease pathogens?	Loss of access to or availability of abiotic habitat.
35.	What if gatewell operation ad dams adversely affects predation on smolts?	Unresolvable engineering or management issues.
44.	What if water quality and temperature changes impact non-target species?	Adverse ecological interactions.
46.	What if harvest management changes or does not work if drawdown is used?	Unresolvable engineering or management issues.
47.	What if habitat management changes or does not work if drawdown is used?	Unresolvable engineering or management issues.
48.	What if hatchery management changes or does not work if drawdown is used?	Unresolvable engineering or management issues.

4. **What is the likelihood that some accepted assumptions prove false?**

   Likelihood or probability that these assumptions are wrong cannot be quantified. The sensitivity of the relative information or data must be examined using projection models that incorporate or account for the mechanisms by which drawdown measures a specific endpoint; in this case, we would be measuring smolt survival. (A risk assessment to provide a quantitative estimation for some of the effects of drawdown alternatives is presented in Section VII of this Phase I Biological Plan.)

5. **What alternatives to drawdown are feasible (including taking no action) and what are their implications? (Implications refer to the risks, costs, and other impacts of the alternatives.) Are there alternatives to using drawdown to increase smolt survival for which the risks and implications are less severe? What are the implications of delaying drawdown? Can some of the critically uncertain assumptions be effectively resolved through literature review or near-term studies? If so, should the be resolved by experiments, studies, or modeling before implementation of drawdown?**

   Five groups of drawdown alternatives for the Snake River are described in Section III of this Phase I Biological Plan. The potential impacts of these alternatives are discussed in Section IV. Additionally, there are three alternatives to drawdown (Upstream Storage, Anadromous Fish Collection and Transport, Existing System Improvements) discussed in Section III. All nine of the drawdown alternatives, as well as the alternatives to drawdown, are feasible.

   a. **What are the implications of these alternatives?** The implications are the same as those stated for drawdown. If the uncertainties needing resolution remain unstudied, the decision to select any alternative must be made at substantial risk of failure and, further, at substantial risk of adversely impacting the smolts that need protection.

b. **Are the risks and implications of alternatives to drawdown (upstream storage, anadromous fish collection and transport, existing system improvements) less severe than the risks and implications of drawdown itself?** The information/data to make this comparison are not currently available. This comparison depends upon resolution of critical (resolvable) uncertainties. A decision at this time will necessarily be made in the face of uncertainty. Risks associated with uncertainty must be contained (managed) by initially designing drawdown in the form of an experiment, evaluating the outcome(s) of the experiment, and then reasonably modifying the strategy. This trial-and-error approach requires that all alternatives be defined and analyzed such that the "best one" can be selected for implementation. The nature of these alternatives, along with an assessment of specific risks associated with each alternative, should affect management decisions. However, in order to analyze the risks and implications of the "best" alternative, we need to resolve the uncertainties identified here.

c. **Can some critically uncertain assumptions be effectively resolved through literature review or near-term studies? If so, should the be resolved by experiments, studies, modeling before implementation of drawdown?** The critical uncertainties that can be resolved by literature reviews, modeling exercises, experiments, engineering analyses, and a one-reservoir drawdown are identified in this section.

6. **What alternatives to drawdown are feasible (including taking no action) and what are their implications? (Implications refer to the risks, costs, and other impacts of the alternatives.) Are there alternatives to using drawdown to increase smolt survival for which the risks and implications are less severe? What are the implications of delaying drawdown? Can some of the critically uncertain assumptions be effectively resolved through literature review or near-term studies? If so, should the be resolved by experiments, studies, or modeling before implementation of drawdown?**

   Five groups of drawdown alternatives for the Snake River are described in Section III of this document. The potential impacts of these alternatives are discussed in Section IV. Additionally, there are three alternatives to drawdown (Upstream Storage, Anadromous Fish Collection and Transport, Existing System Improvements) discussed in Section III. All nine of the drawdown alternatives, as well as the three alternatives to drawdown, are feasible from an engineering standpoint, but the net effects on salmonids from their implementation are unknown.

   a. **What are the implications of these alternatives?** The implications are the same as those stated for drawdown. If the uncertainties needing resolution remain unstudied, the decision to select any alternative will be made at substantial risk of failure and, further, at substantial risk of adversely impacting the smolts that need protection.

   b. **Are the risks and implications of alternatives to drawdown (upstream storage, anadromous fish collection and transport, existing system improvements) less severe than the risks and implications of drawdown itself?** The information/data to make this comparison are discussed in other documents associated with the System Configuration Study. This comparison among other operation strategies also depends upon resolution of critical (resolvable) uncertainties. This risk analysis only addresses drawdown. Before a strategy is selected, a risk analysis for potential strategies should be completed.

c. **Can some critically uncertain assumptions be effectively resolved through literature review or near-term studies?** If so, should the be resolved by experiments, studies, modeling before implementation of drawdown? The critical uncertainties that can be resolved by literature reviews, modeling exercises, experiments, engineering analyses, and a one-reservoir drawdown are identified in this section.

7. **Are there provisions in place for monitoring the outcome(s) of drawing down the Snake River?**

A decision at this time will necessarily be made in the face of uncertainty and the uncertainties allow us to define the risks. However, risks associated with uncertainty can be contained (managed) through monitoring. Drawdown can be implemented using an adaptive management process (even though it poses the risk of uncertain outcomes), providing this risk is contained. Therefore, we now ask, are the provisions in place for monitoring the outcome(s) of drawdown? The answer is that there is currently no monitoring plan in place to contain the risk of drawing down the Snake River reservoirs to increase survival of smolts as they migrate from Lewiston, Idaho, to Bonneville Dam. Monitoring must be planned to ensure efficiency, avoid duplication of effort, track progress toward meeting the objective of increasing smolt survival, and contain the risk of not meeting the objective (figure 5-1). Drawdown monitoring should be consistent with engineering feasibility and management of potential adverse impacts to fish health and behavior. The monitoring plan for Snake River drawdown should measure benefits and risks in the area of smolt survival. Outlined below are the associated risks of accepted assumptions (table 5-3) and unresolvable uncertainties (table 5-4) and the respective biological measures to be incorporated in a monitoring plan for Snake River drawdown.

Table 5-3
Risks Associated With Each Resolvable Assumption for Underlying Drawdown of the Lower Snake River

The question one must ask about each resolvable assumption underlying drawdown as a feasible means of increasing smolt survival		Information to be collected or type of study to be conducted to resolve uncertainty associated with these assumptions	Estimates of time needed to conduct studies to resolve uncertainty associated with these assumptions	Associated risk to Snake River salmonids if these assumptions are false
1.	Do we have enough basic information to evaluate effects of Snake River drawdown on smolt survival?	Information need: current intrareach survival variation in survival estimates among species and with changing environments	3 years	Loss of access to or availability of abiotic habitat
				Loss of access to or availability of abiotic habitat
		Type of Study: Survival study of outmigrating smolts		Change in behavior or physiology of the target species
				Adverse ecological interactions
4.	Is there enough habitat (*e.g.*, spawning, rearing) to support increased adult returns and increased juvenile production?	Information need: habitat inventories	1 year	Loss of access to or availability of abiotic habitat
				Loss of access to or availability of abiotic habitat
		Type of Study: Field surveys and examination of life cycle models		Change in behavior or physiology of the target species
				Adverse ecological interactions
5.	Do we understand the fitness of juvenile salmonids to adapt to estuarine and early ocean conditions and the dependence of this fitness on timing of arrival in the estuary?	Information need: measures of physiological preparedness for Snake River salmonids	2 years	Change in behavior or physiology of the target species
		Type of Study: statistical and field		

6.	Can smolt survival be measured from the point of origin to Bonneville Dam? Can an experiment be designed and implemented to estimate survival?	Information need: experimental design analysis of the variables that will potentially affect survival estimates. Type of Study: statistical and field		Decreased survival
7.	Can smolt survival from the point of origin to Bonneville Dam be estimated with a sufficiently low variance to permit comparison of smolt survival during drawdown with smolt survival during non-drawdown periods?	Information need: experimental design analysis of the variables that will potentially affect survival estimates. Type of Study: statistical and field	1 year	Decreased survival
15.	Does drawdown cause offsetting increases in smolt mortality rates resulting from increased incidence of gas bubble trauma?	Information need: incidence of gas-bubble trauma during bypass passage and turbine passage for different levels of saturation Type of Study: laboratory and field	2 years	Loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Adverse ecological interactions
25.	Will the productivity of food organisms in the lower Snake River remain sufficiently high to supply nutrition to smolts during the outmigration?	Information need: estimates of primary and secondary production nutritional requirements of outmigrating salmonids Type of Study: field and modeling	2 years	Loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Adverse ecological interactions
9.	Is smolt survival through the affected reach related to faster migration time (*i.e.*, is smolt mortality directly related to delayed migration time?)	Information need: relationship between smolt survival and migration time Type of Study: two-reservoir drawdown	2 or 3 years of drawdown	Decreased survival

10.	Does smolt behavior (*i.e.*, distribution activity) change in a way that delays migration under drawdown conditions?	Information need: smolt distribution during drawdown Type of Study: reservoir drawdown	2 or 3 years of drawdown	Loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Change in behavior or physiology of the target species
13.	Is mean smolt travel time proportional to mean water-particle travel time?	Information need: smolt travel time relative to water velocity Type of Study: reservoir drawdown	2 or 3 years of drawdown	Loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Change in behavior or physiology of the target species
14.	Is smolt distribution through the water column similar under full-pool and drawdown conditions?	Information need: smolt distribution during full pool and drawdown Type of Study: reservoir drawdown	2 or 3 years of drawdown	Loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Change in behavior or physiology of the target species
21.	Is the relative survival of hatchery- and naturally-produced fish the same and does drawdown change the survival potential of wild fish?	Information need: Survival estimates for hatchery and wild fish during full pool and drawdown Type of Study: reservoir	This study is not possible at this time. Survival estimates can be generated for hatchery fish, but there is no method of tagging wild fish in their natal streams	Decreased loss of access to or availability of abiotic habitat Loss of access to or availability of abiotic habitat Adverse ecological interactions

28.	Could drawdown cause offsetting increases in smolt mortality rates resulting from passage conditions through the turbines or following passage through turbines?	Information need: survival estimates for fish passing through the turbines Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
29.	Could drawdown cause offsetting increases in smolt mortality rates resulting from changes in passage conditions over the spillways?	Information need: survival estimates for fish passing through the spillway Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
30.	Could drawdown cause offsetting increases in smolt mortality rates resulting from changes in passage conditions through the bypass?	Information need: survival estimates for fish passing through the system Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
31.	Is fish guidance efficiency at the dams decreased during drawdown?	Information need: FGE during drawdown Type of Study: one-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
32.	Are diversion mortalities and impingement rates on barrier screens increased?	Information need: mortality and impingement estimates Type of Study: one-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat

33.	Can modifications to bypass facilities be accomplished to mitigate potential problems associated with drawdown?	Information need: FGE during drawdown Type of Study: one-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
36.	Can adult fish passage facilities be modified to mitigate reduced efficiency or increased mortality, if any?	Information need: Passage races during drawdown Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
37.	Will survival and upstream migration success will be adversely affected (*e.g.*, by difficulties with passage facilities)?	Information need: FGE during drawdown Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
38.	Can sufficient attraction water be provided to guide adults to fish ladder entrances?	Information need: Efficiency of ladders during drawdown Type of Study: two-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat
39.	Can spillways be modified to ensure no substantial increase in juvenile passage mortality occurs?	Information need: Effects of drumgates on passage mortality Type of Study: one-reservoir drawdown (this assumes that all facilities will perform the same)	2 to 3 years of drawdown	Loss of access to or availability of abiotic habitat

Table 5-4
Accepted Assumptions, Associated Risks, and Measures to be Included In a Monitoring Plan for Drawdown of the Lower Snake River

Accepted Assumption Underlying Drawdown to Increase Smolt Survival		Biological Measure To Be Monitored
8.	What if survival rates for smolts traveling from Lewiston, Idaho, to Bonneville Dam are not as fit and their reproductive success is decreased because of drawdown?	Smolt survival (Lewiston, Idaho, to Bonneville Dam.
12.	What if mean water velocity does not increase in reservoirs from tailrace to forebay?	Smolt survival (Lewiston, Idaho, to Bonneville Dam.
17.	What if drawdown increases pre-spawning mortality by delaying adult migration?	Adult escapement. Migration timing.
18.	What if stranding and entrapment of adult salmonids increases?	Adult escapement. Number of spawning adults by stock in basin.
19.	What if returning fish are impacted through changes in homing and straying rates?	Smolt survival (Lewiston, Idaho, to Bonneville Dam. Straying rates on spawning grounds and at hatcheries.
26.	What if spawning-habitat availability, quality, and quantity are adversely impacted?	Estimate of total spawning habitat in Snake River Basin.
27.	What if adult access to tributary streams is repaired?	Adult escapement.
40.	What if the habitat availability, habitat quality, or habitat quantity of non-target (resident species and non-listed stocks) are impacted by lowered water levels?	Estimate of total spawning, rearing, and migration habitat in Snake River Basin.
41.	What if food production is not adequate for non-target (resident species and non-listed stocks) during drawdown?	Biomass estimates for resident fish prey.
42.	What if disease incidence and mortality for non-target (resident species and non-listed stocks) increases?	Incidence of disease for resident fish.
43.	What if predation on non-target (resident species and non-listed stocks) increases?	Feeding habits of resident fish predators.
44.	What if water quality and temperature changes adversely impact non-target species?	Adult escapement.

Table 5-5
Unresolvable Assumptions, Associated Risks, and Measures to be Included In a Monitoring Plan for Drawdown of the Lower Snake River

Unresolvable Assumption Underlying Drawdown to Increase Smolt Survival		Biological Measure To Be Monitored
2.	What if construction activities needed to drawdown the reservoirs adversely affect survival of smolts?	Smolt survival during construction activities.
3.	What if other environmental factors limit the population; that is, increased number of smolts at Bonneville Dam results in decreased production for all stocks of interest?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Adult escapement.
11.	What if rates of mortality are not related to migration time, but to location of exposure to a threat?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Adult escapement.
14.	What if smolt distribution through the water column is such that smolts cannot or do not realize the benefits of drawdown?	Spatial distribution of smolts during the outmigration.
20.	What if generic integrity of stocks is not maintained?	Adult escapement.
22.	What if ocean survival decreases from drawdown?	Adult escapement.
23.	What if drawdown causes offsetting increases in smolt mortality rates resulting from predation due to crowding of smolts or predators?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Smolt and predator distribution.
24.	What if drawdown causes offsetting increases in smolt mortality rates resulting from disease pathogens?	Smolt survival (Lewiston, Idaho, to Bonneville Dam).
35.	What if gatewell operation at the dams adversely affects predation on smolts?	Smolt survival (Lewiston, Idaho, to Bonneville Dam).
44.	What if water quality and temperature changes adversely impact non-target species?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Survival and distribution of non-target species during drawdown.
46.	What if harvest management changes or does not work if drawdown is used to increase smolt-to-smolt survival in the lower Snake River?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Adult escapement.
47.	What if habitat management changes or does not work if drawdown is used to increase smolt-to-smolt survival in the lower Snake River?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Adult escapement.
48.	What if hatchery management changes or does not work if drawdown is used to increase smolt-to-smolt survival in the lower Snake River?	Smolt survival (Lewiston, Idaho, to Bonneville Dam). Adult escapement.

For each risk identified in the risk analysis, we have identified measures that can be monitored. These measures will be input to develop a monitoring plan. Five levels of monitoring are needed to contribute to the containment of risk. Quality control ensures that drawdown is conducted as intended, and that recordkeeping is accurate and complete. Performance monitoring is the measurement of smolt attributes, especially relating to smolt survival from Lewiston, Idaho, to Bonneville Dam. Hypothesis testing monitors the "statement of the objective" for drawdown. By stating the hypothesis for drawdown, it becomes possible to statistically design the collection of monitoring data such that likenesses and differences between survival can be examined relative to various risks identified in the risk analysis. Comprehensive monitoring trucks the progress of drawdown toward meeting the objective of increasing smolt survival. This also contributes to a sensitivity analysis, which helps determine the criticality of an underlying assumption to the success of the overall strategy. (See Section IV of this plan for the initial comprehensive analysis of assumptions underlying drawdown as a strategy for increasing smolt survival.) Stock-status monitoring tracks long-time performance and fitness, involving estimated annual spawning escapement and stock attributes and stock attributes that profile population changes over time.

Finally, each of these levels of monitoring, taken collectively, is a commitment to look for failure. If a decision is made to drawdown the Snake River reservoirs, then we must examine the response variable and associated strategies to determine where they may fail. Monitoring is not about looking for success. Rather, recognition of failure is the only way that change and adaptation can be implemented.

Summary and Conclusions

The stated objective is to increase smolt survival. However, the proponents of drawdown have not completed the planning and research needed to manage the risks of evaluate the benefits of the proposed action. Recovery of the Snake River endangered salmonid populations and doubling of the anadromous runs in the Columbia River Basin will require more than increasing smolt survival. Recovery requires adults to return that are genetically fit and can reproduce successfully. The proponents of drawdown must state their objective in terms of returning adults in order to analyze risk and evaluate benefits.

The specific strategy and reasonable alternatives must be well defined. Currently, there is some confusion as to the "preferred" strategy. There are five categories of alternatives that describe or define drawdown and a total of nine specific alternatives, each requiring modification to the dams or spillways, existing facility operations, and adult passage facilities. All alternatives, with the exception of the "natural river" option, will require new lower-level juvenile fish bypass facilities and modulated operations and structures for adult passage. Specific drawdown strategies and alternatives, including barging, surface collection, flow augmentation, and artificial production, must be better defined.

Some of the uncertainties associated with underlying assumptions needed to define the strategies will involve selecting a strategy while accepting a degree of risk that could result in not meeting the stated objective, and even lead to the extinction of the target species. Tasks should be initiated to resolve the following uncertainties: 1) the relationship between smolt survival and adult returns; 2) the correlation between migration timing and ocean survival for smolts; 3) the correlation between water velocity and smolt survival; 4) the relative survival of hatchery and wild fish during outmigration; 5) the methods for estimating smolt survival during outmigration; 6) the relationship between drawdown and smolt behavior; 7) the potential effects of gas bubble trauma on smolts during outmigration; 8) the potential effects of drawdown on returning adults; and 9) the potential facility and operational changes at the dams (bypass, turbine, fish guidance, *etc.*) that will adversely affect smolt survival.

Without a quantitative objective, the benefits and risks of drawdown cannot be monitored or evaluated. Thus, future decision makers will not be able to balance benefits and risks if drawdown is selected at this time. A successful plan will require regular evaluation of benefits and risks. Only when benefits outweigh risks will it make sense to continue the selected strategy.

In conclusion, the information and planning needed to make an informed selection of drawdown as a strategy to increase smolt survival is not presently available. The proponents of drawdown have not quantitatively stated what they want. Additionally, the semi-quantified objective (*i.e.*, increased smolt survival) has no unknown relationship to the long-term fitness, reproductive success, and genetic integrity of the Snake River salmonids. The objective for any strategy related to the management of the Snake River should be increased adult returns, not smolt survival.

VI. Data Needs

Several data needs were identified as a result of our analysis of drawdown and other operational strategies. The following discussion focuses on missing information relative to general impacts of the drawdown alternatives. The outline for this description of data needs parallels the discussion developed for impact analysis.

A. Drawdown Alternatives

1. Operations

Hydraulic modeling of the four lower Snake River dams will be necessary to obtain design data for developing structural changes required for each drawdown alternative. In addition, studies to determine juvenile survival in relation to anticipated hydraulic and structural modification to facilities will be required during testing of drawdown. For example, juvenile salmonids passing through turbines may suffer increased mortality as a result of reduced turbine efficiency under conditions of lowered head. Effects of turbine passage, including the effects of reduced efficiency with lower heads, on juvenile salmonid survival is poorly understood and needs to be studied further. Data is also needed to evaluate the effects of other changes in passage conditions, including vorticing, shear planes, cavitation, and pressure changes on smolt survival. While these conditions could be isolated and evaluated in the laboratory prior to testing, field tests during drawdown will likely be required to evaluate the combined effects of these changes in conditions to smolts.

Proposed structural modifications to project facilities include planning for pressurized juvenile bypass systems. The range in surface water elevations at which pressurized juvenile bypass systems operated needs to be identified in order to evaluate effectiveness of the modification and to determine the range of potential impacts to juveniles.

Prior to any testing, hydraulic modeling should be used to evaluate potential impacts of drawdown on fish guidance efficiency at intake screening devices and vertical barrier screens. The performance of vertical barrier screens under existing and reduced pool elevation is poorly understood. Impact of existing and lowered pool elevations on vertical barrier screen performance should be assessed.

Assessment of efficiency of adult collection facilities is required to identify the effects of reduced surface water elevation of pools on adult passage. Attraction to bypass and collection facilities at existing and proposed tailwater elevations should be assessed for each project during testing to determine the range where project facilities do not function effectively. A particular concern is the potential for migration delay on adult migrants and influence on pre-spawning mortality.

2. Reservoir Conditions

More precise measurements of water flow velocities are needed to evaluate the relationship between water travel time and fish behavior, particularly for known rearing and staging areas. Water velocity measurements should be taken during testing under a variety of steady flow conditions and compared against modeled values. Measurements should consider potential differences among the four reservoirs and should characterize conditions in the forebays.

Prior to implementation of drawdown, a plan should be developed to evaluate the short- and long-term impacts of drawdown on water quality. An optimal drawdown strategy would need to assure that all water quality parameters remain within acceptable limits for anadromous fish. Of particular concern would be to evaluate the relationship between different drawdown options and spilling practices on total dissolved gas (TDG) concentrations. There is a need to minimize TDG concentrations to reducing gas-bubble trauma while maximizing flow to reduce fish travel time. Thus, it is necessary to examine tradeoffs among different water quality objectives, as well as to establish target thresholds for each water quality parameter based on some measure of acceptable risk to aquatic populations. Therefore, it is important to take into account effects associated with changes in multiple water quality variables. An initial approach to this might be the development of a conceptual model that would allow for the comparison of drawdown alternatives based on a series of water quality scenarios. Scenario development would use existing hydraulic and water quality models to define the direction and approximate magnitude of change that might be expected for each variable (*i.e.*, TDG, temperature, turbidity, nutrient concentrations). This exercise would also be useful for identifying and prioritizing information needed to enhance existing models. Ultimately, additional field testing and model development will be required to help predict changes in water quality associated with each of the proposed drawdown alternatives.

Modeling studies should be continued to document relationships between storage volume, flow, and temperature. These studies should be integrated with the Geographic Information System (GIS) database. In particular, more data is needed on the relationship between meteorological conditions and temperature of the lower Snake River. This information could be used to refine the COLTEMP model.

Changes in sedimentation transport rates and deposition patterns need further study in order to assess potential impacts to aquatic habitats during drawdown. These studies should include sediment mapping (*i.e*., depth, particle size, distribution) and results should be incorporated into the GIS database for comparison with post-testing of drawdown conditions. Contaminant transport and potential for changes in bioavailability to aquatic organisms of toxic materials adsorbed to sediments is also a concern. Thus, measurements of contaminants in suspended sediments should be taken during future tests of drawdown.

3. Anadromous Fish

The primary data need for anadromous fish populations relates to whether increases in average water travel time through lower Snake River reservoirs results in increased survival of smolts. Baseline studies of smolt survival should be continued at Lower Granite reservoir and during dam passage so that data can be collected over a range of flow conditions, including during any future drawdown tests. Tests should be repeated under drawdown conditions. Clearly, more accurate estimates of smolt survival over a range of environmental conditions, including flow, are needed before conclusions can be drawn regarding the relationships among travel time, flow, and smolt survival. These estimates of survival need to be conducted for both hatchery and wild stocks of salmon and steelhead.

Other areas where little data exists and further research and evaluation are necessary include:

a. Prior to Implementation

- Describe migration behavior, including spatial distribution, rate of migration, and residence timing for smolts in the Lower Granite reservoir and forebay.
- Evaluate habitat use of smolts and subyearling chinook salmon, particularly use of, and resident time in backwater areas and embayments during early spring (*i.e.*, March to April).
- Refine existing juvenile survival models to include parameters relevant to drawdown scenarios, including spatial distribution of predators and prey, and density-dependent relationships.
- Evaluate factors influencing the width of the "biological window" (*i.e.*, seasonal, ecological, and physiological factors influencing survival rates) for smolts migrating through the Columbia River, including arrival in the estuary.

b. During Testing

- Assess the impacts of lowered pool elevations on smolt injury and descaling at vertical barrier and travelling screens.

- See also operational impacts related to fish guidance efficiency, turbine passage, and juvenile bypass systems, and for adult passage.

4. Resident Fish

The primary impacts to resident fish during drawdown are related to changes in habitat use or from operational conditions that cause fluctuations in pool level or dewatering of nearshore and off-channel areas. Specific data needs identified prior to and during testing of drawdown include:

- Study how drawdown may disrupt or alter the behavior of resident fish, including their migratory pathways, spawning habitat, and feeding areas.

- Evaluate to what extent the loss of existing nearshore habitat, including riprap and lotic habitats, will impact the ecology of resident fish species.

- Expand current models related to resident fish production, to include drawdown-specific scenarios.

5. Terrestrial Resources

Information needs related to terrestrial resources were grouped into three general areas: 1) characterization of baseline conditions; 2) impacts of changes to plant and wildlife communities during testing; and 3) assessment of mitigation potential.

a. Baseline Characterization

- Assess the status of populations of amphibians, reptiles, small mammals, and aves dependent upon the riparian/wetland habitats.

- Assess furbearer territorial requirements, breeding and denning requirements, and habitats associated with river otter and beaver.

b. Plant and Wildlife Communities

- Monitor the effects of drawdown on wildlife habitat use, predation rates, and affected food webs.
- Conduct mapping of all riparian/wetland habitats associated with river drawdowns, plant succession, habitat composition, and determine the effects of extended drawdown operations.
- Evaluate the impacts of changes in operation and timing on waterfowl production, brooding, and loafing.
- Assess effects on raptor nesting and foraging based on elevational changes in the reservoirs.
- Assess impacts to deer reproductive success and offspring survival as related to reservoir drawdown.

c. Mitigation

- Assess ways to maintain herptile and raptor populations dependent upon riparian habitat.
- Assess ways and sites to provide artificial watering points for upland game, big game, and other animals and to provide nesting opportunities to displaced waterfowl.
- Assess alternatives to provide adequate irrigation to existing habitat management sites established as part of the lower Snake River mitigation process.

6. Aquatic Production

Potential impacts to aquatic production, particularly relationships for non-target species, may be an acceptable risk to decision makers (see section V). However, alterations in the aquatic food base could "cascade" across trophic levels and potentially impact salmonid populations. Specific examples of ecosystem-level relationships that need further study, both prior to and during tests of drawdown include:

- Determine to what extent soft bottom benthic organisms and littoral zooplankton will be impacted by dewatering. This should include the potential for downstream entrainment of food sources used by resident and anadromous fish species.

- Evaluate the effects of crowding on ecological interactions between predator and prey species during drawdown.

- Determine the importance of littoral zooplankters as food items to resident and anadromous fish populations.

- Determine the relationships among nutrients, algal production, pelagic zooplankton production, and smolt bioenergetics. This may include modeling of the aquatic food chain under different operational conditions.

- Characterize the type and amount of substrate in the reservoirs and determine relationships to habitat requirements of important aquatic species.

B. Other Operational Alternatives

Study needs for the collection and transport alternatives include those mainly related to construction impacts and to potential habitat alterations. For example, information is needed on the types and quantity of wildlife habitat that would be displaced by fish collection and transport alternatives and associated activities. Detailed information on the response of resident fish species to large screening facilities, such as the proposed upstream collection systems, are needed. Examples of data needs include development of downstream passage criteria for juveniles and upstream criteria for adults. Thus, migration patterns, specific habitat requirements, and behavior (*e.g.*, swimming performance, jumping ability) relative to instream barriers needs to be studied. A monitoring and evaluation plan needs to be developed at the proposed screening and collection facilities to evaluate the effectiveness of the facility and to evaluate impacts to both anadromous and resident fish species.

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Footnotes:

1Analysis and assessment are often used interchangeably. We have used analysis here to describe the process for separating or breaking up the whole (*i.e.*, the plan to drawdownthe Snake River) into parts to find the nature, proportion, and relationships between the plan and potential results (*i.e.*, benefits and risks). Assessment implies the setting of a certain sum, to fix a value, or set and amount.

2The use of a one-pool or two-pool drawdown of the lower Snake River reservoirs should not be confused with the selection of drawdown as a strategy to increase smolt survival. One-pool and two-pool drawdowns are "tests" to acquire information. "Drawdown" is a potential strategy that could change the operation of the lower Snake River dams, year-after-year, to increase smolt survival between Lewiston, Idaho, and Bonneville Dam.

3The objective for drawing down the lower Snake River reservoirs has not been quantitatively defined. This will make selecting a strategy, and monitoring the benefits and risk very difficult, probably impossible. The risk analysis is continued in this plan. However, before a decision to draw down the Snake River reservoirs to increase survival, the "increase" must be quantified.