DOE/BP--2728

PREFACE: SETTING THE STAGE FOR THE SYSTEM OPERATION REVIEW

WHAT IS THE SOR AND WHY IS IT BEING CONDUCTED?

The Columbia River System is a vast and complex combination of Federal and non–Federal facilities used for many purposes including power production, irrigation, navigation, flood control, recreation, fish and wildlife habitat and municipal and industrial water supply. Each river use competes for the limited water resources in the Columbia River Basin.

To date, responsibility for managing these river uses has been shared by a number of Federal, state, and local agencies. Operation of the Federal Columbia River system is the responsibility of the Bureau of Reclamation (Reclamation), Corps of Engineers (Corps) and Bonneville Power Administration (BPA).

The System Operation Review (SOR) is a study and environmental compliance process being used by the three Federal agencies to analyze future operations of the system and river use issues. The goal of the SOR is to achieve a coordinated system operation strategy for the river that better meets the needs of all river users. The SOR began in early 1990, prior to the filing of petitions for endangered status for several salmon species under the Endangered Species Act.

The comprehensive review of Columbia River operations encompassed by the SOR was prompted by the need for Federal decisions to (1) develop a coordinated system operating strategy (SOS) for managing the multiple uses of the system into the 21st century; (2) provide interested parties with a continuing and increased long–term role in system planning (Columbia River Regional Forum); (3) renegotiate and renew the Pacific Northwest Coordination Agreement (PNCA), a contractual arrangement among the region's major hydroelectric–generating utilities and affected Federal agencies to provide for coordinated power generation on the Columbia River system; and (4) renew or develop new Canadian Entitlement Allocation Agreements (contracts that divide Canada's share of Columbia River Treaty downstream power benefits and obligations among three participating public utility districts and BPA). The review provides the environmental analysis required by the National Environmental Policy Act (NEPA).

This technical appendix addresses only the effects of alternative system operating strategies for managing the Columbia River system. The environmental impact statement (EIS) itself and some of the other appendices present analyses of the alternative approaches to the other three decisions considered as part of the SOR.

WHO IS CONDUCTING THE SOR?

The SOR is a joint project of Reclamation, the Corps, and BPA—the three agencies that share responsibility and legal authority for managing the Federal Columbia River System. The National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and National Park Service (NPS), as agencies with both jurisdiction and expertise with regard to some aspects of the SOR, are cooperating agencies. They contribute information, analysis, and recommendations where appropriate. The U.S. Forest Service (USFS) was also a cooperating agency, but asked to be removed from that role in 1994 after assessing its role and the press of other activities.

HOW IS THE SOR BEING CONDUCTED?

The system operating strategies analyzed in the SOR could have significant environmental impacts. The study team developed a three–stage process—scoping, screening, and full–scale analysis of the strategies—to address the many issues relevant to the SOR.

At the core of the analysis are 10 work groups. The work groups include members of the lead and cooperating agencies, state and local government agencies, representatives of Indian tribes, and members

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of the public. Each of these work groups has a single river use (resource) to consider.

Early in the process during the screening phase, the 10 work groups were asked to develop an alternative for project and system operations that would provide the greatest benefit to their river use, and one or more alternatives that, while not ideal, would provide an acceptable environment for their river use. Some groups responded with alternatives that were evaluated in this early phase and, to some extent, influenced the alternatives evaluated in the Draft and Final EIS. Additional alternatives came from scoping for the SOR and from other institutional sources within the region. The screening analysis studied 90 system operation alternatives.

Other work groups were subsequently formed to provide projectwide analysis, such as economics, river operation simulation, and public involvement.

The three–phase analysis process is described briefly below.

- **Scoping/Pilot Study**—After holding public meetings in 14 cities around the region, and coordinating with local, state, and Federal agencies and Indian tribes, the lead agencies established the geographic and jurisdictional scope of the study and defined the issues that would drive the EIS. The geographic area for the study is the Columbia River Basin (Figure P–1). The jurisdictional scope of the SOR encompasses the 14 Federal projects on the Columbia and lower Snake Rivers that are operated by the Corps and Reclamation and coordinated for hydropower under the PNCA. BPA markets the power produced at these facilities. A pilot study examining three alternatives in four river resource areas was completed to test the decision analysis method proposed for use in the SOR.

- **Screening**—Work groups, involving regional experts and Federal agency staff, were created for 10 resource areas and several support functions. The work groups developed computer screening models and applied them to the 90 alternatives identified during screening. They compared the impacts to a baseline operating year—1992—and ranked each alternative according to its impact on their resource or river use. The lead agencies reviewed the results with the public in a series of regional meetings in September 1992.

- **Full–Scale Analysis**—Based on public comment received on the screening results, the study team sorted, categorized, and blended the alternatives into seven basic types of operating strategies. These alternative strategies, which have multiple options, were then subjected to detailed impact analysis. Twenty–one possible options were evaluated. Results and tradeoffs for each resource or river use were discussed in separate technical appendices and summarized in the Draft EIS. Public review and comment on the Draft EIS was conducted during the summer and fall of 1994. The lead agencies adjusted the alternatives based on the comments, eliminating a few options and substituting new options, and reevaluated them during the past 8 months. Results are summarized in the Final EIS.

Alternatives for the Pacific Northwest Coordination Agreement (PNCA), the Columbia River Regional Forum (Forum), and the Canadian Entitlement Allocation Agreements (CEAA) did not use the three–stage process described above. The environmental impacts from the PNCA and CEAA were not significant and there were no anticipated impacts from the Regional Forum. The procedures used to analyze alternatives for these actions are described in their respective technical appendices.

For detailed information on alternatives presented in the Draft EIS, refer to that document and its appendices.

WHAT SOS ALTERNATIVES ARE CONSIDERED IN THE FINAL EIS?

Seven alternative System Operating Strategies (SOS) were considered in the Draft EIS. Each of the seven SOSs contained several options bringing the total number of alternatives considered to 21. Based on review of the Draft EIS and corresponding adjustments, the agencies have identified 7 operating strategies that are evaluated in this Final EIS. Accounting for options, a total of 13 alternatives is now under consideration. Six of the alternatives remain unchanged from the specific options considered in the Draft EIS. One is a revision to a previously considered alternative, and the rest represent replacement or new alternatives. The basic categories of SOSs and the numbering convention remains the same as was used in the Draft EIS. However, because some of the alternatives have been dropped, the numbering of the final SOSs are not consecutive. There is one new SOS category, Settlement Discussion Alternatives, which is labeled SOS 9 and replaces the SOS 7 category. This category of alternatives arose as a consequence of litigation on the 1993 Biological Opinion and ESA Consultation for 1995.

The 13 system operating strategies for the Federal Columbia River system that are analyzed for the Final EIS are:

SOS 1a Pre Salmon Summit Operation represents operations as they existed from around 1983 through the 1990–91 operating year, prior to the ESA listing of three species of salmon as endangered or threatened.

SOS 1b Optimum Load–Following Operation represents operations as they existed prior to changes resulting from the Regional Act. It attempts to optimize the load–following capability of the system within certain constraints of reservoir operation.

SOS 2c Current Operation/No–Action Alternative represents an operation consistent with that specified in the Corps of Engineers' 1993 Supplemental EIS. It is similar to system operation that occurred in 1992 after three species of salmon were listed under ESA.

SOS 2d [New] 1994–98 Biological Opinion represents the 1994–98 Biological Opinion operation that includes up to 4 MAF flow augmentation on the Columbia, flow targets at McNary and Lower Granite, specific volume releases from Dworshak, Brownlee, and the Upper Snake, meeting sturgeon flows 3 out of 10 years, and operating lower Snake projects at MOP and John Day at MIP.

SOS 4c [Rev.] Stable Storage Operation with Modified Grand Coulee Flood Control attempts to achieve specific monthly elevation targets year round that improve the environmental conditions at storage projects for recreation, resident fish, and wildlife. Integrated Rules Curves (IRCs) at Libby and Hungry Horse are applied.

SOS 5b Natural River Operation draws down the four lower Snake River projects to near river bed levels for four and one–half months during the spring and summer salmon migration period, by assuming new low level outlets are constructed at each project.

SOS 5c [New] Permanent Natural River Operation operates the four lower Snake River projects to near river bed levels year round.

SOS 6b Fixed Drawdown Operation draws down the four lower Snake River projects to near spillway crest levels for four and one–half months during the spring and summer salmon migration period.

SOS 6d Lower Granite Drawdown Operation draws down Lower Granite project only to near spillway crest level for four and one–half months.

SOS 9a [New] Detailed Fishery Operating Plan includes flow targets at The Dalles based on the previous year's end–of–year storage content, specific volumes of releases for the Snake River, the drawdown of Lower Snake River projects to near spillway crest level for four and one–half months, specified spill percentages, and no fish transportation.

SOS 9b [New] Adaptive Management establishes flow targets at McNary and Lower Granite based on runoff forecasts, with specific volumes of releases to meet Lower Granite flow targets and specific spill percentages at run–of–river projects.

SOS 9c [New] Balanced Impacts Operation draws down the four lower Snake River projects near spillway crest levels for two and one–half months during the spring salmon migration period. Refill begins after July 15. This alternative also provides 1994–98 Biological Opinion flow augmentation, integrated rule curve operation at Libby and Hungry Horse, a reduced flow target at Lower Granite due to drawdown, winter drawup at Albeni Falls, and spill to achieve no higher than 120 percent daily average for total dissolved gas.

SOS PA Preferred Alternative represents the operation proposed by NMFS and USFWS in their Biological Opinions for 1995 and future years; this SOS operates the storage projects to meet flood control rule curves in the fall and winter in order to meet spring and summer flow targets for Lower Granite and McNary, and includes summer draft limits for the storage projects.

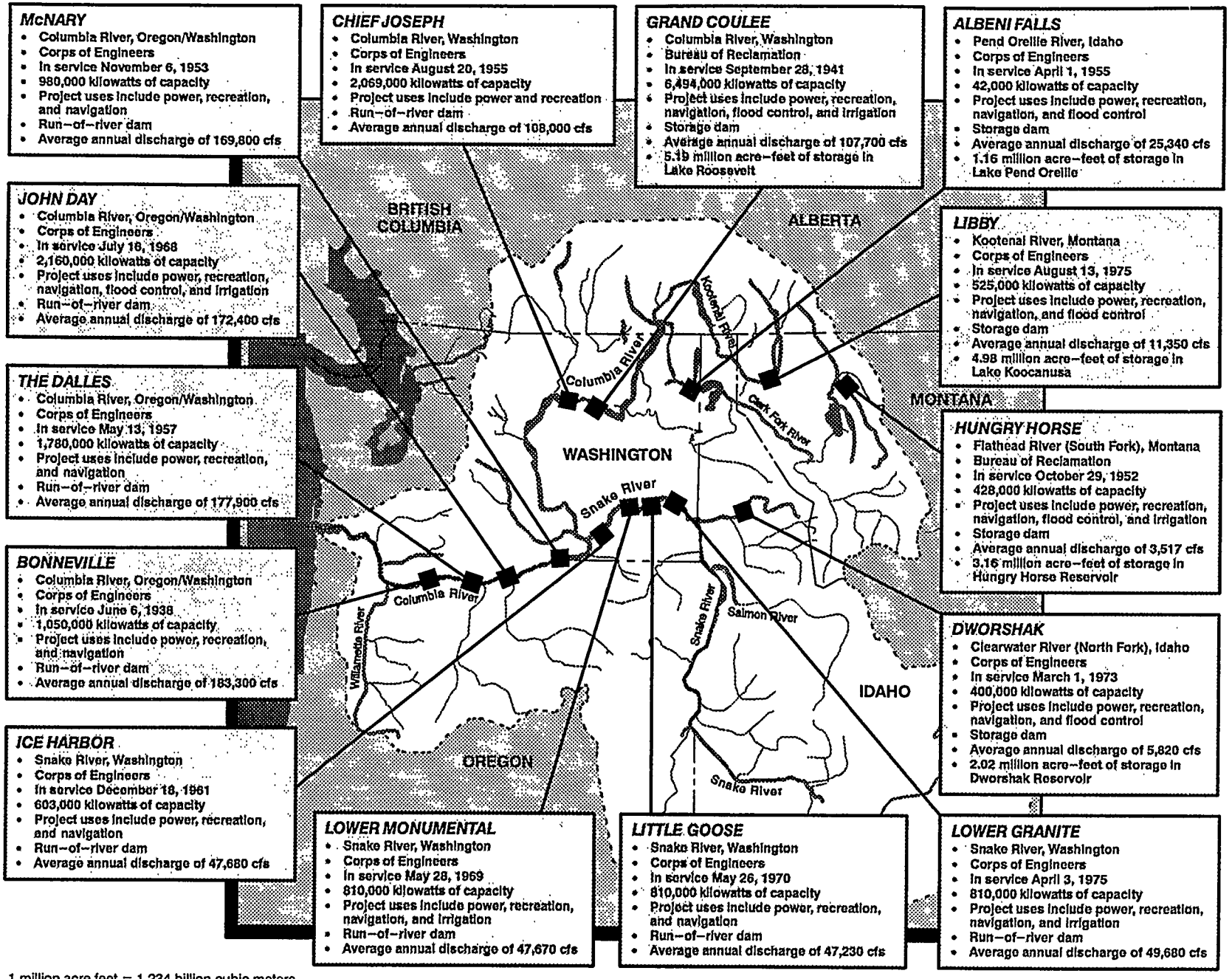
WHAT DO THE TECHNICAL APPENDICES COVER?

This technical appendix is 1 of 20 prepared for the SOR. They are:

A. River Operation Simulation
B. Air Quality
C. Anadromous Fish
D. Cultural Resources
E. Flood Control
F. Irrigation/Municipal and Industrial Water Supply
G. Land Use and Development
H. Navigation
I. Power
J. Recreation
K. Resident Fish
L. Soils, Geology, and Groundwater
M. Water Quality
N. Wildlife
O. Economic and Social Impacts
P. Canadian Entitlement Allocation Agreements
Q. Columbia River Regional Forum
R. Pacific Northwest Coordination Agreement
S. U. S. Fish and Wildlife Service Coordination Act Report
T. Comments and Responses

Each appendix presents a detailed description of the work group's analysis of alternatives, from the scoping process through full–scale analysis. Several appendices address specific SOR functions (e.g., River Operation Simulation), rather than individual resources, or the institutional alternatives (e.g., PNCA) being considered within the SOR. The technical appendices provide the basis for developing and analyzing alternative system operating strategies in the EIS. The EIS presents an integrated review of the vast wealth of information contained in the appendices, with a focus on key issues and impacts. In addition, the three agencies have prepared a brief summary of the EIS to highlight issues critical to decision makers and the public.

There are many interrelationships among the different resources and river uses, and some of the appendices provide supporting data for analyses presented in other appendices. This Anadromous Fish Appendix relies on supporting data contained in other Appendices. For complete coverage of all aspects of River Migration, readers may wish to review all appendices in concert.



1 million acre feet = 1.234 billion cubic meters
1 cubic foot per second = 0.028 cubic meters per second

Figure P–1. Projects in the System Operation Review.

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CHAPTER 1

BACKGROUND, SCOPE, AND PROCESS

1.1 INTRODUCTION: HISTORY AND BACKGROUND

The Columbia River basin is a huge watershed that supports a varied and growing number of human activities. These activities include power generation, recreation, navigation, irrigation, and flood control. In addition, the basin encompasses thousands of acres of fish and wildlife habitat. Over the decades since the 1930s, when the Federal government entrusted joint responsibility for operating the Federal portion of the Columbia River hydrosystem to the Bureau of Reclamation (BOR), the US Army Corps of Engineers (Corps), and the Bonneville Power Administration (BPA), demands on the river by the different user groups have increased exponentially.

Early on, when the demands on the system were primarily technical – involving improved flood control, power generation, navigation and irrigation – the problems associated with them were relatively straightforward. The demands were answered by more and better dams and locks.

In the mid–20th century, the base of user groups began to expand, including more hunters, fishermen, boaters, hikers, campers, and backpackers. These groups introduced a more widespread environmental awareness to the discussion of river use. Fish and wildlife management were added to the list of demands. Tensions among the user groups began to emerge. Those people interested in the river mostly for the power it generated, or the waterway it provided for navigation, now had to compromise with fishermen who wanted the system operated in such a way that salmon and steelhead continued to thrive and return to their spawning streams in the spring, summer, and fall.

Still, the river continued to be viewed as belonging uniquely to its human users. If competing demands escalated and made system operation more complex, humans at least could compromise on their demands.

Increasingly, people are coming around to the idea that the river is not just the domain of humans, but also is the domain of fish and wildlife that inhabit the river and adjacent areas. Unlike the needs of humans, however, the needs of fish and wildlife are not simply preferences, but life cycle requirements that cannot be compromised.

1.1.1 The Anadromous Fish Work Group (AFWG)

To initiate the SOR process, technical work groups were appointed to represent user groups and resource areas. Each technical work group was charged with developing hydrosystem operating strategies beneficial to its topical interests, as well as means for analyzing the effects of *all* operating strategies for impacts to its interest.

The Anadromous Fish Work Group (AFWG) represents the interests of anadromous fish – those species of fish that hatch and rear in freshwater lakes and rivers, migrate downriver to the ocean to mature, and return to freshwater as adults to spawn. The principal anadromous fish in the Columbia basin include salmonid species (chinook, coho, and sockeye salmon, and steelhead), and nonsalmonid anadromous species (sturgeon, lamprey, and shad).

The AFWG is made up of members from the US Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), Washington Department of Fish and Wildlife (WDFW), consultants and concerned citizens, as well as members from the three lead agencies. In addition to the active working members, several more agencies, interest groups, and individuals have been kept informed of the group's activities through regularly mailed meeting notes.

1.1.2 Salmonid Wild Stock Status

While the AFWG represents the interests of all species of anadromous fish, special mention needs to be made concerning wild stocks of salmon in the Pacific Northwest. Three stocks are presently listed under the Federal Endangered Species Act (ESA): Snake River sockeye salmon (endangered); Snake River spring/summer chinook salmon (threatened); and Snake River fall chinook salmon (threatened). Meanwhile, mid–Columbia summer chinook salmon have been petitioned for protection under ESA. Under the provisions of ESA, any proposed major change in hydrosystem operation must consider the potential effects on listed species. Therefore, it is appropriate to talk about the life cycle requirements of wild salmonids as they relate to hydrosystem operations.

Overview of Salmonid Life Cycle Requirements and Human Impacts

Each salmonid population in its struggle to survive has, over time, developed its own survival strategy, its own internal clock, its own life cycle requirements. In describing human impacts to the wild stocks of salmon for this introduction, this section will describe the basic life cycle requirements of a generic population, rather than attempt to describe all the adaptive features of each population (*see Chapter 2 of this Appendix for a full description*).

A salmon begins its life cycle as an egg deposited in a spawning bed by the female, and then fertilized by the male. Before depositing her eggs, the female excavates a depression in the spawning gravel (redd) with her tail, loosening the gravel so that water may flow around and over the eggs, bringing them oxygen and washing away metabolic byproducts until the eggs hatch. Streambeds that are silted due to logging or agricultural practices reduce the eggs' chances of successfully developing at this stage by inhibiting the flow of cleansing water around the eggs.

Newly hatched fish reside in the gravel for several weeks before emerging as free swimming fish. Most species feed and grow in this freshwater habitat for up to one year. River conditions such as flow, water velocity, water temperature, substrate, and water depth are among the factors that determine the amount of suitable habitat available for rearing fish. The make–up of the streambed is important in rearing because it is the production zone for the invertebrates that serve as food for the juveniles. The amount, type, and location of vegetation along streambeds is also important during rearing because this cover provides food, shade, temperature stability, protection from predators, and overwintering habitat. At this stage of the life cycle, logging, agriculture, and recreation can adversely affect juvenile development by degrading food producing zones and reducing bank cover. Hydrosystem operations have relatively little impact on salmon and steelhead during spawning and rearing, since – except for fall chinook – most spawning and rearing activities take place in the tributaries, too far upstream to be influenced by dams and reservoirs.

Following rearing, the juvenile population, driven by an internal biological clock and cues from the external environment, leaves its rearing area and moves into the Snake or Columbia River to begin migrating to the sea. This is the lifestage at which the juveniles are most affected by the hydrosystem. While juveniles of some wild stocks spend additional time rearing in–river as they migrate, for most stocks the river system is a simple pipeline to the estuary and ocean.

Although no one is certain exactly *how* quickly fish *ought* to make it through this migratory corridor, probably the less the journey is impeded the better for the population. This requires a minimum of physical obstacles, and a way around the obstacles that do exist. Adequate flow velocities are necessary to move juveniles through the system. Also, external environmental factors such as flow velocities and water temperature help cue smoltification, the process of physiological and morphological change that salmon undergo as they migrate. Smoltification adapts each fish to its new saltwater environment. Numerous morphological changes such as the weight to length ratio, coloration, and changes in body and fin shape result in a smolt profoundly changed from its earlier developmental stage. Smoltification also produces behavioral changes, including restlessness,

elimination of territoriality, the onset of schooling behavior and active downstream migration.

While delays in migration due to hydrosystem operation are an indirect factor influencing smolts' ability to survive, passage through and around dams is a direct factor. Each passage route results in some mortality.

One route for juveniles to pass a dam is over the spillway when the dam is spilling water. Mortality related to spill is caused by descaling, injury, and disorientation that makes the smolt an easier target for predators staging downstream of the tailrace. Mortality also results from gas bubble trauma to juveniles passing through gas supersaturated water during periods at high spill volume.

Another route is through the powerhouse. As the fish approach the turbines, they may be guided away from them by large screens and shunted into a bypass channel, where they will either pass around the dam back to the river below, or be collected for transportation downstream by truck or barge.

Guiding fish by the screen into the bypass system, and then through the bypass system, may result in mortality from injury and descaling, from stress incurred during bypass (including handling, if fish are handled for tagging), and from exiting the bypass system into the river where predators are concentrated.

Fish collected from the bypass system and transported on barges to a release area downstream may die from the stress of bypass, collection, and transportation, including delayed mortality from a stressor such as disease transmitted in the barge.

Juveniles missing the turbine screen will pass through the turbines. A trip through the turbines is typically regarded as the most dangerous route, and mortality may occur from injury, descaling, and from rapid pressure changes associated with turbine operations.

Once reaching the ocean, the salmon feed and grow to their adult size. Little is known of ocean habitat requirements of the salmonid populations, or of the impact of human activities on these requirements. There is speculation that worldwide oceanic environments are being degraded by human development and resource exploition. Commercial harvest obviously affects the fishes' chances of survival and reproduction, and has had a major effect on some stocks. Climatic cycles may affect survival as well.

Following ocean rearing, some members of a single population (cohort) return upstream after a year, some after two years, some three years, some four years, and a very few after five years. This is a unique adaptive feature of each population, since fish returning in any given year may encounter potentially lethal conditions such as low water, high water temperatures, and/or gas supersaturation of the water. By spreading the return across different years, the odds of the entire population encountering catastrophic instream conditions are significantly reduced.

In returning to its natal stream, the now–adult population is guided by a combination of celestial, magnetic, and olfactory cues. During this time, adult salmon are re-adapting to fresh water. They do not feed during this lifestage, each fish living instead off of energy reserves stored as fat.

The hydrosystem comes back into play during the return migration. Water velocities and temperature effects caused by system operations, may assist or impede a population's progress upstream. Non–operational measures intended to assist returning adults include flip lips installed on spillways to reduce gas supersaturation below dams, and fish ladders to enable the salmon to ascend the river around dams.

Once the spawning stream is reached, the spawning cycle begins anew. Following spawning, the adult salmon die.

History of Human Impacts on Salmon Populations

Prior to the arrival of the European explorers into the Columbia River basin in the late 1700s, an estimated 11 to 16 million salmon and steelhead returned yearly to the Columbia River (NPPC, 1987). At that time, Native Americans were harvest-

ing up to five million fish per year (Ted Strong, pers. comm. 1993).

The coming of the Europeans began a chain of events that affected the abundance of Columbia river salmon and steelhead.

Initially, the introduction of diseases to the natives by seafaring explorers – and then by overland explorers, trappers, and settlers – decreased the American Indian populations, which decreased the rate of salmon and steelhead harvest (Petersen and Reed, in publication). As early trappers and settlers joined the Native Americans in harvesting salmon and steelhead, or bartered or bought fish from the Tribes, conflicts between Euroamericans and the Native Americans further reduced the Native American population and their use of the salmon and steelhead.

In 1855, Governor Stevens entered into treaties with northwest Indian tribes which, through subsequent court action, guaranteed their right to harvest salmon and established them as co–equal managers of anadromous fish resources with the state fishery agencies (Marsh and Johnson, 1985).

At the same time, Euroamerican use of the rivers and streams began to decrease the size of the fish runs. Early attempts at commercial exploitation of salmon by Euroamericans were unsuccessful until the advent of the canning process, introduced to the west coast in the 1860s, and to the Columbia River in 1866 (Netboy, 1974; Mighetto and Ebel, 1995). By the mid–1880s, 55 canneries were in operation, yet even these canneries were not able to keep pace with harvest by gillnetters, seiners, fishwheels, and trollers. So many fish were harvested that fish left to spoil on cannery floors were dumped back into the river along with the tons of waste from fish that were processed. During this early peak, up to 43 million pounds of salmon and steelhead were landed annually, and fish runs began to decline precipitously.

By the 1880s, the region recognized overfishing as a menace to the existence of the Columbia River salmon runs. In 1887, Congress ordered the Corps to investigate the salmon fisheries of the Columbia, referring the Corps especially to possible obstructions to navigation by such fishing devices as fish wheels, river fences, fyke traps, etc.

During the overfishing menace of the 1880s, Major Jones of the Corps reported to the Congress on "....an enormous reduction in the numbers of spawning fish, brought about by the fishing industry...." The Major also noted stream pollution as a factor in the decline and recommended that, as mitigation measures, fish hatcheries be investigated, and that the season be closed for a week to help recover the runs (Willingham, 1992).

Commercial fishery interests had already turned to artificial production in the 1870s to restore depleted runs. By 1877, they had constructed their first hatchery, just 11 years after completion of the first cannery.

Around the turn of the century, the states and Federal authorities appointed fish wardens (Mighetto and Ebel, 1995), signaling the advent of modern day fishery agencies. The fishery agencies joined the commercial interests in establishing fish hatcheries in the 1890s. Early efforts relied on taking and hatching eggs, then returning the hatchlings to the rivers. Poor results led to longer rearing in the hatcheries by the early 1900s, but salmon production was still poorly understood, and many runs were depleted even further by well–meaning fishery managers. As an example, between 1898 and 1902, salmon runs to the Wallowa River in northeastern Oregon were eliminated by managers who took the eggs, hatched them, and stocked the fry into the river at Bonneville, hundreds of miles downstream (Wallowa Chieftain, 1992). The fish were genetically programmed to return to the Wallowa River, but because moving them so far downstream interfered with their homing abilities, the adults could not return to the Wallowa River to spawn. Wallowa River chinook, coho, and Wallowa Lake sockeye became extinct as a result of this well–intentioned but poorly planned effort to increase the salmon runs.

As experiments with artificial production went on, gillnetters and trapmen competed to harvest as much as they could as fast as they could. By 1884, both groups were lobbying the Federal government for

legislative action. In 1900, 132 fishermen applied for permits for fishwheels or traps (Willingham, 1992). Eventually, the gillnetters won the battle and fish wheels were banned in Oregon in 1926, and in Washington in 1934.

Meanwhile, an increasing number of sport fishermen joined the onslaught on the dwindling fish runs. By 1900 there was concern over the tackle used by sport fishermen and the numbers of fish they harvested, although many sport fishermen, such as Rudyard Kipling, released more fish than they kept (Mighetto and Ebel, 1995).

Fishery managers set lengths for fishing seasons and restricted harvest. Even though efforts were often thwarted by lack of funds and personnel for enforcement (Mighetto and Ebel, 1995), and illegal overharvest and poaching continued, the measures proved successful enough that harvest again peaked at 46 million pounds in 1911 (Netboy, 1974). Still, by the 1930s, Columbia River harvest was half the 1911 level.

At the same time that the numbers of migrating fish were being reduced by harvest, spawning and rearing areas were being affected. Trappers and settlers caused the earliest effects, disturbing spawning and rearing areas, and diverting water for irrigation, domestic use, and to drive mill wheels. These activities increased dramatically in the 1860s when gold was discovered. Mining degraded habitat, and logging to meet the timber demands for mines, towns, boats, barges, and railroad ties added new impacts. Also, livestock and crops grown to feed the burgeoning population began to affect stream quality.

Private dams built for mines, mills, irrigation, and water supplies also destroyed salmon habitat (Mighetto and Ebel, 1995). Even though the 1848 constitution of the Oregon Territory directed that dams on streams and rivers be constructed to "....allow salmon to pass freely up and down such rivers and streams....," by the early 1930s, the Fish Commission of Oregon reported that dams had taken "....approximately 50 percent of the most important salmon producing area in the basin...." (Mighetto and Ebel, 1995). A dramatic example was the Sunbeam Dam on the Salmon River that blocked access of Snake River sockeye salmon into the Stanley Basin lakes from 1910 to 1934, as well as access for spring chinook and steelhead that spawned above the damsite.

Following World War I, interest in mainstem dams on the Columbia River increased. With the onset of the Great Depression, Federal involvement in dam construction was advocated both as a way to employ people, and as a way of bolstering the economy of the Northwest. Studies were conducted that would lead to lower Columbia River Federal dams at such sites as Warrendale (Bonneville Dam), The Dalles Rapids (The Dalles Dam), Biggs (John Day Dam) and Umatilla (McNary Dam), in addition to an up–river storage dam at Grand Coulee for irrigation and power. Also in the 1920s, Congress requested studies of the potential for dams and navigation in the Snake River basin. Between 1938 and 1975, the eight Federal dams on the Columbia–Snake River system were constructed.

The completion of Bonneville Dam in 1938 provided the first real opportunity to count Columbia River adult salmon and steelhead passing above the dam. Although the count was not complete, 471,144 adult salmon and steelhead were counted in 1938. According to the first complete count in 1939, 497,154 fish passed upstream. By this time, harvest had declined to less than 20 million pounds per year, and the number of fish canneries had reduced to 11 (Netboy, 1974). Though restricted, commercial and sport harvest were probably still taking too many fish, and too few were returning to diminished spawning areas to sustain the runs of earlier years.

The catastrophic effects of harvest, logging, mining, and agriculture on the salmon runs indicated by the low fish counts of 1938 and 1939 were added to by Federal and non–Federal dams built on the Columbia and Snake rivers. Due to lack of understanding of the life cycle requirements of anadromous fish by both biologists and engineers, and to the high priority placed by the public on power production, flood control, irrigation, and navigation, mitigation measures for salmon and steelhead either were not considered when the dams were designed, inadequately researched or underfunded.

Storage dams were built without fish passage facilities, thus eliminating thousands of river–miles in the upper reaches of the system that had once been

spawning and rearing habitat. Historically, salmon migrated nearly 1,200 miles up the Columbia River to Lake Windermere, Canada, and 600 miles up the Snake River to Shoshone Falls near Twin Falls, Idaho. Completion of Grand Coulee Dam in 1941 blocked access to over 500 miles of the upper Columbia River, excluding tributaries. Another 52 miles of the mainstem were lost with the building of Chief Joseph Dam, the current upstream limit of salmon and steelhead in the Columbia River. Dworshak Dam blocked upstream migration on the North Fork of the Clearwater River when it was built in the early 1970s. (Figure 1–1)

Non–Federal dams, such as the Idaho Power Company's Brownlee, Oxbow, and Hells Canyon dams, completed from 1958 through 1967, also blocked off extensive areas. Over 50 percent of the originally inhabited mainstem of the Snake River is no longer accessible to anadromous fish, including up to 90 percent of the Snake River fall chinook spawning and rearing habitat. Hells Canyon Dam now limits access to the lower 247 miles of this river.

The listings of Snake River wild spring/summer and fall chinook, and sockeye salmon as threatened or endangered species has raised the consciousness of the region to the current status of salmon, and the ecosystem in which the salmon live. As this brief history indicates, the role that the hydrosystem plays in salmonid health is only one piece of the story. Because the life cycle of wild salmonid fish is dynamic, taking place over several years, throughout several biologically distinct life stages, and ranging over thousands of square miles, planning for recovery must take into account habitat requirements at each lifestage. Below is a short summary of mainstem recovery organization and efforts.

Mainstem Salmonid Recovery

Physical and operational mitigation efforts for salmon are the result of long–standing regional involvement in fish passage issues.

The **Fish and Wildlife Coordination Act** (PL 85–624) of 1934 formalized the coordination process between Federal water resource development agencies and the Federal and state fish and wildlife agencies. The law was amended in 1946 and 1958 to its present form. The FWCA has been the primary legal basis for including fish and wildlife mitigation measures as dams and reservoirs were constructed. Precedents for interagency coordination set during the construction of the Bonneville Dam fish facilities in the late 1930s included the formation of an interagency coordination group (Interstate Fish Conservation Committee), and the funding of the Bureau of Commercial Fisheries (BCF – now the National Marine Fisheries Service – NMFS) to assist in planning.

As planning began for additional dams, the **Fisheries Engineering Research Program** (FERP) was formalized in 1951. The FERP was comprised of Corps biologists, representatives of the Idaho, Oregon, and Washington fish and wildlife agencies, the BCF (NMFS), and the USFWS. The FERP was open to the public. Occasionally, fishery interests from universities or other entities attended meetings. Until the late 1960s, FERP research funded by the Corps and conducted by the BCF and state fishery agencies concentrated on survival of juvenile fish through turbines and spillways, and on methods of improving adult fish facilities. In the late 1960s and early 1970s, emphasis switched to juvenile fish passage problems in response to the severe gas supersaturation problems from 1968 through the 1970s. Development of juvenile fish bypass systems, fish screening devices, and the transportation program were emphasized in the 1980s. In the 1980s, the FERP became the Fish Passage Development Evaluation Program (FPDEP), and the Columbia basin Fish and Wildlife Committee merged into the Columbia Basin Fish and Wildlife Authority (CBFWA).

Ongoing research in the 1990s has concentrated on evaluation of new fish facilities constructed under the Corps' **Columbia River Juvenile Fish Mitigation Program**, and on the improvement of fish guiding efficiency through development of extended–length fish screens and improved vertical barrier screens.

The gas supersaturation crisis of 1968 at John Day Dam, and the anticipated crisis from completion of Lower Monumental (1969) and Little Goose (1970) dams resulted in the formation of the **Nitrogen Task**

Force. This task force included the Corps, state and Federal fishery agency representatives, university and private consultants, and state and Federal water quality agency representatives. Regional support for solution to the gas supersaturation problem was captured in a regional agreement signed by the Governors of Idaho, Oregon, and Washington, and sent to Congress, emphasizing the need for speed and an effective solution to the problem. The Nitrogen Task Force was instrumental in supporting research to define the problem, in providing information for the establishment of state and Federal standards for gas supersaturation, and for instigating corrective measures. Corrective measures included: (1) completion of upstream storage projects to lessen the spring peak flows in the river system; (2) expedited installation of turbines at The Dalles and the four lower Snake River dams; (3) and installation of spillway deflectors at Lower Granite, Little Goose, Lower Monumental, McNary, and Bonneville dams to lessen gas supersaturation when spill occurred. A fourth solution, perforated bulkheads (holy gates) was attempted in 1972, but was a failure. The Nitrogen Task Force met monthly during the height of the crisis, and as needed thereafter. The group continued its coordination activities through the mid–1970s, until the above mentioned solutions were in place or under construction.

The **Pacific Northwest Electric Power Planning and Conservation Act** (PL 96–501), passed by Congress in 1980, was a mandate to the BPA to fund the establishment of the Northwest Power Planning Council (NPPC) that was assigned the responsibility of developing a fish and wildlife program. After the passage of PL 96–501, the NPPC began preparation of the **Columbia River Basin Fish and Wildlife Program**. Based on input received from the fishery agencies, tribes, and energy/water management agencies, the NPPC drafted their first Fish and Wildlife Program (Program) in 1982. The Program was the first systemwide approach to dealing with the impacts of the hydroelectric system on the region's fish and wildlife resources. It outlined several measures in the areas of downstream passage, harvest management, upstream migration, and wild, natural and artificial propagation for increasing salmon and steelhead populations.

One measure, introduced in 1984, was the Water Budget, a block of water to be discharged from storage projects to increase spring and summer flows for juvenile fish migration in the Snake and Columbia rivers. The Water Budget is used by the fishery agencies to offset irrigation/flood storage impacts to the natural flow regime needed for juvenile fish migration. The Council Program is amended periodically to include additional mitigation measures for salmon, resident fish, and wildlife.

In 1989, fisheries agencies, Indian Tribes, BPA, and others signed a **Long–Term Spill Agreement** that established a plan for spilling water at Federal dams without bypass systems to help juvenile salmon and steelhead migrating from their spawning grounds to the ocean. The Water Budget and Spill Agreement are both instream flow measures to help fish, but they are quite different. The Water Budget moves fish *between* dams, while spill is used to move fish *past* dams.

With the potential listing of Snake River salmon, under the ESA, a new coordination process known as the **Salmon Summit Conference** was convened late in 1989 at the request of Senator Mark Hatfield of Oregon. This coordination process called together all fisheries and river interests in an effort to improve river conditions immediately to head off the ESA listing. Although the Salmon Summit was not successful in heading off ESA listing, it did bring forward many competing interests and resulted in ideas for improving conditions for the fish.

The **System Operation Review** (SOR) process began in 1990 in an effort to evaluate the operation of the Federal Columbia River Power System on all river uses. One goal of the SOR is to define a long–term operating strategy that will meet the region's needs for salmon enhancement and provide a balance among the region's water uses.

About the same time, the Corps initiated the **Columbia River Salmon Mitigation Analysis** (CRSMA), in part to respond to the General Accounting Office (GAO) finding that the Corps did

not have a defined mitigation goal. The CRSMA became the vehicle for continuation of studies evolving from the Salmon Summit Conference. It is divided into short and long–term study programs instigated by the Salmon Summit Conference. The short–term studies, called the **System Configuration Study** (SCS), is a reconnaissance level study of the recommendations for drawdown, bypass canals/pipelines, and other ideas stemming from the Salmon Summit or succeeding coordination processes.

With the listing of Northwest salmon as threatened and endangered, NMFS commissioned a group of technical experts, known as the **Recovery Team** to produce a **Draft Recovery Plan.** This group of independent scientists, made up of educators, ecologists, biologists, engineers, and economists, spent two years reviewing information from agencies around the region before producing a Draft Recovery Plan for NMFS' review. NMFS' Proposed Recovery Plan was made available to the public in March of 1995.

Meanwhile, the operating agencies – the Corps, BOR, and BPA – consult with NMFS as part of the Section 7 Consultation procedures, as directed by the ESA, for the upcoming operation of the hydrosystem.

1.2 THE JUVENILE FISH TRANSPORTATION PROGRAM

With the listing of wild Snake River salmon species as threatened or endangered under the ESA, there developed an acute need to analyze the impact of the Federal hydrosystem operation and other existing fish mitigation programs, on anadromous salmonid species in the Columbia River basin. For this reason, the AFWG study includes not only analysis of the potential environmental effects of alternative hydrosystem operating strategies on wild salmonids, but also takes a hard look at the effects of these alternative strategies with and without the Corps' Juvenile Fish Transportation Program (JFTP) in place.

The JFTP is a major mitigation program, begun in 1968 as an experiment by NMFS to protect salmonids from the unnatural environmental conditions created by Federal dams and reservoirs on the lower Snake and Columbia rivers (Ebel, 1970).

Protection is accomplished by collecting juvenile salmon (genus *Oncorhynchus*) and steelhead (O. *mykiss*) at dams as they migrate downstream, and transporting them in trucks or barges around dams and reservoirs for release downstream.

Specific conditions from which fish are protected by transportation include direct and cumulative mortality from passing through turbines at the dams; from predation in the reservoirs; from passage over dam spillways, and from gas supersaturation caused by spill at the dams. Transportation is also designed to mitigate against delays in migration caused by slack–waters in the reservoirs between dams.

In 1981, the program became fully operational under the Corps (Park, *et al.*, 1982; Park and Athearn, 1985), with oversight by the Corps, NMFS, the USFWS, state fishery agencies, and the Columbia River Intertribal Fish Commission (CRITFC) (Figure 1–2).

Juvenile salmon and steelhead are transported in the area between Lower Granite Dam, located at river mile (RM) 107.5 on the Snake River, 30 miles downstream from Clarkston, Washington, to the Columbia River below Bonneville Dam, located at RM 146.1 about 40 miles upstream from Portland, Oregon.

Under a permit from NMFS, endangered Snake River sockeye (O. *nerka*) and threatened chinook salmon (O. *tshawytsha*) are collected along with unlisted hatchery and wild salmon and unlisted hatchery and wild steelhead at Lower Granite, Little Goose, and Lower Monumental dams on the Snake River, and McNary Dam on the Columbia River (Figure 1–3).

Some fish may be bypassed back to the river below the dam where they are collected if numbers of fish collected exceed holding or transport vehicle capacities, or if flow conditions meet criteria for bypass of yearling salmon under the "Spread the Risk" policy expressed in the ESA Permit for transportation issued by NMFS.

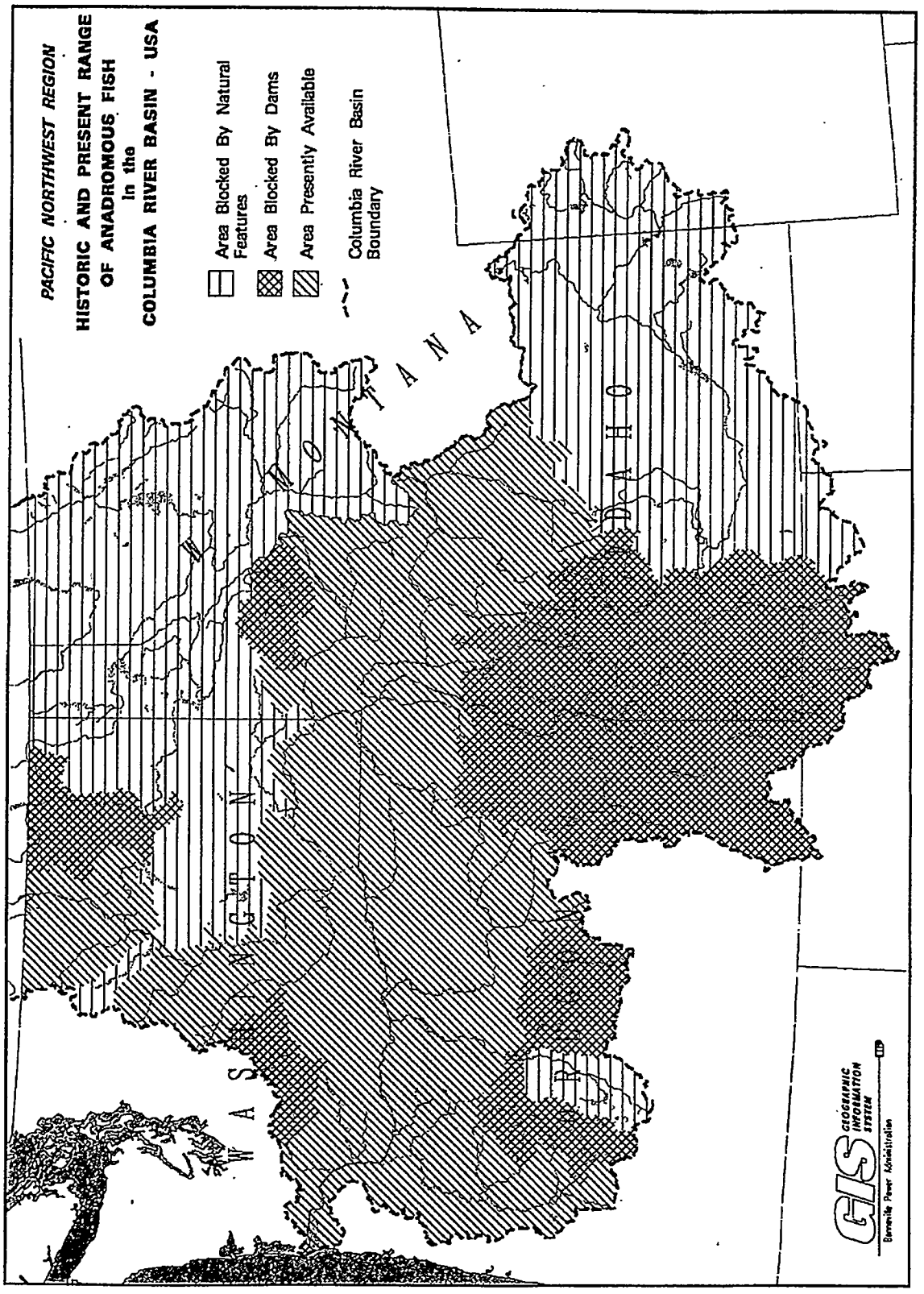


Figure 1–1. Historic and Present Range of Anadromous Fish in the Columbia River Basin – USA

Juvenile Fish Transportation

Research Phase:

1968 - 70	Ice Harbor Dam
1971 - 73	Little Goose Dam
1975 - 80	Lower Granite and Little Goose Dams
1978 - 80	McNary Dam
1986	Lower Granite Dam
1989	Lower Granite Dam

Operations Phase:

1981 - 92	Lower Granite, Little Goose, and McNary Dams
1993 -	Lower Granite, Little Goose, and Lower Monumental, and McNary Dams

Figure 1–2. Summary of research and operations for the juvenile fish transportation program at Corps dams, 1968 to present

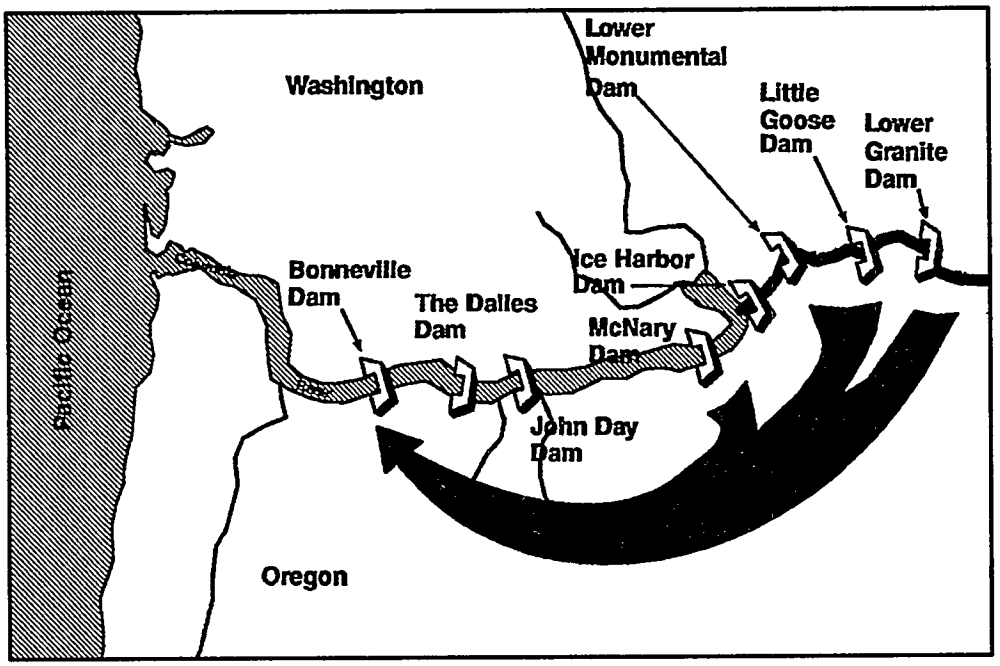


Figure 1–3. Juvenile fish transportation route from Lower Granite, Little Goose, Lower Monumental, and McNary dams to release areas below Bonneville Dam

Subsets of collected salmon and steelhead are handled by Corps or fishery agency personnel to obtain species composition, fish condition, fish size, and other information necessary to carry out the transport program. Fishery agency personnel (under a separate ESA permit to the Fish Passage Center [FPC]) handle sampled fish for Smolt Monitoring Program (SMP) purposes at all collector dams, and may mark subsets of collected fish for monitoring progress of the outmigration. Researchers (also under separate ESA permits) handle, mark, obtain scale, blood, or other tissue samples, or sacrifice fish obtained from subsets of fish collected at the transport facilities.

The transport season typically lasts from March 25 through October 31 at Lower Granite, Little Goose, and Lower Monumental dams, and March 25 through December 31 at McNary Dam. Juvenile Snake River spring/summer (yearling) chinook, sockeye, and steelhead are typically collected and transported during the spring (April through June), while late migrating yearling chinook, steelhead, sockeye, and subyearling fall chinook are collected and transported from July through October. At McNary Dam, yearling chinook (mid–Columbia River spring chinook and Snake River spring/summer chinook), sockeye, coho, and steelhead are transported in the spring, while summer and fall migrants are predominantly subyearling (summer/fall) chinook from the mid–Columbia River.

1.2.1 Juvenile Fish Collection

The number of juvenile fish collected each year is a function of how many wild and hatchery fish are produced above the collector dams, how many survive to the collector dams, the fish guidance efficiency (FGE) of fish screens in the turbines, and the quantity of spill occurring at each dam. Each one of these factors varies from year to year, causing the numbers of fish collected and transported to vary as well (Figure 1–4).

Collection Facilities

Juvenile salmon and steelhead approaching one of the collector dams generally travel near the surface of the reservoir. Juvenile fish migrate through the dam with the water whether the water is going through the powerhouse or through the spillway. When they approach the powerhouse, juvenile fish dive and enter turbine intakes through the trash racks (typically gratings with six–inch spacing between bars intended to keep larger trash from going through turbines) (Figure 1–5). As they dive down near the ceiling of the rectangular, funnel–shaped turbine intake (there are three intakes per turbine), the fish encounter traveling fish screens, which divert them upward into vertical slots (bulkhead slots) that lead up toward the powerhouse intake deck. The fish swim upward to within six to 11 feet of the water surface, where they swim or are drawn by suction through an orifice into a collection channel or tunnel within Lower Granite, Little Goose, or Lower Monumental Dam. At McNary Dam, the tunnel is replaced by a flume in the ice/trash sluiceway of the dam. Fish collected in the tunnel move with the flow of water toward a pipeline or flume which carries them from the dam to a collection facility below the dam. At the collection facility, most of the water is removed at a separator where adult fish and debris are bypassed back to the river (Figure 1–5). Juvenile fish swim downward between bars in the separator. They exit through orifices from the separator into distribution flumes which route the juvenile fish into holding tanks (raceways), sample tanks, or directly into barges.

According to criteria worked out with Fish Passage Advisory Committee (FPAC) over the years (FPP, 1993), fish are held at collection facilities less than 48 hours from the time they are collected.

New Facilities

In April 1994, new juvenile fish collection and bypass facilities at McNary Dam became operational. At the beginning of the season before collection started on a routine basis, this facility was rigorously evaluated by NMFS. The facility became fully operational on April 1. Other new facilities for 1994 included a roof over the raceways and separator at Little Goose Dam. New facilities are also scheduled for Lower Granite Dam. According to the current

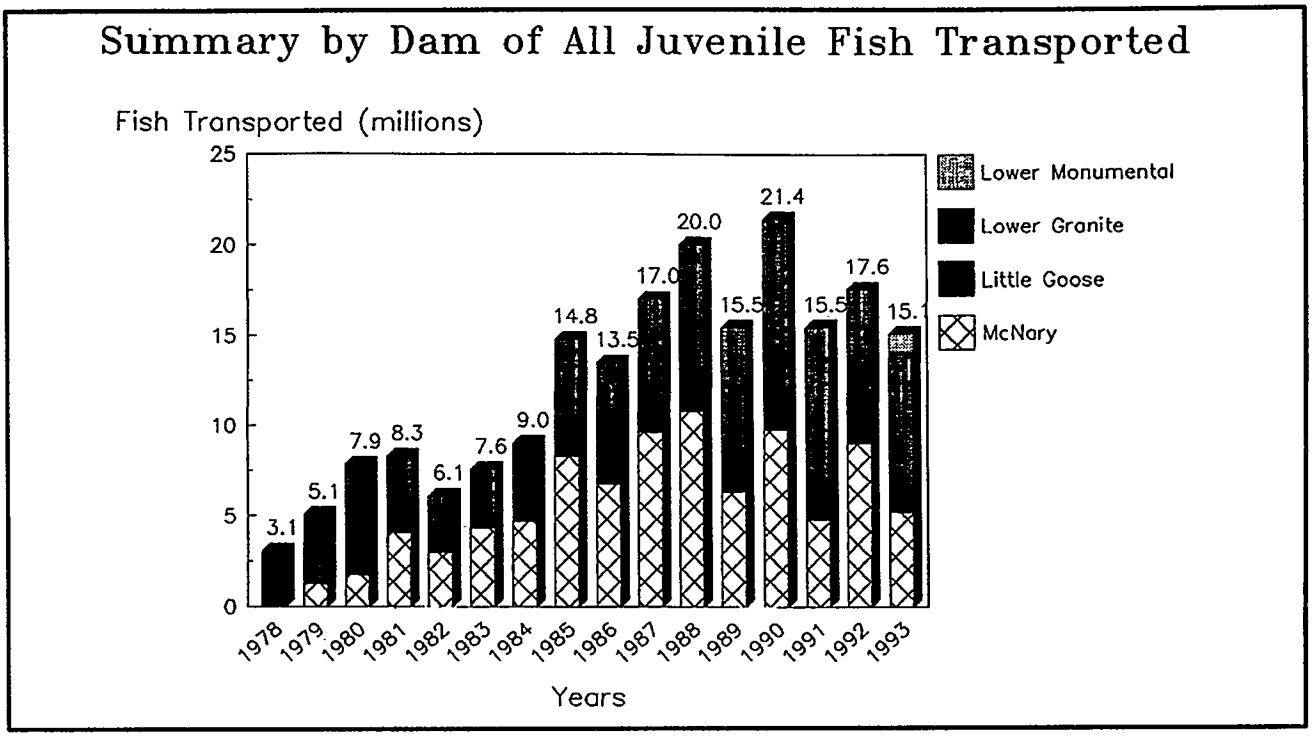


Figure 1–4. Summary by dam of all juvenile fish transported from 1978 through 1993

schedule, these facilities will be operational in 1998. Extended–length turbine intake screens are under study at McNary and Little Goose dams. According to the current schedule, if these screens prove out, they will be installed at McNary Dam by 1997, and Little Goose and Lower Granite dams by 1996. New bypass facilities will also be installed at Ice Harbor Dam by 1996, and the Dalles Dam by 1998, although collection and transportation facilities will not be included.

Bypass Water Supply

River water enters the juvenile fish collection systems through orifices from the bulkhead slots within the turbine intakes of each dam. A 12–inch orifice typically passes 11 to 15 cfs at up to 25 fps. The cumulative total in the collection channel ranges from about 240 cfs at Lower Granite Dam to over 700 cfs at McNary Dam. It takes about 60 cfs to run the distribution system, holding tanks, and raceways at each facility. Excess water flows back to the river at Lower Granite Dam, or is used in the adult fish collection system at Little Goose, Lower Monumental, and McNary dams.

Fish are held in water continuously throughout the collection facilities except when sample fish are handled in the laboratory.

Due to concerns over water quality, fish are not fed during holding at collection facilities or during transport; food and waste products would diminish water quality. Yearling salmon and steelhead typically feed very little during their outmigration, so there would be little effect from not feeding during the 96 hours in collection and transport. Subyearling salmon typically feed, but the collection/transport period is short enough that the period without food is probably less detrimental than would be the effect of food and waste products on water quality, which is essential to the well–being of the fish.

Size Separation

At Little Goose, Lower Monumental, and McNary dams, smaller fish (predominantly subyearling and yearling salmon) are separated from larger fish (predominantly larger salmon and steelhead) by separator bars that are spaced closer together (about 5/8–inch) on the first half of the separator, or further apart (about 1 1/4–inch) on the last half of the separator. Small juvenile fish are diverted to raceways, sample tanks, or into barges by flumes that are separate from those that divert larger juvenile fish. When loaded on trucks or barges, the fish are kept separated by size.

Raceways

The raceways at Lower Granite and Little Goose dams are typically 4 feet wide, 5 feet deep, and 80 feet long. Each raceway can hold 6,000 lbs. of juvenile salmonids at 0.5 lbs./gal. At an average size of 10 per lb., 6,000 lbs. would be 60,000 fish per raceway. The sex of specimens is not determined. Spring/summer chinook and sockeye are typically yearling fish, while fall chinook are typically subyearlings. At Lower Monumental and McNary dams, the raceways are 8 feet wide, 5 feet deep, 80 feet long and can hold 12,000 lbs. of fish at 0.5 lbs./gal. At 10 fish per lb., 120,000 fish could be held in each raceway at Lower Monumental and McNary dams. At all projects, fish are distributed among the raceways to limit loading in individual raceways below the loading criterion. The criterion of 0.5 lbs./gal is only met when facilities are filled to capacity. When the capacity is exceeded, excess fish are bypassed back to the river. During the majority of the season, fish are held and transported at lower densities. Raceways at Lower Granite, Little Goose, and Lower Monumental dams have been shaded. Those at McNary will be shaded in 1995.

Biological Sampling Methods

Sample fish are automatically diverted several times per hour, 24 hours per day into sample holding tanks. Sample rates vary. Approximately 92 to 97 percent of the collected migrants are routed to raceways or directly into barges without ever being sampled or handled. During the late season, when numbers of collected fish are very low, 100 percent may be routed into the laboratory where they can be held in shaded, cool conditions. When this happens, all collected fish are handled. As a result, from 10 to 87 percent of the fall chinook are sampled at the different dams. Automatic sampling systems divert approximately 3 to 8 percent of the collected spring/summer chinook and O. *nerka* (used generically for sockeye and kokanee) into sample tanks.

Biological sampling is limited to collecting information by visual inspection of sampled fish. Sampled fish are anesthetized, handled, and inspected to determine species, condition, and presence of marks or brands. Subsets are measured and weighed.

All fish are handled according to criteria established cooperatively with the FPAC of the CBFWA (FPP, 1993). Juvenile fish are inspected for marks, and some may be used for other purposes in the Smolt Monitoring Program (SMP). As permitted by other ESA permits, some of the sampled fish may be handled or sacrificed for research purposes. Live fish from the sample are transported with non–sampled fish. Juvenile fish are not held more than two days in the collection facilities.

Specimens taken for one type of research may be used for other research to minimize the number of fish that must be sacrificed (reference ESA Section 10 Permit applications for research submitted to NMFS for 1994 activities).

Mortalities removed from the collection facilities are discarded or provided to squawfish removal program personnel to be used for bait. Mortalities removed from the trucks or barges are discarded.

Two drugs are used in the collection process, Benzocaine with alcohol, and MS–222 (Matthews, *et al.*, 1987). Benzocaine is administered to fish held in pre–anesthetic tanks before passing into the laboratory. MS–222 is administered in the sorting trough in the laboratory. All fish are anesthetized in water without handling.

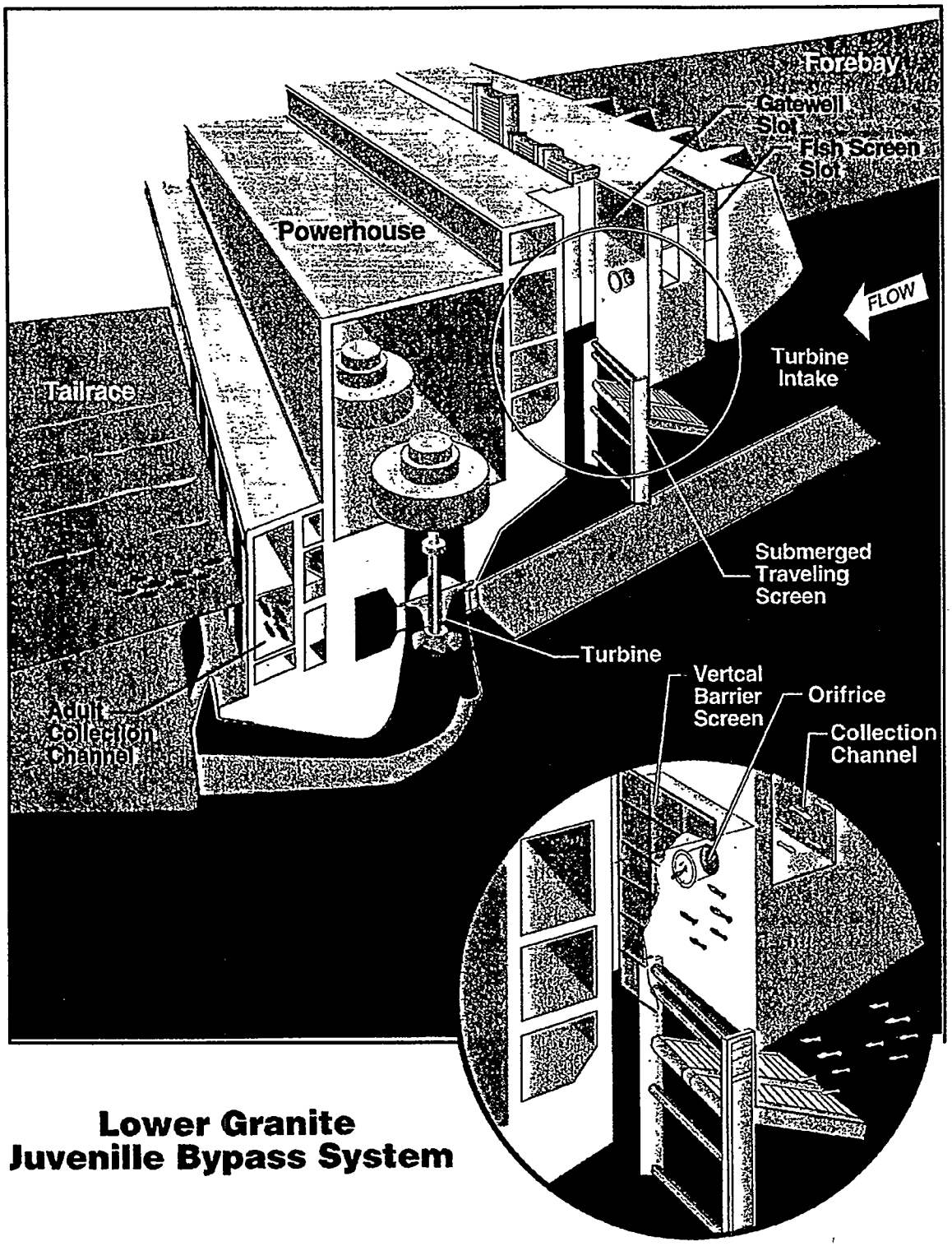


Figure 1–5. Lower Granite juvenile bypass system showing location of fish screen, orifice, and collection channel.

1.2.2 Juvenile Fish Transportation

Juvenile salmon and steelhead are transported from the collector dams to release areas below Bonneville Dam. Early in the season when numbers are low, fish are trucked and released from the shore below the Bonneville First Powerhouse. When the majority of the fish are transported, they are barged, with the trip originating at Lower Granite Dam and additional fish loaded into the barge at the other collector dams. At the beginning and end of the spring barging season, a barge leaves Lower Granite Dam every other day. During the peak, barges leave Lower Granite every day. In the summer, barging shifts to McNary Dam, and trucking resumes from the Snake River dams. Until the end of October, trucks are loaded on a barge below Bonneville Dam and barged out into mid–river where they release their fish. Summer barging lasts through mid–August, then fish trucked from McNary Dam are also barged mid–river for release through the end of December, unless icy conditions cause earlier shut down of the transportation program.

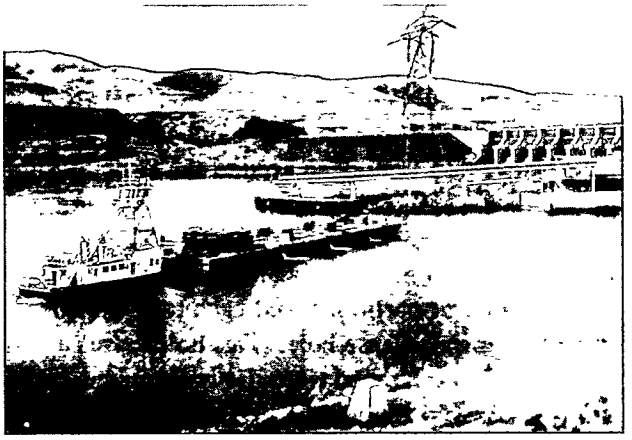


Figure 1–6. New juvenile fish transportation barge approaching new juvenile fish collection facilities at Little Goose Dam, 1990

Fish Loading

Fish loading procedures are overseen by project biologists, state agency biologists, and trained facility or equipment operating personnel. Fish collected in raceways are mechanically crowded to the exit pipe as the water level is lowered in the raceway. The last few fish are manually crowded through the exit pipe. Water is flushed through the pipe to ensure that all fish are loaded into the truck or barge. Pipes to trucks or barges are typically 10–inches in diameter. Loading systems may be a combination of 12–inch aluminum flumes and pipes. All loading to trucks and barges is by gravity flow, and pipes and flumes are constructed according to FPDEP Fish Facility Design Review Subcommittee criteria.

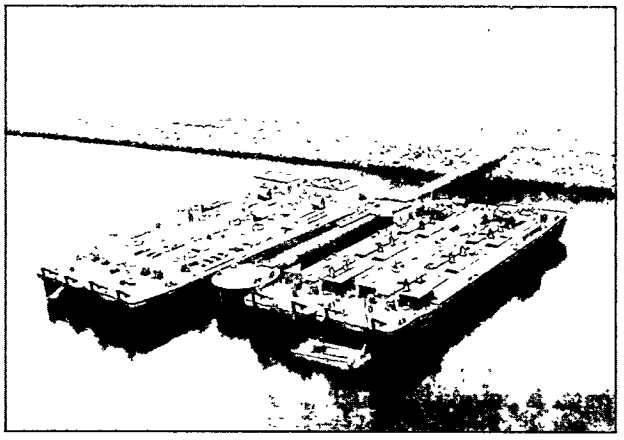


Figure 1–7. Fish barges (two 86,000 gal, two 100,000 gal, and two 150,000 gal capacity) used in the juvenile fish transportation program.

Sample fish, pre–anesthetized and anesthetized before handling, are allowed to recover from the anesthetic before being loaded into transport vehicles.

Transport Barges

Six barges are available for juvenile fish. All are painted–steel construction with compartments varying from four feet deep around the perimeter to six feet deep at the release hole. Two barges are Army surplus barges acquired in 1978. Three tanks were constructed in–line bow to stern. The tanks are separated by partitions, and each tank slopes toward a central release hole. This hole serves a dual function as pumped water flows through screens and is discharged to the river during loading and transport. For release, the screen mechanism and a stopper are lifted vertically to allow water and fish to exit from each tank through a 17–inch hole. These barges are equipped with three pumps capable of providing 4,600 gallons per minute (gals./min.) of inflow. Water is pumped upward against a baffle and allowed to fall back into the holding tanks to aerate or degassify the water. Each barge can hold 85,000 gallons of water, but loading capacity is rated on 5 pounds (lbs.) of fish/gal./min. inflow, so these barges are capable of transporting up to 23,000 lbs. of fish under CBFWA FPAC/Corps criteria.

The two medium–sized barges were constructed in 1981 and 1982. They have four compartments, two forward and two aft on either side of the centerline. These barges are capable of holding a total of 100,000 gals of water. Like the small barges, they have three pumps, but these are capable of providing 10,000 gals./min. inflow. At 5 lbs/gals./min., they can haul up to 50,000 lbs. of fish. Each tank slopes toward a stopper near the centerline through which fish are released. The screened water overflow system is separate from the fish release system. Water is pumped through packed columns to provide aeration and degassification.

The two large barges were constructed in 1989. They are similar to the medium–sized barges in design, but have two additional compartments. Therefore, they hold 150,000 gallons of water, and the pumps are sized to provide 12,500 gals./min. of inflow. They can hold up to 75,000 lbs. of fish at 5 lbs/gal./min. inflow. The medium– and large–sized barges are also equipped so that inflow can be shut off and water within the barge can be recirculated in the event of a chemical spill or poor water quality along the transport route.

Each barge has at least one backup pump system. When fully loaded, three pumps out of four on the large barges, or two pumps out of three on the medium and small barges, are required. If a pump fails, the backup pump is started. When a barge is less than fully loaded, only one or two pumps are needed to maintain oxygen levels. Then, additional backup pumps are available. Each barge is equipped with a warning system to alert the barge rider or towboat crew if a pump fails. Each barge is equipped with an oxygen sensing system that monitors gas levels within the barge continuously when the barge is filled with water. When fish are loaded on board, the barge rider typically monitors fish condition, temperature, and oxygen levels for the first hour or two after leaving the collector dam. As the trip progresses, monitoring occurs every other hour, then every four hours until release. If there is spill at dams in the transport route, each barge is equipped with gas stripping equipment. This equipment was tested in 1993 on the medium and large barges, and with gas supersaturation in the river at 130 to 135 percent, levels within the barges were 100 to 102 percent (Hurson, *et al.*, 1994). The medium– and large–size barges are also equipped with recirculation equipment so that if a chemical spill, or other pollution is encountered in the river, intakes can be closed, and water recirculated and aerated in the barge until the barge is past the problem.

Transport Trucks

Early and late in the season when fish numbers are less than 20,000 per day at Lower Granite Dam, 3,500 gallon fish trucks are used to transport fish (Figure 1–8).

Up to seven 3,500 gallon fish trucks will be used, two at Lower Granite Dam, one at Little Goose Dam, one at Lower Monumental Dam, two at McNary Dam, and one spare. The trailers have painted steel or stainless steel tanks divided into three compartments. The floors of the tanks slope toward the central unloading trough, which slopes to the rear of the truck where the exit is equipped with an air–operated knife valve for unloading. Hand–operated knife gates are

available to separate the compartments. The tanks are equipped with air stones, agitators, and a recirculating pump. Liquid oxygen and compressed air cylinders are carried for maintaining oxygen levels. A refrigeration unit is included in the recirculation system for maintaining water temperature. The tanks are surrounded by insulation, and the trucks are covered with metal skin plate. Three 150 gallon mini–tankers (pickup mounted units) will be used for transport operations from Lower Granite, Little Goose, and Lower Monumental dams in late summer and fall when fish numbers are very low (Figure 1–9). These are fiberglass tanks, insulated, equipped with agitators, an oxygen supply, refrigeration units, and can be divided into two compartments.

Truck drivers are trained on the operation of environmental control equipment on the fish trucks, and on the symptoms of fish exhibiting stress in transportation. During a typical truck trip, the drivers stop several times to inspect fish and to remove dead fish that may have been loaded with live fish when raceways were emptied into the truck. Trucks are equipped with redundant systems (e.g. liquid oxygen, aeration, and compressed air systems). If all systems fail, truck drivers are trained to go to alternate release sites so fish can be returned to the river.



Figure 1–8. One of seven 3,500 gal fish transport trucks used in the juvenile fish transportation program

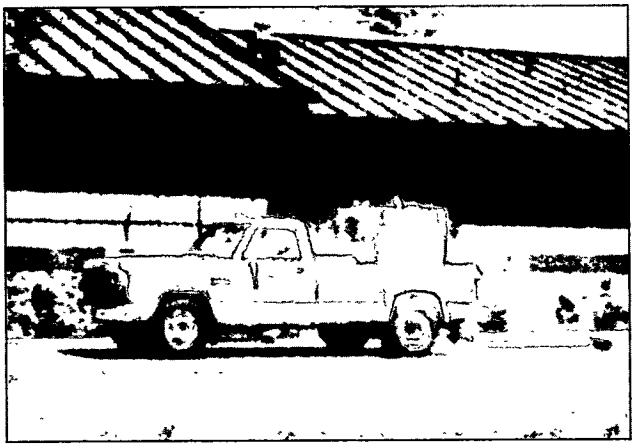


Figure 1–9. One of three 150 gal fish transport trucks used in the juvenile fish transportation program

Length of Time in Transit

Truck transport to the release point below Bonneville Dam from Lower Granite Dam takes six to ten hours; from Little Goose Dam takes six to eight hours; from Lower Monumental Dam takes from five to seven hours, and from McNary Dam takes four to five hours. Barge transport from Lower Granite Dam to the release point below Bonneville Dam takes about 36 hours; from Little Goose Dam about 30 hours; from Lower Monumental Dam about 24 hours; and from McNary Dam about 15 hours.

Holding time in transport vehicles is limited to 48 hours. No fish are to be held more than 96 hours from time of collection to release below Bonneville Dam.

Transport Release Areas/Methods

From the beginning of the transport season until mid–April, fish will be trucked from Lower Granite and McNary dams to Bradford Island (north end of Bonneville First Powerhouse), where they will be released through an established release pipe into the river. From about mid–April to mid–June (spring barging season), fish will be barged from Lower Granite, Little Goose, Lower Monumental, and McNary dams to random release sites between

lighted buoy No. 92 (RM 144) and Warrendale, Oregon (RM 141). After collection drops to about 1,750 lbs. per day at Lower Granite Dam, barging will shift to McNary Dam (summer barging season), and trucking will resume from Lower Granite, Little Goose, and Lower Monumental dams. Barging will continue from McNary Dam until about the end of July, then trucking will resume there also. From mid–June until the end of the season, large fish trucks or 150 gallon mini–tankers will be used from Snake River dams. Large and small trucks will be transported to mid–river on a barge below Bonneville Dam so fish can be released away from concentrations of predators along the shore.

Ongoing research includes evaluation of releasing fish at locations closer to the estuary. For example, in 1992, 1993, and 1994, six groups of marked steelhead were released near Tongue Point, Oregon (RM 19). A separate ESA Section 10 permit application was filed with NMFS to cover continuation of this research in 1994. Incidental chinook or sockeye were transported to Tongue Point with these groups.

Operational Staffing and Oversight

The JFTP is carried out in coordination with the CBFWA, representing a broad spectrum of experience and qualifications. Senior biologists represent the agencies and Tribes on the FPAC. Within the Corps, the program is supervised by a Fishery Biologist, managed by a Fishery Biologist, and operated at the projects by Fishery Biologists. Fishery Biologists are also provided for quality control by the Washington Department of Fish and Wildlife (Lower Granite, Lower Monumental, and McNary dams), and Oregon Department of Fish and Wildlife (Little Goose Dam).

At each collector dam, a crew of trained biological technicians (often with degrees in fishery biology) staff the collection facilities 24–hours–per–day, 7–days–per–week during the transport season. This requires six facility personnel at each of the four collector dams.

Truck drivers hired by the Corps are trained to monitor fish condition and physical conditions in the trucks during transport to assure that no problems occur. Each barge has a Corps biological technician (often with a degree in fishery biology) assigned to ensure that water quality and fish condition are maintained during barge transport. Both truck drivers and barge riders are trained in emergency situations to release fish back into the river as soon as possible if other solutions fail. Two qualified truck drivers are available at each collector dam. Six barge riders are available from Lower Granite Dam during the spring barging program, and two are available from McNary Dam during the summer barging program.

Barge riders and facility operators are temporary personnel who usually have college degrees in fishery biology or closely related biological fields. Truck drivers and maintenance personnel meet Government qualification standards as appropriate for their positions.

Emergency Plans

Facility operators have access to facility operation plans that include emergency procedures. They are also instructed by project biologists on measures to take if emergencies occur. A detailed emergency telephone list is provided to each facility operator, truck driver, or barge rider. This list includes Corps biologists, CBFWA FPAC members, dam managers, state agency biologists, and research personnel involved at the juvenile fish facilities. In the event of an emergency, personnel are instructed to notify appropriate persons on that list. Key personnel on the list are available 24–hours– per–day, 7–days–per–week during the transport season to deal with emergencies. Truck drivers are provided with the locations of emergency release sites between collector dams and release sites. Barge riders are instructed to release fish if major equipment failures occur that they and the towboat crew cannot correct.

1.2.3 Facility Maintenance

Because the JFTP runs from mid–March through October or December at the various collector projects, major maintenance must be conducted in the winter. The major maintenance item is repairing or replacing mesh and drive chains on submerged traveling screens (STSs). Each project has one or

two spare STSs, so replacement screens are available if one is damaged or fails. The life of the mesh on STSs ranges from three to eight years, so, for example, at McNary Dam where 42 STSs are used, one third of the screens receive new mesh each year.

Other maintenance includes repair or replacement of equipment at the collection facilities or on the transport equipment.

Routine maintenance performed during the season while facilities are operating are described below.

Trash Rack Maintenance

Debris that accumulates on the trash racks can cause injury and mortality to fish entering the turbine intakes. To minimize the amount of trash reaching the trash racks at Lower Granite Dam, a debris boom is installed. The other collector dams do not have debris booms. At Lower Granite Dam and the other dams, debris that floats against the upstream face of the powerhouse is dipped by a trash raking crane from the forebay and hauled away. To monitor the effect of debris that sinks and collects on the trash rack, orifices, or other locations in the collection system, descaling of the fish is evaluated in the laboratory each day. If descaling increases in the sample taken in the laboratory, project biologists and operators begin looking for causes upstream in the collection facility. If trash on the trash racks is the cause, project operators rake the trash to clean the trash racks. This is done at the beginning of the season and on an "as–needed" basis throughout the transportation season.

Fish Screen Inspections

Turbine Intake Screens

Traveling fish screens move like a conveyer belt to carry debris that accumulates on the screen over to the back side where it is flushed off by flow through the screen. Fixed–bar screens have a mechanized brush that sweeps debris off the screen so it can be flushed through the turbine. When small fish that are weaker swimmers are present, STSs are run continuously to keep them clean. When larger fish are present, STSs may be run 20 minutes off and 4 minutes on to save wear and tear on screen equipment (McCabe and Krcma,1983). Traveling fish screens and debris brushes on fixed bar screens are driven by electric motors. A warning system is provided from the screens to the control room in the dam, as well as to screen electrical control boxes in the access gallery above the fish bypass. If a screen or trash brush fails electronically, a warning signal alerts the project operator. Fish screens are inspected when they are removed, maintained and repaired over the winter, and inspected again before they are installed. Fish screens are also inspected with underwater video cameras once per month while they are in use. Any tears, lost fasteners, or other damage is usually detected during these inspections. According to criteria established with the CBFWA FPAC, units with known damaged fish screens are shut down until the screen can be repaired or replaced. Turbines are not to be run with a damaged screen or without a screen unless coordinated with the CBFWA FPAC.

Vertical Barrier Screens

Vertical barrier screens prevent fish that are guided into the bulkhead slots from swimming back down through the operating gate slots into the turbines. The vertical barrier screens are inspected whenever the turbine units are dewatered. They are also inspected with underwater video cameras. Worn or damaged vertical barrier screens are repaired. This requires taking the generating unit out of service and dewatering the turbine while repairs are being made.

Gatewell Debris

Debris that goes through the trash rack and rises in the bulkhead slot can accumulate at the surface of the water. When this happens, the debris is dipped out of the gatewell by project operators. Criteria in the FPP require dipping before the gatewell is half covered with debris. This is in compliance with NMFS' Biological Opinion for operation of the dams.

Oil in Gatewells

Fish screen drive mechanisms and operating gate hydraulic cylinders contain oil. When seals fail, oil

can accumulate in gatewells. Oil can come from other sources above the dams, and be drawn from the reservoir into turbine intakes when vortices occur. When oil appears on the water surface in gatewells, it is removed by project operators using absorbent pads or oil skimmers in compliance with NMFS' Biological Opinion.

Debris on Orifices

Sticks or other debris that block orifices can cause serious injury or mortality to fish. Orifices are inspected daily by Corps or state agency biologists, and are cycled on and off to dislodge any debris. When a blockage is suspected, orifices are equipped with an air line so the orifice valve can be closed and air can be injected behind the valve to flush debris from the orifice.

Dewatering Screens, Pipelines, and Flumes

Debris that passes through the orifices is generally too small to block collection channels or transport flumes or pipes. However, even fine debris can block dewatering screens. Such screens are typically equipped with debris removal brushes. Debris brushes are operated automatically or manually to keep screens functioning properly. Screens and flumes are typically inspected daily. Water level sensing devices are installed at critical locations with automatic alarm signals in the dam control room.

Wet Separators, Distribution Flumes, Raceways, and Pipes

Facility personnel inspect the separators at least four times per hour, and inspect distribution flumes, raceways, and pipes at least hourly. Where raceway covers or other structures impede visual inspection from the separator control building, closed circuit television is used to provide adequate inspection. Debris and dead fish collected in the system are removed from the separator, from raceways, sample tanks, or in the laboratory.

Winter Maintenance

From November through mid–March at the Snake River collector dams, and from January through mid–March at McNary Dam, facilities will be dewatered, modifications will be made, and facilities will be maintained for the upcoming transport season. Worn or defective parts and equipment will be replaced for the coming season. Maintenance may be as minor as repairing or acquiring new fish nets, to replacement of engines or pumps on barges.

Sanitation Practices

Facilities and transport equipment are drained when not in use. Trucks are rinsed and flushed after each trip. A chlorine solution is used as needed for rinsing truck tanks. Barges are filled with river water and flushed prior to loading of fish. Large fish including squawfish, smallmouth bass, and other potential predators are removed at the fish separator. Squawfish may be removed, but other fish are returned to the river via flume or pipe. Avian predators are deterred at holding facilities by bird wires netting, roofs, or by proximity of facility operation personnel.

1.2.4 Fish Mortality

Many of the juvenile fish migrating downstream through the reservoirs have external fungal infections, parasites, or internal or external bacterial or viral infections. Many are injured by predators prior to reaching the dams. These fish, if they die within the collection or transportation facilities, are counted as part of the collection/transportation mortality although pre– dam injuries and disease are noted in project reports. Because of environmental factors upstream of the dams, juvenile fish experience some descaling. In high flow years when there are large amounts of debris in the river, descaling before fish reach Lower Granite Dam may exceed 10 percent. In low flow years when water temperatures are higher than normal, fish entering the collection facilities may have decreased mucus layers and may be descaled from prolonged passage through reservoirs and from being chased by predators (Ceballos, *et al.*, 1993).

Potential for Injury or Mortality

Within the collection system, the potential for injury or mortality starts as fish pass through the trash racks. When clean, the openings between the bars are six inches, and descaling injury levels are low.

As debris collects, injury (typically descaling) and mortality can rise. Similar problems arise if vertical barrier screens or orifices are blocked by debris.

Over the past five years, an average of 22,200,000 hatchery and wild spring/summer and fall Snake River chinook have been collected at Lower Granite, Little Goose, and McNary dams each year. Approximately 450,000 dead fish (2 percent) were observed in collection facilities and transport equipment. Some of these fish were diseased, some were injured by bird and fish predators prior to collection at the dams, and some were injured or stressed in the collection and transportation process. Over the same period, approximately 70,000 Snake River sockeye were collected. Approximately 1,400 dead sockeye were observed, presumed to have died for the same reasons as chinook.

Estimates of Mortality

From the time they enter the turbine intakes until they are loaded on barges, mortalities are removed by facility workers. Since 1981 at Lower Granite Dam, total collection mortality has ranged from 0.1 to 0.7 percent. Chinook mortality has ranged from 0.3 to 1.2 percent. O. *nerka* mortality was 0.6 percent in 1993. At Little Goose Dam, overall mortality has ranged from 0.4 to 2.1 percent since 1981, with chinook mortality ranging from 0.4 to 6.2 percent and O. *nerka* mortality ranging from 0.6 to 6.3 percent over the same period. Preliminary results indicate overall mortality at less than 0.5 percent at Lower Monumental Dam in 1993. At McNary Dam mortalities have ranged from 0.4 to 3.9 percent. Yearling chinook morality has ranged from 0.3 to 1.9 percent, subyearling chinook from 0.4 to 5.0 percent, and O. *nerka* from 0.5 to 4.1 percent. Overall mortality was the highest in years during 1992 at McNary Dam, probably because of low outflow and warm water temperatures. With the exception of McNary Dam, seasonal mortality was less than 1 percent at the collector dams in 1992. Mortality was down at McNary Dam in 1993, with a seasonal mortality of 1.3 percent. In the trucks and barges, seasonal mortality typically is less than 1 percent.

Steelhead from the Snake and Columbia rivers, Columbia River chinook, coho, and sockeye will be collected and transported with Snake River chinook and sockeye salmon. Mortality rates (Ceballos, *et al.*, 1993) generally are lower for steelhead, ranging from less than 0.1 to 0.4 percent at Lower Granite Dam since 1982. Since 1985, wild and hatchery steelhead mortalities have been separated. Wild steelhead mortality has been less than 0.1 percent each year. At Little Goose Dam, steelhead mortality has ranged from 0.1 to 0.8 percent since 1981. At McNary Dam, steelhead mortality has ranged from 0.2 to 1.5 percent with the highest levels occurring in 1992 when wild fish experienced 1.0 percent mortality and hatchery fish 1.5 percent mortality. Coho mortality ranged from 0.0 to 0.5 percent from 1982 through 1991. In 1992, coho mortality rose to 1.1 percent. Sockeye mortality ranged from 0.5 to 4.1 percent with 1992 tying the highest previous mortality level.

Collection and transportation mortalities are estimates based on immediate recoveries of dead or moribund fish. Fish that are diseased or injured when they come into the system are collected and transported as 'live' fish. Fish that are stressed or injured in the collection and transportation process are also counted as 'live' fish unless they die and are removed during collection and transportation. Therefore, mortality levels reported for collection and transportation exceed levels caused by the actual collection and transportation process, but can underestimate mortalities caused by the process in the case of fish that die after release.

Steps Taken to Avoid or Decrease Mortality

Descaling and injuries are monitored in the daily sample at the collection facility by state agency and SMP personnel. When descaling or mortality rise, biologists check facilities upstream in the collection system to find the cause. Orifices and screens are inspected, and if necessary, cleaned or repaired. If the problem continues, trash racks will be cleaned. If that does not correct the problem, biologists may dip fish from the gatewells to ascertain whether fish are entering the system with higher than normal descaling. Local weather conditions can contribute

to high descaling if debris, especially tumbleweeds (Russian thistle) accumulates in the river above the dams (Ceballos, *et al.*, 1992).

Each year, the function and operation of collection and transport facilities and equipment at each collector dam are reviewed by Corps and State agency biologists working at the fish collection facilities. They recommend improvements to the Corps program manager who reviews these recommendations with representatives of the FPAC. Depending on the magnitude of changes recommended, modifications are made over–winter for the next season, or within a couple of years for modifications requiring line–item budgeting. Also, the Corps annually funds research to find new methods of improving fish guiding equipment and fish collection and transportation facilities. Improvements range from removing sharp curves in pipes or flumes to major facility reconstruction such as that completed at Little Goose Dam in 1989, at Lower Monumental Dam in 1993, and due to be completed at McNary Dam by the spring of 1994. Major modifications are coordinated with regional fishery agencies and Tribes through the FPDEP Fish Facility Design Review Subcommittee. Future improvements that have been recommended or are under development include upgrading the bypass collection system to provide size separation and to install a bypass flume at Lower Granite Dam, closure of the fish screen slots at Lower Granite Dam, increasing the number of fish barges to allow direct loading at all collection facilities, and installation of double length screens at McNary, Lower Granite, and Little Goose dams.

Post–Transportation Mortality

Concern over the potential effects of stress and injury in the transportation process prompted delayed mortality investigations by NMFS (Park, et al. 1983; Park and Athearn, 1985). These and subsequent long–term holding studies by NMFS (Matthews, et al. 1988) indicated that there was some level of delayed mortality due to collection and transportation. However, as pointed out by Williams and Matthews (1995), and as evidenced by fish transportation annual reports, stress and mortality in collection and transportation have, for the most part, been minimized.

Other investigations are continuing to evaluate the effects of stress, disease transmission, and post–release mortality (Pascho and Elliott (1993, 1994), and Schreck and Davis (1993, 1994)). Juvenile salmon equipped with radio tags were tracked up to 100 miles after release from barges, with no abnormal mortality levels found (Schreck and Davis, 1994). These studies failed to substantiate high post–release mortalities assumed by some modelers in the region.

NMFS' March 1995 Biological Opinion, which took into consideration the concerns addressed above, concluded that transportation should be maximized in low flow years, and that the decision to transport in normal and high flow years should be based on real time interpretation of events by the Technical Management Team (TMT).

Numerous studies have evaluated stress on fish transported in trucks and barges, some indicating that trucking is more stressful than barging (Mundy et al. 1994; Schreck et al. 1985). Schreck et al. 1993 and 1994, indicated that stress levels declined during transport, and that because truck transport took considerably less time, fish were still stressed at release whereas barged fish had longer to recover. Studies have also shown that stressed migrants are more susceptible to predation at time of release (Olney et al. 1992; Congleton et al. 1985; Mundy et al. 1994; USFWS 1993). Annual records show that generally over 95 percent of the fish transported in the transport program are barged downstream. To minimize predation, barged fish are released mid–river at night. During the summer and fall, trucked fish are barged mid–river and released to minimize predation.

1.2.5 Research and Monitoring

Passive Integrated Transponder (PIT) Tag Systems

In the 1980s, NMFS began seeking a better fish tagging system for transportation and other research studies. The coded wire tag/adipose fin clip/freeze brand technology used for transport studies in the

1970s (Ebel, *et al.*, 1973) required marking of large groups of test and control fish, and wire tags and adipose fin clips were being extensively used for hatchery contribution studies throughout the Columbia basin.

NMFS (Prentice, *et al.*, 1987) was instrumental in the development of PIT tag technology for fish. Working with manufacturers, tags small enough to be injected into juvenile salmon were developed. Each tag is essentially a miniature radio without a power source. The PIT tag consists of a crystal, a computer chip, and an antenna, all encased in an inert glass case approximately 0.1 inch in diameter and 0.3 inches long. The detector consists of a sending unit and a series of antennas encased in a shroud that controls radio emissions. As the PIT tagged fish goes through the detector, the sending unit sends a strong radio beam to the tag. This activates the crystal causing the computer chip to send a 10 digit alpha–numeric code back to the detector. At least one of the three or four antennas in the detector will pick up the weak signal from the PIT tag. With 10 digits (10 possible numbers and 26 letters for each digit), there are some 33 billion possible codes available at any given time.

As studies began, it became apparent that PIT tag detectors in the juvenile fish collection/bypass systems at the dams would provide valuable information on travel time and to some extent, on survival to the dams. PIT tag detectors were installed first at Lower Granite Dam in 1988, then at McNary Dam in 1989. Typically, PIT tag detectors were installed on distribution flumes or pipes so that the destination of each PIT tagged fish could be monitored. Destinations included distribution to holding raceways, into the laboratory building, into truck or barge loading pipes or flumes, or into bypass pipes for fish being returned to the river.

As the PIT tag technology improved, the potential for using PIT tags to evaluate transportation, or the effect of bacterial kidney disease (BKD) infection in transportation, also evolved. This led to the development of PIT tag deflector systems (Matthews, *et al.*, 1990). PIT tag detectors were linked to automatic gates so that a portion of the population of the PIT tagged fish could be transported, and a portion could be bypassed to the river. With this technology, handling, anesthetization, and marking of fish at the dams could be eliminated, and fish marked long beforehand at hatcheries or in wild rearing areas could be used for tests. To evaluate BKD implications in transportation, high BKD versus low BKD groups were to be tested. Pilot studies to verify the effectiveness of such studies (Pascho and Elliott, 1992; Matthews, 1992) gave some indication that low BKD groups survived better to the collector dams, and to subsequent dams downstream. Surprisingly, wild fish were found to survive over winter at very low rates (1 to 20 percent for the many groups marked). Low returns to hatcheries made it impossible to further carry out these studies, so only preliminary results were obtained.

Further use of the PIT tag deflector systems evolved. With the advent of drawdown proposals in the early 1990s, the Federal agencies agreed that background survival information was needed. Following the physical drawdown test of Lower Granite reservoir 1992, NMFS and University of Washington collaborated with BPA and the Corps in the development of a study protocol to obtain baseline information. This protocol called for PIT tagging fish for release at various locations and through various migration routes (spillway, bypass, turbine) to gather more information on current in–river survival levels. This information would be compared with similar information gathered during biological drawdown tests to determine whether drawdown increased fish travel speed and survival. At this writing, the Federal agencies are still finalizing the SCS to determine if drawdown will be tested, and to determine the exact study protocol needed for the tests.

In addition to development for such studies, the PIT tag detection systems have been developed at the Federal dams for Smolt Monitoring Program activities and other survival studies. At this writing, full PIT tag detection systems are installed at Lower Granite, Little Goose, Lower Monumental, and McNary dams. PIT tag detection equipment is also installed on the Bonneville Dam Second Powerhouse bypass system. Plans are underway to install PIT tag detection systems on the bypass at Ice Harbor Dam

(1996), John Day Dam (1996), and The Dalles Dam (1998). PIT tag deflector systems are installed at Lower Granite, Little Goose, Lower Monumental, and McNary dams so that PIT tagged fish can be returned to the river if desired under test protocol.

Installation of PIT tag systems has been a cooperative effort with the NMFS developing and installing the technology, the BPA funding installation of PIT tag equipment, the Corps providing space and accommodations for detectors and computer equipment, and the Pacific States Marine Fisheries Commission (PSMFC) maintaining the systems under contract to the BPA. Under current operations, each PIT tag detection is recorded on a computer (one computer for each detector) within the laboratory at fish collector dams. At mid–night each day, this data is telephonically downloaded to a central data collection point at the PSMFC office in Portland. From there, the data is accessible to fishery agencies, the Tribes, and other interested parties the next day. In this way, data on migration and survival of PIT tagged fish is available almost on a real time basis for evaluation of migration conditions.

The PIT tag technology for tagging juvenile salmon is fairly well developed. PIT tags if retained in the body cavity, remain viable throughout the life of the salmon. Therefore, if the technology were developed such that adult fish could be interrogated by PIT tag detectors, it would be possible to gather even more information through the rest of the salmon's life cycle. NMFS is working at this time on adult fish PIT tag detectors, which could be installed in fish ladders at the dams and at fish hatcheries or collection weirs. At the present time, information can be obtained from adult fish caught in fisheries or on spawning grounds by using hand–held PIT tag detectors. With the large numbers of PIT tagged fish being released for various purposes, developing and installing juvenile and adult PIT tag detectors at all Corps fish facilities is a high priority.

1.3 THE SCOPING PROCESS

In August of 1990, the SOR scoping process was initiated to identify public concerns. Over several months, meetings were held in 14 locations around the region.

Comments concerning anadromous fish came from the USFWS, NMFS, CBFWA, CRITFC, state fishery agencies, environmental groups, concerned citizen groups, public and private utilities, irrigation districts, and the general public.

The scoping process gave everyone an opportunity to voice opinions as to their preferred operation of the Federal hydrosystem. Normal operating requirements such as those for flood control, power generation, and fish migration were hypothetically eliminated, giving individuals the latitude to suggest any operation within the physical limits of the dams.

1.3.1 Issues

Issues raised during the scoping process became a starting point for the SOR process. As the process unfolded, the various analyses raised new issues while removing old ones.

Those issues raised during Scoping fell into the following categories:

- the need to examine threatened and endangered species identified under the ESA;
- the need to provide equitable treatment to anadromous fish;
- the need for operational improvements for migration and habitat;
- opinions as to the reasons for the decline in fish populations (dams, habitat losses, timber practices, overharvesting, agricultural practices, pollution, drift net fishing, water diversions, hatchery practices, mismanagement of stocks, estuary conditions, and river temperatures).

Also during Scoping, a debate developed over the priority that ought to be given to anadromous fish in hydrosystem operations. Some felt that native stocks deserved the highest priority, while others thought that priority should be given to identifying and enhancing the potential for survival of fish better adapted to current river operations.

While some participants questioned the degree to which fish runs could and should be recovered, others lobbied for the need to ensure a balance between the fish populations and the economic health of the region. Overall, the majority of comments supported enhancement of the regions' salmon and steelhead populations.

Other concerns outside the scope of the hydrosystem effects, such as habitat, harvest, and hatchery practices, were discussed but have not been evaluated.

Summarized below are the, significant issues raised during the SOR process relating to the interaction between the hydrosystem and anadromous fish.

1.3.1.1 Flow/Survival Relationship

Considerable debate exists within the scientific community over the relationship between flow (water velocity) and smolt survival. If the assumption is that the rate of juvenile salmonid travel is directly related to water velocity, then increasing flow would decrease the amount of time fish spend in the reservoirs. Increased water velocity, as measured by water particle travel time through the reservoirs, would presumably translate into increased survival for migrating smolts. However, it is not clear that increasing water particle travel time alone would recreate the productivity levels of earlier times (Recovery Team, 1994). Other factors (smoltification, water quality, turbidity, predation, water temperature, fish health) are also at play and have significantly changed since the 1970s when the flow and travel time research was initially conducted (OA/EIS 1992).

For further information, the reader is directed to the OA/EIS (1992, Section 4), which details much of the information surrounding this debate and refers the reader to published literature for further information.

1.3.1.2 Transportation

The ability of the Corps' Juvenile Fish Transportation Program to enhance salmon survival, at least as an interim measure until better alternatives are researched and developed, is another major issue hotly debated within the region. Review of the research conducted to evaluate relative survival of transported versus non-transported fish supports the effectiveness of transportation.

Still, concern remains over the benefits of transporting fish. One concern is that survival of transported fish is not as high as would be expected.

Some biologists believe that the assumptions used in determining transport benefit are flawed. In particular, analysts have traditionally assumed that transported fish survive at some fixed percentage, regardless of in–river conditions. This assumption may be flawed, if in fact the survival of transported fish varies with flow conditions (if, for instance, fish arriving at a collection facility for transport in low–flow years are more likely to be injured and not survive barging, than fish arriving in high–flow years). Since the transport survival assumption directly affects model output relating to transportation and in–river survival, the assumption needs to be carefully evaluated.

Substantive issues dealing with juvenile transportation research and operation fall into one of several categories:

- whether collection and transport is safer for migrating juvenile salmon than in–river passage through the dams and reservoirs as they are currently operated;
- whether in–river bypass, including combinations of powerhouse bypass systems, augmented flows, altered reservoir operations, and/or spill is the safest downstream route for migrating salmon;
- whether transportation protects migrating fish from high concentrations of dissolved gas created by spill, or whether fish may be safely subjected to higher levels of dissolved gas;
- whether current Federal agency–derived mortality rate estimates for dam passage routes and reservoirs are adequate for decision making;
- whether current Federal agency–derived rates for both in–river survival and for

transportation survival (transport/benefit ratios [TBRs], transport/control ratios [TCRs], or transport/in–river [TIR]) are realistic; whether current estimates of delayed mortality due to transportation are realistic; whether the Federal agencies are accurately depicting the relationship between juvenile escapement and adult returns as a measurement of transportation success.

A sensitivity analysis that compares in–river survival to survival with transport, under various transport survival hypotheses, is treated in Chapter 5.

1.3.1.3 Spill/Dissolved Gas

Another issue is the use of spill to pass juvenile salmon and steelhead, and its effectiveness in improving in–river passage conditions. The issue of dissolved gas supersaturation as it relates to spill, and its impact on both juvenile and adult fish, is contested by various regional interests.

Spilled water traps atmospheric air deep in the water of the plunge pool where increased hydrostatic pressure dissolves the air into the water. At depth, the water is supersaturated with gas. This gas will eventually either come out of solution and equilibrate with atmospheric conditions, or form bubbles. If these bubbles form within the tissue of aquatic organisms, they can injure or kill the organism. Gas levels can successively increase downstream as water is passed over successive dams. State and Federal water quality standards of 110 percent are often exceeded when spill at run–of–the–river dams on the lower Snake and Columbia Rivers causes high levels of total dissolved gas (TDG). There is considerable controversy over what level of TDG is acceptable, and disagreement on interpretation of extensive data which appears to justify the existing 110 percent standard.

Gas supersaturation may also be an issue relating to fish guidance. Fish guidance systems are designed on the assumption that smolts travel in the upper 15 feet of the water column; if smolts are sounding in the forebay to avoid supersaturated conditions, it may have an effect on the ability of the guidance system to intercept fish.

1.3.1.4 Wild Vs. Hatchery Fish

Prior to 1968, nearly all returning Snake River basin adult salmon were of natural origin. Since then, adult returns have been composed of ever–increasing numbers of hatchery–reared progeny. The tremendous increase in hatchery production may be contributing to the decline of natural Snake River stocks. Little is known about the interaction and competition between hatchery and wild stocks, or how wild stocks respond to major regional programs such as transportation or Water Budget.

1.3.1.5 Predation

With the development of the dams, fishery agencies became concerned that the conversion of the free flowing river to a series of slow moving reservoirs would both provide better habitat for predacious fish, and concentrate smolts with these predators for longer periods.

Furthermore, as turbine mortality studies progressed, it became apparent that fish stunned in passing through turbines were more easily captured by predators. Indeed, some studies showed that mortality due to predation below the dams was as high or higher than losses due to the turbines themselves.

Estimates of losses from predation have always played a part in fish management strategies, and earlier high estimates were a rationale leading NMFS to suggest that fish be transported around dams and reservoirs. Presently, however, uncertainty surrounding the extent of predation has led to requests for updated estimates.

1.4 THE ANALYTICAL PROCESS

1.4.1 The Pilot Analysis

A pilot analysis was completed by four work groups in April 1991. Those work groups included, Anadromous Fish, Resident Fish, Recreation, and Power. The purpose of the pilot analysis was to begin preliminary discussions of issues surrounding the

particular river uses to develop a conceptual framework and scope for the technical evaluations, and to begin identifying important variables and key uncertainties. It became a starting point from which to begin the screening analysis.

1.4.2 The Screening Analysis

The Screening Analysis began with each technical work group, on the basis of public and scientific input, developing operating alternatives that addressed issues identified during Scoping. In all, 90 different hydrosystem operation alternatives were identified by the work groups.

The AFWG sponsored several alternatives that it felt would benefit the needs of anadromous fish, including hastening the recovery of wild salmon populations. These included a variety of proposals for drafting storage reservoirs to increase spring and summer flows. Several alternatives proposed drawing down the four lower Snake River reservoirs to increase water velocities for migrating fish.

Following development of the 90 alternatives, each was screened or modeled under varying water conditions by the River Operation Simulation Experts (ROSE). Data on instream flows and reservoir elevations produced by each alternative at specific project/locations was passed on to the technical groups for use in their models. (*A complete account of the Screening Analysis may be found in the Columbia River System Operation Review; Screening Analysis, volumes 1 & 2, August 1992.*)

1.4.3 Full Scale Analysis

The results of the Screening process were used to set the stage for the Full Scale Analysis. Screening alternatives were sorted, categorized and blended into seven basic System Operating Strategies (SOS). Each SOS has one or more options. These strategies and their options are explained in Chapter 4 of the SOR Draft EIS. Following public review and comment on the SOR Draft EIS, some alternatives were eliminated or revised. The resulting alternatives were analyzed for the SOR Final EIS. See Chapter 4 for a complete description of alternative hydrosystem operating strategies.

CHAPTER 2

AFFECTED ENVIRONMENT

2.1 SALMON AND STEELHEAD

Four species of Pacific salmonids (genus Oncorhynchus) occur in the Columbia River basin above Bonneville Dam: chinook salmon (O. *tshawytscha*); coho salmon (O. *kisutch*); sockeye salmon (O. *nerka*); and steelhead trout (O. *mykiss*), the anadromous form of rainbow trout. There are two races of chinook salmon: spring/summer and fall chinook. The spring/summer run fish have traditionally been considered separate runs based on the difference in timing of adult returns to spawning areas. However, in determining whether Snake River spring/summer chinook salmon should be considered together or separately as a species as defined by the Endangered Species Act, the National Marine Fisheries Service (NMFS) determined that the two runs were not reproductively isolated and elected to place both the spring and summer run chinook together as one species.

There are two races of steelhead: winter and summer. Two other salmon species; chum (O. *keta*), and pink salmon (O. *gorbuscha*) occur in the Columbia River below Bonneville Dam with only small populations existing.

Four distinct phases of life history characterize these anadromous salmon and steelhead: freshwater spawning and rearing; juvenile migration to the ocean; ocean residence; and adult upriver migration. Pacific salmon spawn in the gravel beds of freshwater rivers, tributary streams and lakes. After rearing in fresh water from a few days up to three years, they migrate to sea where they spend from one to five years feeding. Some of the stocks migrate over very long distances during their ocean residence. They have a strong tendency to return to their river of origin and to use a wide variety of freshwater habitats. This results in the development of a wide range of adaptations and many reproductively isolated populations or stocks.

These native stocks of salmon and steelhead evolved over thousands of years within the natural ecosystem of the Columbia River basin. The timing of juvenile seaward migration of many species and races coincided with the high runoff months of April, May, June, and less so in July (Mains and Smith 1964). The high velocity, volume and turbidity associated with spring runoff helped the juvenile migrants move rapidly downstream with a minimum of energy expended and with protection afforded from predators. High flows also provided favorable conditions for most adult salmon and steelhead migrating upstream.

While the basic biological requirements of salmon and steelhead have remained unchanged, pressure on all four phases of their life cycle has increased. As an example, over time the migration corridor in the Columbia River basin has changed dramatically. Today the river is a series of reservoirs with large cross–sectional areas, lower water velocities and upstream storage reservoirs that allow for the shifting of spring and summer flows into the fall and winter. The emplacement of hydroelectric dams and altered hydrographic conditions, in combination with other factors such as irrigation withdrawals, degradation of spawning and rearing habitat and over–fishing have led to the extinction of some stocks and the listing of Snake River sockeye, spring/summer and fall chinook salmon as endangered under the Endangered Species Act.

2.1.1 Salmon and Steelhead Population Status

Salmon and steelhead stocks historically used much of the Columbia River and its tributaries. Prior to development, chinook salmon migrated 1,200 miles up the Columbia River to Lake Windemere in Canada and 600 miles from the confluence of the Snake and Columbia rivers to Shoshone Falls near Twin Falls, Idaho (Fulton 1968; Van Hyning 1968). The Columbia and Snake rivers once supported the largest chinook salmon and steelhead populations in the world (Van Hyning 1973). The Northwest Power Planning Council estimates that Columbia River basin salmon and steelhead runs ranged between ten and 16 million wild fish prior to development.

Chapman (1986) estimates predevelopment run size at 7.5 to 8.9 million salmon and steelhead.

Since 1970 the minimum number of adult salmon and steelhead entering the Columbia River has ranged from 0.9 million fish in 1983 to 2.9 million fish in 1986. In 1990 a total of 1.1 million adult salmon and steelhead entered the Columbia River, which was the smallest run since 1983 (ODFW/WDF 1991). Artificial propagation facilities, built throughout the basin as compensation for the loss of wild runs, now account for about three–quarters of all fish returning to the Columbia River basin (ODFW/WDF 1991).

The decline of wild runs has been so severe that three stocks of salmon in the Columbia River basin are now listed as endangered under the Endangered Species Act: Snake River sockeye salmon; Snake River spring/summer chinook salmon; and Snake River fall chinook salmon. NMFS concluded that Snake River spring and summer chinook should not be treated as independent evolutionary lineages under the Endangered Species Act because of the possibility of substantial gene flow between the two forms in streams where they co–occur (Matthews and Waples 1991).

NMFS in their status review of Snake River fall chinook salmon concluded that Snake River fall chinook is a distinct population for ESA purposes that differs genetically and ecologically from upper Columbia River fall chinook (Waples et al. 1991). Lower Columbia River coho salmon also were proposed for listing but the NMFS determined that a listing was not warranted at that time. Upper Columbia and Snake River coho salmon are now considered extinct.

Table 2–1 presents the recent dams counts including jacks for each species.

Table 2–1. Adult Salmon and Steelhead (including jacks) Counts at Selected Corps Projects (1971–80, 1981–85,1986–90 are 5–year averages)

Species	Bonneville	McNary	Ice Harbor/ Lower Granite
Spring Chinook			
1971–80	118,801	48,143	32,208
1981–85	67,956	36,611	17,216
1986–90	100,621	53,621	28,664
1990	96,252	44,499	20,730
1991	61,235	22,527	11,281
1992	90,582	50,504	26,052
1993	112,172	59,556	24,935
1994	20,566	8,987	3,167
1995	12,573	5,930	1,563
Summer Chinook			
1971–80	50,399	34,266	11,369
1981–85	27,076	18,228	4,972
1986–90	33,254	24,346	6,505
1990	28,021	22,248	5,794
1991	21,953	17,588	5,861
1992	19,245	14,413	4,377
1993	23,616	20,374	6,919

Table 2–1. Adult Salmon and Steelhead (including jacks) Counts at Selected Corps Projects (1971–80, 1981–85,1986–90 are 5–year averages) – CONT

Species	Bonneville	McNary	Ice Harbor/ Lower Granite
Summer Chinook			
1994	19,531	14,313	864
Fall Chinook			
1971–80	209,027	62,838	4,282
1981–85	233,189	95,471	3,959
1986–90	340,026	161,335	6,277
1991	191,301	73,725	6,049
1992	146,243	70,688	5,458
1993	141,528	63,276	3,120
1994	203,353	105,568	1,046
Sockeye			
1971–80	57,818	39,769	299
1981–85	105,136	47,597	127
1986–90	69,259	51,235	14
1991	76,482	69,364	14
1992	84,998	68,732	8
1993	80,182	66,479	11 *
1994	12,678	10,602	5
Coho			
1971–80	50,832	12,693	749
1981–85	41,172	3,817	26
1986–90	52,467	1,888	0
1991	117,430	2,990	0
1992	17,360	1,804	0
1993	10,239	459	0
1994	22,794	1,735	0
Steelhead			
1971–80	142,555	109,795	28,057
1981–85	238,979	117,211	83,338
1986–90	286,574	151,917	96,229
1991	274,030	157,866	92,753
1992	314,378	194,949	108,970
1993	187,855	92,551	61,504
1994	161,978	94,427	47,550

Data source: Corps, 1991b for 1971 – 1990 counts, Fish Passage Center data for 1991 – 1993 counts.
* Fish Passage Center Bi–weekly report #94–24

For chinook salmon, Ice Harbor counts are shown for each year. For all other stocks, Ice Harbor counts are shown for 1971 through 1974, and then Lower Granite Dam counts thereafter.

2.1.1.1 Chinook Salmon

Spring and Summer Chinook Salmon

Snake River. Historically spring and summer chinook salmon were produced in numerous tributaries of the Snake River in both Oregon and Idaho. During the late 1800s, the Snake River probably produced in excess of 1.5 million juvenile spring and summer chinook salmon in some years (Matthews and Waples 1991). Access to tributaries and the mainstem in the upper Snake River was eliminated by the construction of Swan Falls, Brownlee, Oxbow, and Hells Canyon dams.

Wild production in the Snake River basin in the 1960s was returning 50,000 to 80,000 adult spring chinook annually to the Columbia River basin (ODFW 1991). Returns of wild spring chinook in the Snake River basin has declined to about 10 to 20 percent of the estimated level of the 1960s (ODFW 1991). The estimated average annual escapement of wild adult spring chinook salmon at Lower Granite Dam was 6,100 from 1987 through 1991 (ODFW 1991). Escapement trends in Oregon streams indicate that there were relatively stable wild spring chinook salmon escapements from the mid–1950s to early 1970s and from then the completion of the two upper most dams on the Snake River contributed to a sharp decline in escapement (ODFW 1991). The estimated average escapement of hatchery spring chinook over Lower Granite Dam during the same time period was increasing annually and estimated to be an average of 12,900 (USFWS 1992).

The Snake River wild summer chinook run has declined substantially from an average run at Ice Harbor Dam in the 1960s of 22,000 fish to an average estimated run of 3,100 fish in the 1980s (ODFW 1991). Hatchery production of summer chinook began in the 1980s. The estimated hatchery summer chinook run at Lower Granite Dam has ranged from 671 in 1982 to 3,883 in 1988 (ODFW 1991).

Upper Columbia River. The summer chinook salmon historically was the dominant run into the upper Columbia River (Mullan 1987). Very little information is available on the historical abundance of spring chinook salmon in the upper Columbia River but Bell (1937) concludes that only 4 percent of the spring chinook salmon that entered the Columbia River originated above Rock Island Dam. Based on geographic distribution of habitat, 500,000 chinook historically may have been produced in the upper Columbia River (Haas 1975).

As a result of overfishing and habitat degradation spring chinook runs to the upper Columbia River had declined substantially by the 1930s. Rock Island Dam counts of spring chinook salmon ranged from 180 to 4,256 from 1935 through 1942. The construction of Grand Coulee Dam blocked anadromous salmonids from access to the upper Columbia River in 1939. Salmon and steelhead returning to the upper Columbia River have been trapped downstream at Rock Island Dam and released above temporary weirs in the Wenatchee and Entiat rivers or used as hatchery broodstock at Leavenworth, Entiat, and Winthrop National Fish Hatcheries (Mullan 1987).

Redd counts in the upper Columbia River for spring chinook have shown little long–term change while adult passage counts at Priest Rapids Dam indicate a substantial increase since the mid–1970s (ODFW 1991). The average annual count of spring chinook at Priest Rapids Dam was 7,600 in the 1960s and increased to 14,300 in the 1980s (ODFW 1991). The increase in spring chinook salmon returns above Priest Rapids Dam is due primarily to increased hatchery production. The hatchery and natural/wild components of the spring and summer chinook salmon runs above Priest Rapids have not been estimated.

The summer chinook run in the upper Columbia River has been relatively stable over the past thirty years. Redd counts in the mid–Columbia River tributaries averaged 1,775 in the 1960s and 1,927 in the 1980s. Counts of summer chinook also show little change with an average annual count at Priest

Rapids Dam of 15,200 in the 1960s and 14,040 in the 1980s (ODFW 1991).

Fall Chinook Salmon

Snake River. Historically fall chinook salmon were very abundant in the Snake River. Fall chinook spawned in the mainstem river from the confluence with the Columbia River upstream to Shoshone Falls, and in the lower reaches of the major tributaries of adjoining the Snake River (Waples et al. 1991). Dams constructed on the mainstem of the Snake River reduced the abundance and distribution of Snake River fall chinook salmon through both spawning and rearing habitat modification. The mean number of fall chinook salmon returning to the Snake River declined from 72,000 from 1938 to 1949 to 29,000 in the 1950s (Irving and Bjornn 1981). Even after this decline, the Snake River remained the most important area for natural production of fall chinook salmon in the Columbia River Basin through the 1950s (Fulton 1968).

Average annual counts of fall chinook at the uppermost Snake River dams declined from 12,720 fish during 1964 to 1968 to 610 from 1975 to 1980 (Waples et al. 1991). This decline coincided with the construction of the lower Snake River dams (1961 to 1975) which eliminated a substantial proportion of suitable spawning conditions in the lower 146 miles of the Snake River. Estimated escapement of wild fall chinook at Lower Granite Dam ranged from 720 in 1982 to only 78 fish in 1990 (Waples et al. 1991). Fall chinook spawning also occurs in restricted areas in the Snake River and in tributaries below Lower Granite Dam. Fall chinook salmon have been observed spawning in the lower Tucannon River (Bugert 1991) and the tailraces of Lower Granite and Little Goose dams in 1993 (Dennis Dauble, Battelle, personal communication, 1993). No evidence of spawning near the dams had been documented previous to 1991 (Waples et al. 1991), indicating that the extended juvenile bypass and transport seasons implemented since ESA listing may be a contributing factor to creating higher velocity tailrace conditions that are preferred for spawning activity.

Upper Columbia River. Fall chinook historically spawned throughout much of the mainstem of the upper Columbia River. Based on geographic distribution of habitat, 500,000 chinook historically may have been produced in the upper Columbia River (Haas 1975). The fall chinook run destined for the upper river was substantially depressed from historical levels before the construction of Grand Coulee Dam blocked access in 1939. Counts of fall chinook salmon at Rock Island Dam from 1933 to 1942 ranged from only 165 to 3,287 fish (Mullan 1987). The construction of the mainstem dams in the Columbia River below Grand Coulee Dam eliminated most of the remaining important fall chinook spawning habitat.

The number of fall chinook that spawn in the Hanford Reach of the Columbia River, the last major fall chinook spawning habitat remaining in the mainstem, increased substantially in the 1960s after construction of downriver dams and inundation of spawning habitat caused an upstream translocation (Mullan 1987). Redd counts in the Hanford Reach increased from an average of 1,100 from 1960 to '64 to 3,300 from 1965 to 1969 (ODFW/WDF 1991). Since 1964 returns of adult upriver bright fall chinook salmon have ranged from 66,600 to 419,400, with the lowest returns occurring in 1980 and 1981. Returns have declined each year from the peak of 419,400 in 1987 to only 102,200 in 1991 (ODFW 1991).

Hatchery releases, primarily from Priest Rapids, Little White Salmon, Lyons Ferry, Bonneville and Irrigon hatcheries, also contribute to the upriver bright fall chinook runs. Hatchery upriver bright fall chinook above McNary Dam from 1986 to 1990 ranged from 4,700 to 24,800 adult returns. Returns of hatchery bright fall chinook released below McNary Dam ranged from 17,000 to 93,000 adults from 1986 to 1990 (ODFW 1991).

Returns of Bonneville Pool hatchery fall chinook (tules) were fairly stable from 1964 to 1982 and then declined dramatically. The average annual return, which was 108,000 for 1978 to 1982, declined to only 19,700 for the period from 1986 to 1990 (ODFW 1991). Natural spawning of Bonneville Pool hatch-

ery fall chinook also occurs in the lower reaches of the Wind, Big White Salmon and Klickitat rivers. Natural spawning escapement in these areas ranged from 900 to 2,650 adults from 1986 to 1990 (ODFW 1991).

2.1.1.2 Sockeye Salmon

Snake River. Historically sockeye salmon were abundant in several lake systems in Oregon and Idaho. The only remaining population resides in Redfish Lake in the Stanley Basin of Idaho, which currently supports the southernmost sockeye salmon population in the world (Waples et al. 1991). The commercial harvest of sockeye salmon in the Columbia River in some years exceeded 4.5 million pounds in the 1890s and early 1900s (ODFW 1991). The existence of commercial canneries in the Snake River basin, such as the one near Wallowa Lake, is an indication that sockeye salmon historically were abundant (ODFW/WDF 1990).

Declines in the Snake River sockeye salmon run in the early 1900s are attributed to over-harvest and construction of hydroelectric and irrigation diversion dams in Snake River tributaries (ODFW 1991). Sunbeam Dam built in 1910 about 20 miles downstream from Redfish Lake on the main Salmon River was not passable until 1912, and possibly not until as late as 1920 when a concrete ladder was completed (Waples et al. 1991). The dam was partially removed in 1934, allowing unobstructed passage. Sockeye salmon were observed spawning in Redfish Lake in the late 1920s, 1930s, and early 1940s and were abundant in the 1950s (Waples et al. 1991).

In the 1960s some of the lakes in Idaho that were accessible to sockeye salmon were blocked and chemically treated to convert them to resident fish management (ODFW 1991). Alturas and Redfish lakes (2,300 acres) remained accessible (ODFW 1991).

The Snake River sockeye salmon run at the uppermost dam on the Snake River averaged 720 fish from 1965 to 1969. From 1985 to 1989 the average annual run had declined to 20 fish. No sockeye were documented in Redfish Lake in 1990, four were counted in 1991, and one male returned in 1992.

NMFS determined that the recent sockeye salmon in Redfish Lake are descended from the original sockeye salmon gene pool and should be considered separately from the non-anadromous kokanee which also reside in the lake, and other sockeye salmon populations (Waples et al. 1991). NMFS listed the Snake River sockeye salmon as an endangered species in November 1991.

Upper Columbia River. Historically sockeye salmon in the upper Columbia River had access to nursery lakes with a surface area of about 216,000 acres (Mullan 1986). Annual catches of sockeye salmon in the Columbia River ranged from 250,000 to 1.3 million fish before 1900 (Mullan 1986). Habitat loss due to blockage by dams on tributary streams was the major cause of the early post-1900 decline (Mullan 1986).

Grand Coulee Dam construction blocked access in 1939 to most of the historical spawning areas. Wenatchee and Osoyoos lakes were the only remaining lakes accessible to sockeye salmon with a surface area (8,174 acres) of only four percent of the original area. From 1939 to 1943 sockeye salmon were trapped at Rock Island Dam and relocated to Lake Osoyoos and Lake Wenatchee and to Leavenworth, Entiat, and Winthrop National Fish Hatcheries. From 1938 to 1959 run sizes at Bonneville Dam ranged from a low of 10,900 sockeye in 1945 to a high of 335,300 in 1947. The 1950s was a period of relatively stable run sizes which sustained an average annual harvest of 95,900 sockeye (ODFW 1991). Hydroelectric dams on the mainstem Columbia River constructed in the 1950s and 1960s account for the most recent general decline (Mullan 1986).

At Priest Rapids Dam escapement between 1960 and 1990 has varied widely from a low of 14,900 in 1978 to a high of 170,100 in 1966. The escapement at Priest Rapids Dam has averaged 52,500 from 1986 to 1990. Approximately equal numbers of spawners returned to Lake Osoyoos and Lake Wenatchee during this time period (ODFW 1991).

2.1.1.3 Steelhead

Summer steelhead

Limited information is available on the historical size of summer steelhead runs in the Columbia River basin. Counts began at Bonneville Dam in 1938 and no distinction was made between Group A and Group B upriver summer steelhead until after 1968. The largest run of upriver summer steelhead of record was 423,000 fish in 1940. The combined upriver summer steelhead run remained relatively high until the 1950s and then gradually declined hitting a low during the latter half of the 1970s. The combined upriver summer steelhead run at Bonneville Dam ranged between 84,000 and 195,000 fish from 1975 to 1979 (CBFWA 1991). Transportation of juvenile steelhead and increased hatchery production resulted in larger returns of upriver steelhead in the 1980s. From 1984 to 1989 the upriver steelhead run ranged between 285,000 and 384,000 fish. Hatchery fish usually exceed 65 percent of the Group A run and at least 80 percent of the Group B run (CBFWA 1991). Wild/natural runs are a different story. Since 1986 no progress towards rebuilding wild/natural steelhead runs has been evident. Abundance indices indicate declining trends in wild/natural steelhead abundance throughout the upper Columbia River (ODFW 1991).

Snake River. The interim escapement goal of wild/natural Group A steelhead at Lower Granite Dam is 20,000 fish. Escapements of wild/natural Group A steelhead at Lower Granite Dam have ranged from a low of 7,400 fish in 1974 to a high of nearly 20,000 fish in 1986. Escapements have declined since 1986 (ODFW 1991).

Estimated Group B steelhead escapement at Lower Granite Dam was 2,900 fish in 1974 and increased to 7,000 fish in 1982. The escapements since 1982 have been variable, ranging from 5,100 to 8,900 fish (ODFW 1991). The interim escapement goal is 10,000 wild/natural Group B steelhead at Lower Granite Dam. All Group A and Group B wild/natural spawning areas surveyed in Idaho to determine percent carrying capacity indicate that all areas are underseeded (ODFW 1991).

Upper Columbia River. Wild steelhead escapements to the Wenatchee and Methow rivers have remained steady or increased in recent years, while escapements in the Yakima and Wind rivers have decreased. Estimated escapement of wild steelhead above Priest Rapids Dam was 2,300 in 1986, 3,700 in 1987, 2,200 in 1988, 2,660 in 1989, and 1,380 in 1990 (ODFW 1991). The escapement goal at Priest Rapids Dam is 5,250 adults.

Lower Columbia River. Relatively little data exists on the historical status of lower river summer steelhead. Hatchery production in the 1970s and 1980s greatly increased returns of lower river summer steelhead. From 1969 to '79 the estimated minimum return ranged from 18,000 to 51,000 fish. The minimum return ranged between 20,000 and 90,000 fish between 1980 and 1988 (CBFWA 1991).

Winter steelhead

Between the 1960 to 1961 and 1986 to 1987 run years, index counts of winter steelhead in the lower Columbia River ranged from 45,000 to 169,000 fish (CBFWA 1991). Hatchery fish contribute significantly to the runs and most lower Columbia River tributaries have been routinely supplemented with hatchery releases.

2.1.1.4 Coho Salmon

Snake and Upper Columbia Rivers. Coho salmon historically were abundant in many of the tributaries of the Columbia River above Bonneville Dam. The longest distance coho salmon are known to have migrated in the Columbia River was 700 miles from the ocean to the Spokane River (Fulton 1970). About 300,000 to 400,000 coho salmon were landed annually in the lower Columbia River between 1866 and 1919 (Mullan 1984). Mullan (1984) suggested that between 120,000 and 166,500 coho salmon originated from the mid and upper Columbia River. However, as a result of over–fishing, dam construction, and habitat destruction, from 1933 to 1940 only 10 to 183 coho salmon were recorded annually passing Rock Island Dam.

In the Snake River basin, the Grande Ronde River was an important coho salmon producer. As recently as 1968 over 6,000 coho salmon were counted at

Ice Harbor Dam destined primarily for the Grand Ronde River. From 1973 to 1985, after the construction of the additional Lower Snake River dams, dam counts declined from 1,300 to 8 fish. No coho salmon have been counted over Ice Harbor Dam since 1985 (ODFW 1991).

Wild coho salmon now are considered to be extinct in the Snake and upper Columbia River subbasins (CBFWA 1991). The only remaining native upriver coho salmon stock is in the Hood River, an Oregon tributary to the Bonneville reservoir. There are no current run size estimates but between 100 to 300 fish were counted each year from 1963 to 1971 (CBFWA 1991). Current runs of early and late–stock coho salmon above Bonneville Dam are almost exclusively supported by hatchery releases. In the 1960s, the success of hatchery production quickly increased the coho salmon hatchery returns. By the latter half of the 1960s coho salmon counts at Bonneville Dam ranged from 49,000 to 96,000 fish. In the 1980s the counts at Bonneville Dam ranged from a low of 15,000 coho salmon in 1983 to a high of 131,000 in 1986 (CBFWA 1991).

2.1.2 Salmon and Steelhead Life History

2.1.2.1 Juvenile Rearing

The timing of hatching and fry emergence of salmon and steelhead varies among the different stocks because of differences in incubation temperatures where they spawn, and due to differences in the number of temperature units required for hatching and development[1]. After hatching, salmon alevins (yolk–sac larvae) remain in the gravel interstices for an extended period. Alevins are negatively phototactic (shun light) which encourages further submergence in the gravel and prevents premature emergence (Godin 1982). As the yolk sac is absorbed, alevins develop positive rheotactic (the movement of an organism in response to a current) and phototactic responses and begin an upward migration in the gravel (Dill 1969).

Reiser and Bjornn (1979) and Rondorf and Miller (draft report) report that salmon fry emerge primarily at night and disperse into a wide variety of freshwater habitats. Different species select different rearing habitats which reduces competition for space and food. Flow, water velocity, and water depth determine the amount of suitable habitat available for rearing fish. The amount, type, and location of cover is important during rearing in streams because cover provides food, shade, temperature stability, protection from predators, and overwintering habitat. Substrate composition is also important for rearing because the highest production of invertebrates is in shallow water habitats with gravel– and rubble–sized materials. Production decreases as the size of the substrate particles decrease.

Chinook Salmon

Spring chinook in the Salmon River usually hatch in December and emerge from the gravel in February or March (Bjornn 1960). Spring chinook fry emergence in the John Day River occurs from late February to mid–June (Knox et al. 1984). Mid Columbia River summer chinook fry in the Wells spawning channel emerged from January through April (Allen et al. 1968, 1969, 1971). Fry emergence of fall chinook occurs from late March through June in the Snake River. The estimated date of peak emergence of fall chinook salmon fry from their redds in the Snake River in 1991 was about May 25. Estimated peak emergence of fry in 1992 occurred about May 1 or about three weeks earlier than 1991 (Dennis Rondorf, National Biological Survey (NBS), personal communication).

Movement of fry downstream immediately after emergence is typical of most chinook populations (Bjornn 1971, Reimers 1971, Healy 1980; Kjelson et al. 1982). Movement of chinook fry occurs mainly at night (Reimers 1971, Lister et al. 1971, Mains and Smith 1964). River discharge plays a role in stimu-

[1]A temperature unit is defined as a unit of water temperature (usually 1°C) prevailing over a defined period of time (usually one day), expressed in terms of a reference temperature (usually the freezing point). For example, 5°C sustained for 48 hours (2 days) equals 10 temperature units; and 20°C sustained for 12 days equals 240 temperature units.

lating movement of chinook fry downstream (Kjelson et al. 1981, Healy 1980) and may be a key dispersal mechanism. Other factors such as inter– and intra–specific competition may also play a role in dispersal.

Chinook fry in tributary streams change habitats as they grow older. Spring chinook juveniles hide under large rocks and debris during overwintering (Chapman and Bjornn 1969). After an initial hiding period associated with bank cover and shorelines, they move progressively into deeper, high water velocity areas, and rockier habitats (Lister and Genoe 1970; Everest and Chapman 1972). Juvenile subyearling fall chinook salmon in the mainstem Snake and Columbia rivers exhibit a contrasting behavior. They show a propensity to occupy nearshore rearing areas characterized by low velocity (Bennett et al. 1991, 1992), even in free–flowing sections of the rivers (Dauble et al. 1989).

Preliminary analysis of Passive Integrated Transponder (PIT)–tagged Snake River subyearling chinook in 1991 suggests that the fish started migration when they attained a threshold size of about 85 mm (Dennis Rondorf, NBS, personal communication). Seine catches of subyearling chinook salmon in rearing areas of the free–flowing Snake River declined as water temperatures increased to 15–17°C, indicating that most of the fry had migrated out of the area. No subyearling chinook were captured by seining by the third week of July when water temperatures reached 20°C.

Recently emerged chinook fry historically reared in the Columbia River estuary. They were found as early as December and were abundant in the estuary in March and April (Rich 1920).

The primary foods of chinook rearing in freshwater streams are larval and adult insects of both terrestrial and stream origin, and amphipod crustaceans. Crustacean zooplankton, primarily Cladocera, are important in the diet of chinook in the impounded lower Columbia River in July and August but insects are the predominate food item during other times of the year (Craddock et al. 1976).

Sockeye Salmon

Sockeye salmon fry emerge in March and April in the Okanogan system (Allen and Meekin 1980) and in April in the Little Wenatchee and White rivers (Allen and Meekin 1973) in Washington state. Fry move out of the spawning tributaries soon after emergence and migrate to the nursery lakes where juveniles feed on pelagic zooplankton from one to three years before migrating to the ocean. The percentages of one and two year old smolts in the migration from Redfish Lake, Idaho varied from 2 to 98 percent from 1955–66 (Bjornn et al. 1968).

Steelhead

No information is available on timing of fry emergence for wild winter steelhead in the Columbia River basin. Summer steelhead fry in the Columbia River generally emerge from July through September (West et al. 1965; Mullarkey 1971; Thurow 1985).

Juvenile steelhead tend to occupy the shallow riffle areas, particularly during the first year of life (Hartman 1965) and are more closely associated with the bottom of streams than are coho or chinook (Hartman 1965; Edmundson et al. 1968). The highest densities of juvenile steelhead occur in areas containing instream cover (Johnson 1985). They may migrate to lower stream reaches to avoid freezing conditions in upper tributaries (Howell et al. 1985).

Juvenile steelhead spend from one to three years in fresh water feeding on aquatic insects, amphipods, aquatic worms, fish eggs, and occasionally small fish (Wydoski and Whitney 1979).

Coho salmon

No information is available on the time of emergence of wild coho in the Columbia River basin. After emergence from the gravel, coho fry initially congregate in schools in areas with cover such as side channels (Sandercock 1991). As they become older, coho salmon juveniles set up territories in both pool and riffle areas and are best adapted to holding in pools (Hartman 1965). Their abundance in streams is limited by the number of suitable territories available (Larkin 1977) and they are

generally displaced downstream if they are unable to defend a territory. Coho primarily feed on drifting stream and terrestrial insects (Mundie 1969). They usually spend about 18 months in fresh water (Mullan 1984).

2.1.2.2 Juvenile Migration

Before impoundment, the Columbia and Snake rivers consisted primarily of pools and riffles of fairly high velocity. Historically, chinook salmon smolts began their seaward migration just before the peak of river flow and steelhead migration coincided with the peak of river flows (Raymond 1979). Freshets allowed smolts to quickly move through the river with a minimum of energy expended and with protection from predation afforded by the high volume of runoff, high river velocities, and associated high turbidity. The physiological, morphological, and behavioral changes which occur during the smoltification process prior to and during migration evolved under these conditions when seasonal increase in runoff provided for rapid migration. Raymond (1979) estimated the rate of migration in the free flowing river was 24 to 54 km/day under high to low flow conditions. When the Columbia and Snake rivers were in their natural state it took smolts only 22 days to migrate from the Salmon River to the lower Columbia River below Bonneville Dam (Ebel 1977).

Juvenile Migration Mechanisms

Smoltification. The onset of migratory behavior is closely associated with the smoltification process in juvenile salmonids. Smoltification includes changes in both morphology and physiology, resulting in migratory behavior and the ability to live in seawater (Bern 1978; Folmar and Dickhoff 1980). Numerous morphological changes such as the weight to length ratio, coloration, change in caudal peduncle shape, fin shape and coloration, and development of recurve teeth in the mouth result in a smolt profoundly changed from the freshwater parr (Vanstone and Market 1968; Gorbman et al. 1982; Winans and Nishioka 1987). Many physiological changes are related to each of these general changes and collectively typify smoltification (Folmar and Dickhoff 1980; Wedemeyer et al. 1980; Hoar 1988). Behavioral changes associated with smoltification include restlessness, elimination of territoriality, onset of schooling behavior, and becoming semi–pelagic (Hoar 1965, McKeown 1984). The cumulative effect of the above changes is that smolts are no longer adapted to remain in freshwater habitats, but are well adapted for saltwater entry.

The migration of juvenile salmonids from their freshwater habitats to the ocean must be by active swimming, passive transport by the current, or both. In considering these modes, Thorpe et al. (1981) stated "It would be energetically inefficient and ecologically imprudent for smolts to swim actively downstream when a river could transport them passively over the same route. Pressure to evolve such active behavior would only arise if the passive transport system was too slow, or resulted in the delivery of smolts into the sea at an inappropriate season". Smith (1982) shares this perspective and postulated that smolts actively swim upstream, but because of their reduced swimming performance are swept downstream. In fact, the only active migration of smolts that occurs routinely appears to be associated with sockeye migration through lakes (Johnson and Groote 1963; Groote 1965) and the movement of fish out of backwaters.

Passive Migration. There are several mechanisms that could result in passive downstream displacement: development of negative rheotaxis; a decrease in swimming proficiency; and, a decline in swimming stamina in smolts when compared to parr (Folmar and Dickhoff 1980; McCormick and Saunders 1987). Annual rhythms in rheotaxis have been observed in Atlantic salmon (Salmo salar) with strong negative rheotaxis in smolting juveniles (Lundquist and Eriksson 1985). A reduction in swimming stamina among smolts compared to parr has also been observed (Folmar and Dickhoff 1980). The swimming ability for coho salmon parr is 3.5–7.3 body lengths per second (BLs–1) and for coho salmon smolts about 2–5.5 BLs–1 (Glova and McInerney 1977; Smith 1982). A similar decline for Atlantic salmon from up to 7 BLs–1 for parr to about 2.0–2.5 BLs–1 for smolts indicates that this is not unique to coho salmon, but may be common among all salmo-

nid smolts (McCleave and Stred 1975; Thorpe and Morgan 1978). However, Muir et al. (1988) observed an increase in swimming performance for two hatchery stocks of spring chinook salmon as they migrated through the Snake River.

Early observations on chinook salmon support the hypothesis of a mostly passive migration. In a study conducted on the Sacramento River from 1896 to 1901, Rutter (1904) stated "there is no doubt that in migrating the fry drift downstream tail first, keeping the head upstream for ease in breathing as well as for convenience in catching food floating in the water" (his reference to fry is somewhat misleading in that the fish were about 5 cm in length). The hypothesis of passive migration is also supported by numerous observations on Atlantic salmon. Studies on Atlantic salmon by Thorpe and Morgan (1978), Tytler et al. (1978), and Thorpe et al. (1981) in Scottish rivers, lochs and estuaries and by Fried et al. (1978) in the Penobscot River estuary suggest the migratory behavior is mostly passive. In each study juveniles drifted with the current at night for six to nine hours. Although random movements occurred for various lengths of time during the night, the overall displacement was downstream at a speed consistent with the current velocity.

Active Migration. In contrast to passive migration, there are investigators who characterize smolt migration as being an active, directed process that may be correlated with smolt size and/or degree of smoltification. Northcote (1984) reviewed evidence for active versus passive migration and noted: "Solomon (1978) suggested that downriver progression of Atlantic salmon smolts in an English chalkstream was an active process not a passive displacement, but Thorpe et al. (1981) found evidence to the contrary in a Scottish river–reservoir system." Healy (1991) concluded that "The rapid migration of smolts through impoundments on the Columbia River indicates that yearling smolts undertake a directed migration that is independent of river flows".

Attempts to classify smolt migrations as specifically active or passive are probably not helpful. The central issue in the Columbia system is that once parr transform into smolts and exhibit migratory behavior they transit a river more quickly as the river flow increases. There is evidence to indicate this is the situation for yearling stream–type chinook and steelhead, particularly through the Snake River from the uppermost dam to the lower Columbia. Raymond (1979) concluded from studies of smolt migration from the Snake River from 1966 to 1975 that the rate of fish migration increased the higher the water velocity. Sims and Ossiander (1981) concurred with and expounded upon the conclusions reached by Raymond. They gathered smolt migration data from 1973 to 1979, plotting average travel time per project during each year against average flows occurring at Ice Harbor Dam during the peak of migration, plus or minus seven days. Sims and Ossiander (1981) confirmed travel time was related to river flow, noting faster migrations in years of higher flow and slower migrations in years of lower flow. Travel time in 1977, a drought year, measured twice that of other years. Sims and Ossiander concluded travel time differences were more pronounced in periods of low flow than in periods of high flows. Berggren and Filardo (1991) noted smolt travel time was inversely related to average river flows for Snake River subyearlings and yearling chinook, as well as Columbia and Snake River steelhead. Average river flow made the largest contribution to explaining the variation in travel time. Berggren and Filardo showed evidence of a curvilinear relation between travel time and river flow, with a decreased rate of change in transit time at higher flows. Berggren and Filardo (1991) demonstrated the similarity of juvenile salmon response in relation to water particle travel time. This similarity supports a causative relationship, rather than a simply correlative one, between smolt travel time and flow (Petrosky 1991).

However, NMFS investigators, characterization of subyearling chinook responses to flow differ with Berggren and Filardo (1991). Sims and Miller (1982), Miller and Sims (1983, 1984) and Giorgi et al. (1990) could not demonstrate a relationship between flow and fish travel time in any of three years of study in John Day Reservoir. Furthermore, they regularly observed pronounced upstream excursions, extending up to 82 km – a behavior inconsis-

tent with passive downstream displacement. The relationship of river flow to travel time, and therefore the significance of river flow to survival, remains one of the most controversial issues among river passage experts.

Other Factors. Some theories suggest that factors other than flow levels influence smolt travel time, as well. An increased level of stress in migrating smolts increases their travel time and alters their behavior. The prevalence of bacterial kidney disease (BKD) also influences travel time, by affecting speed directly or by skewing the travel time data as a result of predation losses. It is possible that BKD infected smolts may be more susceptible to predation than non–infected smolts. The level of smoltification has an impact on smolt travel time, as well. Fish which exhibit elevated levels of sodium and potassium ions, adenosine triphosphate activity (ATPase), and plasma thyroxine concentrations in gill tissue (and therefore are further along in the smoltification process) travel faster than fish with lower ATPase and thyroxine levels (Beeman et al. 1990). The more advanced in smoltification, the stronger a smolt's reaction to flow. Beeman et al's data show that fully smolted fish travel as fast in low flows as non–smolted fish travel in very high flows.

Control of Juvenile Migratory Behavior

Genetic Influences. Migratory behavior is controlled by genetic and environmental factors (Randall et al. 1987). Genetic selection favors behavior that improves the chances for survival (Smith 1985). As early as the 1920s the migration patterns of juvenile chinook salmon were considered to be inherited by subsequent generations in the Columbia River (Rich and Holmes 1929). In a review, Randall et al. (1987) pointed out that the genetic influences on the age of smolting within species have been underestimated in the past. Recent findings indicate chinook in the Nanaimo River, British Columbia, which are characterized by a specific age and size at seaward migration, can be associated with significantly different frequency of allozymes and are seemingly a genetically distinct sub–population (Carl and Healey 1984). At the turn of the century apparently a wide variety of migratory traits existed, as Rich (1920) observed juvenile chinook salmon in the Columbia River estuary throughout the year. Current knowledge suggests that the wide variety of migration patterns among hatchery and wild stocks has a genetic basis.

Environmental Influences. Environmental cues serve to synchronize the initiation of migratory behavior and the more general endogenous rhythmicity associated with smoltification. Smoltification is controlled by the endocrine system which responds to both environmental and hormonal stimuli (Groote 1981; Schreck 1981; Barron 1986). Important environmental factors involved with the development of a disposition to migrate are photoperiod, water temperature and stream discharge. When fish are in a proper state of migratory readiness, a proximal stimulus, such as lunar phase or stream flooding initiates migration (Hoar 1988).

Role of Photoperiod. Photoperiod is a key environmental cue influencing the timing of downstream migration in juvenile steelhead (Wagner 1974). The role of photoperiod cues apparently result from the direction and rate of change of day length (Wedemeyer et al. 1980). Baggerman (1960) and Wagner (1974) emphasize that, while photoperiod–controlled changes may bring the animal into a state of preparedness, priming it for migration, other released stimuli initiate and maintain migration. Consequently, McKeown (1984) concluded there is relatively little evidence in support of photoperiod being an important cue in the actual initiation of migration.

Temperature Influences. Temperature influences smoltification by controlling the rate of the physiological response to photoperiod, such that effects are apparent sooner at elevated temperatures (Wedemeyer et al. 1980; Hoar 1988). The migratory movements of Atlantic salmon smolts are closely correlated with water temperature with only small numbers moving below a threshold temperature (Solomon 1978). Similarly, water temperature explained 89 to 95 per cent of the yearly variation in the date of cumulative smolt migration by Atlantic salmon through a combination of temperature increase and ambient river temperature during

spring (Jonsson and Hansen 1985). Average stream temperature explained 60 per cent of the variation in the median date of emigration of coho salmon smolts from Carnation Creek, British Columbia (Holtby et al. 1989).

In contrast to these findings, Bjornn (1971) could not establish a causal relationship between stream temperature and the seaward migration of salmon smolts. Although the smolt migrations coincided with increasing stream temperatures in the spring, the increasing temperatures seemed coincidental since steelhead reared in a spring–fed pond migrated from the pond which had a relatively constant temperature at the usual time.

Relationship to Runoff. Mains and Smith (1964) found that seaward migration of chinook salmon in the Snake River during 1954 and 1955 was predominantly in the spring, which coincided with the spring runoff. They stated that, "While temperatures may play an important role in initiating the downstream migration of chinook salmon, the occurrence of the first spring freshet was the primary factor responsible for stimulating this phenomenon. In both years during which this study was made, the discharge required in the Snake River before migration commenced was approximately 70,000 cfs". More recently, NMFS researchers have observed that wild populations of summer chinook readily migrated past Lower Granite Dam when flows ranged from about 40,000 to near 70,000, in 1990 (Matthews et al. 1992). Furthermore, they concluded after three years of study, 1989–1991, that the relationship between flow volume and migrational timing of wild spring/summer chinook in the Snake River at Lower Granite Dam was not apparent (Marsh and Achord 1992).

Juvenile Physiological Development

Hormone Changes. Physiological changes in juvenile salmon encourage migration and prepare them for residence in seawater. The behavioral motivation for migration has long been recognized as having an endocrinological basis (Hoar 1958). The thyroid hormones have been implicated in behavioral changes associated with migration, but the relations have not been completely elucidated (Leatherland 1982; Eales 1985; Dickhoff and Sullivan 1987; Grau 1988). Godin et al. (1974) injected juvenile Atlantic salmon with thyroid hormones and observed that swimming activity, aggressive behavior, and upstream orientation were significantly reduced. They concluded that the hormones initiated the migratory tendencies. Similarly, others have concluded that increased plasma thyroxine permits smolting Atlantic salmon to resist displacement in high flows and orient head–downstream in moderate flows, thereby increasing ground speed at no extra metabolic cost (Youngson et al. 1985; Thorpe 1989). The thyroid hormones do have an endocrine role in controlling migration behavior, but as Hoar (1988) concluded, they do not regulate behavior per se.

Osmoregulation. The migratory behavior of smolts has also been related to the physiological changes associated with the development of osmoregulatory capacity, particularly the level of gill sodium, potassium and adenosine triphosphotase (ATPase) activity. (Zaugg and Wagner 1973; Wagner 1974; Zaugg et al. 1985; Rodgers et al. 1987). The coincidence of an increased percentage of juvenile steelhead migrating from experimental releases and the seasonal rise in gill ATPase has been demonstrated for winter steelhead from the Alsea River, and for summer steelhead at Dworshak National Fish Hatchery, Idaho (Wagner 1974; Zaugg 1981a; Zaugg 1981b). The same general relationship has been observed in yearling spring chinook salmon from the Deschutes River, Oregon that were allowed to migrate in an artificial stream (Hart 1981).

Many of the observed relations between migratory behavior and gill ATPase activity in smolts are derived from juvenile salmon held in the captive environments of the laboratory or hatchery. Chinook and steelhead smolts released to migrate freely usually exhibit remarkable smolt development indicated by rapid increase in ATPase activity (Ewing et al. 1980; Zaugg 1981a; Zaugg 1981b; Zaugg et al. 1985). In contrast, the smolt development, including gill ATPase and plasma thyroxine responses, of fish held in the captive environment is often suppressed (Zaugg et al. 1985; Nishioka et al.

1985; Patino et al. 1986; Rodgers et al. 1987; Maule et al. 1988).

The duration of the elevated gill ATPase levels among migrants is of interest because a decline may indicate a reversion to a parr status accompanied by a loss of migratory behavior. Zaugg (1981b) found that yearling coho held at hatcheries beyond normal May releases showed a decline in ATPase levels and a reversion to the parr appearance. Despite this reversion, fish released in June and July rapidly migrated seaward and experienced renewed high ATPase levels. Although it is apparent that at least coho can regenerate high ATPase levels, it is not known how long high levels are normally sustained in migrants. Although the migration experience is stimulatory, ATPase activity collected from migrating coho smolts of hatchery and wild origin suggests an early June decline similar to the seasonal rhythmicity observed in captive environments. We have no measure of ATPase in most races of wild chinook, however.

Juvenile Salinity Preference and Tolerance

The development of osmoregulatory capabilities is concurrent with a change in behavior that results in a strong salinity preference (Baggerman 1960; Otto and McInerney 1970). Salinity preference has been proposed as an orientation mechanism for migration, particularly in the estuary (McInerney 1964). The salinity preference is a behavioral attribute of smolts that is restricted to a limited time (Baggerman 1960; McInerney 1964). Experimental results show a preference for salinity at the time of migration and a reversion to freshwater preference if the migrants continue their freshwater residency.

The migratory disposition in juvenile steelhead and coho salmon has been found to be preceded by the development of salinity tolerance from as much as several weeks to six months (Conte and Wagner 1965; Conte et al. 1966). The development of some salinity tolerance among juvenile salmonids in a wide range of sizes and physiological conditions independent of migratory behavior is not surprising, but the high salinity tolerance and subsequent rapid seawater growth without stunting is an attribute of smolts (Kepshire and McNeil 1972; Woo et al. 1978; McCormick and Saunders 1987).

Residualism. Continued freshwater residency is associated with reversion to a parr–like fish with a lower salinity tolerance (residualism) in steelhead, coho, and chinook salmon (Conte and Wagner 1965; Wagner 1974; Woo et al. 1978). Chrisp and Bjornn (1978) concluded that hatchery and wild steelhead could not tolerate saltwater at a concentration equal to 30 parts per thousand in a 10 day challenge, by the time the migration from the upriver areas terminated in early June. Similarly, Adams et al. (1975) concluded that saltwater survival of steelhead transferred directly to saltwater at 10 to 11.3°C was low in early March, near 100 per cent in mid–April, and declined by early May. Fall chinook differ from other salmonids since their seawater adaptability increases in early May and remains high well into July (Clark and Blackburn 1978; Clarke and Shelbourn 1982). In early August, the latter part of the subyearling chinook migration at McNary Dam exhibited a reduced osmoregulatory ability (Maule et al. 1988; Schreck et al. 1984). Similarly, fall chinook from Spring Creek National Fish Hatchery, on the lower Columbia River, exhibited a sharp decline in ability to withstand direct exposure to sea water in the laboratory (Gould et al. 1985).

Windows of Biological Timeliness and Their Management Implications

The concept of "biological windows" has been developed by numerous investigators (Walters et al. 1978; Bilton et al. 1982; Boeuf and Harache 1982; Holtby et al. 1989) primarily to explain the timing of smolt migration relative to coastal predators, marine productivity, and oceanographic conditions that are likely determinants of early marine survival. Smolt migration can also be considered to have windows limited by photoperiod, temperature, and other factors controlling the behavior and the physiology of smolts. The duration of such windows is delineated by the onset and decline of migratory behavior, seawater preference, seawater tolerance, and selected physiological attributes such as gill ATPase.

Effects of Delay. Excessive delay in migration might expose some portion of the migration of some stocks

to rising water temperatures that may reach deleterious levels. Since gill ATPase activity and migratory disposition are sensitive to elevated temperatures, exposure to such temperatures during migration may have deleterious effects. The temperature effects on steelhead are of particular concern because steelhead migrate later than yearling chinook and are more temperature sensitive than coho salmon. Based on laboratory experiments, water temperatures of 15°C caused a steep decline in the gill ATPase activity of yearling steelhead; the authors suggested an upper limit of 12°C (Zaugg et al. 1972; Adams et al. 1975; Zaugg 1981a). Similar evidence does not exist for other species/races in the Columbia River basin, and physiological profiles as well as associated migratory behavior differ among species.

Validity of the Concept of Biological Windows. While the concept of biological windows has merit, little information exists on the temporal and spatial bounds of such biological windows. There is poor understanding of the ecological condition of the estuary in terms of productivity, competition and predation, and the physiological preparedness of the smolts for particular species and races. It could be argued that the migrational characteristics of several stocks of salmon suggest that, if there is a biological window, it is broad and the ocean condition facet of the window would be expected to vary in timing and intensity from year to year. For example, subyearling chinook salmon, including both summer and fall races, migrate from the Columbia River from late spring through much of the summer and continue to trickle out well into fall. These patterns are well documented in both NMFS and FPC reports. Furthermore, these patterns were evident over three decades ago, when only Bonneville and Rock Island dams were in place (Chapman et al. 1991). If there is a window at the ocean interface, it is probably quite large.

Yearling chinook in the Snake river drainage also exhibit protracted outmigrations. In 1989 and 1990, wild stocks of summer chinook from the Snake River system have been observed passing Lower Granite Dam in mid–April for the last two years. Wild spring stocks from the same system outmigrate later, continuing into July (Matthews et al. 1990 and Chapman et al. 1991). The timing of these yearling chinook is consistent with observations made by Raymond (1979) in 1966 and 1967 at Ice Harbor Dam, which was then the uppermost dam on the Snake River. These fish moved out of the tributaries and downstream through the mainstem over an extended period, even prior to dam construction. This suggests that if ocean condition is an important element of the biological window, it must be broad enough to have embraced the later migrating stocks for millennia. To the extent that water velocity influences the rate of migration, and water velocities are slower due to impoundment, the duration of the biological window for each species is of concern. At this time, there is inadequate information to characterize the bounds of such biological windows. The differing views concerning the concept of biological windows characterized above suggest the need for further species–specific studies.

Predation on Juveniles

Historical accounts of the fish populations in the Columbia River are primarily related to the abundance of salmon, steelhead, and sturgeon. The relative historical abundance of important predators of salmonids is unknown. Northern squawfish (Ptychocheilus oregonensis) were probably the principle stream dwellers and played an important role as a predator of juvenile salmon and steelhead. Dolly varden (bull trout) (Salvelinus confluentus) may have been a keystone predator which tended to reduce competition at lower trophic levels by holding competitor populations in check (Mullan 1979).

The assemblage of species is very different today as a result of impoundment of the river system and because of the introduction of exotic species. Bull trout are now considered rare in the Columbia River basin. The US Fish and Wildlife Service determined in June 1994, that bull trout listing was warranted but precluded at this time under the Endangered Species Act. Impoundment converted most of the mainstem rearing habitat for juvenile salmon into pool area increasing the suitable habitat for new species complexes. Northern squawfish and three introduced species – walleye (Stizostedion vitreum),

smallmouth bass (Micropterus dolomieui), and channel catfish (Ictalurus punctatus) – are the major fish predators in John Day reservoir, with northern squawfish accounting for 78 percent of the estimated smolts lost to fish predators (Rieman et al. 1991). About 1.7 million smolts, or approximately 11 percent of the annual outmigration, are lost to predation each year in John Day reservoir (Beamesderfer et al. 1990). Nearly the same percentage of spring chinook smolts are lost to squawfish in Lower Granite Reservoir (Bennet et al., 1993, Chandler, 1993). Increasing data collection suggests that smallmouth bass are likely the dominant predator on rearing and outmigrating subyearling chinook in Lower Granite Reservoir (Bennett et al. 1993, Curet 1993). For comparison, about 2 percent of the juvenile salmonid population was lost to bird predation at Wanapum Dam (Rugerone 1986). Northern squawfish predation upon juvenile salmonids is influenced by many factors including prey density, prey species, prey condition, predator size, temperature, and time of year (Peterson et al. 1990; Poe et al. 1991; Vigg et al. 1991).

Time Exposure to Predators. Smolt mortality caused by northern squawfish and other predators also depends on the amount of time smolts are exposed to predators as a function of flow. The impact of low flows on predation is likely the result of longer exposure to predators. Northern squawfish predation has been shown to increase rapidly with temperature (Beyer et al. 1988; Vigg 1988). Beamesderfer et al. (1990) estimated that 150,000 smolts were lost in John Day reservoir for each 1°C rise in temperature.

Consumption Rates in Relation to Temperature. Temperature is probably the most important physical variable affecting the consumption rate and growth of predatory fishes (Brett 1979; Kitchell 1983). Consumption rate of northern squawfish, as a function of temperature, has been examined in the field and in the laboratory. Average consumption rate was significantly affected by temperature, prey density, and predator weight in analyses of John Day reservoir data (Vigg 1988; Peterson and DeAngelis, In press). Analyses showed that consumption increased rapidly with increasing temperature. Laboratory studies on digestion rates of northern squawfish showed faster digestion and prey evacuation at high temperature (Falter 1969; Steigenberger and Larkin 1974; Beyer et al. 1988). Laboratory experiments (Vigg and Burley 1990) demonstrated that maximum consumption of salmonid prey increased from 0.5 smolts/day at 47°F to 7 smolts/day at 71°F (Vigg and Burley 1990). Above the optimum temperature, consumption rate declines rapidly, eventually falling to zero near the maximum lethal temperature for the species.

Juvenile Migration Past Dams

Once smolts enter the mainstem Columbia and Snake rivers they encounter hydroelectric dams owned and operated by Federal agencies and/or Public Utility Districts. The first transition is from swift free–flowing tributaries to the slower moving impoundments. Migration rates and encounters with predatory fish are altered from those occurring in a free–flowing river. Generally, migration rates decrease and predator encounters may increase. These processes and effects will be more fully addressed in a following section (2.1.7.2).

Smolts arriving at dams pass the facilities by way of two primary routes, the spillway or the powerhouse. Negligible passage may also occur through adult ladders. Also, some dams have ice/trash sluiceways, which provide an additional avenue for passage, e.g., The Dalles and Ice Harbor.

Dams on the mainstem Snake and Columbia rivers are equipped with bypass screens that extend about one–third of the distance into the turbine intake from its ceiling. The screens divert water and smolts upward into large chambers called gatewells. Openings (orifices) lead from these chambers to a collection/bypass channel. The channel either discharges into the tailrace for continued migration in–river, or at some dams (Lower Monumental, Lower Granite, Little Goose and McNary) fish can be routed to holding areas (raceways) or directly into the transportation barges. From the raceways, fish are placed in barges (and tanker trucks in some instances) for transport to release sites downstream from Bonneville Dam.

Passage Route Survival. Typically, the most benign passage routes are the spillway, sluiceway and bypass, where smolt survival is generally accepted as being higher, in the order of 98 percent. Turbine survival is lower, generally presumed to be near 85 to 90 percent, although, survival estimates can vary considerably depending on the species and dam investigated, and whether the experimental design captured both direct and indirect mortality associated with passage. For example, recent NMFS investigations at Bonneville Dam indicate that for summer migrant subyearling chinook salmon, bypass survival is no better and may be worse than turbine survival. Bonneville Dam is the only facility to receive a comprehensive evaluation to date. Whether the results represent survival dynamics at other sites as well has not been determined.

Spill Passage Efficiency. It is typically assumed that smolts pass the spillway equal to the proportion of water spilled, for example, 20 percent spillage passes 20 percent of the smolts. However, most field evaluations have found the proportion of smolts passing through the spillway at specific spill levels (spill efficiency) may differ at each dam and vary with the configuration of the facility, as well as operations. For example, evaluations at Lower Granite Dam indicated that 40 percent of the yearling chinook passed through the spillway with only 20 percent of the river discharged through that route (Wilson et al. 1992). Disproportionate spillway passage has also been documented at all dams in the mid–Columbia River.

Another factor that can influence the effectiveness of spill is the timing of smolt passage at the dam. At certain dams the majority of smolts delay passage until nightfall as indicated by pronounced diel passage patterns, e.g., John Day Dam (Hawkes et al. 1993). Reasonably, spill should be provided at the times when passage readiness is greatest, and in fact fisheries operations employ this strategy. Spill where stipulated for fish, is usually targeted for the dusk to dawn period.

Bypass Efficiency. Not all fish entering turbine intakes are intercepted and guided into the bypass system. Some fraction remain unguided and pass under the screens and on through the turbines. Fish guidance efficiency (FGE), expressed as the percentage of smolts diverted from turbine intakes, is the common measure of bypass effectiveness. FGE is species–, dam–, and season–specific. Generally, FGE ranges from 30 to 80 percent; with subyearling chinook at the lower levels and steelhead highest.

Sluiceway Efficiency. Some facilities have ice/trash sluiceways with entrances located across the face of the dam, near the surface over a false weir. Water carries smolts into the sluiceway and provides an effective passage route for smolts. At The Dalles, approximately 40 percent of the smolts use this passage route. At Ice Harbor, estimates range from 30 to 70 percent. Both projects, however, are scheduled for mechanical bypass systems (1998 and 1996, respectively) coupled to their submerged screen systems.

Chinook Salmon

Juvenile chinook salmon migrate down the Snake and Columbia rivers or reside in the estuary virtually year–around (Dawley et al. 1986). In general, spring chinook migrate fairly quickly to sea as yearling smolts and fall chinook tend to migrate more slowly as subyearlings. Summer chinook salmon in the upper Columbia River migrate as subyearlings (Giorgi et al. 19__) but in the Snake River summer chinook resemble spring chinook and migrate as yearlings.

Historical Timing. Information on historical timing of migration of juvenile salmon in the Columbia River is limited. Most of the passage information available was collected after hydro development and is not representative of pre–development run timing. Raymond (1979) found that yearling chinook salmon passage at Ice Harbor Dam, before the construction of the other Snake River dams, usually peaked between April 26 and May 13 and was completed by mid–June. The range of yearling chinook migration past Ice Harbor Dam was from early April to late June. Raymond (1979) noted that the earliest migration occurred in years when water warmed earlier. Migrations were later when runoff was delayed because of cold weather or reduced water temperature.

The outmigration of juvenile fall chinook salmon in the Hanford Reach of the Columbia River was bimodal in 1955 and lasted from March through July (Mains and Smith 1964). The first peak occurred in March and April and consisted entirely of age–0 through fry. The second peak occurred in June and July and was largely fingerlings. Wild fall chinook PIT tagged in the Hanford Reach of the Columbia River passed McNary Dam between the middle of June and late August in 1991. The median date of passage occurred in mid–July (FPC 1992).

Current Migration Timing. Based on timing of marked Snake River chinook salmon in 1991, wild spring chinook passed Lower Granite Dam between early April and mid–July and wild summer chinook from the middle of April to late July. At McNary Dam passage of wild Snake River spring and summer chinook occurred between early May and early June. However, NMFS investigators concluded after three years of study, 1989–1991, that there was no relationship between flow and migrational timing of wild spring/summer chinook in the Snake River at Lower Granite Dam (Marsh and Achord 1992). No information is available on the timing of passage of wild spring and summer chinook in the mid–Columbia River. Wild spring chinook smolts from the John Day River migrate past John Day Dam between mid–April and early June (Lindsey et al. 1986).

Wild Snake River fall chinook tagged in the Snake River above Lower Granite Dam passed Lower Granite between mid–June and early September in 1991. Preliminary analysis of PIT tag data suggest fall chinook started migration as they attained a threshold size of 85 mm (Dennis Rondorf, NBS, personal communication). The median passage date for wild Snake River fall chinook in 1991 was July 25 (FPC 1992). This date also matched the peak date of passage for the subyearling chinook run–at–large. Peak dates of passage for the run–at–large in 1982, 1983, 1985, and 1986 occurred between June 29 and July 9 (FPC 1992).

Sockeye Salmon

Snake River. Sockeye smolts migrate out of Redfish Lake from late April through May (Bjornn et al. 1968). Recoveries at Lower Granite Dam of Redfish Lake sockeye salmon PIT–tagged and released at the outfall of Redfish Lake in 1991 indicated that passage at Lower Granite Dam occurred between May 23 and June 15. Median travel time from release to Lower Granite Dam, a distance of 462 miles, was 10.3 days (FPC 1992).

Upper Columbia. Based on reports of smolt migration past Tumwater Dam, smolt outmigration in the Wenatchee River begins in mid–April and continued for about a month (Mullan 1986). The peak of juvenile sockeye salmon abundance at Wells Dam is usually in mid–May (Johnson and Sullivan 1985). Sockeye migration past McNary Dam usually occurs between early May and early June. The historic 10 percent median passage date at McNary Dam, based on data from 1984–90, is May 1 and the 90 percent median passage date is June 3 (FPC 1992). During 1946 through 1953 the median passage dates for juvenile sockeye salmon at Bonneville Dam were between April 23 and May 13 (Davidson 1965). The average median passage date at Bonneville Dam for 1987 through 1990 was May 23 (FPC 1992). Most sockeye smolts move through the estuary during May and early June and some remain until late July (Dawley et al. 1984).

Steelhead

Most summer steelhead rear in freshwater for two years and some for three years before migrating to the ocean (CBFWA 1991). Peak migration of juvenile steelhead at Whitebird on the Salmon River occurred between May 1 and May 19 for the years 1966 through 1975 (Raymond 1979). Steelhead migration past Ice Harbor Dam usually peaked in mid to late May and generally coincided with maximum river discharge (Raymond 1979). However, the linkage between juvenile outmigration timing and discharge remains somewhat tenuous, with further research needed. In 1991, wild steelhead migration past Lower Granite Dam occurred between mid–April and early July. At McNary Dam wild steelhead migration occurred between early May and early June.

Coho Salmon

Coho salmon usually spend about 18 months in freshwater before migrating to the sea (Mullan 1983). Coho smolt outmigration occurred in Cedar, Gnat and Big creeks in April and May and in the Clackamas River in May and June (Howell et al. 1985).

2.1.2.3 Ocean Residence

Our understanding of the ocean distribution patterns of Columbia River salmon and steelhead stocks is limited. Most information on ocean distribution is based on coded–wire tag recoveries of hatchery stocks in coastal fisheries from California to Alaska. Other information is available from sampling in coastal waters and on the high–seas, and from high–seas tagging studies.

When salmon and steelhead smolts enter the marine environment they encounter differences in salinity, ocean temperatures, currents, food abundance, and predator diversity and abundance. The annual variation in these conditions encountered during early marine life may be largely responsible for much of the variation seen in marine survival. However, the effects of the various factors on marine survival are poorly understood.

Effects of the Dams on the Columbia River Estuary

Assessing the effects of dams on the Columbia River estuary is complicated. Most natural or anthropogenic processes in the estuary are highly interactive and dynamic, such that the specific role of a single process may change over time and location. Numerous factors have affected the estuary, including navigational dredging, diking and increases in human populations and subsequent use (Weitkamp 1994). All these factors can cause impacts similar to those caused by dams including flow reduction and temporal shaping.

Dams are thought to affect the physical environment of the estuary primarily through flow regulation. The floods that are suppressed by flow regulation historically transported large amounts of sediment into the estuary, provided circulation and promoted biological productivity. High flows also prevented the extrusion of salt water into the estuary. With the suppression of large floods by dams, downstream sediment transportation decreases, estuarine biological production may decline, and evolutionary selective pressure created by floods diminishes.

Meanwhile, decreased maximum flows and increased minimal flows or less variable or stable flows regulated by dams have impacted the seasonal variability of saltwater intrusion. This decreased variability affects the distribution of most estuarine organisms partially determined by each organism's salinity tolerance.

While dams on the Columbia River have altered sediment transportation rates and salinity intrusions, such effects seem to have little impact on salmonids in the estuary. Some biologists are concerned that the high numbers of juvenile salmonids entering within the estuary from hatchery origins may exceed the undefined current carrying capacity of the estuary, where conditions reflect reduced productivity. Juvenile salmonids, most of which are of hatchery origin and may spend little time in the estuary, should be able to adapt to the resulting physical changes in the estuary. Dams may also impact water quality, although the relative degree of impact has not been documented. Without further studies of present–day physical processes and biotic interactions that can be used to define a carrying capacity for the Columbia River estuary, and without a large and accurate historic database, the true impacts of dams will remain largely unsubstantiated and unquantified.

Chinook Salmon

Information on the distribution of Columbia River chinook salmon offshore on the high–seas is limited. The high–seas squid fishery in the North Pacific has been sampled at an extensive rate since 1989 for coded–wire tagged salmon and steelhead. No Columbia River chinook salmon have been recovered, though millions of marked fish are released from the Columbia River every year. Chinook salmon recoveries from the squid fishery are primarily from stocks from the Yukon River and north (Dave Hanson, PMFC, personal communication).

Spring chinook stocks from the upper Columbia and Snake rivers spend one to three years rearing in the ocean (Howell et al 1985). Summer chinook in the Snake River also spend from one to three years rearing in the ocean (Matthews and Waples 1991). Upper Columbia River stocks spend from one to five years in the ocean. Upper Columbia River Bright fall chinook also spend from one to five years rearing in the ocean but are predominately one–, two– and three–year ocean fish (Howell et al 1985).

Fall chinook generally spend most of their ocean life nearshore while spring chinook often leave nearshore waters in their first year and disperse more offshore (Hartt 1989; Healy 1983). Marked 1970 and 1971 brood spring chinook from Snake River hatcheries were recovered in nearshore fisheries from California to Alaska, which indicates a fairly wide ocean distribution (Wahle et al. 1981). Upper Columbia and Snake River spring and summer chinook presently are not harvested significantly in ocean fisheries (Howell et al. 1985) which may be due to their offshore distribution, and the current timing and location of marine fisheries.

Most of the harvest of upriver bright fall chinook from the Columbia and Snake rivers occurs in British Columbia and Alaska (Howell et al. 1985; Chapman et al 1991), which indicates a northerly distribution of these stocks. Preliminary information on the distribution of Snake River bright fall chinook indicates that they may not migrate as far north as other upriver bright fall chinook (CBFWA 1991). Ocean distribution of upper Columbia River summer chinook is similar to upriver bright fall chinook, with most of the harvest also occurring off British Columbia and from troll catches from Southeastern Alaska (Howell et al 1985). Tule fall chinook are caught primarily in ocean fisheries off British Columbia and Washington (Wahle and Vreeland 1978), which indicates a more southerly distribution than upriver bright fall chinook and upper Columbia River summer chinook.

Pritchard and Tester (1944) recorded 21 different taxonomic groupings in the diet of chinook salmon in marine waters in British Columbia and concluded that chinook were opportunistic feeders. Virtually all studies of chinook salmon food habits in marine waters show that fish are the most important food items, with herring, sand lance, anchovies and rockfishes varying in importance depending on the location (Healy 1991).

Sockeye Salmon

Little is known about the ocean distribution of Columbia River sockeye salmon. However, their ocean distribution may be similar to British Columbia and other Washington stocks. Based on scale analysis, British Columbia–Washington stocks do not migrate as far west in the North Pacific as central Alaska sockeye stocks. British Columbia–Washington stocks also tend to be distributed farther south than Alaskan stocks (to 46° N latitude) but utilize the area east and south of Kodiak Island with Alaskan stocks (Burgner 1991).

Most Snake River and Wenatchee River sockeye salmon spend two years rearing in the ocean (Bjornn et al 1968). Okanogan River sockeye salmon are a mix of one– and two–year ocean fish (Mullan 1986). Euphausids, amphipods, squid and small fish are the most important food items for sockeye salmon during ocean rearing (Burgner 1991). Sockeye are consistently found in the ocean in areas of high abundance of large zooplankton (Burgner 1991).

Steelhead

Columbia River steelhead probably are distributed over a much broader area of the North Pacific Ocean than any of the other Columbia River salmon stocks. Juvenile steelhead move quickly offshore after reaching the ocean and distribute over a wide area (Light et al 1989). Summer steelhead from Idaho have been taken in the high–seas squid fisheries as far west as near 165° E. longitude (Dave Hanson, PMFC, personal communication) which is over 4,000 miles from the Washington coast. Columbia River steelhead are distributed to the west from the North American coast across the North Pacific in a broad band from about 40° N latitude up to the Aleutian Island chain (Light et al 1989). Summer and winter–run steelhead of wild and hatchery origin show no clear differences in ocean distribution (Light et al 1989).

About half of the Group A summer steelhead spend one year in the ocean and the rest spend two years. Most of the Group B steelhead are two–ocean fish but a small percentage are one and three–ocean fish (CBFWA 1991). Most Columbia River winter steelhead spend two years rearing in the ocean and some spend three years (CBFWA 1991).

Coho Salmon

Early run coho salmon from the Columbia River migrate south along the Oregon and northern California coasts. Late–run coho salmon primarily migrate north along the Washington coast and contribution to the British Columbia and Alaskan fisheries is minimal (CBFWA 1991). Adults return as two or three–year–old fish (Mullan 1983). Four–year–old coho are rare in the Columbia River (CBFWA 1991).

2.1.2.4 Adult Migration and Spawning

Water volume and velocity play key roles in the life cycle of salmon and steelhead. Adult salmon and steelhead enter the Columbia River and begin their upstream migration virtually every month of the year. The timing of many runs of anadromous salmonids corresponds with peak flow (Collins 1892; Pritchard 1936; Cramer and Hammock 1952; Andrew and Geen 1960; reviews in Major and Mighell 1966, and Banks 1969; and Baker 1978). For example, summer chinook salmon migration in the Columbia River historically coincided with the time of highest river discharge (Thompson 1951). Upstream migration of historical runs of sockeye salmon in the Columbia River was initiated with the rising waters of spring (Collins 1892).

Energy Reserves and Temperature Effects

Extreme flows (both high and low) and high water temperatures can cause delays in the spawning migrations of some salmonid stocks in the Columbia, Snake, and other rivers, resulting in mortality of adults and reduced egg viability. (Thompson 1945; Fish and Hanavan 1948; Cramer and Hammack 1952; Major and Mighell 1966; ODFW 1977; Johnson et al. 1982; Liscom et al. 1985; Shew et al. 1985). Salmon exhaust nearly all their energy reserves for migration, egg and milt production and spawning since they do not feed after entering the rivers on their spawning migrations (Idler and Clemens 1959; Gilhousen, 1980). Any flow–related or temperature–related delays in reaching the spawning grounds may extend the fish to the point that it has insufficient energy reserves to spawn successfully. Extreme flows and high temperatures occurred in pre–development time, and so are not exclusively dam–related.

High water temperatures, in addition to blocking migration, can increase the rate at which limited energy is consumed for standard metabolism (Fry 1971). Females are more susceptible to delay (Godfrey et al. 1954), perhaps because they have less surplus energy than males (Gilhousen 1980). There are also differences among runs, and between early and late components of runs, with respect to energy reserves and swimming ability (Gauley 1960; Gauley and Thompson 1963; Gilhousen 1980).

Migration Timing

Columbia River salmon stocks evolved discrete populations that home to particular areas which allow them to make effective use of a wide variety of habitats in the basin. Different temperature regimes that regulate maturation, incubation, and fry emergence have a major effect on run timing. As water temperatures decrease from upstream to downstream reaches in the fall, biological windows for egg deposition in specific sites determine the spawning sequence. For example, mid–Columbia River spring chinook spawn in cooler headwater tributaries from July until mid–September, while summer chinook spawn in warmer downstream areas during October, and fall chinook spawn in the mainstem during late October and November (Meekin 1963). Royal (1953) hypothesized that the sharp peaks or modes in the timing of migration and spawning indicate that sockeye salmon encounter advantageous conditions for survival that extend over a relatively short time period. Additionally, the chronological order of migration and spawning of individual races of sockeye salmon in the Fraser River shows remarkable consistency (Killick 1955).

Velocities

Water velocities are an important factor in redd site selection and construction (Chambers 1956, 1960; Meekin 1967a; McCart 1969), and as a result adults often locate their nests at the head of a riffle in the tailout of a pool. Adequate flows are necessary to prevent dewatering and keep redds clean of sediment and well aerated. A shortage of oxygen caused by the lack of sufficient flow through the gravel beds jeopardizes egg and larvae survival (Royce 1959). The most important factor in egg and larvae survival is the quality of the water circulating in the spawning gravel (Chambers 1956). This flowing water must circulate adequate oxygen, be a suitable water temperature, and lack any deleterious chemicals.

Sediment Flushing

Seasonally high flows can play an important role in flushing harmful fine material from spawning gravel (Reiser et al. 1985). The amount of water circulating through the gravel increases with the seasonal increase of water flow during spring runoff. The lack of seasonally high flows has led to a compacting of gravel in some areas and an accumulation of fine material in the gravel (Chapman et al. 1986). Silting is one cause of low survival in salmonid eggs and larvae (Shapovalov and Taft 1954), and consequently the lack of flow (and subsequent siltation process) hinders salmonid spawning success.

Gravel can become sedimented except where spawning is concentrated each year. The tendency of spawners to concentrate in high–use spawning areas in the Hanford Reach (Dauble and Watson 1990) may reflect the high relative suitability of gravel that has been cleansed of fines by redd construction in prior years. High flows during spawning can provide a greater wetted area for spawning when space is limiting, but of equal or greater importance is the maintenance of flow levels close to those that prevailed during spawning until fry have emerged. (Thompson 1974; Graham et al. 1980; Chapman et al. 1986).

Chinook Salmon

Chinook salmon in the Columbia River basin are divided into three runs based on the period of time adults enter the Columbia River. Spring chinook salmon enter the river during March, April and May and pass Bonneville Dam from mid–March through the end of May. Summer chinook salmon begin their upstream migration during late May, June and July and pass Bonneville Dam in June and July. Fall chinook salmon enter the river beginning in late July and August and pass Bonneville Dam during August, September and October. The three runs are comprised of many separate stocks that maintain genetic integrity by spatial or temporal separation during spawning.

Spring Chinook[2]. Spring chinook migrate to the headwaters of the Columbia during peak flows and use higher elevation streams for spawning. Spring chinook spawn in most of the Columbia subbasins with the exception of the Tualatin River, and rivers of the Willamette Coast Range in Oregon; Elochoman River, Grays River, in the Columbia River below Bonneville Dam and from Priest Rapids Dam to Chief Joseph Dam in Washington and in all three Idaho subbasins. Many of the runs are supplemented with hatchery production. Peak spawning ranges from August through October. Typical examples include the wild spring chinook salmon in the Deschutes River that spawn primarily in September (Cates 1981) and in the Tucannon River in September (Howell et al. 1985). Spring chinook spawning in the Yakima River is earliest in the colder water areas and later in the warmer water areas (Howell et al. 1985). Spring chinook spawn in the Salmon River in August and early September (Bjornn 1960). Elevation is a key factor in timing of migration and spawning. In streams where both spring and sum-

[2]NMFS in their deliberations concerning the listing of the spring and summer chinook for threatened or endangered status, determined that these two races were not reproductively isolated and so combined them into a single designation: spring/summer chinook. However spring and summer chinook will be referred to separately in this and other sections since most of the biological and management data refers to these two races separately.

mer chinook are present, the spring chinook tend to spawn earlier and at higher elevations than the summer chinook (Matthews and Waples 1991).

Summer Chinook. Summer chinook have historically dominated upper Columbia River spawning grounds in lower elevation streams. In the Snake River summer chinook use small high elevation tributaries more typical of spring chinook (Matthews and Waples 1991). Peak spawning for summer chinook occurs in the Methow, Okanogan and Similkameen rivers between October 20 and October 30 (Meekin et al. 1966; Meekin 1967b). In the Upper South Fork Salmon River peak spawning of summer chinook occurs between late August and mid–September (Ortman and Richards 1964).

Fall Chinook. The fall chinook salmon in the Columbia River are comprised of two distinct types: "tules" and "upriver brights". Tules are generally confined to tributaries in the lower river from Bonneville pool downstream and spawn from late September to about mid–October. Upriver brights spawn in upriver areas and retain a silvery ocean phase coloration because they spawn much later than the tules. Upriver bright fall chinook spawn in the Hanford Reach of the Columbia River usually from mid–October to the third week in November (Dauble and Watson 1990). About 70 percent of upper river fall chinook spawning occurs within the Hanford Reach (Carlson and Dell 1990). Most spawning in the Hanford Reach occurs in the upper 15 miles, primarily in the Vernita Bar area (Bauersfeld 1978). Upriver bright fall chinook also spawn in the lower Yakima and Deschutes rivers. Spawning of fall chinook in the Snake River occurs in October and November from the upper extent of Lower Granite Dam pool to Hells Canyon Dam in the mainstem and in the lower reaches of major tributaries (Waples et al. 1991).

Sockeye Salmon

Adult sockeye salmon enter the Columbia River beginning in late May. The migration period over Bonneville Dam occurs from May through August with the peak of migration ranging from late June to mid–July. The Wenatchee stock generally migrates earlier than the Okanogan stock. Specific information on the timing of Snake River sockeye salmon at Bonneville Dam is not available. Sockeye migrate past Priest Rapids Dam about two weeks after passing Bonneville Dam (Howell et al. 1985).

Upper Columbia River. Sockeye salmon enter the Okanogan and Wenatchee rivers and reach Lake Osoyoos and Lake Wenatchee between mid–July and August (Mullan 1986). In some years water temperatures of 20–21°C and greater in the Okanogan River inhibit passage (Major and Mighell 1966), with documented delays in passage of up to a month (Allen and Meekin 1980). The adult fish remain in Lake Osoyoos up to a month before beginning their migration upstream to the spawning grounds in Canada in mid–September when river temperatures begin to cool (Major and Mighell 1966).

In the Okanogan River system sockeye salmon spawn in September and October with most spawning occurring October 10 through 20 (Allen and Meekin 1980). Most of the spawning occurs in the Okanogan River between McIntyre Dam and Oliver, BC. Limited spawning occurs along the shoreline of Lake Osoyoos (Allen and Meekin 1980). Spawning activity peaks in the Wenatchee River about one month earlier than in the Okanogan River. Most spawning occurs in the lower reaches of the Little Wenatchee River and the White River (Howell et al. 1985). Mullan (1986) concluded that spawning habitat has not been a limiting factor at recent levels of abundance for sockeye salmon in the Okanogan and Wenatchee rivers.

Snake River Sockeye. In the Snake River basin, sockeye salmon returning to Redfish Lake travel about 900 miles from the Pacific Ocean. Peak migration of adult sockeye salmon at Lower Granite Dam ranges from early to mid–July. Arrival of sockeye salmon at Redfish Lake peaks in August and peak spawning occurs in mid–October (Bjornn et al. 1968). Bowler (1990) reported that sockeye only spawn along the shoreline of the lake. Bjornn et al. (1968) found that spawning during the 1950–60s occurred in shoreline areas of Redfish Lake as well as Fishhook Creek.

Steelhead

There are two distinct types of steelhead in the Columbia River. Winter–run steelhead, or "winter steelhead", enter the Columbia River from November through April and spawn the same year from December to June. Summer–run steelhead, or "summer steelhead", enter the Columbia River and migrate upstream in the spring and summer but do not mature and spawn until the following spring (Bley and Moring 1988).

Winter Steelhead. Winter steelhead are produced primarily in tributaries of the Columbia River below Bonneville Dam. The upstream limit of their distribution is Fifteenmile Creek, an Oregon tributary of The Dalles pool (CBFWA 1991). Steelhead passing Bonneville Dam between November 1 and March 31 are considered to be winter steelhead. Fish counting during this time period at Bonneville Dam has been conducted recently for a variety of reasons, including for ESA purposes.

Summer Steelhead. Upriver summer steelhead are divided into two segments: the Group A and B populations. Group A steelhead mainly enter the Columbia River from June to early August and Group B fish from late August into October. Both groups spawn from April into June almost one year after entering the Columbia River (CBFWA 1991). Group A steelhead are found in almost all of the subbasins above Bonneville Dam including the Clearwater and Salmon rivers (CBFWA 1991). Group B steelhead are produced only in the Clearwater and Salmon rivers in the Snake River basin. Group B steelhead on average spend more time rearing in the ocean and are significantly larger than Group A steelhead. Summer steelhead also spawn in the Hanford Reach of the mainstem Columbia River from February through May (Fulton 1970; Watson 1973). Wild summer steelhead are also produced in several Washington tributaries below Bonneville Dam.

Coho Salmon

Coho salmon in the Columbia River have a wide range of run timing. They enter the Columbia River from August through December (CBFWA 1991). Current returns of coho salmon above Bonneville Dam are supported almost entirely by hatchery production. The only native upriver stock of coho salmon is located in the Hood River, an Oregon tributary to Bonneville Pool, and production is very low (CBFWA 1991). Peak migration of coho salmon at Powerdale Dam on the Hood River occurred in September and October and spawning occurs during October and November (Howell et al. 1985).

Below Bonneville Dam. Below Bonneville Dam a natural coho salmon run in the North Fork of the Clackamas River returns from November through March (Cramer 1991). Coho salmon of apparent wild origin have been observed in Gnat Creek from mid–September to mid–February (Hirose 1983). Small numbers of coho salmon spawn naturally in other tributaries of the lower Columbia River but most are considered to be feral hatchery fish and only a few of non–hatchery origin (Johnson et al. 1991).

Early– and Late–runs. Coho salmon in the Columbia River in recent times have been managed primarily for hatchery fish which are divided into early–run and late–run types. The early–run or Type S group has a southerly marine distribution from the mouth of the Columbia River and returns to the river in August and September (Johnson et al. 1991). The late–run or Type N group has a northerly marine distribution and returns to the Columbia River in October and November. Early–run (Type S) coho salmon migration past Bonneville Dam peaks in early September, and they spawn in October and early November (CBFWA 1991). Late–run (Type N) coho salmon migration over Bonneville Dam peaks in mid–October and they spawn in November and December (CBFWA 1991).

2.1.3 Factors Affecting Populations

2.1.3.1 Effects of Hydroprojects

Juvenile Migration

Passage At Dams. The emplacement of hydroelectric dams and the impoundments they create, present downstream migrant salmonid juveniles with a variety of adverse conditions. Direct mortality and injury is incurred by a portion of the smolts passing

through the various routes at the structures: turbines, spillways and bypasses. In addition to these effects, some degree of indirect mortality is also associated with passage. Fish stunned or disoriented while passing the dam, or entrained in tailrace eddies such as backrolls (eddies near the face of the dam) may be subjected to increased predation. Furthermore, smolts collected in bypass systems and released in high densities at outfall sites can also be subjected to increased predation activities associated with those sites.

Gas Saturation. Excessive spillage can result in elevated nitrogen gas saturation of river water. If severe enough this can cause a condition referred to as "gas bubble trauma". This condition can result in debilitation or mortality. Gas levels typically increase with the volume of water being spilled. The design of the spillway and whether the spillways were retrofitted with flow deflectors are factors that influence the degree of gas saturation.

Migration Speed. The creation of impoundments has reduced the instream water velocity, cumulatively slowing the migration speed of yearling salmon and steelhead that migrate during the spring (Berggren and Filardo 1993). The effects of water velocity on the migration speed of subyearling chinook salmon that migrate principally during the summer, are not as clear. Subyearling chinook rear in the shallow water habitats of the impoundments for an extended period, up to several months, and engage in a slower seaward migration. This makes it difficult to distinguish between rearing and migratory phases. Consequently, it is difficult to make reliable inferences regarding migratory responses to changing environmental (water temperature and velocity) and/ or biological (smolt development, fish size) conditions, all of which have been implicated as mechanisms affecting migratory dynamics (Berggren and Filardo 1993, Giorgi et al. 1990, Rondorf and Miller 1993). The migratory dynamics of sockeye in the Snake and Columbia Rivers are not well understood, but are presumed to be similar to yearling chinook.

The degree of migrational delay, the extent to which it is influenced by water velocity, and the consequences in terms of affecting smolt survival have been vigorously debated for more than a decade. One theory is that speedier migrants are exposed to riverine predators for shorter periods and that migrational delay impairs seawater adaptation. The implication is that such processes are responsible for the preponderance of juvenile mortality incurred through the system. It is further held that this is the principal factor limiting the production of upper basin stocks.

With regard to migrational delay and seawater adaptability, the limitations vary with species. There are data to suggest a physiologically–based window of opportunity may exist for coho and steelhead (Hoar 1976). However, the data available for chinook (Hoar 1976) and sockeye (Foote et al. 1992) indicate they are quite flexible with respect to seawater adaptation, successfully making the transition over protracted periods, up to several months.

The premise that slower smolt migration increases the probability for encounters with predators appears generally sound. Nevertheless, regardless of flow volumes, smolts still congregate at the face of some dams and delay passage until nightfall as evidenced by diel passage patterns documented at the dams. Since predator–related effects are concentrated near the dams, the net benefits of swifter migration through the main body of the reservoir may not be as great as some perceive. Conversely, increased velocity can alter the distribution of predatory fish in the tailrace, perhaps reducing their effectiveness at consuming smolts. The collective effects of these mechanisms on predator–related smolt mortality are difficult to predict. At least two passage models, CREM and CRiSP, have attempted to represent some or all of these processes. Even so, a considerable number of assumptions are required.

The debate regarding the effectiveness of flow augmentation, as well as reservoir drawdown, has been fueled by the absence of reliable measures of smolt survival either through the hydroelectric system or at seawater entry. Thus, it is not possible to confidently determine how much delay is too much, and to what extent specific water management alternatives increase smolt survival, and ultimately survival to adult return. There is no question that

the emplacement of hydroelectric dams has dramatically decreased salmon and steelhead productivity in the Snake and Columbia rivers, particularly with respect to effects on juvenile survival. Turbines, bypasses, gas saturation, in combination with piscivorous predators and slower migration all take their toll on downstream migrants. However, it is not clear to what extent decreasing system travel time by several days to perhaps a week, reduces the overall juvenile mortality. Because of the uncertainty surrounding the relationship between water velocity, fish travel time and smolt survival, the SOR analysis has included a range of values for each of these variables in an attempt to encompass the true relationship.

Transportation. Collecting and transporting smolts to release sites below Bonneville Dam is an alternative passage strategy that has been tested by NMFS researchers, and employed for nearly two decades. At selected dams, smolts are guided from turbine intakes and routed to a collection system. Smolts are then transported primarily by barge (but sometimes by tanker truck) to release sites below Bonneville Dam. Fish are currently transported from Lower Granite, Little Goose, Lower Monumental and McNary dams. Transportation does not necessarily occur under all river conditions. When instream flow volumes are deemed to be sufficiently high, the guided and collected smolts can be released back into the river in the tailrace of the collector dam.

The effectiveness of transportation has been debated as vigorously as the issue of smolt migration speed. NMFS investigators have empirically demonstrated that Snake River yearling chinook and steelhead barged from Lower Granite Dam survive at considerably higher rates than those permitted to migrate instream. For example, in the most recent evaluations conducted in 1986 and 1989, transported chinook survived at rates 60 percent and 150 percent higher, respectively, than counterparts permitted to migrate downstream from the release site in the tailrace of Little Goose Dam, past six projects (Matthews 1992). Transported steelhead show similar benefits.

This relative measure of survival is based on the recovered portions of marked treatment groups recovered as adults at dams and in–river sampling sites, hatcheries and in some cases spawning grounds. The ratio of the recovery proportion of transported to in–river migrants is referred to as the transport/in–river ratio (TIR). For example, a TIR of 1.5 indicates that 50 percent more transported fish survived to adulthood than their counterparts that were permitted to remain in the river and migrate downstream. Evaluations are replicated within a year, and variances are calculated from these data. Confidence limits around the point estimate can be considerable. For example: NMFS reported (Matthews et al. 1992) for the 1986 yearling chinook transport evaluation at Lower Granite Reservoir, a TIR of 1.6 with a 95 percent confidence interval of 1.01 to 2.47.

The experimental population is the run–at–large arriving at the collector/transport dam. Today the population is predominantly hatchery fish, hence the TIR is weighted to reflect performance of hatchery fish. The experimental protocol employed in the NMFS studies is developed by a technical committee composed of Federal, state, and tribal representatives.

The NMFS evaluations also demonstrated that subyearling chinook barged from McNary Dam survive at about 2 to 3 times the rate as those permitted to migrate in–river past John Day, The Dalles, and Bonneville dams. Similar investigations have not been conducted for fall chinook salmon in the Snake River. But NMFS expects the relative benefits to be similar or greater than observed from McNary (as evidenced by their recent decision to maximize transport of fall chinook in the Snake River), since the fish would avoid the additional dams and reservoirs. Until only recently, Snake River fall chinook have been transported by tanker truck, rather than barge. The two modes of transport are not equivalent, and evaluations have emphasized the preferable mode, barging. Inference derived from barging evaluations may not necessarily apply to trucked smolts.

Critics of transportation argue that in the Snake River adult return rates of spring/summer chinook remain depressed in spite of transportation. They also suggest that current evaluations may not be representative of wild stock responses to transportation and contend this requires evaluation; that delayed effects affect spawning success and survival; and real controls were not used in experiments. These contentions have merit and should be examined experimentally. However, they do not refute the fact that NMFS evaluations indicate that for the population–at–large arriving at a Snake River collector dam, transported fish fair better than downstream migrants, even in moderate flow years. Based on their own research, NMFS has determined that transportation remains the best passage option available for endangered Snake River stocks. Lacking additional information, SOR used TCRs reported by NMFS in modeling analyses.

Adult Migration

Passage Routes. Adult salmon and steelhead pass hydroelectric dams by way of adult ladders. The number of ladders at a single dam ranges from 1 to 3. Ladders are in place at all dams from Bonneville to and including Lower Granite Dam on the Snake River, and Wells Dam on the Columbia River. The absence of ladders at dams upstream from these sites has eliminated access to vast areas that were once suitable for both spawning and rearing.

Fish enter ladders by way of entrances at discharge ports in the tailrace, or by entering a passage channel that leads to the ladder. Channels span the face of the powerhouse, and are fitted with ports through which fish enter.

Migrational Delay and Fallback at Dams. Dams and their operation affect upstream passage in two manners, migrational delay and fallback. Encountering the structures themselves imparts some delay. Fish have to locate ladder or channel entrances and ascend the ladder. Operating conditions can affect their ability to locate entrances. Furthermore, excessive spill, or particular spill patterns, can create flow conditions that can occlude entrances at some dams, and increase migrational delay.

Once fish ascend and exit to the forebay, some fraction fall back downstream, usually through the spillway or powerhouse. This can result in either direct injury/mortality, or increased migrational delay. River discharge can affect the rate of fallback. For example, Wagner and Hilson (1992) reported that the fallback rate for fall chinook increased with project discharge at McNary Dam. In general, fall chinook may be more prone to fallback than other species, by virtue of their apparent proclivity to wander. Mendel et al. (1992) observed that 53 percent of a group of radio–tagged fall chinook fell back at Lower Granite Dam in 1991.

Gas Supersaturation. Chronic exposure to gas supersaturation can have an adverse effect on migrating adults, increasing mortality (Ebel et al. 1975) or injury (Bjornn et al. 1994). Historically, this condition was more prevalent when generating capacity was low, forcing excessive water volumes to be spilled. Today, gas supersaturation is generally not problematic due to increased generation capability, as well as the installation of spillway flow deflectors (flip–lips), which reduce plunging and associated supersaturation. However, reservoir drawdown and other alternatives which increase spill for juvenile fish passage increase the probability that adults will be exposed to gas supersaturated in–river conditions.

Migration Speed Through Impoundments. Migration of adults through impoundments is rapid in comparison to rates observed in free–flowing sections. Bjornn et al. (1992) tracked spring and summer chinook through the four impoundments on the Snake River and on into the tributaries. They reported an average velocity of 55 to 58 km/day through the impounded section from Ice Harbor Dam to the head of Lower Granite Pool. In the various free–flowing tributaries migration was much slower, with mean migration speeds ranging from 8.7 to 31.0 km/day d.

However, there are operations that can occur during the late summer and fall in the Snake River that can reduce migration speed through impoundments. Periodically, at night, no water is discharged past dams resulting in "zero–flow" conditions. Steelhead

migrate through the system during this time of year and appear to reduce migration speed under these conditions. However, since water temperature is also high during this period, a condition also known to slow migration, it has been difficult to isolate the causative agent.

Estimates of Adult Loss or Mortality. Adult passage survival appears to be higher than once presumed. Bjornn et al. (1992) estimated that 87 percent of their tagged spring and summer chinook salmon survived from Ice Harbor tailrace to Lower Granite forebay. Consistent with this Chapman et al. (1990) estimated a 5 percent loss per project for spring and summer chinook through the Columbia and Snake River. According to Dauble and Mueller (1993), losses reported by the International North Pacific Fisheries Commission, for adult salmon in general during the 1970 migration, were estimated to be near 13 percent per project. Undoubtedly, variations in river conditions from year to year will influence passage survival, and may in part be responsible for the seemingly disparate estimates. Also, the methods used to estimate survival have differed over the years.

2.1.3.2 Effects of Harvest

Salmon and steelhead from the Columbia River are harvested in the Pacific Ocean from Alaska to California. The ocean fisheries along the coasts of Washington, Oregon and California that harvest Columbia River salmon stocks are managed under the Magnuson Fishery Conservation and Management Act (MFCMA) by the Pacific Fisheries Management Council (PFMC). The North Pacific Fisheries Management Council (NPFMC) is responsible for management of fisheries off the coast of Alaska that harvest Columbia River stocks. The PFMC is composed of Federal, state and tribal representatives from the states of California, Oregon, Idaho and Washington PFMC includes representatives of commercial, sport and charter fishing. Representatives from each council also sit on the companion council to ensure coordination. The management of fisheries occurring in Canadian and United States waters that intercept salmon from the other country is the responsibility of the Pacific Salmon Commission (PSC) under the U. S.–Canada Pacific Salmon Treaty of 1985. To ensure coordination among Canadian, Alaskan and other West Coast ocean fisheries, representatives of PFMC and NPFMC participate in the PSC. Recommendations from the PFMC and NPFMC concerning bag limits, time and area closures and gear restrictions for sport and commercial salmon fisheries from three to 200 miles offshore of the western United States are forwarded to the Secretary of Commerce for consideration and promulgation of annual fishing regulations. Ocean fisheries occurring in state waters, zero to three miles offshore, are managed by the state having jurisdiction over the maritime area adjoining the respective state.

Treaty Indian commercial, ceremonial and subsistence fisheries and non–Indian commercial fisheries occurring in the mainstem Columbia River are managed by the states of Washington and Oregon and the treaty Indian tribes through the Columbia River Compact and the Columbia River Fish Management Plan (Plan). The Plan initially was created in 1977 by order of the Federal court under US v. Oregon. The Plan provides a framework whereby each of the parties may exercise their management authority in a coordinated manner to protect, rebuild, and enhance Columbia River fish runs which provide harvest for both treaty Indian and non–Indian fisheries. The primary species managed under the plan include chinook, sockeye and coho salmon, steelhead, white and green sturgeon, and shad. Each state in the Columbia River basin manages its recreational fisheries for anadromous and resident fish populations.

The general trend in harvest of Columbia River basin salmonid stocks has been downward, with the exception of relatively high harvest levels of some stocks in 1987 and 1988.

Ocean Fisheries

Chinook Salmon. Since 1971 total landings of chinook salmon in ocean commercial and recreational fisheries coastwide have ranged from a high of 2,121,000 in 1988 to a low of 438,000 in 1992. During the 1970s total landings averaged 1,400,000 chinook. During the 1980s landings averaged 1,150,000 chinook.

Ocean exploitation rates for six Columbia River basin chinook stocks managed under the Pacific Salmon Commission have all declined from the base period.

The impact of ocean harvest on Snake River spring/summer chinook is assumed to be insignificant (PFMC 1993a). Coded–wire tag (CWT) analyses of Lyons Ferry fall chinook stock indicate that the total mortality on Snake River fall chinook associated with ocean fisheries declined by 50 percent in 1991, compared to the three previous years (PFMC 1993a). The analyses show that 1991 ocean fisheries represented a total adult equivalency exploitation rate of 13.9 percent. This is 18 percent lower than the 1988–1990 average of 16.9 percent.

Sockeye Salmon. Ocean troll catches of sockeye salmon since 1985 in the PFMC management area have been less than 100 fish (PFMC 1993b). The majority of these fish are thought to be of Fraser River and Puget Sound origin.

Coho Salmon. Since 1971 total landings of coho salmon in commercial and recreational fisheries coastwide have ranged from a high of 5,328,000 in 1976 to a low of 310,000 in 1984 (Figure 2) (PFMC 1993a). The decline in landings has been due to stringent regulations to protect Oregon coastal natural coho stocks and some depressed Puget Sound coho stocks.

Mainstem Columbia River Fisheries

Historically, commercial drift gill net fisheries occurred below Bonneville Dam (known as zones 1–5) throughout the year. In 1960 this fishery was open for 101 days. In recent years the fishery has been open for a "late winter fishery" in February and March targeting on lower river spring chinook, an "early fall fishery" during August and early September, and a "late fall fishery" from mid–September through mid–November. The early fall fishery targets on fall chinook while the late fall fishery targets on coho salmon. Since 1975 (except 1977), no fisheries have occurred in the lower river targeting on spring chinook destined for the upper Columbia basin. Summer chinook have not been harvested as a commercial target species in the Columbia River since 1964. To reduce the incidental catch of steelhead and other non–target species, mesh restrictions have been placed on the net fisheries. A ban on the commercial sale of steelhead in 1975 halted the incidental landing of steelhead in the lower river non–Indian drift net fisheries during the early and late fall seasons.

A treaty Indian fishery for the four treaty tribes (Warm Springs, Nez Perce, Umatilla and Yakama) occurred in zone 6 (Bonneville Dam to McNary Dam) during most of the year. Recently this fishery has been restricted due to the depressed status of upper river chinook stocks. There has been no treaty Indian commercial season in zone 6 for spring chinook since 1975 (except 1977) and for summer chinook since 1964. However, very limited ceremonial and subsistence fishing in zone 6 is allowed on spring and summer chinook.

Spring Chinook Salmon. Columbia upriver spring/summer chinook stocks provided the foundation for treaty Indian and non–Indian fisheries prior to the 1970s. Since then these stocks have been at all time lows. Their depressed condition has resulted in very constrained fisheries in order to provide for escapement. In–river harvest rates during the period from 1960–1974 averaged 49 percent (TAC 1993). Since 1975 the harvest rate on these stocks has averaged 7.5 percent (TAC 1993).

Fishing seasons are now designed to harvest hatchery surplus and to protect depressed upriver spring chinook runs (PFMC 1993). Commercial harvest of upriver spring chinook adults below Bonneville Dam since 1971 has ranged from a high of 68,500 in 1972 to a low of less than 100 in 1976. Since 1975, harvest has been very restricted, usually less than 1,000 fish, except in 1977 when 8,600 were harvested and in 1988 when 5,100 were taken (ODFW/WDF 1992). In 1992 commercial landings were 5,100 adult chinook which included an estimated 200 spring chinook of upper river origin (PFMC 1993). The recreational fishery landed 5,300 spring chinook adults in 1992. An estimated 1,200 were of upper river origin (PFMC 1993).

Since 1979, non–Indian harvest of Snake River wild spring chinook has ranged from zero to 1,200 fish (TAC 1993). During the same time period treaty Indian harvest of Snake River wild spring chinook has been between 300 and 1,300 fish (TAC 1993). In 1992, lower Columbia River mainstem fisheries (zones 1–6) harvested an estimated 732 wild Snake River adult spring chinook, compared to 778 adults in 1991 and a 1986–1990 average of 1289 fish (PFMC 1993a). In–river harvest rates on this fish stock is estimated at 5.5 percent in 1992, compared to 10.7 percent in 1991 and 10.6 percent during the period 1986–1990.

Summer Chinook. A target fishery for summer chinook has not occurred since 1964 in the Columbia River below Bonneville Dam (zones 1–5) (TAC 1993). From 1967–1973 some incidental harvest was allowed during the shad and sockeye salmon seasons (TAC 1993). Since 1973 no harvest has occurred except for 100 fish in 1979 (TAC 1993).

Harvest of summer chinook adults in mainstem recreational fisheries has not been allowed since 1974. Harvest of summer chinook jacks was allowed from 1977–1991 during the summer steelhead fishery. Harvest of summer chinook jacks in the lower Columbia River from 1977 to 1991 ranged from 50 to 300 (TAC 1993). CWT analysis indicates many of these were two year old hatchery spring chinook smolts that are released at a larger size and spend a short time in the marine system (TAC 1993). During 1992 harvest of spring/summer chinook jacks was prohibited in mainstem Columbia River recreational fisheries by emergency ruling. This ruling was made permanent in 1993.

Directed harvest of summer chinook has not been allowed since 1965 in the zone 6 treaty–Indian commercial fishery. Incidental catches occurred in 1966–73 during the shad and sockeye seasons (TAC 1993). During the 1985–1988 commercial sockeye seasons summer chinook were allowed for sale as incidental catch. Treaty–Indian commercial incidental landings and ceremonial and subsistence harvest of adult Columbia River summer chinook have averaged less than 1000 fish since 1979 (TAC 1993). Harvests from 1988 through 1992 have been less than 100 fish.

Treaty–Indian harvest of Snake River wild summer chinook during commercial, ceremonial and subsistence fisheries is estimated to have ranged from zero to 350 fish since 1979 (TAC 1993). Harvest since 1988 has been less than 20 fish per year.

Fall Chinook. Commercial harvest of adult lower river fall chinook in zone 1–5 since 1980 has ranged from a high of 224,900 in 1988 to a low of 20,400 in 1990 (ODFW/WDF 1992). Recreational mainstem Columbia River and tributary harvest of adult lower river fall chinook since 1980 has varied from 200 in 1980 to 29,900 in 1987 (ODFW/WDF 1992).

Commercial harvest of adult Bonneville Pool hatchery fall chinook in the lower river fishery (zone 1–5) since 1980 has ranged from 35,700 in 1982 to 100 fish in 1985 (ODFW/WDF 1992). Commercial harvest of this stock in the zone 6 fishery has ranged from 48,900 in 1982 to 1,700 in 1987 (ODFW/WDF 1992). Recreational mainstem and tributary harvest of this stock has varied from 2,300 in 1984 to less than 100 in 1980, 1981 and 1983 (ODFW/WDF 1992).

Adult upriver bright fall chinook adult harvest since 1980 in the zone 1–5 commercial fishery has ranged from 104,300 in 1987 to 2,400 in 1981. During the same time period recreational mainstem and tributary harvest has ranged from 18,200 in 1987 to 200 in 1982. Zone 6 commercial harvest of this stock has varied from a high of 224,400 in 1987 to a low of 7,300 in 1982 (ODFW/WDF 1992).

Zone 1–5 commercial landing of adult mid–Columbia bright fall chinook salmon adults since 1982 has varied from a high of 46,200 in 1989 to a low of 700 in 1982. The zone 6 commercial harvest on this stock has varied from 900 in 1982 to 21,100 in both 1988 and 1989. The recreational mainstem and tributary catch of this stock has varied from less than 100 in 1982 to 3,700 in 1989 (ODFW/WDF 1992).

The 1992 harvest rate on wild Snake River fall chinook salmon for the Columbia River chinook fisheries was estimated at 20 percent. The 1991 estimated harvest rate was 27 percent and the 1988–1990 average harvest rate was 47 percent (TAC 1993).

Sockeye Salmon. The commercial harvest of sockeye in the lower river fisheries since 1938 has ranged from a high of 190,900 in 1958 to no harvest in several recent years. Since 1989 there has been no commercial harvest of sockeye (ODFW/WDF 1992). Commercial harvest of sockeye in the treaty Indian fishery in zone 6 since 1938 has varied from a high of 64,700 fish in 1940 to less than 100 in recent years (ODFW/WDF 1992). Some recreational harvest of sockeye has occurred in Lake Wenatchee. The ceremonial and subsistence tribal fishery since 1977 has ranged from no harvest to 2,100. There is no information on the ceremonial and subsistence harvest of sockeye in zone 6 prior to 1977 (ODFW/WDF 1992).

Steelhead. Lower river commercial landings of winter steelhead from 1953 to 1975, when non–Indian commercial sales of steelhead were banned, varied from a high of 23,400 in 1953–54 to a low of 100 in 1974–75 (ODFW/WDF 1992). The mainstem and tributary recreational fisheries since 1953 have harvested between 29,900 (1982–83) and 124,100 steelhead (1971–72) (ODFW/WDF 1992).

Lower river commercial harvest of summer steelhead from 1938 to 1975 varied from 4,000 in 1974 to 239,800 in 1940. The zone 6 treaty commercial fishery harvest has ranged from 500 in 1962 to 86,300 in 1985 (ODFW/WDF 1992). Ceremonial and subsistence (C&S) harvest prior to 1979 is unknown. Since 1979 C&S harvest has ranged from about 400 in 1979, 1983 and 1990 to 6,700 in 1989 (ODFW/WDF 1992).

Recreational harvest of summer steelhead in the lower Columbia River (below Bonneville Dam) since 1963 has varied from no harvest in 1975 and 1976 to 30,000 fish in 1967. Since 1973 the harvest has not exceeded 8,000 fish (ODFW/WDF 1992).

Coho Salmon. Annual lower river commercial catches of adult coho salmon averaged 162,700 from 1971–1979, and 270,500 between 1980–1989. The harvest in 1990 was 75,000 and in 1991 the harvest was 406,500. During this time annual catches have ranged from 7,100 in 1983 to 981,000 in 1986 (ODFW/WDF 1992).

Annual harvest in the lower river and tributary recreational coho fisheries averaged 10,900 from 1971–1979. From 1980–1989 the average harvest was 64,700. During 1990 to 1992 the harvest has averaged 104,800. From 1971 to 1992 the harvest has ranged from a low of 6,200 in 1977 to a high of 234,000 in 1991 (PFMC 1993a).

Treaty coho catch in zone 6 has ranged from a low of 200 in 1983 to a high of 16,800 in 1986. Annual average catch has been 4,900 fish during 1971 to 1992 (ODFW/WDF 1992).

Columbia River Tributaries

Columbia River tributaries are not open to commercial harvest of chinook. Columbia River tributaries in Oregon open to spring chinook recreational fishing include the Willamette, Sandy, Hood and Deschutes rivers. From 1988 to 1992 the Oregon Department of Fish and Wildlife estimated an average annual catch of 139,800 adult and jack spring chinook (TAC 1993).

Columbia River tributaries in Washington open to recreational spring chinook fishing include the Cowlitz, Kalama, Lewis, Wind, Little White Salmon, Big White Salmon, and Klickitat rivers below the mouth of the Snake River and the Wenatchee River on the Columbia River above the Snake River confluence. During the period 1987 to 1992 an estimated average annual harvest of 103,400 adult and jack spring chinook occurred (TAC 1993).

Treaty Indian ceremonial and subsistence fisheries in Oregon occur in several tributaries including the Deschutes, John Day, Umatilla, Imnaha, and Grande Ronde rivers. The spring chinook fishery in the Deschutes River at Shearar's Falls (RM45) since 1980 has harvested from less than 100 to over 600 fish (ODFW 1993). Estimated harvest of adult fall chinook in this fishery from 1972 to 1986 has ranged from 1,600 to just over 600 fish (ODFW 1988).

Treaty Indian subsistence fisheries in Washington occur in the Wind, Little White Salmon, Klickitat and Yakima rivers. From 1987 to 1992 these fisheries annually harvested an average of 8,800 fish (TAC 1993).

Non–Indian commercial fisheries have not occurred in the Snake River basin since the early 1900s. Significant steelhead recreational fisheries exist in the mainstem Snake River and in tributaries of Washington, Oregon and Idaho. Due to the large numbers of returning hatchery summer steelhead these fisheries have increased in recent years. Regulations in Oregon and Washington target only marked hatchery summer steelhead. These sport fisheries do not allow retention of adult chinook or sockeye. To minimize impacts, barbless hooks are required in most areas of the Snake River basin upstream from the Washington–Idaho border.

Treaty–Indian commercial fisheries have not occurred in the Snake River basin. Ceremonial and subsistence fisheries do occur at various sites within the basin, generally targeting surplus hatchery stocks. These fisheries usually occur near the hatcheries where these stocks are returning such as the Rapid River hatchery in Idaho.

2.1.3.3 Effects of Hatchery Management

The first fish hatchery in the Columbia River basin was built on the Clackamas River in Oregon in 1877. Several other facilities were constructed around the turn of the century in response to over–exploitation of the runs by the commercial fishery. Older hatcheries that are still in operation today have all been modernized and expanded in the last 30 years to mitigate for fish losses due primarily to development of large multi–purpose dams in the basin for hydroelectric power, flood control irrigation, and navigation.

The major hatchery construction phase occurred in the basin in the 1950s under the Mitchell Act, which was passed by Congress in 1938 in response to the loss of fish in the Columbia River due to dam construction and other human activities. Most of these facilities were constructed in the lower Columbia River below Bonneville Dam. NMFS currently funds 25 facilities in the basin with Mitchell Act funding. Another major hatchery program was initiated in 1976 when Congress authorized the Lower Snake River Fish and Wildlife Compensation Program to replace wildlife and fish losses caused by Lower Granite, Little Goose, Lower Monumental, and Ice Harbor dams on the lower Snake River. Twelve hatcheries and eleven satellite facilities have been constructed throughout the Snake River basin. Other hatchery mitigation facilities have been built in the Columbia River basin with funding from the Corps of Engineers, Bonneville Power Administration, the states, and public utility districts and private power companies.

Nearly 200 million juvenile salmon and steelhead are released annually from about 90 artificial rearing facilities in the Columbia River basin. Hatchery fish now comprise over 95 percent of the coho, 70 percent of the spring chinook, about 80 percent of the summer chinook, over 50 percent of the fall chinook and about 70 percent of the steelhead produced in the basin (CBFWA 1990). Because of severely depressed natural production, hatchery production supports important treaty Indian, sport, and commercial fisheries. The annual catch from Mitchell Act production averaged about 2.0 million adult salmon and steelhead per year for the period 1960–85 (CBFWA 1990). However, the success of hatchery production has come at some cost to natural production. Coho salmon populations in the Columbia basin declined in the early years because of irrigation development and other water use projects. The remaining natural coho production was nearly eliminated because mixed–stock fisheries relied heavily on the more abundant hatchery coho which resulted in over–harvest of the less abundant natural coho stocks.

Hatchery Production of Salmon and Steelhead

Chinook Salmon

Spring Chinook. The lower Columbia River spring chinook run is supported primarily by hatchery production because of habitat loss and construction of high dams in the lower river tributaries. Naturally produced spring chinook salmon comprise only 5 to 15 percent of the lower river run (CBFWA 1991). The lower river run of spring chinook salmon usually exceeds the upriver spring chinook salmon run and has provided significant commercial and recreational harvests in recent years.

Prior to the 1970s hatchery production of spring chinook salmon in the upper Columbia River was limited. Since then hatchery production has increased to where the upriver run is now comprised of about 60 percent hatchery fish (ODFW 1991). Annual adult spring chinook returns to hatcheries above Bonneville Dam peaked at over 37,000 in 1986 and 34,900 in 1990 (PFMC 1993).

Summer Chinook. Hatchery production of summer chinook salmon in the Columbia River basin is limited to only four hatcheries: McCall and Pahsimeroi hatcheries in the Snake River basin, and Wells and East Bank hatcheries in the mid–Columbia River. The estimated hatchery composition of adult summer chinook passing Lower Granite Dam from 1985–1990 was 44 percent (ODFW 1991). The hatchery composition of the upper Columbia River summer chinook run has not been estimated.

Fall Chinook Salmon. Lower river fall chinook salmon production is heavily influenced by hatchery production. With the exception of wild fish in the Lewis, Sandy and Cowlitz rivers, fall chinook spawning in the lower river tributaries are considered to be hatchery fish. Seven hatcheries in Washington and four in Oregon produce lower river fall chinook which between 1980 and 1989 supported adult runs ranging from 83,000 fish in 1983 to 344,600 fish in 1987. Lower river wild fall chinook adult returns ranged from 13,000 to 42,000 fish during the same time period (ODFW 1991).

Spring Creek National Fish Hatchery produces the bulk of the Bonneville Pool hatchery fall chinook. Historically the Spring Creek stock was one of the more productive chinook stocks. Enteric red mouth and bacterial gill disease devastated releases in the mid–1980s. The depressed status of this hatchery stock resulted in limitations on ocean and in river harvests to achieve escapement. In–river run size has improved from the poor returns of 1986–1988 (9,100 to 16,000 fish) to 52,400 in 1991 and 29,500 in 1992 (PFMC 1993).

Upriver bright fall chinook reared at hatcheries below McNary Dam are released at Bonneville, Little White Salmon and Klickitat hatcheries and are outplanted at various locations in the mid–Columbia area. Upriver bright fall chinook above McNary Dam are reared at Priest Rapids, Rocky Reach, Ringold, and Lyons Ferry hatcheries. The combined hatchery and wild in–river run size of Columbia River adult upriver bright fall chinook decreased from a peak of 420,600 in 1987 to 80,600 in 1992.

Sockeye Salmon

Hatchery production of sockeye salmon currently is limited to experimental programs at the East Bank Hatchery located at Rocky Reach Dam, a small scale program to test the potential of re–introducing sockeye salmon to the Yakima River, and captive rearing of endangered Snake River sockeye salmon from Redfish Lake.

Steelhead

Hatchery fish contribute significantly to winter steelhead runs in the lower Columbia River. Most of the tributaries in the lower reaches of the Columbia River in Washington and Oregon are supplemented with hatchery fish. The vast majority of the summer run steelhead in the lower river are also produced in hatcheries.

An average of 11,200,000 juvenile steelhead were released from hatcheries above Bonneville Dam from 1986 to 1990 (ODFW 1991). The combined hatchery A and B summer steelhead run above Bonneville Dam from 1985–1990 ranged from 141,900 in 1990 to 304,200 in 1986. The average hatchery composition of the total A and B summer steelhead run over Bonneville Dam during this time period was 73.5 percent (ODFW 1991).

Coho Salmon

The majority of the coho salmon below Bonneville dam are produced in hatcheries. Coho salmon runs in recent years have fluctuated from a low of 138,000 fish in 1983 to 1,553,000 in 1986 (ODFW 1991). Current runs of both early– and late– coho stocks above Bonneville Dam are almost entirely supported by hatchery production. Coho salmon production from about 10 hatcheries is released into the Little White Salmon, Klickitat, Yakima, Umatilla, and the mid–Columbia River.

2.1.3.4 Effects of Artificial Propagation on Wild/Natural Fish

NMFS identified artificial propagation as a factor contributing to the decline of Snake River spring/summer chinook and Snake River fall chinook salmon (NMFS 1991). Artificial propagation can affect wild/natural fish through water withdrawal, hatchery effluent, horizontal transmission of pathogens, competition for food and space, direct and indirect predation, straying and other behavioral influences and through the collection of broodstock. Unfortunately, there is little or no information to quantify many of the impacts of hatchery propagation on wild/natural fish populations.

Competition

Hatchery fish can compete directly with wild/natural fish for food and space. Competition may occur where food and space are limited in the spawning and rearing areas and throughout the migration corridor but data quantifying the impacts are limited. Impacts from competition are assumed to be greatest in the release areas where the highest densities of hatchery fish occur and diminish as hatchery smolts disperse downstream (USFWS 1993). However, hatchery fish appear to be deficient in foraging and habitat selection (Ware 1971, Bachman 1984, Marnell 1986). It may take some time after release for hatchery fish to adapt to their new environment and to become efficient in food selection. As a result, competition may be reduced after release until the hatchery fish adapt. Competition near release sites between steelhead smolts and chinook fry and presmolts also may be reduced because of differences in habitat preference (Cannamela 1992).

There is little data evaluating the adverse behavioral effects of hatchery fish on wild/natural fish. Hillman and Mullan (1989) found that larger hatchery fingerling chinook salmon pulled smaller wild chinook salmon with them as they drifted downstream which resulted in predation of smaller fish by other salmonids. However, they found no evidence that steelhead released in April affected normal movement and habitat use of age−0 chinook.

Juvenile chinook salmon feed as they migrate through the Columbia River system. With rapid emigration times, competition for food should be minimal. However, increased emigration time through the reservoirs could increase competition between hatchery and wild/natural fish for food. Differences in outmigration timing may reduce the potential for competition. For example, the outmigration of spring/summer chinook in the Snake River is much more protracted than the hatchery smolt outmigration which would reduce the potential for interaction. No studies have been conducted in the Columbia River to quantify the impact of the interaction during outmigration.

Predation

The level of predation of hatchery fish on wild/natural fish is difficult to quantify with the limited data available. Salmonid predators generally are thought to prey on fish about one−third or less their size (Parkinson et al. 1989). The relative size of hatchery smolts and wild/natural smolts suggests that the potential for predation in the migration corridor is low. The greatest potential for hatchery fish predation on wild/natural fish exists where smolts are released directly over emerging wild/natural chinook salmon (USFWS 1993). However, there is no evidence that hatchery chinook salmon prey on wild/natural chinook salmon (USFWS 1993). There is some evidence that juvenile steelhead prey on chinook fry/fingerlings. Contor and Cannamela (1992) found three stomachs out of 6,762 hatchery steelhead stomachs that contained a total of ten chinook salmon fry in the upper Salmon River in 1992. Martin et al. (1993) examined 1,713 hatchery steelhead smolt stomachs and found three that contained salmon fry. This limited empirical data suggests the number of fry/fingerlings eaten by steelhead is low.

Disease

Pathogens that cause disease in salmon and steelhead are present in both wild/natural and hatchery populations. Some examples of pathogens found in hatchery fish that are present in wild/natural fish include outbreaks of infectious hematopoietic necro-

sis virus in sockeye salmon and kokanee (Williams and Amend, 1976; Banner et al. 1991) and bacterial kidney disease in trout and salmon (Mitchum et al. 1979; Banner et al. 1986). Elliott and Pascho (1991) sampled sockeye salmon smolts at Priest Rapids Dam, which are all from wild/natural production, and found Renibacterium salmoninarum infection was present in 97 percent of the fish although the infection levels were low.

There is very little information on the impact of infectious diseases on natural production. Hatchery populations probably have a higher potential than wild/natural populations for serving as reservoirs of pathogens because in the hatchery environment fish are held at high density increasing the amplification of the pathogen and potential for spread among the host fish. However, there is no direct evidence of increase in disease incidence or prevalence in wild/natural fish downstream of hatcheries.

Although there is no evidence of horizontal transmission of disease from hatchery fish to wild fish in the natural free–flowing river environment, the potential for horizontal transmission of disease from hatchery fish has not been adequately assessed. Environmental factors may exacerbate existing disease in both hatchery and wild/natural fish and increase the spread of disease to healthy fish. Epizootics are often triggered by increased population density and unusual changes in the environment (Saunders 1991). For example, fish held at high densities during the collection and barging process may be more susceptible to horizontal transmission of disease than fish that are dispersed and free–ranging. Elliott and Pascho (1991) examined the potential for healthy salmonid smolts to become infected from bacterial kidney disease during transportation. They found viable Renibacterium salmoninarum cells in barge water samples and based on live–box tests with healthy brook trout suggested that horizontal transmission can occur during collection and transportation. However, their study also documented the high level of bacterium found in river water, raising the question of whether short–duration spent in a barge may be better than long–duration in the river.

Genetic Effects

Busack (1990) identified four types of genetic risk associated with hatchery activities: (1) extinction, (2) loss of within population variability, (3) loss of between population variability, and (4) inadvertent artificial selection (domestication). Extinction can occur when removal of broodstock reduces the wild/natural donor population below the minimum viability level. Early broodstock collection activities may have depleted wild stocks in some areas in the basin. More recent broodstock collection efforts have been limited to reduce the impact on the donor populations. Extinction of stocks can also occur if mixed stock fisheries are managed to harvest hatchery surplus production at the expense of individual wild/natural stocks.

Loss of within population variability can occur as a result of a number of hatchery activities, including the nonrandom selection of brood fish from the donor population, maintaining too small of a hatchery population, and using only a part of the hatchery population in mating and fertilization. Steward and Bjornn (1990) identified a number of hatchery stocks in which run timing was shifted earlier through selection of earlier returning adults. Current operations avoid this type of selection.

Loss of between–population variability can occur when hatchery broodstock are taken from distant locations. Historically, hatchery stocks were derived from a mixture of nonindigenous stocks and stock transfers and outplantings of hatchery salmon and steelhead throughout the Columbia River basin (Matthews and Waples 1991). The impact of these transfers and outplantings on wild/natural production received little attention. In recent years emphasis has been on establishing hatchery stocks from the local indigenous stocks and restricting stock transfers. High rates of straying of hatchery fish into nontarget streams can also reduce between–population variability. Straying of adult hatchery fall chinook of Columbia River origin into the Snake River is a potential threat to the genetic integrity of Snake River fall chinook (NMFS 1993). This threat is expected to be reduced through marking of hatchery fish and completion of a flow augmentation

project in the Umatilla River where the majority of the strays originate.

Inadvertent artificial selection (domestication) can occur from a variety of hatchery practices that cause nonrandom mortality and nonrandom selection and where rearing and release strategies differ substantially from the natural life history pattern. Inadvertent selection can be avoided through implementation of strict mating and fertilization protocols, and by ensuring that hatchery fish are qualitatively as similar to wild fish as possible. Some researchers suggest that inadvertent selection can cause reduced performance of hatchery steelhead trout compared to wild fish (Chilcote et al. 1986, Reisenbichler and McIntyre 1977). However, Kapuscinski et al. (1991) suggest that other genetic factors may have influenced the results of these studies.

2.1.3.5 Effects of Habitat Degradation

While much of the salmon and steelhead spawning and rearing habitat in the Columbia River basin is in good condition, considerable habitat degradation has resulted from logging, mining and agricultural activities.

An indication of the magnitude of this habitat degradation is provided by research conducted by the Pacific Northwest Research Station. Researchers there compared stream surveys conducted from 1934 to 1946 with recent stream surveys. This study examined over 975 km of streams throughout the Columbia River basin (Sedell & McIntosh 1992). River systems impacted by human activities have lost 37 percent of the large pools over the past 50 years. Over the same 50–year period in rivers and streams in wilderness areas and relatively unmanaged river drainages, the number of large pools has increased in wilderness and relatively unmanaged river drainages by 79 percent. The loss of pools resulting from human activities has reduced the carrying capacity of streams for juvenile salmonids, decreased holding areas for returning adults, and caused both adults and juveniles to be more susceptible to predation, disease and catastrophic events (Sedell & McIntosh 1992).

The state and Federal fish and wildlife agencies and Indian tribes in the Columbia basin cooperated in a 3–year system planning effort initiated in 1987 to produce an integrated system plan. This plan was designed to develop strategies to meet the Northwest Power Planning Council's goal of doubling the anadromous fish runs in the Columbia Basin. As part of this planning effort, the agencies and tribes documented habitat degradation in each of 31 major subbasins or watersheds within the Columbia basin (CBFWA 1991).

Logging

Early logging in the Columbia River basin occurred mainly in the lowland areas, resulting in little damage to rivers and streams. However as logging progressed up the watersheds, increasing habitat degradation occurred. Logging increased sharply during and after WW II. Logging in the Snake River drainage increased most dramatically in the early 1960s from lows of 1– to 30–million board feet per year to over 600 million board feet per year, and remained high through the 1980s (NPPC, 1986).

Logging can have significant adverse effects on fish habitat including: increased sedimentation, reduced egg survival, loss of streamside cover, increased stream temperatures, and reduced instream habitat. Such negative impacts to fish habitat have been documented for Snake River tributaries since the advent of increased logging activities in the 1960s (Chapman et al. 1991).

Streambanks are the most susceptible to damage from logging activities. Streambanks and stream margins provide lower water velocities than main–stream currents and are ideal for rearing salmon and steelhead fry. Undercut banks, overhanging root complexes, vegetation and stable debris provide shade and protection from predators. Root networks contribute to streambank stability and minimize bank erosion during high flows (USFS 1982).

Timber harvesting operations that can damage streambanks include felling and yarding across streams, machine operation near streams and the removal of vegetation that has roots which strengthen soil structure. Water–table increases in riparian

zones also contribute to the weakening of streambank structure and lead to streambank erosion and channel widening.

Improperly designed culverts in logging road stream crossings often obstruct passage of adult salmon and steelhead, blocking access to spawning areas. Improper design includes outfall barriers, excessive water velocity in the culvert, insufficient water in the culvert, lack of resting pools below culverts or a combination of these conditions (USFS 1982). A large number of such culverts exist throughout the Columbia River basin. The overall loss of spawning areas resulting from this blockage is estimated to be quite high (CBFWA 1991).

River Log Drives

River log drives that occurred from about 1880 to 1920 caused significant damage to salmon and steelhead habitat that is still detectable nearly a century after such drives ceased. Prior to beginning a log drive, streams had to be "improved" to remove obstructions that could cause expensive log jams. Sloughs, swamps, and other low areas had to be blocked off. Obstructions such as boulders, large rocks, leaning trees, floating or sunken logs and brush in the main bed were removed. River channels were straightened and widened, spawning gravel was gouged out, streambank erosion and sedimentation increased, and complex sloughs and side channels that served as valuable rearing habitat were eliminated (Sedell et al. 1980). Stream gradients were evened out and habitat complexity was lost. Splash dams were constructed in small streams to sluice logs down. These surges of water and logs eroded streambeds, gouged banks, straightened river channels, and prevented fish from spawning.

Forest Roads

Salmon and steelhead habitat has often been adversely affected by forest roads, log sorting and log–storage areas. Such adverse changes include increased sediment and organic debris in streams, changes in water quality and quantity, formation of physical migration barriers, and increased human access to previously remote or isolated areas (USFS 1980). Increased sediment in streams after construction of roads often cause severe and long–lasting damage. Sediment loading from this activity often is many times greater than that from any other land management activity.

Mining

Mining has caused severe damage to anadromous fish spawning areas in several Columbia River subbasins, particularly where gold dredges were operated in streambeds (CBFWA 1991). Some of the heaviest instream mining occurred in salmon and steelhead habitat in tributaries of the Snake River, causing extensive habitat loss (NPPC, 1986). Idaho had more gold and silver mining activities than in Washington or Oregon. Other mining impacts include acid mine leaching and heavy sediment deposition. Most of the damage from mining occurred in the first half of this century, but degraded habitat still exists in tributaries of the Salmon and Clearwater rivers in Idaho.

Mining activities can result in significant amounts of bedload and suspended sediment in streams and rivers. Damage to the stream ecosystem occurs when amounts of sediment become excessive (Platts & Megahan 1975). Deposition of excessive fine sediment on the stream bottom eliminates habitat for aquatic insects; reduces the density, biomass, number and diversity of aquatic insects; reduces the permeability of spawning gravels and blocks the interchange of subsurface and surface waters. Toxic heavy metals can precipitate on bedload sediment particles and remain in the aquatic environment to be released later. Stream microorganisms can feed on sediments containing organic material and lower the dissolved oxygen content of the water (USFS 1981a).

Sediments also contain nutrients, such as nitrogen and phosphorous. These excessive nutrient levels can lead to blooms of undesirable algal and plankton species and killing of fish from depletion of oxygen. The effects of suspended sediment on the aquatic system are more direct. Photosynthesis may be reduced because of light reduction; fish migration may be affected; fish may not be able to feed under turbid conditions, resulting in small size; and suspended solids may interfere with efficient respiration

of gilled animals. Young salmonids are particularly susceptible to gill irritation caused by turbid water, which in turn exposes them to infection by fungi and bacteria.

Agriculture

Agricultural activities have adversely affected salmon habitat throughout the Columbia River basin. Over 12 percent of the basin is farmland, located mostly in central Washington and southern Idaho. Irrigated farmland has increased substantially in the basin from .5 million acres in 1900 to 7.6 million acres by 1980 (NPPC 1986). Adverse effects of agricultural activities includes: loss of streamside vegetation, increased temperature, increased erosion adding silt to spawning beds, reduced flow in rearing areas, blockage of fish migration, addition of toxicants and nutrients to streams, and loss of fish in unscreened irrigation diversions. Unscreened diversions are one of the major problems. While most irrigation intakes have been screened, many screens are not functional. Some have washed out of the river channel, reducing or eliminating efficiency, and some damaged screens can trap fish (NPPC 1986). Many of these problems have been reduced, but not eliminated.

Fish production capacity throughout the Columbia River Basin has been greatly reduced from stream channelization due to road building and agricultural activities (CBFWA, 1990). Roads are commonly built along streams, which are often channelized to aid in construction. Channelization generally destroys the stream margin which is the most productive area of the stream. Channelization may reduce the fish production capacity of impacted stream sections by 80 percent or more (CBFWA 1990).

Water Withdrawal

Water withdrawal for agriculture, as well as for flood control and power production has resulted in increased juvenile salmon mortality and may dry out spawning areas (US Dep. Commerce 1991).

In the Columbia River basin above the confluence with the Snake River, a significant amount of water is withdrawn for agricultural irrigation. For instance, irrigation diversion at the Bureau of Reclamation's (BOR) Columbia Basin Project above Grand Coulee Dam averaged 2.3 MAF (2.84 cubic kilometers) annually between 1968 and 1987 (BOR 1989). BOR (1989) determined that smolt survival for Columbia and Snake River spring chinook and steelhead decreased with increased Columbia River agricultural water withdrawal.

Chapman et al. (1990) listed agricultural water diversion among the causes of the sockeye salmon's decline from all Stanley Basin lakes, including Redfish lake. There are more than 68 agricultural diversions present on the Salmon River and tributaries within the Sawtooth National Recreation Area (SNRA). Agricultural diversion at Busterback Ranch on Alturas Lake Creek in the Stanley Basin, for example completely dewaters the creek, totally blocking sockeye salmon from Alturas Lake (Bowles and Cochnaur 1984; Chapman et al. 1990). Screens have been installed in the Salmon River basin since the mid–1950s to prevent fish from entering diversions (Delarm and Wold 1985). However, many Stanley Basin streams in the SNRA were not screened until the mid to late 1970s and some unscreened diversions still exist.

Pesticides and Herbicides

Pesticide and herbicide use can directly and indirectly affect anadromous fish and their habitat. Direct toxic effects are those resulting from the exposure of fish to a chemical in water, food or sediment. Increased temperature and sedimentation from herbicide use may adversely affect salmonid populations through vegetation removal and subsequent erosion. Sedimentation may reduce egg and fry survival and the quality of rearing habitat. Reduction of streamside vegetation by herbicide use would also reduce cover, a major requirement of salmonids (USFS 1983).

The most important process by which chemicals enter streams is direct application, but drift from nearby treatment areas or units is also important. Mobilization of residues in ephemeral stream channels during the first storms after application is sometimes important.

Riparian Grazing

Livestock grazing is a major factor affecting the quality of stream habitat, particularly in the Snake River drainage. About 80 percent of anadromous fish habitat in the Snake river drainage lies in areas managed by Federal agencies, and much of this land is open to grazing (Chapman et al. 1991). Stream habitat, and its ability to produce salmonids, deteriorates in regions that are over–grazed. Grazing affects the streamside environment by changing, reducing or eliminating vegetation bordering the stream (USFS 1981b). Channel morphology can be changed by accrual of sediment, alteration of channel substrate, disruption of the relation of pools to riffles, and widening of the channel. The water column can be altered by increasing water temperature, nutrients, suspended sediment, bacterial populations, and in the timing and volume of streamflow. Livestock can trample streambanks causing banks to slough off, creating false setback banks, and exposing banks to accelerated soil erosion.

2.2 AMERICAN SHAD

2.2.1 American Shad Population Status

American shad (*Alosa sapidissima*) were introduced to the Sacramento River in 1871 using stock from the Susquehanna River. These anadromous fish spread rapidly along the Pacific coast, appearing in the Columbia River in 1876–77. In 1885, the first releases of Susquehanna River shad fry were made into the Columbia. Shad flourished in the Columbia River and a century later, eggs from this river were shipped to the Susquehanna River to revive the declining shad population there (Wyodoski and Whitney 1979; WDF & ODFW 1992).

American shad are well established in the Columbia River and its tributaries (WDF & ODFW 1992). Slackwater impoundments provide excellent shad spawning and rearing habitat. Shad colonized the Columbia and Snake rivers as dams were constructed. Colonization of the Columbia River above Celilo Falls was restricted until The Dalles Dam flooded the falls in 1957 (ODFW 1991). A passage barrier at Priest Rapids Dam currently prevents colonization into the upper Columbia River. Colonization into the upper Columbia River may occur however, if shad passage becomes available past Priest Rapids Dam (Swartz 1991).

The number of shad passing Bonneville Dam since 1978 has exceeded 1 million (WDF & ODFW 1992). In 1990, the estimated population exceeded 4 million, the largest run ever on record. These are considered minimum estimates of abundance, since only shad passing through the fish ladders are enumerated, others migrate through navigational locks. Additionally, an unknown number spawn and rear below Bonneville Dam (ODFW 1991).

Similar trends are exhibited as dam construction occurred throughout the Columbia and Snake Rivers. Shad populations at McNary Dam remained relatively constant from 1956 through 1972 then began to increase through 1992. Shad began colonizing the lower Snake River with the construction of Ice Harbor Dam. Populations showed dramatic increases beginning in 1987. A similar trend was observed at Lower Granite Dam. It is uncertain whether the dramatic shad population increases observed at all four dams in recent years are a result river and reservoir conditions stemming from the recent drought in the Pacific Northwest, or whether population increases occurred independently of climatic conditions.

2.2.2 American Shad Life History

2.2.2.1 Juvenile Rearing and Migration

Reservoirs provide ideal rearing habitat for juvenile shad (Emmett et al. 1991). Juveniles in the Columbia River rear in the productive shallow–water zones of reservoirs until they reach four to five inches in length (USACE 1992). They then outmigrate as subyearlings with the majority passing mainstem dams in late October and early November. While most juveniles migrate out to sea before winter, some may reside more than a year in rivers and estuaries (Stevens et al. 1987).

The National Marine Fisheries Service Smolt Monitoring Project provided data on the seaward migration of juvenile salmon and steelhead at McNary, John Day, The Dalles and Bonneville dams from 1988 to 1991. Shad migration was monitored through incidental catches of shad juveniles at Bonneville and John Day dams. Table 2–2 summarizes cumulative juvenile shad numbers captured from 1988 to 1991 at Bonneville Dam. Juvenile shad counts show a significantly increasing trend.

Table 2–2. Cumulative Juvenile Shad Collection Count, 1988 to 1991.

Year	Juvenile Shad Counts at Bonneville Dam Counts
1991	1,481,768
1990	2,934,762
1989	435,441
1988	34,747

Data Source: Johnsen et al. 1990; Hawkes et al. 1991; Hawkes et al. 1992.

Juvenile shad had not been observed in the bypass systems at the lower Snake River dams until the 1990 extended transport season. Until 1990, the juvenile facilities at Little Goose dam were routinely closed following the estimated bulk of the juvenile salmonid passage.

Juvenile shad are just initiating the bulk of what their migration would entail during this timeframe (August through November). However, the extended transport seasons since 1990 has allowed for observations of juvenile shad passing through the bypass facilities. The data is currently still in raw form. During the 1992 extended passage season for salmonids, 100 percent samples for juvenile shad were maintained from August through October at Little Goose dam. A very rough estimate from the Corps of Engineers indicates several thousand individuals for relatively short time periods. The relatively small database for juvenile shad detection indicates an increasing trend for shad in Little Goose reservoir (Chris Pinney, COE, Walla District, personal communication).

2.2.2.2 Adult Migration and Spawning

Adult shad, the only member of the herring family found in the costal streams of the Pacific, return to their natal river to spawn. Adults begin entering estuaries when water temperatures are 10–15°C and typically remain there for two or three days before moving upstream (Leggett and O'Boyle 1976). Shad begin entering the Columbia River in April and continue to pass the mainstem dams through August. The majority of upstream passage occurs from mid–May at Bonneville Dam through July (USACE 1992).

Spawning peaks from July 20 to August 5 at Bonneville Dam and upstream. In the Willamette River Slough, peak spawning occurs before June 25 (Wydoski and Whitney 1979). However, the peak varies slightly from year to year depending on flow and water temperature (usually between 14–21°C). Many shad die soon after spawning with post–spawning survival highest in northern estuaries (Emmett et al. 1991). Those that do survive however can continue to reproduce (WDF & ODFW 1992).

Shad prefer to spawn in shallow, gently sloping areas with clean sand or gravel substrates in the open water of the mainstem reservoirs (Emmett et al. 1991). Most spawning probably occurs during late afternoon and evening (Facey and Van Den Avyle 1986). During spawning, females accompanied by one or more males, swim near the surface, often with their backs out of water (Wydoski & Whitney 1979). A female may produce from 30,000 to 300,000 eggs, depending on body size (Moyle 1976). Eggs are semibuoyant and float downstream near the bottom in slow currents as they develop (Emmett et al. 1991). The eggs hatch in 7 to 10 days and the fry remain in the river during their first summer.

Adult shad spend three to four years at sea before returning to their natal stream to spawn (Wydoski and Whitney 1979). Mature adults may reach a length of 2.5 feet and a weight of 15 lbs. The maximum size of adult shad from the Columbia River is

about 8 lbs. Female shad from the Camas–Washougal fishery on the Columbia River range from 17 to 22 inches in length and weigh 3.5 to 5 lbs. Male shad from this fishery are 16 to 19.5 inches long and weigh 2.5 to 4 lbs (Wydoski and Whitney 1979).

In the ocean, adults follow the diel movements of zooplankton, migrating vertically (Neves and Depres 1979). Adults and ocean–dwelling juveniles may be found down to 340 m depth, but most reside within the 50–100 m isobath (Neves and Depres 1979). Shad are highly migratory; for example, Whitehead (1985) reports that individuals have been caught 3,000 km from where they were tagged.

2.2.2.3 Food

All life stages of American shad are planktivorous (Wang 1986). Larvae eat small zooplankton (copepods and cladocerans) and midge larvae and pupae (Facey and Van Den Avyle 1986). Riverine– and estuarine–dwelling juveniles consume primarily zooplankton, such as copepods, cladocerans (*Daphnia spp.*), and crustaceans such as amphipods (*Corophium spp.*), mysids (*Neomysis spp.*), and shrimp (*Crangon spp.*) (Stevens 1966 & Hammann 1982). Juveniles also eat aquatic and terrestrial insects. The diet of American shad in Pacific coast marine waters is not well–studied; however Hart (1973) believes it likely consists of euphausiids, copepods, decapod larvae, cephalopod larvae and small fishes.

Some of the literature suggests that mature shad do not normally feed while on their spawning migration. However, Wydoski and Whitney (1976) speculate that this might be due to the absence of food items of the right size, since they readily strike small lures and flies. Additionally, Hammann (1981) and Wendler (1967) report that adult shad do prey on juvenile chinook salmon in the Columbia River.

2.2.2.4 Predation

Juvenile shad in rivers and estuaries are eaten by white sturgeon (*Acipenser transmontanus*), juvenile salmonids, walleye (*Stizostedian vitreum*), bass (*Micropterus spp.*) striped bass (*Morone saxatilis*), gulls, osprey (*Pandion haliatus*), bald eagles (*Haliaetus leucocephalus*), harbor seals (*Phoca vitulina*), and other large predators (Emmett et al. 1991). Some studies have not found juvenile shad to be extensively preyed on by northern squawfish, or walleye (Swartz, 1991). However, Gray et al. (1982) found that shad juveniles made up 28.4 percent by weight of the diet of a sample of 749 northern squawfish (>250 mm) in the John Day reservoir from April to December. The Corps of Engineers has documented steelhead smolts collected at Little Goose dam with extended stomachs filled with juvenile shad (C. Pinney, COE, Walla Walla, pers. comm.).

CRITFC (1992) speculated that shad juveniles which remain in the river later than juvenile salmon may sustain salmonid predators at higher levels than possible without the presence of the shad juveniles. After moving offshore in the ocean, shad are likely prey for sharks, tuna, porpoises, sea lions, salmonids and other piscivorous fishes.

2.2.2.5 Competition

The introduction of American shad to the Pacific coast does not appear to have displaced native species, but competition may occur (Emmett et al. 1991). Both Chapman et al. (1991) and Kaczinsky et al. (1992) speculate that the extremely large numbers of shad in the Columbia River may result in a significant source of juvenile mortality for salmon, in terms of predation, competition for food, as well as causing passage problems for adult salmonids migrating through the ladders.

While adult shad are considered planktivorous, Hammann (1981) and Wendler (1967) report that adult shad prey on large items and have consumed large numbers of chinook salmon. Hence, it is more likely that shad are opportunistic feeders than simply planktivorous. Wendler (1967) found one adult shad had sixteen juvenile chinook salmon in its gut, and suggest that further investigations be made to determine the amount of salmon predation that actually occurs.

McCabe et al. (1983) found that juvenile American shad and salmonids had significant diet overlap in the Columbia River Estuary. Kaczinsky et al. (1992) elaborate on this, pointing out that 4 million adult shad can produce a tremendous number of juveniles,

which would present a significant source of dietary competition in the Columbia River.

The enormous number of shad may interfere with juvenile and adult salmonid passage at Columbia River projects. USACE (1982) reported that upstream migrating adult shad caused an avoidance and delay for upstream migrating adult salmon at dam fish ladders. Adult shad migration from May to August overlaps the migration of sockeye and spring and summer chinook potentially causing migration delays or adult mortality in these threatened and endangered species (Chapman et al. 1991). Kaczynski et al. (1992) (citing Basham et al. 1982, 1983) found that juvenile shad created passage problems for subyearling chinook salmon at the McNary Dam juvenile bypass system and caused mortalities. Chapman et al. (1991) suggested that adult shad may reduce orifice passage efficiency and fish guiding device efficiency at Columbia River projects.

High concentrations of shad in the fishways have disrupted salmonid sampling at Bonneville Dam North Shore Trap (Swartz 1991). Other problems caused by extremely high numbers of shad may also exist, such as inaccurate counts of other concurrently migrating species, and juvenile shad may be sustaining salmonid predator populations. A passage barrier specific to shad exists at Priest Rapids Dam resulting in shad stacking up in the ladders at the dam, causing possible delays of adult salmonid migration and possible disease transmission (Swartz 1991).

2.2.2.6 Environmental Requirements

The American shad is a euryhaline anadromous species (Emmett et al. 1991). Eggs can tolerate moderate salinities (7.5 to 15.0 percent, depending on water temperatures) (Facey and Van Den Avyle 1986). Juveniles rear in both freshwater and estuarine habitats. Adults apparently need two or three days in estuaries to acclimate to fresh water (Weiss–Glanz et al. 1986). This species is very temperature–sensitive and many aspects of its life cycle are cued by specific temperatures (Emmett, et al. 1992).

In marine waters adults reside within a temperature range of 3–15°C (Neves and Depres 1979). Their oceanic and freshwater migration patterns are closely linked with water temperature. Optimum temperatures for egg survival are 15.5 to 26.6°C (Leggett and Whitney 1972). This optimum temperature range is significantly higher than that for salmonids. This may help explain the increasing population numbers during the recent low flow years, as well as their later juvenile migration out of the Snake River.

Dissolved oxygen levels above 4.0 mg/l are required for spawning (Facey and Van Den Avyle 1986) and dissolved oxygen levels above 2.5–3.0 mg/l (perhaps 5.0 mg/l are necessary for all life stages (Facey and Van Den Avyle 1986 & Weiss Glanz et al. 1986). Spawning has been observed at water velocities ranging from 30.5 to 91.0 cm/sec.

Juvenile shad are tolerant to relatively high levels of gas supersaturation for short–term exposures. Backman et al. (1991) exposed subyearling American shad to 5 levels of gas supersaturation that included pressure increases above equilibrium from 10 to 205 mm Hg (101–128 percent saturation) for 4 hours. Multifactor analysis of variance showed no significant differences in behavior or survival of fish before or after treatment.

2.2.3 Factors Influencing Populations

2.2.3.1 Habitat

All shad life stages can be affected by alteration of temperature regimes (Leggett and Whitney 1972 & Facey and Van Den Avyle 1986). River flow and water temperatures during, and immediately after, spawning appear to influence shad year–class strength (Leggett 1976). However Crecco and Savoy (1985) stress that larval survival ultimately determines year–class strength. Stevens et al. (1987) found that high river flows during spawning and early life stages positively affect population abundances in the Sacramento–San Joaquin river systems. Probably the largest factor influencing populations on the Pacific coast has been the creation of dams and reservoirs. Given the tremendous population increases of shad in the Columbia River system, it is apparent that the presence of dams and reservoirs create conditions conducive to shad productivity.

2.2.3.2 Harvest

Commercial Harvest

Commercial shad landings were made from the Columbia River by 1889 and exceeded one million pounds in 1926–30 and 1946–47. Commercial shad landings during the 1980s averaged 210,000 lbs. (Swartz 1991). Harvest has not kept pace with the rapid growth in shad numbers in the Columbia River for two primary reasons. First, a poor shad market depresses use and catch (ODFW 1991). Second, the shad run coincides with depressed runs of spring and summer chinook, sockeye and summer steelhead. Severe time, area and gear restrictions are required by the Columbia River Fish Management Plan to minimize incidental catch and handling of protected salmonids in the shad gill–net fishery. These restrictions make only a small portion of the total run available for harvest. Together with the poor market, these restrictions limit commercial catch to a small portion of the total available for harvest (WDF & ODFW 1991).

Shad are harvested below Bonneville in two small areas during short shad gillnet seasons in late May and June. Incidental mortalities of salmonids in this fishery are enumerated annually and considered to be low (ODFW 1991). The commercial 1990 harvest of 167,800 shad (4.2 percent of the run) is the highest since 1967) (ODFW 1991). The 1991 landings during shad seasons were 43,100 shad totaling 120,800 pounds (WDF & ODFW 1992).

Exploration of harvest methods has occurred in several shad test fisheries, but low shad catches with high incidental salmonid mortalities have discouraged large scale commercial shad fisheries (WDF & ODFW 1991).

Indian Harvest

Tribal treaty fishermen land shad during the sockeye fishery with set nets in years when sockeye salmon runs are large enough to harvest. However, in 1991 no sockeye fishery occurred until the fall season opened in August. During that early fall season treaty fishery, a few shad were landed incidental to fishing for steelhead and salmon. Treaty subsistence fishermen also land significant numbers of shad using dip nets. Most of these are sold to the public at the site or taken home by the fishermen (WDF & ODFW 1992). Treaty shad sales are usually less that 1,000 fish during years with no commercial sockeye fishery and more than 10,000 fish during years with commercial sockeye fisheries (WDF & ODFW 1992).

Recreational Harvest

Sport catches during the 1980s averaged about 50,000 shad. The recreational shad fishery has increased in recent years, resulting in record catches of 82,700 in 1989 and 134,800 in 1990 (ODFW 1991). The 1991 lower Columbia River sport shad catch was 100,600 kept and 15,500 released. 1991 shad angler effort was a record high, with 20,300 trips generated in the 1991 lower Columbia River fishery. The previous record high, set in 1990, was 19,000 shad angler trips. The 1991, lower Willamette sport shad catch was 28,300 kept and 11,700 released from 12,700 angler trips .

The most popular sport fishing areas for shad are just below Bonneville Dam, in the Camas/Washougal area, and below Willamette Falls. Sport fisheries in these areas are monitored by statistical creel sampling programs. Other popular shad fishing locations are just below John Day and McNary dams; however, no monitoring data is available from those sites. As shad runs increase in size, the species is gaining increasing popularity among Columbia River sportsmen. Shad caught on light tackle are widely recognized as prized sport fish. Shad are a preferred food item for some sportsmen, and are also kept for crab bait (WDF & ODFW 1992 & Wydoski & Whitney 1979).

2.3 PACIFIC LAMPREY

The Pacific lamprey (Lampetra tridentata) is the predominant lamprey species in the Columbia and Snake rivers. This anadromous lamprey is parasitic during its adult life in saltwater. It spawns in freshwater, with juveniles remaining in their natal streams from five to six years before migrating to sea. Its distribution in the Columbia and Snake rivers originally coincided with that of spring and summer

chinook salmon. However lamprey distribution and population numbers have declined significantly, although useful estimates are not available (ODFW 1991, USACE 1992).

2.3.1 Pacific Lamprey Population Status

A noticeable decline in lamprey numbers occurred concurrently with dam construction along the Snake and Columbia rivers. There is no documented evidence that dams have resulted in passage mortality, though it is possible. Degradation of spawning and rearing habitat is considered to be a significant factor (ODFW 1991). Willamette River populations also appear to be declining, but not to the same degree as populations in the Columbia River and its tributaries above Bonneville Dam (ODFW 1991).

Run size information is limited for lamprey (ODFW 1991). The Corps conducted adult ladder counts at mainstem Snake and Columbia river dams, but discontinued that effort in 1969. Counting efforts were undertaken at Little Goose Dam beginning in 1983. Table 1 summarizes count data at Bonneville Dam from 1938 to 1969. Lamprey cling to the counting station windows for lengthy periods of time making accuracy in counting difficult. To add to this problem, their migration also coincides with shad returns, which number in the millions. It should be noted that there are numerous ways for lamprey to pass dams and that lamprey counts can only be a rough approximation. Lampreys possess moderately strong swimming ability and are able to use their suctorial disc to climb along surfaces such as those in navigation locks and juvenile fish bypass channels (Scott & Crossman 1973).

2.3.2 Pacific Lamprey Life History

2.3.2.1 Juvenile Migration

After remaining buried in the substrate for five or more years, juveniles metamorphose into the adult form and move out of their burrows to begin seaward migration. They are usually about 4.8 to 12 inches (122–303 mm) at metamorphosis (Scott & Crossman 1973). Migration of the newly metamorphosed juveniles occurs from March to July, with peaks in April and June (Wydoski & Whitney 1979). The lamprey is among the few vertebrates that undergoes such a radical metamorphosis (Kan 1973).

Recent data are available for juveniles from incidental catches made during normal smolt monitoring at Bonneville and John Day dams, and are summarized in Table 2–3. The 1991 juvenile incidental catch of Pacific lamprey at John Day Dam was substantially higher than the 1990 catch, with juveniles first appearing in samples from April 25 through June 15, peaking on May 20th (Hawkes et al. 1992). In 1990 juveniles appeared in samples from March 26 through July 12 with two distinct peaks on May 4 and June 6 (Hawkes et al. 1991).

In 1991 at Bonneville dam the juvenile Pacific lamprey incidental catch was about 2.6 times greater than the 1990 count (Table 2). Incidental catch of juveniles

Table 2–3. Juvenile Pacific Lamprey Incidental Catch

	John Day Dam		Bonneville DSM#1	
Year	Juveniles (numbers)	Peak (dates)	Juveniles (numbers)	Peak (dates)
1989	1,852	3/28 & 5/13	34,747	3/30 & 5/15
1990	992	5/4 & 6/6	1,780	6/13
1991	9,338	5/20	4,568	5/23

DSM#1 is the downstream migrant trap located in the bypass channel in powerhouse 1. This facility is used primarily to monitor juvenile salmonid migration.
Data source: Johnsen et al. 1990; Hawkes et al. 1991 and Hawkes et al. 1992.

started on March 15th and ended on October 17th with peak passage occurring on May 23rd. 1990 counts plunged from the high numbers observed in 1989, with 1990 peak on June 13. In contrast, the 1989 peak occurred on March 30.

As can be seen from Table 2 there is a significant amount of variation from year to year, not only in run size but also for the dates of peak runs. At Bonneville DSM 1 between 1989 and 1990, there was a significant difference in the peak of the migration run. Juvenile migration peaked in late March to early April in 1989, and in mid June in 1990. This observation leads some biologists to speculate that there may be two or more separate subpopulations of lamprey in the Columbia River system (ODFW 1991). Information on these subpopulations is very sketchy however, and further research would be beneficial. Flow or temperature variation may also be factors in lamprey run timing. Additionally these numbers may be a reflection of the sampling methodology in use at the time.

Table 2–4 summarizes recent work conducted by USACE at Little Goose Dam. Bypass estimates are based on the following assumptions: (1) passage/bypass conditions (such as fish guidance efficiency) are the same for lamprey juveniles as for salmonids; and (2) lamprey juveniles have the same likelihood of being accurately detected by the electronic counters as all other juveniles representing all other fish species which pass through the collection facility.

Of these juvenile lamprey estimates on Table 2–4, about 5 percent are the ammocoete form (filter–feeding form which lack the adult head structure) and 95 percent are the true juvenile form (suctorial form with the adult head structure). Although it is generally accepted that lamprey almost exclusively utilize the gravel/cobble substrates of Snake River tributaries for rearing and the mainstem for migrating, the arrival of ammocoetes in the collection system of Little Goose Dam may indicate some rearing (and possibly spawning) of lamprey in the gravel/cobble areas associated with the tailraces of the mainstem Snake River dams (Chris Pinney, COE Walla Walla, personal communication).

Table 2–4. Juvenile Lamprey Bypassed At Little Goose Dam

Year	Little Goose Dam Numbers Bypassed
1983	29,345
1984	41,940
1985	34,487
1986	19,049
1987	18,926
1988	31,728
1989	65,067
1990–1993	analysis not completed

Data source: (Chris Pinney, USACE Walla Walla, personal communication).

2.3.2.2 Adult Migration and Spawning

At sea Pacific lamprey begin a parasitic life and spend 12 to 20 months as parasites before migrating upstream to spawn. During their life at sea they apparently travel great distances (Wydoski & Whitney 1979). For example, Kan (1975) found Pacific lamprey more than 100 km offshore from Oregon and Washington.

Parasitic lamprey use their suckerlike mouths to attach to a fish, rasp an opening into the fish's body with their sharp teeth, and suck the body fluids and blood for their nourishment. Lamprey produce an anticoagulant that prevents clotting of the host's blood. Fish that are parasitized may die either from blood and fluid loss or from infection of the open wound. Pacific salmon species are occasionally observed with one or more lamprey scars which indicate that at least some of the fish survive lamprey attacks. The attacks may seriously reduce the growth of the prey, but at least the surviving fish are capable of reproducing (ODFW 1991).

Pacific lamprey parasitism on salmon and steelhead stocks in the Columbia River and its tributaries does not appear to be significant (ODFW 1991 and

Wydoski & Whitney 1979). Wydoski & Whitney (1979), however, report that lamprey–scarred salmon have been observed in Pacific Northwest rivers as far inland as Idaho. Scott and Crossman (1973) report that up to 20 percent of the coho salmon examined in British Columbia had scars from the Pacific lamprey. Given the greatly reduced numbers of Pacific lamprey in the Columbia River, it is likely that parasitism on salmonids is minimal. Lamprey scars have been found on whales, though lamprey are not generally considered predators of mammals (Wydoski and Whitney 1979).

Adult Pacific lampreys usually begin upstream migration in the Columbia River in April and continue through August; peak passage occurs in July. At Bonneville Dam, the majority of upstream passage occurs from May through mid–July (USACE 1992). Lampreys are not sexually mature at this time and remain hidden under stones until they mature the following March (Scott & Crossman 1973). Feeding appears to cease during the early stages of the upstream migration. Lamprey are an average of 21 inches (537 mm) total length when migrating inward from the sea and attain a maximum of 27 inches (682 mm) (Carl et al. 1967).

Kan (1975) observed that Pacific lamprey spawned predominantly in low gradient stream segments, usually just above riffles at the tail end of pools. Substrate consisted of clean sand and gravel with water depths of 0.4 to 1 m. Kan also noted that spawning sites were often adjacent to the river bank with a slow and soft bottomed stretch nearby which provided an ideal habitat for newly hatched larvae (ammocoetes). The Corps (1992) reported that most spawning occurs in June and July in the upper ends of pools of small tributary streams, including streams feeding the mainstem reservoirs.

Both sexes participate in digging a shallow nest that may be up to 2 feet in diameter. The small eggs (about 1 mm in diameter) are oval and hatch in 2 or 3 weeks (19 days at 15°C). The number of eggs produced by a female range from 34,000 to 106,000 (Wydoski & Whitney 1979). The adults do not migrate downstream and usually die 1 to 14 days after spawning (Scott & Crossman 1973).

The larvae (ammocoetes) emerge and drift downstream to burrow in the mud in low–velocity reaches of small tributary streams. Toothless and eyeless, the ammocoete's mouth is enclosed by a hoodlike flap used to filter microscopic plants and animals from the water (Wydoski & Whitney 1979). Ammocoetes grow to about 4 inches (101 mm) in the first year.

2.3.3 Predation

Pacific lamprey apparently have few predators. They are rarely found in the stomach contents of other animals. On rare occasions they have been found in the stomachs of fur seals and sperm whales (Pike 1951). Pfeiffer and Pletcher (1964) speculate that their low incidence in the diet of salmonids may be the result of distasteful secretions of granular or club cells in the skin. Salmonids in captivity would eat skinned lampreys but not the isolated skin.

2.3.4 Habitat

There do not appear to be any obvious major problems associated with adult migration through fish ladders. It is difficult to determine the amount, if any, of downstream migration mortality. Given the impacts of dam passage on migrating salmon and steelhead however, poor lamprey migration survival, both adult and juvenile, cannot be ruled out as a factor in the apparent decline of lamprey (ODFW 1991). Lampreys require clean cold water and clean gravel for spawning and rearing in tributary streams. Habitat degradation in headwaters areas may also be partially responsible for lamprey population declines (ODFW 1991). Loss of historical habitat due to reservoir filling over riffles and rapids above pools used for spawning is likely a factor as well. Lower Granite and Little Goose had much of this type of habitat prior to inundation (Chris Pinney, USACE Walla Walla, personal communication).

Hazardous material spills have also resulted in lamprey kills. For example, in February 1990, a

tractor–trailer rig overturned and spilled a load of hydrochloric acid in the John Day River, resulting in the death of an estimated 10,000 ammocoetes (ODFW 1991).

2.3.5 Harvest

Columbia River basin tribes historically used lamprey extensively for food, trade, ceremonial, and medicinal purposes. Indians processed lamprey for food by smoking, sun drying and salting. Lampreys were collected at natural waterfalls and rapids along the Columbia River and its tributaries. Construction of dams on the mainstem Columbia and Snake rivers have eliminated these conditions. Harvest now occurs primarily at Bonneville Dam, with some harvest occurring at Sherars Falls on the Deschutes River and at Willamette Falls on the Willamette River (ODFW 1991 & CRITFC 1991).

The Willamette River in Oregon supported a commercial lamprey fishery from 1943 to 1949. The average annual harvest was 233,179 pounds, an estimated 10 to 20 percent of the total run (Wydoski & Whitney 1979). Harvested lamprey were processed into several products such as a vitamin–rich oil, meal for livestock and poultry feed and fertilizer. Additionally, lampreys were used to produce a chemical to aid in blood anti–coagulation (ODFW 1991).

Currently the commercial harvest of lamprey at Willamette Falls ranges from 3,000 to 11,000 pounds annually. The lamprey are sold as bait and to biological supply houses. Non–treaty and treaty personal use harvest also occurs at Willamette Falls. Personal use harvest totals are unknown, but are probably comparable to the present level of commercial harvest (ODFW 1991). Anglers use cut adult lamprey for sturgeon bait, and larvae for trout and smallmouth bass bait. Recently, however anglers have had to turn to other sources of bait as lamprey numbers declined (Simpson and Wallace 1982; ODFW 1991).

With the exception of the Willamette River, lamprey are not managed for commercial, sport or tribal harvest. Recent observation indicates that runs have declined substantially since completion of the dams in the Columbia and Snake rivers. Biologists at Bonneville Dam observed large numbers of adults in clumps of 20 to 30 individuals along both sides of the adult fish ladders 5 to 10 years ago. These large numbers have not been observed recently (ODFW 1991). Such population declines appear to coincide with recent drought conditions in the Pacific Northwest, leading some biologists to speculate that drought conditions influence lamprey abundance and distribution.

The Columbia River Fish Management Plan prohibits commercial lamprey harvest in Zone 6 and its tributaries. However trade or barter among Indian tribes or harvest for personal use by non–Indians is allowable. At present the Columbia River Inter–Tribal Fish Commission (CRITFC) in cooperation with the Corps of Engineers is responsible for coordinating an adult lamprey capture project at Bonneville Dam and distributing to the four Columbia River treaty tribes. Lamprey are captured by CRITFC staff during scheduled dewatering of the adult fish collection facility. In 1987 approximately 200 lamprey were collected at Bonneville Dam on an experimental basis. In 1988 the adult fish trap was under construction and no harvest occurred. In 1989 a total of 817 lamprey were collected from May 9, 1989 to June 23, 1989. The 1990 run was very poor with only 8 lamprey harvested (ODFW 1991).

Sherars Falls in the Deschutes Basin is a traditional collection area for lamprey for the tribes. Although not quantified, lamprey are collected annually by tribal subsistence fishers at Shears Falls and Seuferts Falls. No lamprey were collected by tribal subsistence fishers at Sherars Falls in 1990. Tribal lamprey fishers are permitted access to fishways in Oregon tributaries above Bonneville Dam provided lamprey harvesting does not interfere with the migration of salmon through the fishways. It is unknown if lamprey harvest occurs at fishways other than Sherars and Seuferts falls.

Willamette Falls is also a traditional tribal collection site. Flow conditions however must be at safe levels in order to boat out to the falls. Frequently by the time flows have dropped to a safe boating level, the bulk of the lamprey run has already passed. In 1990 the water conditions were unfavorable for lamprey harvest at the Falls, though there appeared to be abundant lamprey present (ODFW 1991).

Summary

Lamprey are a natural component of the Columbia basin ecosystem and are an important part of predator/prey interactions in the river, especially with sturgeon. Lamprey are also an important resource for traditional tribal harvest. There is some interest in reinstating adult ladder counts to provide information on lamprey population numbers for predator/prey interactions and to monitor relative abundance for harvest management. However, counting adult lamprey is difficult as mentioned previously. Lamprey enumeration would require improved counting methods as well as additional personnel. The lower Columbia River treaty tribes have proposed to enhance the lamprey run to former levels. The tribes have also prepared and submitted lamprey habitat restoration proposals. Table 2–5 presents adult lamprey counts for the years 1938 to 1969 at various locations.

2.4 STURGEON

The white sturgeon (Acipenser transmontanus) and the green sturgeon (Acipenser medirostris) are both endemic to the Columbia River basin. White sturgeon are occasionally found in marine waters and are distributed in the Columbia River from the mouth to the upper Snake River up to Shoshone Falls, and to the upper Columbia River. They also use the Willamette River up to Willamette Falls and other lower Columbia River tributaries (Hanson et al. 1992).

Green sturgeon have a greater marine residence than white sturgeon. They are common in Washington and Oregon coastal bays and appear only in the summer months in the Columbia River estuary. They are harvested almost exclusively in the fall salmon gillnet fishery in the lower Columbia River. About 3,200 green sturgeon were harvested in the 1991 lower Columbia commercial gillnet fisheries (ODFW & WDF 1992). Little is known about the life history of this species and it will not be analyzed in detail in this appendix.

2.4.1 White Sturgeon Population Status

2.4.1.1 Columbia River below Bonneville

White sturgeon are indigenous throughout the Columbia River basin and distinct populations exist below Bonneville Dam and in the impoundments of the Columbia River. The population below Bonneville Dam is considered a discrete population and is relatively healthy and productive (ODFW & WDF 1992). This population exhibits voluntary anadromy and individuals freely migrate to various Oregon and Washington coastal bays and river systems. Because a portion of the population enters marine waters it is difficult to estimate the population size. The abundance of 36 to 72 inch (91–183 cm) white sturgeon in the lower Columbia River was estimated to be 238,700 of fish in 1987 and 217,400 in 1989 (Devore et al. in press). Indices of fish abundance over 72 inches indicate that the broodstock segment of the population is healthy (Hanson et al. 1992).

Peak commercial harvest occurred in the lower Columbia River 1892 when 5.5 million pounds were landed. The fishery collapsed in the lower Columbia River by 1894 and in the remaining river reaches by 1899 (Hanson et al. 1992). The population had collapsed after only 5 to 10 years of unregulated harvest and did not begin to recover until the 1950s when maximum size limits were imposed (Hanson et al. 1992).

Table 2–5. Adult Lamprey Dam Counts, 1938 to 1969

Year	Bonneville	The Dalles	McNary	Ice Harbor	Rock Island	Rocky Reach
1938	227,627					
1939	229,675					
1940	159,133					
1941	66,240					
1942	2,661					
1943	57,641					
1944	49,239					
1945	36,721					
1946	75,497					
1947	96,848					
1948	143,815					
1949	57,928					
1950	32,693					
1951	45,110					
1952	26,203					
1953	47,129					
1954	40,986				938	
1955	42,603				556	
1956	49,911				970	
1957	53,031	63,100	2,748			
1958	98,419	144,253	10,365			
1959	215,083	296,683	19,807			
1960	177,898	259,208	13,960			
1961	364,805	352,444	26,119			
1962	101,426	83,350	14,027	36,863	2,997	2,845
1963	87,937	79,530	9,9654	9,454	2,798	3,741
1964	104,337	64,252	6,176	16,960	1,611	934
1965	108,987	45,180	7,362	9,818	4,475	8,872
1966	67,914	43,383	5,4101	5,106	3,017	1,930
1967	66,171	28,311	1,516	4,836	2,099	6,945
1968	109,029	57,628	1,568	6,676		7,402
1969	379,509	67,252	3,069	5,548		17,208

Data source: Bonneville Fisheries Office 1990.

2.4.1.2 Columbia River above Bonneville Dam

Reservoir populations, cut off from the ocean by hydroelectric development, are less productive and in lesser abundance the farther upstream they are found. Unlike the lower Columbia River white sturgeon populations, the population upstream from Bonneville Dam is regarded as depressed. Catch statistics and research indicate lower sturgeon abundance for all year classes. Lower adult growth rates, coupled with fewer years of successful spawning, indicate a weaker population structure (ODFW & WDF 1992).

The reservoirs upstream of Bonneville Dam contain a series of isolated white sturgeon populations. Movement between reservoirs is limited (Hanson et al. 1992), although Rien et al. (1991) indicates some movement occurs between reservoirs. Genetic testing indicates that differences exist among white sturgeon of the Columbia, Snake and Kootenai rivers (Setter and Brannon 1992).

Malm (1978) estimated a population of 32,000 white sturgeon in Bonneville reservoir from 12–96 inches (30–245 cm) in length. Abundance of fish greater than 24 inches (61 cm) was estimated to be at least 48,500 in 1989 (Hanson et al. 1992). Recruitment occurs in the Bonneville reservoir but recruitment was low from 1986–1988 when flows were reduced (Duke et al. 1990).

The estimated number of white sturgeon greater than 24 inches (61 cm) in The Dalles reservoir declined from 30,100 fish in 1987 to 12,000 fish in 1988 with nearly 6,000 removed by sport and commercial fisheries (Hanson et al. 1992). The white sturgeon population in the John Day reservoir in 1990 was estimated at 4,000 fish greater than 24 inches (61 cm). Poor recruitment and recent high harvest rates may be contributing to the low abundance of sturgeon in the John Day reservoir (Hanson et al. 1992).

Data on abundance of sturgeon for the remaining reservoirs on the mainstem Columbia River is limited. Based on a review of various sampling efforts Mullan (1979) concluded that there are only small numbers of sturgeon from the Hanford Reach upstream to Grand Coulee Dam. Based on catch–per–unit effort (CPUE) data in Lake Roosevelt, white sturgeon appear to be moderately abundant with CPUE values for setline fishing exceeding values in Bonneville, The Dalles, and John Day reservoirs (Hanson et al. 1992).

2.4.1.3 Kootenai River

A natural barrier at Bonnington Falls downstream of Kootenai Lake has isolated the Kootenai River population from other white sturgeon populations in the Columbia River basin since the last glacial age, approximately 10,000 years (Hanson et al. 1992). Recent genetic analysis indicates that the Kootenai River sturgeon is a unique stock and constitutes a distinct interbreeding population (58 FR 36379 7/7/93 No. 128).

The USFWS has listed the Kootenai River population of the white sturgeon as an endangered species (59FR45989 9/6/94). Since the turn of the century physical attributes of the Kootenai River have been altered by human activity in a number of ways. The lower expanses of the river have been extensively diked eliminating most slough and backwater habitat considered to be important rearing habitat for juvenile sturgeon. Industrial pollutants created acute water quality problems into the 1960s and products remain bound in sediment today. Additionally, the free–flowing river habitat for the Kootenai River white sturgeon population has been modified and impacted by construction and operation of Libby Dam. Today hydropower and flood control operations at Libby Dam have transformed the natural hydrograph of the Kootenai River, thus reducing river flows critical to successful reproduction during the May to July sturgeon spawning season. The dam has also affected the biological productivity of the system by removing nutrients. In concert, pollution, diking and dam construction have contributed to the population decline. This population has declined to an estimated 880 individuals, with approximately 80 percent of the sturgeon over 20 years old. There has been an almost complete lack of recruitment of juveniles into the population since 1974, soon after Libby Dam began operation.

However juvenile recruitment had been seriously impacted prior to the dam construction.

2.4.1.4 Snake River

Commercial sturgeon fishing in the Snake River in Idaho began in the mid–1890s and was terminated in 1943. Recreational fishing for sturgeon became a catch–and–release fishery in the Snake River in 1970 (Hanson et al. 1992).

No information is available on the recent abundance of white sturgeon in the Snake River below Lower Granite Dam. Sturgeon are relatively abundant between Lower Granite and Hells Canyon dams (Cochnauer 1983; Cochnauer et al. 1985; Lukens 1985). The sturgeon population in 1972–1975 between Lower Granite Dam and Hells Canyon Dam was estimated at 8,000 to 12,000 fish 18 inches (46 cm) or larger (Coon et al. 1977). Recent population estimates are 4,000 fish (Lukens 1983, 1985) but he cautioned against making comparisons with earlier estimates because of differences in methodology. Bennett (1993) in studies of the Lower Granite Reservoir, estimated a sturgeon population of approximately 1,300 > 45 cm total length in the reservoir. Reproduction appears to be successful in this reach of the Snake River (Lukens 1984). Sturgeon are not present in the pool above Hells Canyon Dam but are caught in the Oxbow pool in the Brownlee Dam tailrace (Welsh and Reid 1971). White sturgeon are found in varying abundance from Brownlee upstream to Shoshone Falls (Hanson et al. 1992).

2.4.1.5 Hatchery Production

Supplementation of sturgeon populations in the Columbia River with hatchery reared fish has only occurred on a small scale in limited areas. The ODFW has stocked fingerling white sturgeon in the Willamette River above Willamette Falls in recent years to mitigate for the loss of production of wild broodstock that have been collected. Idaho has recently initiated experimental programs in the Snake River that involve releasing PIT tagged juvenile white sturgeon into the upper Snake River. IDFG, the Kootenai Indian Tribe, and the BPA have developed a sturgeon hatchery now in operation for sturgeon enhancement efforts in the Kootenai River. None of these efforts have been in place long enough to evaluate their impact on the sturgeon populations. However, the impact of these supplementation efforts on sturgeon abundance is probably minimal because they have only recently been implemented.

2.4.2 Sturgeon Life History

The white sturgeon is the largest fish found in the fresh waters of North America. In the Columbia River, white sturgeon reach the minimum legal length of 36 inches (92 cm) when they are 8 to 9 years old. This species is long lived. One fish from the Columbia River was determined to be 82 years old. During the 1800s, white sturgeon were in great demand for their caviar and smoked flesh. Today there is less demand for sturgeon, although some commercial and recreational fisheries do occur. Adult white sturgeons are found in deeper holes in the Columbia and Snake Rivers. While primarily bottom dwellers, they occasionally leap out of the water (Wyodoski and Whitney (1979).

2.4.2.1 Juvenile Rearing

The incubation period is 7 to 14 days depending on water temperature. After hatching, the larvae are planktonic and drift downstream (Hanson et al. 1992). Based on studies in aquaria, the larvae initially swim constantly in the water column and then enter a hiding phase where they sink to the bottom and seek protection from predators by burrowing in the rocks and detritus while the yolk sac is absorbed. The hiding phase may start sooner if water velocities are high (Brannon et al. 1985). Feeding begins about 12 days after hatching and larval development is complete after 20–30 days. No information is available on the food habits of wild larvae. (Hanson et al. 1992).

Young of the year and juveniles prefer the deeper, slower velocity areas (McCabe and Hinton 1991; Miller et al. 1991; Parsley et al. 1992) and depend on the currents to transport them into the rearing areas. They are most often captured within the thalweg and

rarely adjacent to the thalweg in shallower water (Parsley et al. 1992).

The average sturgeon in the lower Columbia River reaches a total length of 36 inches (92 cm) by age 9. Sturgeon growth rates in the lower Columbia River declined by about 10 percent from 1947–1953 to 1980–1983 (Hess 1984). Sturgeon up to 100 years old have been found in the Columbia River (Hanson et al. 1992). One large female sturgeon from the Columbia River was 12 1/2 feet long and weighed 1,285 pounds (Wydoski and Whitney 1979).

2.4.2.2 Ocean Distribution and Rearing

At least a portion of the white sturgeon population in the Columbia River uses fresh, brackish, and marine waters and is considered semi–anadromous. At some point in the juvenile rearing phase in freshwater a part of the population moves into marine waters, but the proportion is unknown (Hanson et al. 1992). Marine use is not necessary for completion of the life cycle.

Tagged white sturgeon from the Columbia River disperse north and south along the Pacific coast and into other estuaries (Bajkov 1951; Galbreath 1985). The incidence of Columbia River sturgeon tag returns from other river systems increased substantially after tons of sediment were deposited in the river following the eruption of Mt. St. Helens in 1980 (Galbreath 1985; Boomer and Joner 1989).

2.4.2.3 Adult Migration and Spawning

Migration

Columbia River below Bonneville Dam. Adult white sturgeon in the lower Columbia River move out of the estuary in fall either upstream or into marine waters. In the late winter and early spring they tend to move downstream to the estuary or ocean (Bajkov 1951). In fresh water there are unaccountable movements of small sturgeon upstream during the fall and early winter with a corresponding move downstream during late winter and early spring. Other vague seasonal movements, such as from deeper water in winter to shallower water in warm weather, and toward the ocean in summer months and freshwater in winter months have been described (Migdalski 1962).

Movements in the sea are not well known, but are thought to be usually only local and to remain in shallow water. However sturgeon have been taken at 100 foot depth (Scott & Crossman 1973) and tagged fish have been known to move as much as 660 miles (Chadwick 1959). It has been taken in water temperatures ranging from 32° to 74°F (9.9°–23.3°C) in salt, brackish and fresh water.

Columbia River above Bonneville Dam. Based on marking studies and dam counts, it appears that white sturgeon do not move freely between impoundments (Hanson et al. 1992). Information cited in Wydoski & Whitney (1973) corroborates this. For example, nearly 4,000 adult sturgeon were tagged in the Columbia River in 1947–1950. Most were captured close to the tagging location, and two fish were taken four times each by sportsmen within a few months. A number of white sturgeon were captured at the mouth of the Columbia, some 100 miles downstream from the tagging locality. One migrated at least 200 miles to the Willapa Bay, Washington. This was the only reported recapture of a tagged fish outside the Columbia River system. Sturgeon in the Columbia appear to migrate upstream during fall and downstream in late winter and spring (Wydoski & Whitney 1979).

Haynes et al. (1978) found that white sturgeon tracked with radio transmitters in the Columbia River were inactive in mid–winter but exhibited movements in summer and early fall. These fish occupied shallower waters in summer when water temperatures were warm (63° – 64°F) and deeper pool areas in winter. Bennett (1993) found that sturgeon tracked in Lower Granite Reservoir traveled a mean distance of 11.2 river run upstream and 5.9 river run downstream during 1991.

The white sturgeon breeds for the first time at a more advanced age than any other freshwater fish. A typical female reaches sexual maturity at about 13 years, and is about 1.25 m (50 in) long (McGinnis 1984). Males may mature at approximately 10 to 12 years of age.

Spawning

Spawning occurs between April and July during the peak of the hydrograph in the Columbia River. Sturgeon are broadcast spawners, releasing eggs and milt in fast water. Most spawning occurs when water temperature is between 10–18°C (Parsley et al. 1992). White sturgeon spawning have been documented immediately downstream of Bonneville, The Dalles, John Day, and McNary dams in the higher velocity areas of the reservoirs (Parsley et al. 1992). Sturgeon eggs have been collected in spawning areas with mean column water velocities ranging from 1.6 to 6.3 feet per second (0.5 to 1.92 meters per second (Miller et al. 1991, and Parsley et al. 1992). Following fertilization, eggs adhere to the river substrate and hatch after a relative brief incubation period of 8 to 15 days, depending on water temperature (Brannon et al. 1985). Faster water disperses the adhesive eggs and prevents them from clumping and smothering each other (Hanson et al. 1992). Newly spawned and incubating eggs are found primarily over cobble and boulder substrates, but are also found over sand, gravel and bedrock (Parsley et al. 1992).

Adults survive spawning and return to spawn more than once, but only after increasing intervals of years. In the younger females the interval is 4 years and 9–11 years in older females (Scott & Crossman 1973). Below Bonneville Dam, adults probably migrate downstream in late summer and fall to return to the ocean. Depending on size and age, females carry between 100,000 and 7 million mature eggs (Hanson et al. 1992).

Velocity – a Key Role. Increased flows may stimulate spawning and egg deposition. Reproduction in the mainstem of the Columbia River has been greater in years of higher flows than in years of lower flows (Hanson et al. 1992). In the below average flow years of 1987 and 1988, very weak year–classes of white sturgeon were established in the Bonneville, The Dalles and John Day reservoirs (Parsley et al. 1989). It is not known whether water velocities were insufficient to stimulate reproduction or for dispersal of eggs and larvae. Water temperatures, bottom substrates, and food supply did appear to be adequate for successful reproduction and rearing. Water velocities appear to be a major limiting factor. In the Kootenai River there has been an almost complete lack of recruitment of juveniles into the population since 1974 when spring flows were reduced substantially following the construction of Libby Dam (Partridge 1983; Apperson and Anders 1991). The abundance of sturgeon year classes for the Sacramento–San Joaquin River Delta appears to be positively associated with the volume of freshwater flow through the Sacramento–San Joaquin estuary (Kohlhorst et al. 1991). Flows less than 293,000 cubic feet per second (cfs) may be less favorable than flows over 406,000 cfs for spawning in The Dalles Dam tailrace (Parsley et al. 1989). The duration of high flows may also be important (Hanson et al. 1992).

2.4.2.4 Food

White sturgeon are bottom feeders, with special adaptations that include ventral barbels, and ventral, protrusible, sucker mouths. For individuals larger than 19 inches (483 mm) in length, fish become the principal food with crayfish second. Bennett (1993) found a direct correlation between the abundance of crayfish and white sturgeon in Lower Granite Reservoir. Fish occurred in 48.65 percent of the stomachs that contained food and were more frequent in larger sturgeon. Seasonally abundant foods are important such as eulachon, lamprey, American shad, northern anchovy, and herring eggs (Hanson et al. 1992). Chironomids are also an important part of the diet of adults. The white sturgeon is apparently much more predaceous or piscivorous than any other North American sturgeon (Semakula and Larkin 1968). Fish, as well as a wide variety of invertebrates, probably make up the diet of this species when in the sea.

The food of smaller sturgeon is predominantly chironomids, which occurred in 35.2 percent of the stomachs of sturgeon of all sizes (Scott & Crossman 1973). Lesser amounts of mysids, Daphnia, Chaoborus larvae, molluscs, immature mayfly, caddisfly and stonefly and a few copepods made up the rest of the food.

2.4.2.5 Predation

In the Columbia River downstream from McNary Dam, suckers (Catastomidae), northern squawfish (Ptychocheilus oregonensis), and carp (Cyprinus carpio) have been found with sturgeon eggs in their stomachs (Hanson et al. 1992). There are no published accounts of predators of either young or adult sturgeon other than reports of Pacific lamprey (Entosphenus tridentatus). The sturgeon's large size and protective bony plates (scutes) probably account for this (Scott and Crossman 1973). Scott and Crossman (1973) speculated that white sturgeon likely compete for food in freshwater with the green sturgeon.

2.4.3 Factors Influencing Populations

The combination of long life, slow sexual maturation and intermittent breeding makes the sturgeon one of the least adaptable fish to withstand the pressures of commercial fishing (McGinnis 1984). These traits also make it vulnerable to losses from hydroelectric dam development as evidenced by the Kootenai River population declines.

2.4.3.1 Habitat

Spawning and rearing habitat available to white sturgeon in the Columbia River basin has been altered due to the construction and operation of hydropower projects. Impoundments created by the construction of Bonneville, The Dalles, and John Day Dams have reduced the availability of spawning habitat, but increased the amount of rearing habitat available for young–of–the–year and juvenile white sturgeon (Parsley and Beckman 1992). Since 1974, when spring flows were reduced substantially as a result of the construction of Libby Dam, there has been an almost complete lack of recruitment of juvenile sturgeon into the population (Partridge 1983; Apperson and Anders 1991). Successive year–class failures and poor recruitment also have occurred in the three impoundments below McNary Dam (Miller et al. 1991). Recruitment improved in these impoundments with the increased flows in 1990 and 1991 (Parsley and Beckman 1992).

The dam tailraces now provide the only areas in the impoundments below McNary Dam with water velocities required for spawning (Parsley and Beckman 1992). They simulated spawning habitat in the tailraces at various discharges and found that usable habitat is nearly maximized at about 225,000, 275,000, 300,000, and 325,000 cfs in the Bonneville, John Day, McNary, and The Dalles dams tailraces, respectively. As flows increase, the amount of habitat increases in each tailrace. They found that the greater hydraulic slope of the Bonneville Dam tailrace, compared to the hydraulic slope of the other tailraces, creates higher velocities below Bonneville Dam at low flows. Therefore, the Bonneville Dam tailrace provides habitat for spawning of a high quality at flows that provide only low to medium quality spawning habitat in the other tailraces.

Parsley and Beckman (1992) found that the impounded river reaches have proportionately more rearing habitat than the unimpounded reach in the lower river. The mean length of younger white sturgeon is greater in the impounded areas compared to the unimpounded lower river reach (Parsley et al. 1989) indicating better rearing conditions. However, because of successive year class failures and low recruitment to young–of–the–year, the rearing habitat in the impounded river reaches is probably under–used (Parsley and Beckman 1992).

2.4.3.2 Migration Past Dams

The dams have created a series of isolated white sturgeon populations with limited movement between reservoirs (Hanson et al. 1992). The effect of limiting the movement of white sturgeon on population productivity is unknown. However, limiting movement may result in reproductive isolation and reduced ability of the white sturgeon populations to respond to adverse environmental conditions.

There have also been mortalities during maintenance of hydroelectric facilities such as when turbine draft tubes are dewatered (Hanson et al. 1992). Mortality of juvenile and adult white sturgeon as a result of turbine passage has not been measured.

2.4.3.3 Harvest

Experience in the Columbia River and other locations has shown that fishing can rapidly reduce populations of long–lived, infrequently reproducing fishes such as the sturgeon. Regulations that provide protection for sturgeon stocks have been effective in restoring populations (Wydoski & Whitney 1979).

Lower Columbia River

The sturgeon population in the Lower Columbia River had recovered by the 1970s due to maximum size limits imposed in 1950. White sturgeon harvest from 1950–1970 was primarily incidental catch in the salmon gill net fishery. Commercial fisheries targeting on sturgeon in the Lower Columbia River began to develop in the mid–1970s when a separate season for setlines was established. Commercial setline sturgeon fishing below Bonneville Dam was phased out by 1985 (Hanson et al. 1992).

Target large–mesh gill net fisheries effective on 4 to 6 feet long sturgeon occurred from 1983 to 1988 in the lower river. The recreational fishery in the lower river expanded at the same time as harvest opportunities for salmon declined. By 1987 the Lower Columbia River sport catch peaked at 62,400 sturgeon which was about twice the catch level that occurred in the late 1970s (Hanson et al. 1992).

Washington and Oregon determined that harvest rates were about twice the level believed to be sustainable. In 1989 they began reducing the harvest rate of the combined recreational and commercial fisheries to about 15 percent from the 20 to 40 percent harvest rate that occurred in 1985–1987 (Hanson et al. 1992). This was accomplished by eliminating the target gill net fisheries, imposing mesh restrictions in the salmon fisheries to reduce fishing targeted on sturgeon, raising the minimum size limit in the recreational fishery, and through other restrictions on the recreational fishery. As a result, commercial landings below Bonneville Dam declined from an average of 12,000 fish per year from 1980–1987 to 4,000 to 5,000 fish per year currently (WDF/ODFW, 1992). Sport catch declined from the peak of 62,400 in 1987 to an average annual harvest of 21,800 from 1989–1991 (WDF/ODFW 1992). Good recruitment to the fisheries and a healthy broodstock population indicate that this population currently is healthy and productive.

Only limited information is available on the historical abundance of white sturgeon in the Columbia River basin. White sturgeon were harvested by Native Americans in the Columbia River region (Craig and Hacker 1940). In the early years of the commercial salmon fishery in the lower Columbia River, sturgeon were incidentally harvested by salmon gear and were destroyed as nuisance fish. The commercial value of sturgeon increased in the late 1880s and early 1890s and the fishery expanded quickly (Hanson et al. 1992).

Data has not been worked up for 1990–92 estimates, but raw counts for 1992 are less than 1,000 (possibly even less than 100 individuals). These low 1992 counts are significantly less than the counts for 1991, suggesting a possible effect of the March 1992 Physical Drawdown Test of Lower Granite and Little Goose dams (Chris Pinney, COE Walla Walla, personal communication).

Upper Columbia River

Unlike the lower Columbia River white sturgeon populations, the population upstream from Bonneville Dam is regarded as depressed. Catch statistics and research indicate lower sturgeon abundance for all year classes. Lower adult growth rates, coupled with fewer years of successful spawning, signify a weaker population structure. Exploitation rates have been high for all age classes susceptible to set–net gear. Target fishing in the tribal commercial and recreational fisheries has been decreased by recent state and tribal management actions, but a high mortality still exists for fish. Other problems that affect the relative productivity and recovery of these white sturgeon populations are inaccessibility to the marine environment and habitat alterations mainly due to hydroelectric development. Populations in the Columbia River basin upstream from The Dalles Dam are especially depressed and more strictly regulated.

Commercial fishing above Bonneville Dam by non–treaty fishermen was banned by Washington and

Oregon in 1957. White sturgeon continued to be harvested by both setnet and setline in the treaty Indian fishery and by a small sport fishery. Catch records for sturgeon landings prior to 1976 do not identify gear type but the majority of the treaty catch was incidental to the salmon fisheries (Hanson et al. 1992).

The treaty Indian fishery had separate seasons for setnets beginning in 1976 and the seasons were open for 9 to 10 months each year from 1980–1987. The use of diver nets, which targeted on sturgeon, increased during this time period. The catch of white sturgeon in the treaty Indian fishery increased from 2,800 fish in 1984 to 11,100 fish in 1987. The recreational fishery took about 5,000 sturgeon annually in Zone 6 from 1980–1987. Concern over the rate of increase in harvest prompted the initiation of time, gear, and size limits in 1988 which led to reductions in the commercial and recreational catch. In 1991 harvest rate reductions for the commercial fishery were established for each pool which translated to harvests of 1,250 fish in Bonneville, 300 in The Dalles, and 100 fish in John Day pool (Hanson et al. 1991). In April 1991 the recreational catch was reduced by imposing a size limit and daily bag limits.

Major declines in the abundance of white sturgeon in the exploitable size range, attributable to overharvest, are confined primarily to The Dalles and John Day pools (ODFW, 1991). This decline is being addressed through the implementation of the aforementioned harvest controls.

Only limited harvest of white sturgeon occurs in the area above McNary Dam. A treaty Indian gill net fishery in Priest Rapids Pool has taken small numbers of sturgeon in recent years (Hanson et al. 1992).

Kootenai River

There are no commercial fisheries for white sturgeon in the Kootenai River basin. Idaho has limited the sport fishery in the Kootenai River to catch–and–release since 1984. Montana banned fishing for sturgeon on the Kootenai River in 1979 because of declining stocks.

Snake River

A few fish are taken annually in the sport fishery between Ice Harbor and Lower Granite dams (Hanson et al. 1992). There is no commercial fishery for sturgeon in the Snake River. Sturgeon angling above Lower Granite Dam has been restricted to catch–and–release since 1970 (Hanson et al. 1992).

CHAPTER 3

STUDY METHODS

3.1 INTRODUCTION

This chapter describes the study methods used by the AFWG to prepare this appendix for the SOR Final EIS.

Throughout the entire study phase, the AFWG has emphasized anadromous salmonid species because these fish have been extensively studied, because some populations have been designated as endangered, and because they are considered a cultural resource of the northwest Native American Tribes and are of primary interest within the region.

3.1.1 Models and Biology

The study methods employed in this analysis are primarily quantitative, although there is some qualitative analysis. The quantitative study of a biological system begins with scientists observing, measuring, analyzing, and eventually judging how the system functions in nature, both in its components and as a whole. These observations – called "empirical data" – are then collected, quantified, and used as the basis for mathematical models. The models attempt to mathematically imitate the interactions observed in the biological system they represent.

In the AFWG quantitative analysis, computer models simulate juvenile passage through the hydrosystem and life cycle conditions for discrete salmonid populations, based on reservoir elevations, timing and volume of spill at each dam, and outflows produced by alternative operating strategies.

Results generated by models are only as sound as the data and assumptions on which they are based. The possibility always exists that the models will not truly reflect the natural processes. Because of this uncertainty, predicting absolute survival values for the modeled populations that would result from a particular alternative is difficult. However, in the present analysis of the impacts of the alternatives on salmonid populations, if biased assumptions produce somewhat skewed results, they produce them identically across all the alternatives; therefore, the models are particularly useful for comparing across many alternatives when a limited number of variables is changing.

3.1.2 Value Measures

Value measures are model constructs developed to evaluate the performance of a modeled subject in relation to the circumstance being modeled. In the AFWG analysis, the circumstances modeled are hypothetical hydrosystem operating requirements outlined in the alternatives. The performance of the salmonid populations modeled in response to the requirements is evaluated by reference to three value measures.

Two of the three value measures reflect smolt performance during downstream migration: smolt survival through the hydrosystem and smolt travel time.

Smolt survival through the hydrosystem is an estimate of the overall proportion of smolts that survive from the upstream end of the hydrosystem to below Bonneville Dam. This value measure reflects the direct effects of the hydrosystem on smolt survival and is the most reliable predictor of those effects. **Smolt passage models** developed for Columbia River salmon populations have been written primarily to predict this value.

Smolt travel time is the average number of days it takes for smolts to migrate from their natal streams down through the hydrosystem to below Bonneville Dam. This value measure may relate to a population's likelihood of success, but the extent to which it relates remains a matter of debate. Please refer to section 2.1.2.2 in Chapter 2 for further discussion.

The third value measure is an estimate of the number of adults that return to their natal streams to spawn. There is some uncertainty associated with adult returns as a measure of smolt performance through the hydrosystem because adult return results are also influenced by factors having nothing to do with the hydrosystem (ocean conditions, as an example). The values for adult survival are predicted by a **life cycle model,** in which factors apart from hydrosystem impacts are held constant.

While these value measures reference real–world phenomena such as travel time and juvenile survival through the hydrosystem, they are model constructs because they are *representative* of performance. Real–world performance of smolts through the hydrosystem hinges on an infinite range of real–world conditions, and biological and behavioral responses to those conditions, which can never be fully known or incorporated into a model.

3.1.3 Quantitative Methods Used in the Analysis

3.1.3.1 Hydrologic Modeling

Each SOS outlines specific conditions in terms of river flows, reservoir elevations, spill and timing of flow at run–of–river and storage dams within the hydrosystem.

A hydroregulation model – HYDROSIM – was used to model the hydrological effects of each alternative System Operating Strategy (SOS). HYDROSIM simulates river operations using the historic flow record for 49 years from fall 1929 through spring 1978. Each HYDROSIM run produces monthly average flow, spill, and elevation data (except for April and August which are split into two equal periods) for each year at each dam. These 49 years of data provide the range of possible river conditions used in the analysis.

The smolt passage models use the information generated by HYDROSIM in estimating smolt survival and travel time.

Additional information on the hydroregulation model and the resulting hydrologic conditions can be found in the River Operation Simulation Appendix A.

3.1.3.2 Biological Modeling

Three smolt juvenile passage models are currently in use within the region. Based on comments received during the Scoping Process, the AFWG requested all three smolt passage models be used to analyze smolt migration performance. However only two were available for use in the Draft EIS to estimate smolt survival and travel time: PAM (Passage Analysis Model, NPPC) and CRiSP1.4/1.4.5 (Columbia River Salmon Passage Model, UW).

The Stochastic Life Cycle Model SLCM (Stochastic Life Cycle Model, Resources for the Future and United States Forest Service [USFS]), was used to estimate the third value measure, the number of returning adults. The AFWG also solicited the use of other life cycle models, but none were available for the SOR Final EIS.

One juvenile passage model, CRiSP 1.5, and one life–cycle model, SLCM, were available for the SOR Final EIS.

For the purpose of the AFWG analysis for the Final SOR EIS, 13 alternatives have been grouped into four categories according to the general approach they take to hydrosystem operation. The four categories are: Flow Control Alternatives; Drawdown Alternatives; Natural River Alternatives; and Combination Alternatives, which combine drawdown, spill and flow augmentation. For consistency in presentation, the smolt passage model parameters and the results in Chapter 5, will be grouped into these same categories.

Transportation Modeling

An important non–operational measure to mitigate for juvenile salmonid losses due to hydrosystem operations is the Corps' Juvenile Fish Transportation Program (JFTP). Under the program, smolts are collected from Lower Granite, Little Goose, Lower Monumental and McNary dams and loaded into barges (much less frequently, trucks) for transportation downstream to a release point below Bonneville Dam. The con-

cept underlying the JFTP is that juveniles transported around numerous dams and reservoirs avoid the cumulative mortality associated with passage through the hydrosystem.

A model–based transportation sensitivity analysis is presented in Chapter 5. It examines several transportation survival theories and compares transportation survival estimates based on these theories with estimates of in–river migration survival.

3.1.3.3 Salmon and Steelhead Stocks Included in the Modeling Analysis

Ten indicator stocks were chosen in an effort to represent geographically dispersed stocks that reasonably depict how anadromous salmonid stocks throughout the Columbia and Snake basins might be affected by the SOR alternatives. Selection of the stocks was constrained by the availability of stock–specific data necessary to calibrate and run the life cycle model. Six of the ten stocks, indicated by an asterisk (*), were evaluated by SLCM. The ten indicator stocks are:

Snake River:

* Natural Snake River Spring Chinook
* Natural Snake River Summer Chinook
* Natural Snake River Fall Chinook
* Dworshak Hatchery Summer Steelhead

Mid–Columbia River:

Natural Methow River Spring Chinook
* Natural Methow River Summer Chinook
* Natural Hanford Reach Fall Chinook
Wenatchee Hatchery Summer Steelhead

Lower Columbia River:

Natural Deschutes River Spring Chinook
Natural Rock Creek Spring Steelhead

Analysis of these stocks suggests that, as indicator stocks, they represent basinwide wild spring and fall chinook populations fairly well, yearling summer chinook populations only moderately, and basinwide steelhead populations poorly.

Coho were not considered in this analysis as they are extinct in almost all sub–basins above Bonneville Dam. Sockeye were not modeled because migrational characteristics, such as dam passage parameters and survival estimates, are not available. Some scientists believe they may behave similarly to spring chinook due to their similar migrational timing and size at time of migration.

Although passage information is limited for subyearling chinook, they were modeled using CRiSP1.5.

3.1.4 Qualitative Study Methods

In addition to quantitative analysis, qualitative analysis of the JFTP was conducted through extensive review of literature about and related to the transportation program, other transportation evaluations, and synthesis of that information with current improvements and operating conditions at the dams and in the transportation process. In some instances, engineering and economic evaluations of alternatives to transportation and alternative methods of collecting and transporting fish were conducted. Some elements of the qualitative analysis were drawn from other, ongoing studies and programs such as the SCS, CRJFMP and the CRSMA.

Qualitative analysis was also conducted on the effects of the alternatives on non–salmonid anadromous fish (shad, lamprey, and sturgeon), based on expert opinion.

3.2 QUANTITATIVE METHODS: MODEL DESCRIPTIONS, ASSUMPTIONS, PARAMETERS, AND KEY UNCERTAINTIES

3.2.1 Juvenile In–river Survival: CRiSP1.5

3.2.1.1 CRiSP1.5 Model Description

The AFWG employed one smolt passage model in its final analysis: CRiSP1.5 (Anderson et al. 1995). CRiSP1.5 starts a hypothetical population of juvenile salmonids at an appropriate location in the hydrosystem (appropriate to each population's pre–migratory rearing location) and then simulates the migration of the population downstream through reservoirs and around dams to below Bonneville Dam on the lower Columbia River. Figure 3–1 presents a schematic of the CRiSP1.5 model.

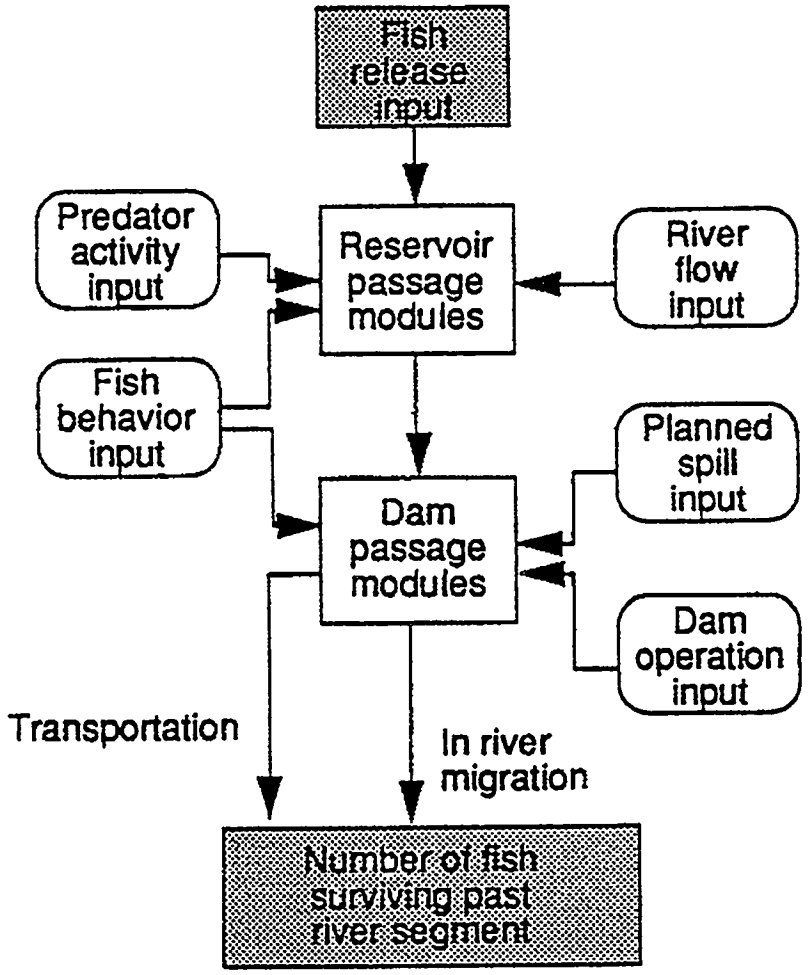


Figure 3–1. Overview of Columbia River Salmon Passage Model (CRiSP1.5)

At each dam and reservoir, a number of smolts are subtracted from the migrating population based on assumptions about mortality factors, which are in turn based on empirical, experimental, and statistical data. The simulation ends with the population emerging below Bonneville Dam. While the model is capable of providing data on survival at any point during simulation, the final output bears directly on the two value measures of travel time and juvenile survival: The model produces the average number of days the migration has taken, and the average percentage of smolts that have survived the migration.

CRiSP1.5 has two main components: dam passage survival, which depends on the route taken past the dam, with different mortalities incurred for spillway, bypass and turbine passage; and reservoir survival which is a function of the amount of time the smolts remain in the reservoirs.

As its dam passage survival inputs, CRiSP1.5 uses flow and spill volumes, and reservoir elevations from HYDROSIM, parameter estimates associated with dam passage, and the proportion of smolts being diverted into the bypass system.

In its reservoir survival component, CRiSP1.5 uses specific mechanisms (primarily predator and smolt behavior and gas supersaturation effects) to estimate reservoir mortality.

CRiSP1.5 runs a number of games (in this case, 50) for each of the 49 water years, performing a Monte Carlo analysis, wherein the parameter values are allowed to vary between a specified range during each game. This allows CRiSP1.5 to provide an expected mean along with some variation.

CRiSP versions 1.4 and 1.4.5 were used by the SOR Federal agencies for the analysis presented in the SOR Draft EIS. CRiSP version 1.5 was used for the analysis presented in the SOR Final EIS. The differences between CRiSP versions 1.4, 1.4.5 and 1.5 are not major, but the SOR Federal agencies believe that it is important to use the most up–to–date model available for the final analysis. CRiSP versions 1.4 and 1.5 differ in two categories: model structure and model calibration.

STRUCTURE

There are two major structural changes in CRiSP from version 1.4 to 1.5:

Gas–related mortality

Both version 1.4 and 1.5 describe smolt mortality, in part, as a function of gas supersaturation. In CRiSP1.4 this was represented by an increasing exponential curve, fit to the data of Dawley et al. 1976. In version 1.5 this is changed to a threshold model that appears to fit the data better. In this formulation, there is a small mortality rate at low gas saturations which increases slowly until a threshold level of saturation (120 percent) is reached, above which point the mortality rate increases sharply in a linear fashion. In shape this is similar to the exponential model, and overall mortality rates are quite similar between the two models.

In version 1.4, there was no accounting for fish depth distribution in the pool. If gas concentration is roughly equal through the water column, fish higher in the water column will experience gas bubble formation due to lower ambient pressure and thus a higher mortality, while those fish lower in the column will experience lower mortality. Version 1.5 of the model includes a fish depth distribution, which, together with the threshold mortality rate function, predicts the total mortality rate on the stock.

Tests of this function versus the old model function show that current calibration of the gas mortality function is somewhat less sensitive to gas supersaturation than previous versions. This implies that high spill alternatives will be modeled as less deleterious than in previous versions.

Fish travel time dynamics

The fish travel time model has been expanded to contain two components. In version 1.4, fish velocity was always a function of water velocity, although the relationship between the two varied with fish age. In version 1.5, this component still exists (the "flow–dependent" component) but there is also potentially an intrinsic fish velocity that does not depend on flow (the "flow–independent" component). The degree to which one or the other component dominates is stock–specific: yearling chinook and steelhead continue to be modeled as having a moderately strong relationship between water velocity and fish velocity, whereas subyearling chinook are now modeled as being insensitive to flow velocity, based on brand release data for mid–Columbia River subyearling fish (Anderson et al. 1995).

CALIBRATION

The most recent version of CRiSP1 is calibrated to a very large number of existing data sets. This has resulted in alterations of some of the previous values for some parameters. These include:

- revised predator densities from most recent squawfish indexing studies;
- revised turbine mortalities from NMFS/UW survival study;
- revised FGE at some Snake River projects from PIT tag data for yearling chinook and steelhead;

- revised gas saturation production coefficients based on monitoring data during high spill periods of 1994;
- revised predator activity coefficients based on John Day squawfish consumption data and updated predator density and travel time information;
- corrected separation operations at transport projects;
- adjusted powerhouse capacities in historical data files for the number of turbines operating;
- transport mortality back–calculated from TIR studies of 1986, 1987, and 1989.

Not all of these changes have an impact on SOR–related model runs. For example, transport mortality models and turbine mortality rates are prescribed by SOR participants. Also, historical changes in powerhouse capacity and FGE are not relevant for forecasting model runs (although they do come into play during model runs for calibration of SLCM).

For a thorough discussion of smolt passage model theory, structure, and parameters, see Anderson et al. 1993 (CRiSP1.4).

3.2.1.2 CRiSP1.5 Assumptions and Parameters

For the Flow Control alternatives (1a, 1b, 2c, 2d and 4c) and the Combination alternatives (9a, 9b, 9c, and the Preferred Alternative), the analysis assumes that the physical hydrosystem remains as it existed in 1994. Future actions designed to improve smolt survival, such as installation and replacement of screens to guide smolts away from the turbines and other improvements at the dams, are not included in this analysis. The analysis also does not include future actions designed to improve reservoir survival, such as the ongoing attempt to reduce the population of predators (the Squawfish Management Program).

For the Drawdown (6b, 6d), and Natural River (5b, 5c) alternatives, the analysis assumes that the physical changes that would be necessary at the dams are in place. There is no attempt to model impacts during construction or a phase–in of the alternative system configuration.

River Flow, Reservoir Elevations, and Dam Spill

The HYDROSIM model estimates monthly average flow and spill volumes, and end of month reservoir elevations for each dam. These values are passed directly to CRiSP1.5, where they are modulated into daily values based on an analysis of recent actual daily, weekly, and monthly patterns of flow at the dams.

Reservoir elevations are specified by the alternatives. As reservoir elevations drop under the drawdown alternatives, a portion of the reservoir may become a free–flowing river again, while the remainder stays as a pool. The relationships between geometry, elevation, and free–flowing river velocities were estimated from the Corps' 1992 Lower Granite reservoir drawdown test.

The amount and timing of planned spill (spill that is voluntary and does not result from a lack of power demand or from flow that exceeds powerhouse capacity) is presented for selected dams in Tables 3–1 and 3–2. Instantaneous fish spill is calculated as the proportion of river flow that is allowed to pass over the spillway during the prescribed spill period. Planned spill requirements at non–transport dams (except Bonneville Dam) on the lower Snake and lower Columbia rivers for the Flow Control, Natural River and Drawdown alternatives are prescribed by the April 1989 Fish Spill Memorandum of Agreement. These spill requirements have been incorporated into thee Corps' 1995 Juvenile Fish Passage Plan for the Federal dams. The Federal Energy Regulatory Commission (FERC) sets the spill requirements at the non–Federal dams on the mid–Columbia River, i.e., Wells, Rocky Reach, Rock Island, Wanapum and Priest Rapids.

During periods when flow volume exceeds the capacity of the turbines (forced spill) or when flows exceed power demand (overgeneration spill), additional spill occurs beyond that provided for juvenile salmonids migrating downstream. In these cases, the spill is shaped into the nighttime hours whenever

possible. Overgeneration spill was not specifically identified in this analysis. Planned spill is prescribed at transportation sites under some alternatives (see Table 4–2). Transport sites are indicated in Tables 3–1 and 3–2 with a (T).

Under the Flow Control (1a, 2c, 2d, 4c) and Drawdown (6b, 6d) alternatives, the analysis assumes that there is no spill at transport projects, i.e., Lower Granite, Little Goose, Lower Monumental and McNary dams. Under the Natural River alternatives (5b and 5c), the analysis assumes that all inflow is passed around Lower Granite, Little Goose, Lower Monumental and Ice Harbor dams. Under the Flow Control (1a, 2c, 2d, 4c) and Drawdown (6b, 6d) alternatives, the analysis assumes that spill at Ice Harbor, John Day and The Dalles dams is as prescribed in the 1989 Fish Spill Memorandum of Agreement. Under the Flow Control (1a, 2c, 2d, 4c), Natural River (5b, 5c) and Drawdown (6b, 6d) alternatives, the analysis assumes that spill at Bonneville Dam occurs 24 hours a day and is 53 percent of inflow between April 15 and June 11 and 41.5 percent of inflow between June 12 and August 23. Alternative 1b assumes that no spill occurs at any of the lower Snake and lower Columbia River dams during the juvenile fish migration period.

Table 3–1 shows the percent spill required (instantaneous) under the Combination alternatives, 9a, 9b, and 9c. Spill is set to achieve 80 percent Fish Passage Efficiency (FPE); spill caps are set to avoid excessive total dissolved gas. Spill cap at mainstem projects is 120% total dissolved gas daily average as measured in the forebay of the next downstream project. Under 9a, maximum spill amounts are: LGR – 60 kcfs; LGO – 60 kcfs: LMN – 60 kcfs; IHR – 60 kcfs; MCN –150 kcfs; JDA – 70 kcfs; TDA – 175 kcfs; and BON – 105 kcfs. Under 9b and 9c, maximum spill amounts are: LGR – 30 kcfs; LGO – 30 kcfs; LMN – 18 kcfs; IHR – 25 kcfs; MCN – 50 kcfs; JDA – 30 kcfs; TDA – 90 kcfs; and BON – 105 kcfs.

Table 3–1. Instantaneous Spill Requirements at Snake River and Lower Columbia River Dams for Combination Alternatives (9a, 9b, 9c)

DAM	Spill Percentage	Hours of Spill	Dates of Spill
Lower Granite (T)	78 99	1800–0600 1800–0600	April 1 – May 31 June 1 – August 31
Little Goose (T)	48 99	1800–0600 1800–0600	April 1 – May 31 June 1 – August 31
Lower Monumental (T)	54 100	1800–0600 1800–0600	April 1 – May 31 June 1 – August 31
Ice Harbor	100	1800–0600	April 1 – August 31
McNary (T)	48 89	1800–0600 1800–0600	April 15 – June 6 June 7 – August 31
John Day	33 85	1900–0700 1900–0700	April 15 – June 6 June 7 – August 31
The Dalles	40% of instantaneous flow based on identified project limitations	24 hours daily	April 15 – August 15
Bonneville	68 77	24 hours daily 24 hours daily	April 15 – June 6 June 7 – August 31

Table 3–2 shows the instantaneous spill requirements at lower Snake River and lower Columbia River dams for the Preferred Alternative. Spill is intended to achieve 80 percent FPE up to a total dissolved gas cap of 115 percent, averaged over a 12–hour period, as measured at the forebay of the next downstream project and derived by the Corps of Engineers. Spill occurs at all projects during the spring. However, when average flow at Lower Granite is less than 100 kcfs, then no spill occurs at that project. When average flow at Lower Granite is less than 85 kcfs, then no spill occurs at that project or Little Goose and Lower Monumental dams. Spill occurs at all non–transport projects during the summer. Spill occurs for 12 hours a day except at Ice Harbor, The Dalles and Bonneville dams which spill for 24 hours. Spill caps are: LGR – 13.5 kcfs; LGO – 12.5 kcfs; LMN – 7.5 kcfs; IHR – 25 kcfs; MCN – 22.5 kcfs; JDA – 9 kcfs; TDA – 90 kcfs; and BON – 75 kcfs.

Table 3–2. Instantaneous Spill Requirements at Snake River and Lower Columbia River Dams for the Preferred Alternative

DAM	Spill Percentage	Hours of Spill	Dates of Spill
Lower Granite (T)	80 0	1800–0600 1800–0600	April 10 – June 20 June 21 – August 31
Little Goose (T)	80 0	1800–0600 1800–0600	April 10 – June 20 June 21 – August 31
Lower Monumental (T)	81 0	1800–0600 1800–0600	April 10 – June 20 June 21 – August 31
Ice Harbor	27 70	24 hours daily	April 10 – June 20 June 21 – August 31
McNary (T)	50 0	1800–0600 1800–0600	April 20 – June 30 July 1 – August 31
John Day	33 86	1800–0600 1800–0600	April 20 – June 30 July 1 – August 31
The Dalles	64	24 hours daily	April 20 – June 30 July 1 – August 31
Bonneville	*	24 hours daily	April 20 – June 30 July 1 – August 31

* 80% FPE is not attainable with spill cap; therefore, Bonneville spills up to the spill cap (75 kcfs).

Dam Passage Survival Assumptions

Survival of smolts past the dams in CRiSP1.5 depends on the route taken, with different mortalities incurred for spillway, bypass, and turbine passage. CRiSP1.5 incorporates uncertainty into the analysis by using a range of input values for key parameters and performing a Monte Carlo analysis, wherein the parameter values are allowed to vary in a random manner within the boundaries of the range for each game. Figure 3–2 shows a flow diagram of how smolts pass a dam.

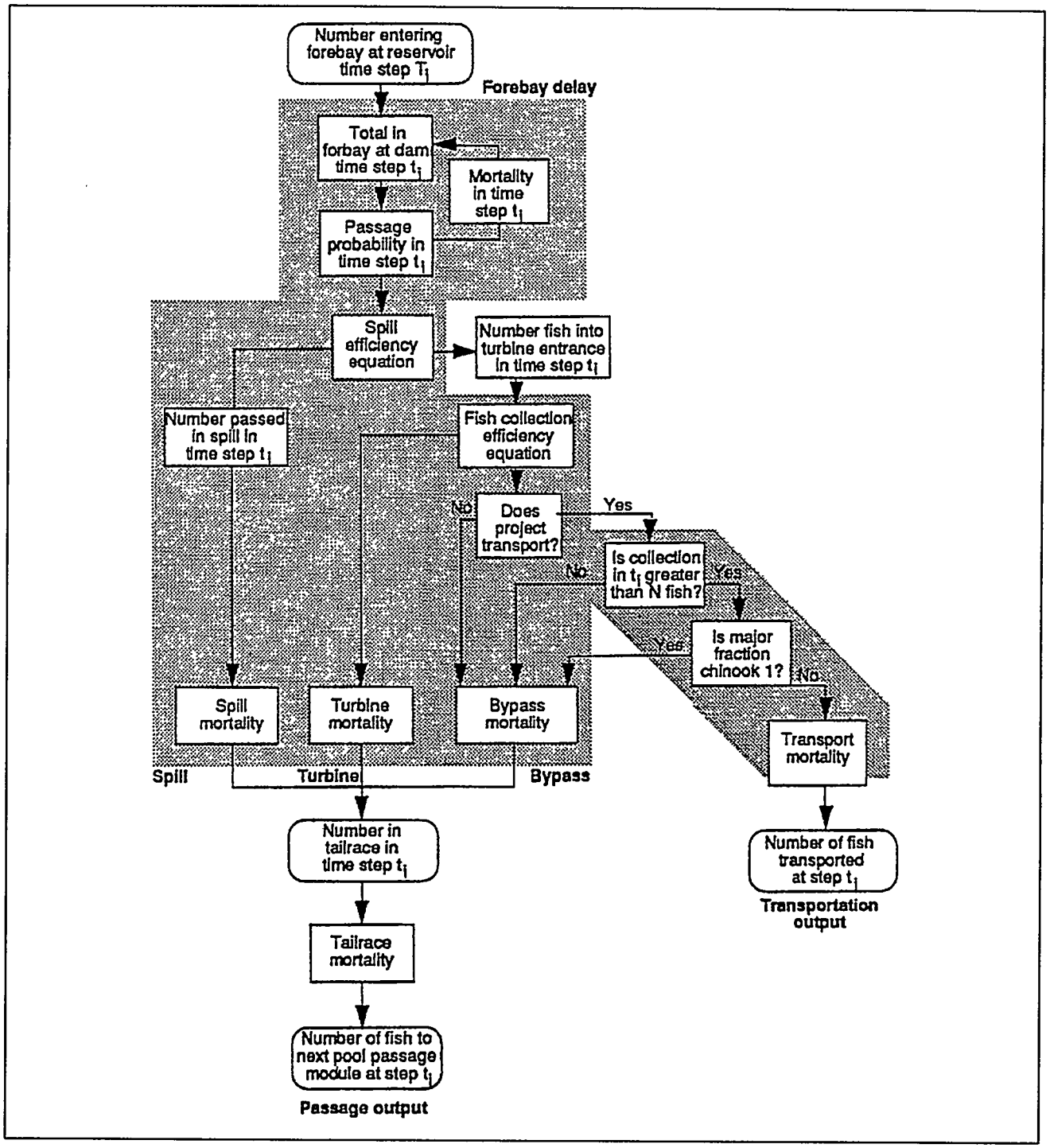


Figure 3–2. Dam Passage Module of CRiSP1.5

Dam Passage Parameters

There are three categories of dam passage parameters in CRiSP1.5. These are: passageway survivals, fish guidance efficiency (FGE), and spillway efficiency. The passageway survivals are the survival values for the smolts through the spillway, the bypass system, and the turbines. FGE is an estimate of the proportion of smolts that approach the turbines that are guided into the bypass system.

The FGE values adopted for the SOR Final EIS analysis are generally consistent with those selected for use in NMFS' 1995 Biological Opinion (BO) analysis. In the SOR Draft EIS, FGE estimates were based on Fyke net studies performed over the last decade. That information has recently been called into question during the NMFS' 1995 BO analysis. With the advent of the recent NMFS/UW survival studies, independent estimates of FGE, based on PIT tag recapture models, indicate that FGEs may be lower at Lower Granite, Little Goose, and Lower Monumental dams than those as measured with Fyke nets.

On the average, this represents about a 20 percent reduction in FGE relative to Fyke net measures. For the SOR Final EIS, this 20 percent is applied to all lower Columbia and Snake rivers dams as well.

Spillway efficiency is the proportion of smolts that is diverted into the spillway, relative to the proportion of flow that is being spilled. Tables 3–3 through 3–7 present the dam passage parameters for all the alternatives.

Dam passage parameters for the Flow Control alternatives are based on currently available information.

Because no information is available on how well smolts would be guided past dams under the Drawdown and certain Combination (spillway crest drawdown) alternatives, two sets of assumptions have been modeled: Optimistic passage values that assume FGEs would increase by 25 percent, and Pessimistic passage values that assume FGEs would decrease by 50 percent. See Tables 3–5 and 3–6 for FGE values based on these assumptions. Optimistic and Pessimistic assumptions for the Drawdown and Combination alternatives were developed by the Technical Advisory Group as part of the analysis for drawdown studies being done by the Corps for their System Configuration Study. These assumptions are used only for the Snake River dams; all other mainstem dams have the same FGE values as the Flow Control alternatives.

The entire river is bypassed around the dam under the Natural River alternatives, and, therefore, dam passage survival and FGE equal 100 percent.

Because the Combination alternative 9b and the Preferred Alternative specify only a moderate drawdown, the dam passage parameter values are identical to those for the Flow Control alternatives.

Table 3–3. Dam Passage Survival Percentages – mean and (range)

	Spillway Survival	Bypass Survival	Turbine Survival
FLOW CONTROL/COMBINATION 9b/ Preferred Alternative	98 (100–93)	98 (100–92)	89 (99–84)
DRAWDOWN/COMBINATION (9a, 9c) – OPTIMISTIC	98 (100–93)	98 (100–92)	98
DRAWDOWN/COMBINATION (9a, 9c) – PESSIMISTIC	93 (100–72)	98 (100–93)	76
NATURAL RIVER	100	100	100

Table 3–4. Fish Guidance Efficiency Percentages for Flow Control and Combination (9b & PA) Alternatives – mean and (range)

DAM	Spring Chinook	Fall Chinook	Steelhead
Lower Granite	46 (26–66)	35 (20–40)	76 (43–91)
Little Goose	45 (40–67)	35 (20–40)	81 (63–90)
Lower Monumental	52 (46–57)	31 (29–35)	76 (55–83)
Ice Harbor	54 (51–61)	31 (29–35)	92 (88–95)
Wells	96 (95–97)	96 (95–97)	96 (95–97)
McNary	56 (29–73)	40 (10–81)	62 (58–67)
John Day	58 (44–62)	26 (13–54)	86 (78–95)
The Dalles*	34 (18–41)	43 (23–51)	43 (23–51)
Bonneville (First Powerhouse)	30 (23–37)	15 (15–15)	78 (50–100)

* Sluiceway Fish Guidance Efficiency

Table 3–5. Fish Guidance Efficiency Percentages at Lower Snake River Dams for Drawdown and Combination (9a & 9c) Alternatives with Optimistic Dam Passage Assumptions – mean and (range)

DAM	Spring Chinook	Fall Chinook *	Steelhead
Lower Granite	58 (38–83)	44 (25–50)	95 (54–100)
Little Goose	56 (50–84)	44 (25–50)	100
Lower Monumental	65 (58–71)	39 (36–44)	95 (69–100)
Ice Harbor	68 (64–76)	39 (36–44)	100

Table 3–6. Fish Guidance Efficiency Percentages at Lower Snake River Dams for Drawdown and Combination (9a & 9c) Alternatives with Pessimistic Dam Passage Assumptions – mean and (range)

DAM	Spring Chinook	Fall Chinook *	Steelhead
Lower Granite	23 (13–33)	18 (10–20)	38 (22–46)
Little Goose	23 (20–34)	18 (10–20)	41 (32–45)
Lower Monumental	26 (23–28)	16 (15–18)	38 (28–42)
Ice Harbor	27 (26–31)	16 (15–18)	46 (44–48)

* Under Alternative 9c, optimistic and pessimistic values are not used since project are refilled by the time out migration occurs.

Table 3–7. Spillway Efficiencies

FLOW CONTROL/COMBINATION (9b & PA)	Percent Passage – All stocks
Lower Granite	(1.0 x % spill)
Little Goose	(1.0 x % spill)
Lower Monumental	(1.2 x % spill)
Ice Harbor	(1.0 x % spill)
Wells	N/A (See Table 3–4)
Rocky Reach	(0.663 x % spill)
Rock Island	$(\%\ \text{spill} \times 100)^{1.0437}/100$
Wanapum	$(15.52 \times \ln(\%\ \text{spill} \times 100)/100)$
Priest Rapids	$e^{(0.819 \times \ln(\%\ \text{spill} \times 100))}/100$
McNary	(1.0 x % spill)
John Day	(1.0 x % spill)
The Dalles	(2.0 x % spill)
Bonneville	(1.0 x % spill)

Reservoir Survival Assumptions

Reservoir survival in CRiSP1.5 is a function of the amount of time a smolt remains in the reservoir. The longer a smolt migrates through the reservoir the greater the exposure to predators and high levels of dissolved gases, if present. Travel time through a reservoir depends on daily river flow and smolt behavior. Mortality rates are then determined from travel time, predator activity, and gas supersaturation levels. Figure 3–3 is a flow chart of the reservoir survival process in CRiSP1.5.

Predation

The rate at which smolts are consumed by predators (such as northern squawfish, bass and walleye) is a function of predator density, water temperature, predator activity levels, and smolt travel time. Each reservoir, tailrace, and forebay has a characteristic density of predators. (Table 3–8.) The rate at which smolts are consumed in the different regions of the reservoir is a function of predator activity which is influenced by water temperatures.

Predation parameter values remain constant for all but the pessimistic cases of the drawdown alternatives. Under pessimistic drawdown assumptions, it is assumed that predation densities are a function of reservoir volume. Therefore, as reservoir volumes decrease under drawdown, predator densities increase proportionally, resulting in higher consumption of smolts.

Gas Supersaturation Effects

When water plunges over spillways, it often entraps air, causing the water to be supersaturated with dissolved atmospheric gases, primarily nitrogen. Smolts exposed to high concentrations of dissolved gases for long periods of time experience a condition known as gas bubble trauma, which can be fatal. CRiSP1.5 accounts for the loss of these smolts in a gas bubble mortality function as part of the reservoir mortality calculation. Mortality is expressed as a

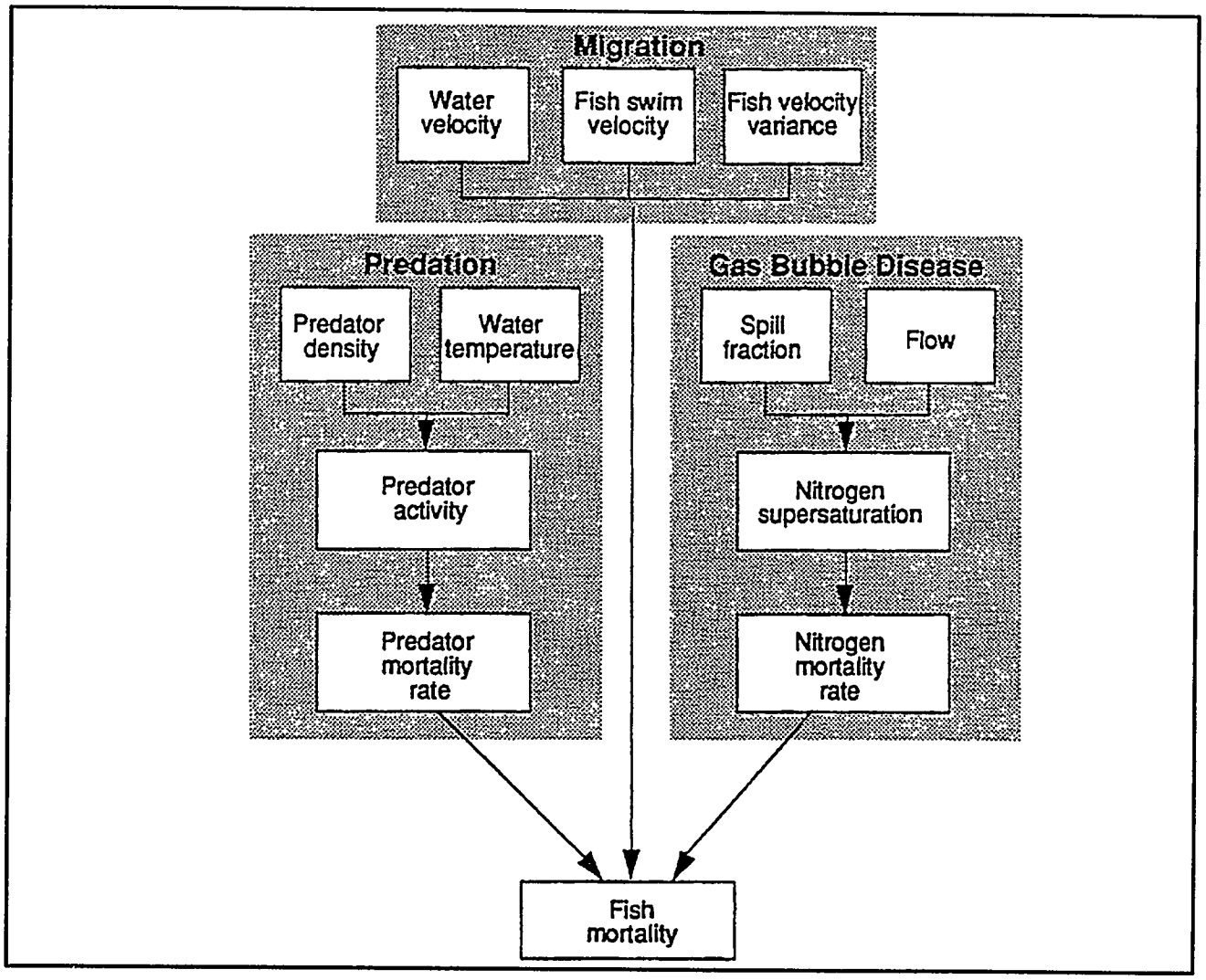


Figure 3–3. Reservoir Passage Module in CRiSP1.5

Table 3–8. Predator Densities

	Predator Density (predators/km^2) (Ward and Peterson (in press))		
Dam	Reservoir	Tailrace	Forebay
BON	824	1456	2042
TDA	635	1398	614
JDA	480	1029	512
MCN	489	909	442
IHR	455	594	429
LMO	550	1192	509
LGS	471	1735	505
LGR	419	1414	484

proportion of smolts that die each day. The mortality rate is a function of the total dissolved gas level (which is a function of flow and spill volume), the number of smolts present, and the amount of time the smolts are exposed to dissolved gas levels in excess of 110 percent saturation.

CRiSP1.5 calculates dissolved gas levels in the reservoirs in a similar manner to the Corps' GAS-SPILL model.

Because of the complexity of the equations and parameters associated with reservoir mortality, see Anderson et al. 1995, for a complete detailed description of model structure and parameters.

3.2.1.3 Key Uncertainties

While smolt passage modeling allows the AFWG to compare survival among the alternatives, much uncertainty exists concerning the ability of the models to accurately predict the actual smolt survival through the hydrosystem to below Bonneville Dam. Following is a discussion of some of the key uncertainties associated with the ability of the models to predict actual smolt survival.

System Survival Estimates

There is considerable uncertainty surrounding historical estimates of smolt survival through the hydrosystem that are used to calibrate smolt passage models, either as a basic relationship or as a form of validation of model predictions. There are no reliable, recent, and reviewed estimates of smolt survival through any reach of the Snake or Columbia rivers that can be used to empirically estimate total smolt survival through the hydrosystem.

Although such estimates may soon become available as researchers more fully exploit the capabilities of PIT tag technology, the models currently rely on limited and suspect survival estimates made during the 1970s.

These system survival estimates are available for yearling (spring and summer) chinook and steelhead smolts through the lower Snake River and a portion of the Columbia River. However, there is evidence that the estimates were not made with sound scientific methodology, a methodology subsequently abandoned in 1982 (Giorgi 1993; Steward 1994). Even though estimates of potential error are lacking, these hydrosystem survival estimates from the 1970s form the basis for quantifying the relationship between smolt survival and river flow that is broadly applied in the Snake and Columbia rivers.

Currently, all smolt passage models, including those employed in SOR, rely on empirical estimates of reach survival to either derive estimates of reservoir mortality that are used to construct flow and mortality relationships or as a means to validate mechanistic models.

Apart from the general failure to characterize the uncertainty inherent in the data and analyses, there is another limitation to the application of historical survival estimates today: the data were acquired 10 to 25 years ago in a different and changing hydrosystem. During the 1970s and since then, dams have been built, and physical structures and dam operations have been greatly modified. Bypass systems, turbine screens, transportation facilities, and flip lips to control dissolved gas have been installed and redesigned. Spill and water management programs have evolved and been implemented.

The ecology of the reservoirs, which may be responsible for most of the hydrosystem mortality of smolts, has probably changed too. The number of hatchery smolts leaving the Columbia River basin has greatly increased, which may have led to increased competition with, and disease transmission to, wild smolts. The population structure of predatory fish has also changed over the years.

Finally, no statistically sound reach survival estimates are available for either sockeye or subyearling (fall) chinook smolts through any segment of the Snake or Columbia rivers. Therefore, the relevance of historical estimates of smolt survival in today's mainstem ecosystem is questionable.

Dam Passage Survival

A proportion of the smolt mortality in a single dam and pool reach is incurred during dam passage. However, few empirical estimates of mortality induced by dam passage exist. Estimates from a small number of Columbia River dams have been adopted and applied uniformly at all dams, even though it is almost certainly true that mortality incurred through turbines, spillways and bypasses varies with species, water conditions, fish condition, dam, and a host of other factors.

The AFWG analysis focuses on evaluating the relative benefits of various operational flow alternatives, including flow augmentation and drawdown scenarios, that affect the magnitude of reservoir mortality. Thus, properly apportioning smolt mortality among reservoirs and dams is a fundamental and important process.

For example, research has shown that smolts using a bypass system incur an average of about 2 percent mortality, while those that pass through the turbines sustain mortality of about 10 percent (values adopted for modeling in SOR). However, other research has shown that subyearling chinook survival through the turbines was found to be higher than survival through other routes at the Bonneville Dam Second Powerhouse (Ledgerwood et al. 1990). This investigation was the most comprehensive conducted at any mainstem Columbia or Snake river dam and includes measures of both direct and indirect effects of dam passage. The study underscores the need to evaluate the relative survival of smolts passed through various routes at other dams.

Gas Supersaturation Effects

The CRiSP1.5 gas mortality function is calibrated to laboratory studies (Dawley et al. 1976), as no field experiments relating gas supersaturation to smolt mortality at the Columbia and Snake river dams have been performed. There is evidence that levels of dissolved gas that are lethal to smolts in a laboratory are safely tolerated by migratory smolts (Weitkamp and Katz, 1980).

In CRiSP1.5 there is a small mortality rate at low gas saturations which increases slowly until a critical level of saturation (120 percent) is reached, above which point the mortality rate increases sharply in a linear fashion.

CRiSP1.5 also accounts for fish distribution in the pool. If gas concentration is roughly equal through the water column, fish higher in the water column will experience gas bubble formation due to lower atmospheric pressure and thus a higher mortality, while those fish lower in the column will experience lower mortality. Version 1.5 of the model includes a fish depth distribution, which, together with the threshold mortality rate function, determines the total mortality rate on the stock.

Gas supersaturation may also relate to the issue of fish guidance. Fish guidance systems are designed to intercept smolts traveling in the upper portion of the water column; if smolts have sounded to avoid supersaturated conditions in the reservoir, it may have an effect on the ability of the guidance system to intercept fish.

No research presently exists on gas supersaturation as it relates to fish guidance.

For additional information about the effects of dissolved gas on smolts, please see Technical Exhibit C, SOR Draft EIS.

Wild Smolt Behavior

Field observations of the migration behavior of wild smolts are limited. Most of the observations of migratory smolt behavior, especially migration speed, have been made on either the general population of outmigrating smolts, which is overwhelmingly composed of hatchery smolts, or on hatchery smolts specifically. However, ESA considerations are directing mitigation activities at wild populations. Migration speed and timing, behavioral characteristics, and, therefore, overall hydrosystem survival of wild smolts almost certainly differ from those of hatchery smolts. For example, recent measurements of migration timing of wild Snake River spring and summer chinook smolts show a difference in timing of outmigration, travel time, and size of wild and hatchery smolt populations in most years; yet these populations are modeled with essentially the same parameters in the smolt passage models.

3.2.2 Juvenile Transportation Survival Modeling

3.2.2.1 Transportation Modeling Description

It is possible that the transportation of smolts downstream from collector facilities in trucks and barges causes mortality from such things as high levels of stress on the juveniles from collection and transportation, and from diseases transmitted horizontally through the transportation conveyances. Delayed mortality from the process may also affect the long–term vitality of the populations. These biological uncertainties raise the question of whether or not to continue transporting fish, and/or under what in–river conditions.

In order to shed light on this issue, a model–based transportation sensitivity analysis is presented in Chapter 5. It examines several transportation survival theories and compares estimates of survival with transport based on these theories with estimates of in–river migration survival.

Survival with transport is compared with in–river survival across 12 alternatives. Of the 13 alternatives analyzed for the SOR Final EIS, only alternative 9a assumes no transportation component whatsoever.

In order to compare estimates of survival with transport to in–river migration survival under alternative hydrosystem operations, two methods for estimating juvenile transportation survival have been developed.

The first method is based soley on observed barge survival and assumes that transportation survival is constant at 98 percent to a release point below Bonneville Dam. This is based on tests with Snake River spring, summer, and fall chinook, and Dworshak Hatchery steelhead only. In the SOR Final EIS, however, the fixed barge survival hypothesis has been applied to all stocks being analyzed with the exception of Rock Creek steelhead and Deschutes spring chinook, since they are not transported.

The second method for estimating transportation survival is based on what is called the Transport/In–river Ratio (TIR). In the SOR Draft EIS, the terms used were TBR (Transport/Benefit Ratio) and TCR (Transport/Control Ratio). These terms were replaced with the term TIR because public comments were received objecting that the use of the terms TBR or TCR implied a regional endorsement of the Corps' Juvenile Fish Transportation Program as an effective means of improving juvenile survival through the hydrosystem.

The TIR is a ratio of the number of returning adults (to a given location) from a transported group of marked juveniles to the number of returning adults (to the same location) from a "control" group of marked juveniles released to migrate in river:

$$\text{TIR} = \frac{\text{returning \% of "transported" adults}}{\text{returning \% of "control" adults}}$$

Assuming that adult returns reflect juvenile survival, it follows that:

$$\frac{\text{returning \% "transported" adults}}{\text{returning \% "control" adults}} = \frac{\text{juvenile transportation survival}}{\text{juvenile "control" survival}}$$

therefore:

juvenile transportation survival = TIR x juvenile "control" survival

Some fishery biologists suggest that every year produces a unique set of both in–river and transportation survivals. Others suggest that TIRs are a measure of in–river passage survival and that transport survival should be fixed to the observed barge survival of 98 percent.

In fact, the TIR studies were not designed to determine juvenile transportation survival. However, due to the lack of other information, TIRs have been used in this analysis to derive estimates of juvenile transportation survival. Over the last 15 years, during which the hydrosystem has changed considerably, the small sizes of the fish runs and a series of low flow years have prevented the marking of enough fish for collection of valid TIR data in most years. The only complete TIR data are from the years 1986 and 1989. However, the CRiSP1.5 analysis for the SOR Final EIS does not use the 1989 fixed transportation survival estimate since it is very close to the value used for fixed barge survival, i.e., the 1989 transportation survival estimate is 100 percent and the fixed barge survival estimate is 98 percent.

The following transportation survival hypotheses attempt to account for any differential mortality transported juveniles may experience in the estuary and during early ocean residence compared to in–river migrants. They account for the difference in adult return rates as a function of juvenile survival.

3.2.2.2 Transportation Modeling Assumptions and Parameters

Derived Fixed Transportation Survival Estimates Based on TIRs

Modeled Stocks: Snake River Spring & Summer Chinook and Dworshak Hatchery Steelhead

This analysis assumes that transportation survival estimates do not vary with flow, or with the location from which the juveniles are collected. Once a juvenile is loaded into the barge, it is assumed to survive at a fixed rate regardless of flow and location of collection. Table 3–9 shows the 1986 TIRs used in the SOR Final EIS analysis.

For Snake River fall chinook, the 1986 transportation survival estimates exceed 100 percent. Since transportation survival in reality cannot exceed 100 percent, either the TIR (which is an empirically generated number), the in–river survival (which is a model–generated number), or both are incorrect. It is more likely that the in–river survival estimate would be in error. For this reason the derived transport survival for Snake River fall chinook has been set at the Fixed Barge Survival rate of 98 percent.

The SOR Draft EIS included a 1989 TIR, the SOR Final EIS does not. As stated earlier, because the 1986 and 1989 derived transport survival for Snake River spring and summer chinook and Dworshak steelhead are so similar, only the 1986 fixed transport survival is used in the SOR Final EIS.

Derived Fixed Transportation Estimates Based on Adjusted TIR Values

Modeled Stock: Snake River spring chinook

TIRs have been challenged as to their accuracy in representing the population at large. Several explanations have been offered by the CBFWA Ad Hoc committee (Olney et at. 1992). These explanations include:

- TIR studies are not designed to investigate adult returns to the hatcheries and spawning grounds but only to investigate adult returns to the dams where they were originally tagged. There is no accounting for presumed additional mortality of adults that had been subjected to transportation as juveniles, as they migrate beyond the dams on their way to hatcheries and spawning grounds;
- TIR studies do not isolate the effects of transportation on wild and hatchery fish;
- TIR "control" groups are not representative of other in–river migrants because the "controls" were trucked to below Little Goose Dam before being released to migrate in–river.

Because of these concerns, the AFWG adjusted the 1986 TIR value downward to 0.7:1 for spring chinook to account for any biases produced by the TIR study methods (Table 3–10). (For a discussion of the assumptions relating to JFTP survival, see SOR Draft EIS, Appendix C2, Technical Exhibit I, Assumptions Underlying the Evaluation of the Juvenile Fish Transportation Program.)

Derived Variable Transportation Survival Estimates Based on 1977 and 1986 TIRs

Modeled stock: Snake River spring chinook

The variable transport theory assumes that in a low flow year transportation survival is lower because juveniles arriving at the dams for collection and transportation are in poorer condition than juveniles arriving in higher flow years. Juveniles arrive in weakened and/or injured condition and are less likely to survive in the short– or long– term. The

NPPC incorporated this theory in their Model 2 analysis for their Rebuilding Schedules and Biological Objectives (McConnaha et al., 1992).

For their Model 2 analysis, the NPPC arbitrarily assumed a TIR of 3:1 in 1977, a record low water year, for spring chinook migrating from Little Goose Dam. Transport survival is then assumed to vary linearly with flow until it reaches the 1986 estimate, after which it remains constant.

It is important to note that the 1977 TIR is an arbitrary value with no empirical basis. In 1977, both the hydrosystem and fish passage facilities were operated considerably differently than they are today. Trash racks in front of the dams were not cleared of debris prior to smolt migration making it difficult for smolts to pass the dams. Turbines were operated outside of peak efficiencies, predator concentrations may have been higher, handled smolts were not anesthetized as is done now to reduce stress.

Furthermore, in the analysis for the SOR Final EIS, CRiSP1.5 could not reconcile the TIR assumed for 1977 with the in–river survival predicted by CRiSP1.5 to yield an absolute transport survival less than the estimated survival for 1986, which the hypothesis requires. As a consequence, it was impossible to evaluate overall system survival using the Variable Flow Transport Hypothesis.

While it is impossible to predict absolute survival with transport for this hypothesis, it is possible to graphically compare in–river survival across the alternatives with transport survival. A comparison of the lines representing in–river survival for all modeled stocks across all alternatives with the curve representing variable transport survival shows higher survivals for transported smolts for all but the lowest water years.

See SOR Draft EIS, Appendix C2, Chapter 4, for graphs showing in–river survival compared with transport survival using the Variable Transport Survival Hypothesis.

3.2.3 Spreadsheet Calculation of Overall Juvenile Passage Survival Estimates

A spreadsheet calculation is used to estimate overall downstream juvenile survival to below Bonneville Dam, with transportation, for each of the alternative hydrosystem operating strategies. The calculation is based on the 49–year water record used by CRiSP1.5. The analysis uses the in–river survival estimates generated from CRiSP1.5 along with the number of juveniles collected at each dam for transportation.

Table 3–9. CRiSP1.5 Fixed (1986) Transport Survival

Stock	1986 "Control" Survival	1986 TIR	Derived Transport Survival
Snake River Spring & Summer Chinook & Methow Spring Chinook	48 %	1.6:1	76 %
Dworshak Hatchery Steelhead & Wenatchee Steelhead	45 %	2:1	90 %

Table 3–10. CRiSP1.5 1986 Adjusted Transport Survival

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

It is then possible to use the spreadsheet to apply any one of the transportation survival theories described above to the number of transported juveniles to determine the number of juveniles that survive transportation. By taking a weighted average of the number of juveniles surviving in–river migration plus the number of fish surviving transportation and dividing that number by the total number of fish that began the outmigration, it is possible to determine overall juvenile survival with the JFTP in place. The results of this analysis are presented in Chapter 5, Tables 5–1 through 5–10.

3.2.4 Adult Returns: Stochastic Life Cycle Model (SLCM)

3.2.4.1 SLCM Description

SLCM simulates the entire life cycle of Pacific salmon and steelhead in the Columbia River basin using a yearly time step. The model is designed to mimic basic mechanisms – such as changes in juvenile recruitment or the number of smolts – that regulate populations of salmon and steelhead.

SLCM can be thought of as a series of compartments corresponding to stages within the life cycle of salmon and steelhead stocks. Transitions from one 'compartment' to the next determine the model's dynamics. At each transition, draws from a probability distribution determine the survival of fish from one stage to the next. For instance, the number of smolts surviving hydrosystem passage, and thus entering the ocean stage, is determined from a survival distribution produced from CRiSP1.5 fish passage output. The probability distributions capture some of the variation in survival in each life cycle stage that naturally occurs due to many factors such as fluctuating weather conditions. Figure 3–4 is a flow chart of the life cycle stages and the probability distributions used to transition between them.

Each population is divided into hatchery and natural stocks. The natural stock consists of fish spawned in the wild and hatchery–produced juveniles that are released as fry, regardless of the origin of their parents. The hatchery stock consists of all fish spawned in the hatchery and released as smolts. In practice, however, hatchery fish share identical parameters with wild fish once they leave the hatchery.

SLCM also simulates the populations on a brood–specific basis. Thus, individual broods of fish are tracked throughout their life cycle. This differs from the smolt passage model that operates on a calendar–year basis. Additional information for each life cycle stage is presented in Technical Exhibit A.

In addition to these biological parameters, a set of control parameters determines the number of games within each simulation, the number of years per game, which production function the modeler chooses, and other logistical information. The user must also specify initial numbers of fish for each life stage. Then, based on repeated sampling, SLCM generates its outcomes.

SLCM generates a wide variety of variables. Because of the stochastic nature of the model, each game using the same set of parameters will produce a different outcome, rendering the results of a single game of little value. Running multiple games and analyzing the outcome collectively is much more meaningful to the modeler. By doing so, the user produces a frequency distribution for each simulation year for a variety of variables, such as subbasin escapement or the number of natural spawners in the population. In the case of SLCM, the outcome is presented in the form of a database, allowing the user to plot or graph the information.

For a more detailed description of SLCM, please refer to Lee and Hyman (1992) and Fisher et al. (1993).

3.2.4.2 SLCM Assumptions and Parameters

There are two steps required to develop parameters for the SLCM analysis. First, values for most of the model parameters must be estimated from the literature, opinions of experts, other models, and other sources of data. Second, the remaining parameters in the model are calibrated to estimates of numbers of returning adults over some historical time period.

The only SLCM parameter that changes with system operations in this analysis is smolt passage survival. All other life cycle parameters such as rearing survival in the tributaries and harvest rates remain constant, since the objective of the SOR analysis is to examine the effects of hydrosystem operations only, in isolation from other actions which affect anadromous salmonid populations. A list of the parameter values and the calibration information for each stock is presented in Technical Exhibit A.

3.3 QUALITATIVE METHODS

3.3.1 Alternatives to Transportation, and Alternative Methods and Modes of Transportation

Transportation alternatives analyzed in the qualitative analysis section relate to various strategic, tactical, and technological aspects of transportation. They were evaluated by reviewing reconnaissance–level studies and other research.

Strategic alternatives to transportation include such alternatives as bypassing all fish in–river or removing the dams. Tactical and technological alternative methods of transportation include, respectively, such things as transporting varying percentages of the total juvenile migration, and the use of such transportation conveyances as net pens or airplanes.

3.3.2 In–river Survival – Non–salmonids

3.3.2.1 Shad and Lamprey

Models for shad and lamprey have not been developed for this region. Therefore, AFWG members evaluated the effects of system operation alternatives on the basis of expert opinion on the relationship between life cycle activities and river flow, spill, and reservoir elevation.

3.3.2.2 Sturgeon

Models for sturgeon have not been developed. For sturgeon below Bonneville Dam – the only sturgeon populations that remain anadromous – AFWG members evaluated the effects of system operation alternatives on the basis of expert opinion on the relationship between life cycle activities and river flow, spill, and reservoir elevation.

The Resident Fish Work Group is evaluating sturgeon populations above Bonneville Dam.

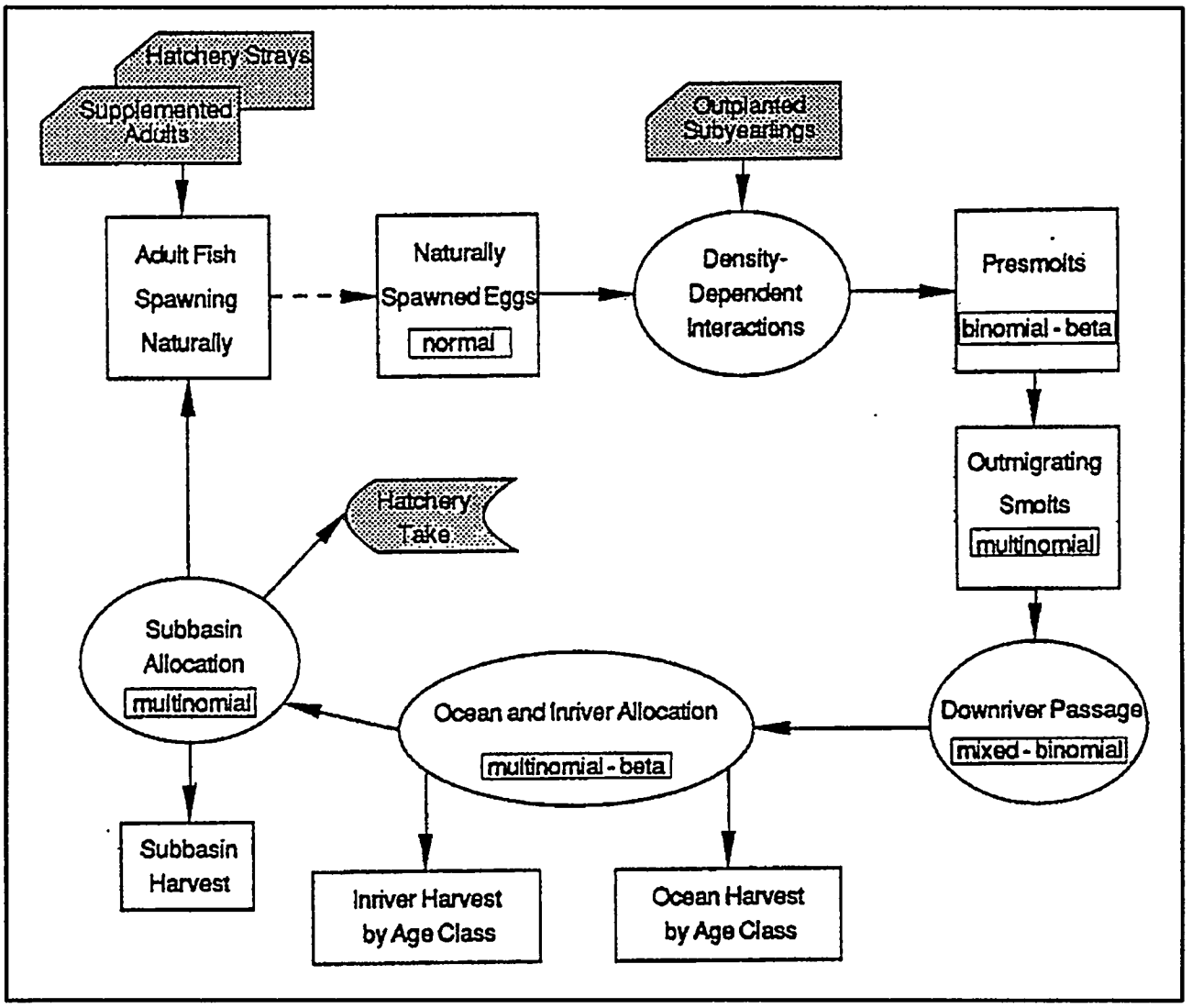


Figure 3–4. Flow Chart for SLCM. At each life cycle stage, the survival to the next stage is drawn from the stated probability distribution (*e.g.*, a normal distribution is used to simulate the transition from spawners to the egg stage).

3.4 LITERATURE REVIEW AND EVALUATION

In the preparation of this document, the authors have reviewed extensive quantities of literature on the historic aspects of the JFTP, and on research into the various aspects of the program or related activities that affect the program or could provide information to support or counter continuance of the program. Where cited in this report, literature is annotated and listed in the literature cited section of the report. As evidence of the quantity of research that has been conducted in relation to the fish passage problems at the dams, research has been listed in the SOR Draft EIS, Appendix C2, Technical Exhibit C.

CHAPTER 4

DESCRIPTION OF ALTERNATIVES

4.1 GENERAL DESCRIPTION OF ALTERNATIVES

Seven alternative System Operating Strategies (SOS) were considered in the Draft EIS. Each of the 7 SOSs contained several options, bringing the total number of alternatives considered to 21. This Final EIS also evaluates 7 operating strategies, with a total of 13 alternatives now under consideration when accounting for options. Section 4.1 of this chapter describes the 13 alternatives and provides the rationale for including these alternatives in the Final EIS. Operating elements for each alternative are summarized in Table 4–1. Later sections of this chapter describe the effects of these alternatives on anadromous fish.

The 13 final alternatives represent the results of the third analysis and review phase completed since SOR began. In 1992, the agencies completed an initial effort, known as "Screening" which identified 90 possible alternatives. Simulated operation for each alternative was completed for five water year conditions ranging from dry to wet years, impacts to each river use area were estimated using simplified analysis techniques, and the results were compared to develop 10 "candidate SOSs." The candidate SOSs were the subject of a series of public meetings held throughout the Pacific Northwest in September 1992. After reviewing public comment on the candidate strategies, the SOR agencies further reduced the number of SOSs to seven. These seven SOSs were evaluated in more detail by performing 50–year hydroregulation model simulations and by determining river use impacts. The impact analysis was completed by the SOR workgroups. Each SOS had several options so, in total, 21 alternatives were evaluated and compared. The results were presented in the Draft EIS, published in July, 1994. As was done after Screening, broad public review and comment was sought on the Draft EIS. A series of nine public meetings was held in September and October 1994, and a formal comment period on the Draft EIS was held open for over 4 1/2 months. Following this last process, the SOR agencies have again reviewed the list of alternatives and have selected 13 alternatives for consideration and presentation in the Final EIS.

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

The 13 alternatives have been evaluated through the use of a computerized model known as HYDROSIM. Developed by BPA, HYDROSIM is a hydroregulation model that simulates the coordinated operation of all projects in the Columbia River system. It is a monthly model with 14 total time periods. April and August are split into two periods each, because major changes can occur in streamflows in the first and second half of each of these months. The model is based on hydrologic data for a 50–year period of record from 1928 through 1978. For a given set of operating rule inputs and other project operating requirements, HYDROSIM will simulate elevations, flows, spill, storage content and power generation for each project or river control point for the 50–year period. For more detailed information, please refer to Appendix A, River Operation Simulation.

The following section describes the final alternatives and reviews the rationale for their inclusion in the Final EIS.

Table 4–1. SOS Alternative–1

Summary of SOS

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

Actions by Project

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

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

Table 4–1. SOS Alternative–1

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

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

1 kcfs = 28 cms

1 ft = 0.3048 meter

Table 4–1. SOS Alternative–2

Actions by Project

HUNGRY HORSE

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

ALBENI FALLS

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

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

Table 4–1. SOS Alternative–2

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

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

1 kcfs = 28 cms

1 ft = 0.3048 meter

Table 4–1. SOS Alternative–3
Actions by Project

GRAND COULEE

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

PRIEST RAPIDS

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

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

Table 4–1. SOS Alternative–3

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

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

1 kcfs = 28 cms

1 ft = 0.3048 meter

Table 4–1. SOS Alternative–4

Actions by Project

SNAKE RIVER ABOVE BROWNLEE

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

BROWNLEE

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

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

Table 4–1. SOS Alternative–4

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

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

1 kcfs = 28 cms

1 ft = 0.3048 meter

Table 4–1. SOS Alternative–5

Actions by Project

	SOS 1	SOS 2	SOS 4
DWORSHAK	**SOS 1a** • Draft up to 600 KAF in May to meet Water Budget target flows of 85 kcfs at Lower Granite • Provide system flood control storage space **SOS 1b** • Meet minimum project flows (2 kcfs, except for 1 kcfs in August); summer draft limits; maximum discharge requirement Oct. to Nov. (1.3 kcfs plus inflow) • No Water Budget releases	**SOS 2c** Same as SOS 1a, plus the following supplemental releases: • 900 KAF or more from April 16 to June 15, depending on runoff forecast at Lower Granite • Up to 470 KAF above 1.2 kcfs minimum release from June 16 to Aug. 31 • Maintain 1.2 kcfs discharge from Oct. through April, unless higher required • Shift system flood control to Grand Coulee April–July if runoff forecasts at Dworshak are 3.0 MAF or less **SOS 2d** • Operate on 1.2 kcfs minimum discharge up to flood control rule curve, except when providing flow augmentation (April 10 to July 31) • Provide flow augmentation of 1.0 MAF plus 1.2 kcfs minimum discharge, or 927 KAF and 1.2 kcfs, from April 10-June 20, based on runoff forecasts, to meet Lower Granite flow target of 85 kcfs • Provide 470 KAF from June 21 to July 31 to meet Lower Granite flow target of 50 kcfs • Draft to 1,520 feet after volume is expended, if Lower Granite flow target is not met; if volume is not expended, draft below 1,520 feet until volume is expended	**SOS 4c** Elevation targets established for each month: 1,599 feet Sept.-Oct.; flood control rule curves Nov.-April; 1,595 feet May; 1,599 feet June-Aug.;

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

Table 4–1. SOS Alternative–5

SOS 5

SOS 5b

- Operate to local flood control rule curve
- No proportional draft for power
- Shift system flood control to lower Snake projects
- Provide Water Budget flow augmentation as in SOS 1a
- Draft to refill lower Snake projects if natural inflow is inadequate

SOS 5c

- Operate to flood control during spring
- Refill in June or July and maintain through August
- Draft for power production during fall

SOS 6

SOS 6b

Same as SOS 5b

SOS 6d

Same as SOS 5b

SOS 9

SOS 9a

- Remove from proportional draft for power
- Operate to local flood control rule curves, with system flood control shifted to Grand Coulee
- Maintain flow at 1.2 kcfs minimum discharge, except for flood control or flow augmentation discharges
- Operate to meet Lower Granite flow targets (at spillway crest) of 74 kcfs April 16-June 30, 45 kcfs July, 32 kcfs August

SOS 9b

- Similar to SOS 9a, except operate to meet flow targets at Lower Granite ranging from 85 to 140 kcfs April 16-June 30 and 50-55 kcfs in July
- Can draft to meet flow targets to a min. end-of-July elevation of 1,490 feet

SOS 9c

- Similar to SOS 9a, except operate to meet Lower Granite flow target (at spillway crest) of 63 kcfs April-June
- Can draft to meet flow targets to a min. end-of-July elevation of 1,520 feet

SOS PA

SOS PA

- Operate on minimum flow-up to flood control rule curve year-round, except during flow augmentation period
- Draft to meet flow targets, down to min. end-of-Aug. elevation of 1,520 feet
- Sliding-scale Snake River flow targets at Lower Granite of 85 to 100 kcfs April 10-June 20 and 50 to 55 kcfs June 21-Aug. 31, based on runoff forecasts

1 kcfs = 28 cms

1 ft = 0.3048 meter

Table 4–1. SOS Alternative–6

Actions by Project

	SOS 1	SOS 2	SOS 4
LOWER SNAKE	**SOS 1a** • Normal operations at 4 lower Snake River projects (within 3 to 5 feet of full pool, daily and weekly fluctuations) • Provide maximum peaking capacity of 20 kcfs over daily average flow in May	**SOS 2c** • Operate reservoirs within 1 foot above MOP from April 16 to July 31 • Same as SOS 1a for rest of year	**SOS 4c** Same as SOS 2c
	SOS 1b Same as 1a, except: • No minimum flow limit (11,500 cfs) during fall and winter • No fish-related rate of change in flows in May	**SOS 2d** Same as SOS 2c	
LOWER COLUMBIA	**SOS 1a** • Normal operations at 4 lower Columbia projects (generally within 3 to 5 feet of full pool, daily and weekly fluctuations) • Restricted operation of Bonneville second powerhouse	**SOS 2c** Same as SOS 1a except: lower John Day to minimum irrigation pool (approx. 262.5 feet) from April 15 to Aug. 31; operate within 1.5 feet of forebay range, unless need to raise to avoid irrigation impacts	**SOS 4c** Same as SOS 2c, except operate John Day within 2 feet of elevation 263.5 feet Nov. 1 through June 30
	SOS 1b Same as 1a, except no restrictions on Bonneville second powerhouse	**SOS 2d** Same as SOS 2c	

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

Table 4–1. SOS Alternative–6

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

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

1 kcfs = 28 cms

1 ft = 0.3048 meter

4.1.1 SOS 1-Pre–ESA Operation

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

- **SOS 1a (Pre–Salmon Summit Operation)** represents operations as they existed from 1983 through the 1990–91 operating year, including Northwest Power Act provisions to restore and protect fish populations in the basin. Specific volumes for the Water Budget would be provided from Dworshak and Brownlee reservoirs to attempt to meet a target flow of 85 kcfs (2,380 cms) at Lower Granite Dam in May. Sufficient flows would be provided on the Columbia River to meet a target flow of 134 kcfs (3,752 cms) at Priest Rapids Dam in May. Lower Snake River projects would operate within 3 to 5 feet (0.9 to 1.5 m) of full pool. Other projects would operate as they did in 1990–91, with no additional water provided from the Snake River above Brownlee Dam.

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

4.1.2 SOS 2-Current Operations

This alternative reflects operation of the Columbia River system with interim flow improvement measures made in response to ESA listings of Snake River salmon. It is very similar to the way the system operated in 1992 and reflects the results of ESA Section 7 consultation with NMFS then. The strategy is consistent with the 1992–93 operations described in the Corps' *1993 Interim Columbia and Snake Rivers Flow Improvement Measures Supplemental EIS* (SEIS). SOS 2 also most closely represents the recommendations issued by the NMFS Snake River Salmon Recovery Team in May 1994. Compared to SOS 1, the primary changes are additional flow augmentation in the Columbia and Snake Rivers and modified pool levels at lower Snake and John Day reservoirs during juvenile salmon migration. This strategy has two options:

- **SOS 2c (Final SEIS Operation- No Action Alternative)** matches exactly the decision made as a result of the 1993 SEIS. Flow augmentation water of up to 3.0 MAF (3.7 billion m^3) on the Columbia River (in addition to the existing Water Budget) would be stored during the winter and released in the spring in low–runoff years. Dworshak would provide at least an additional 300 KAF (370 million m^3) in the spring and 470 KAF (580 million m^3) in the summer for flow augmentation. System flood control shifts from Dworshak and Brownlee to Grand Coulee would occur through April as needed. It also provides up to 427 KAF (527 million m^3) of additional water from the Snake River above Brownlee Dam.

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

In cases such as the SOR, where the proposed action is a new management plan, the No Action Alterna-

tive means continuing with the present course of action until that action is changed (46 FR 13027). Among all of the strategies and options, SOS 2c best meets this definition for the No Action Alternative.

4.1.3 SOS 4-Stable Storage Project Operation

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

- **SOS 4c (Stable Storage Operation with Modified Grand Coulee Flood Control)** applies year–round Integrated Rule Curves (IRCs) developed by the State of Montana for Libby and Hungry Horse. Other reservoirs would be managed to specific elevations on a monthly basis; they would be kept full longer, while still providing spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. Grand Coulee would meet elevation targets year–round to provide acceptable water retention times; however, upper rule curves would apply at Grand Coulee if the January to July runoff forecast at the project is greater than 68 MAF (84 billion m^3).

4.1.4 SOS 5-Natural River Operation

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

- **SOS 5b (Four and One–half Month Natural River Operation)** provides for a lower Snake River drawdown lasting 4.5 months, beginning April 16 and ending August 31. Dworshak would be drafted to refill the lower Snake River projects if natural inflow were inadequate for timely refill.

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

4.1.5 SOS 6-Fixed Drawdown

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

shak would operate for local flood control. This alternative has two options:

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

4.1.6 SOS 9-Settlement Discussion Alternatives

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

- **SOS 9a (Detailed Fishery Operating Plan [DFOP])** establishes flow targets at The Dalles based on the previous year's end–of–year storage content, similar to how PNCA selects operating rule curves. Grand Coulee and other storage projects are used to meet The Dalles flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to near spillway crest level for 4 1/2 months. Specific spill percentages are established at run–of–river projects to achieve no higher than 120 percent daily average total dissolved gas. Fish transportation is assumed to be eliminated.
- **SOS 9b (Adaptive Management)** establishes flow targets at McNary and Lower Granite based on runoff forecasts. Grand Coulee and other storage projects are used to meet the McNary flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and the upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to minimum operating pool levels and John Day is at minimum irrigation pool level. Specific spill percentages are established at run–of–river projects to achieve no higher than 120 percent daily average for total dissolved gas.
- **SOS 9c (Balanced Impacts Operation)** draws down the four lower Snake River projects to near spillway crest levels for 2 1/2 months during the spring salmon migration period. Full drawdown level is achieved on April 1. Refill begins after June 15. This alternative also provides 1994–98 Biological Opinion flow augmentation (as in SOS 2d), IRC operation at Libby and Hungry Horse, a reduced flow target at Lower Granite due to drawdown, limits on winter drafting at Albeni Falls, and spill to achieve no higher than 120 percent daily average for total dissolved gas.

4.1.7 SOS PA-Preferred Alternative

This SOS represents the operation recommended by NMFS and USFWS in their respective Biological Opinions issued on March 1, 1995. SOS PA is intended to support recovery of ESA–listed species by storing water during the fall and winter to meet spring and summer flow targets, and to protect other resources by managing detrimental effects through maximum summer draft limits, by providing public safety through flood protection, and by providing for reasonable power generation. This SOS would operate the system during the fall and winter to achieve a high confidence of

the fall and winter to achieve a high confidence of refill to flood control elevations by April 15 of each year, and use this stored water for fish flow augmentation. It establishes spring flow targets at McNary and Lower Granite based on runoff forecasts, and a similar sliding scale flow target at Lower Granite and a fixed flow target at McNary for the summer. It establishes summer draft limits at Hungry Horse, Libby, Grand Coulee, and Dworshak. Libby is also operated to provide flows for Kootenai River white sturgeon. Lower Snake River projects are drawn down to minimum operating pool levels during the spring and summer. John Day is operated at minimum operating pool level year–round. Specific spill percentages are established at run–of–river projects to achieve 80–percent FPE, with no higher than 115–percent 12–hour daily average for total dissolved gas measured at the forebay of the next downstream project.

4.1.8 Rationale for Selection of the Final SOSs

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

In the Draft EIS, SOS 2 represented current operation. Three options were considered. Two of these options have been eliminated for the Final EIS and one new option has been added. SOS 2c continues as the No Action Alternative. Maintaining this option as the No Action Alternative allows for consistent comparisons in the Final EIS to those made in the Draft EIS. However, within the current practice category, new operations have been developed since the original identification of SOS 2c. In 1994, the SOR agencies, in consultation with the NMFS and USFWS, agreed to an operation, which was reflected in the 1994–98 Biological Opinion. This operation (SOS 2d) has been modeled for the Final EIS and represents the most "current" practice. SOS 2d also provides a good baseline comparison for the other, more unique alternatives. SOS 2a and 2b from the Draft EIS were eliminated because they are so similar to SOS 2c. SOS 2a is identical to SOS 2c except for the lack of an assumed additional 427 KAF of water from the upper Snake River Basin. This additional water did not cause significant changes to the effects between SOS 2a and 2c. There is no reason to continue to consider an alternative that has impacts essentially equal to another alternative. SOS 2b is also similar to SOS 2c, except it modified operation at Libby for Kootenai River white sturgeon. Such modifications are included in several other alternatives, namely SOS 2d, 9a, 9c, and the Preferred Alternative.

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

Table 4–2. Summary of Alternatives in the Draft and Final EIS

Draft EIS Alternatives	Final EIS Alternatives
SOS 1 Pre–ESA Operation	SOS 1 Pre–ESA Operation
SOS 1a Pre–Salmon Summit Operation	SOS 1a Pre–Salmon Summit Operation
SOS 1b Optimum Load Following Operation	SOS 1b Optimum Load Following Operation
SOS 2 Current Practice	SOS 2 Current Practice
SOS 2a Final Supplemental EIS Operation	SOS2c Final Supplemental EIS Operation – No–Action Alternative
SOS 2b Final Supplemental EIS with Sturgeon Operations at Libby	**SOS 2d 1994–98 Biological Opinion Operation**
SOS2c Final Supplemental EIS Operation – No–Action Alternative	
SOS 3 Flow Augmentation	
SOS 3a Monthly Flow Targets	
SOS 3b Monthly Flow Targets with additional Snake River Water	
SOS 4 Stable Storage Project Operation	SOS 4 Stable Storage Project Operation
SOS 4a1 Enhanced Storage Level Operation	**SOS 4c Enhanced Operation with modified Grand Coulee Flood Control**
SOS 4a3 Enhanced Storage Level Operation	
SOS 4b1 Compromise Storage Level Operation	
SOS 4b3 Compromise Storage Level Operation	
SOS 4c Enhanced Operation with modified Grand Coulee Flood Control	
SOS 5 Natural River Operation	SOS 5 Natural River Operation
SOS 5a Two Month Natural River Operation	SOS 5b Four and One Half Month Natural River Operation
SOS 5b Four and One Half Month Natural River Operation	**SOS 5c Permanent Natural River Operation**
SOS 6 Fixed Drawdown	SOS 6 Fixed Drawdown
SOS 6a Two Month Fixed Drawdown Operation	SOS 6b Four and One Half Month Fixed Drawdown Operation
SOS 6b Four and One Half Month Fixed Drawdown Operation	SOS 6d Four and One Half Month Lower Granite Drawdown Operation
SOS 6c Two Month Lower Granite Drawdown Operation	
SOS 6d Four and One Half Month Lower Granite Drawdown Operation	
SOS 7 Federal Resource Agency Operations	**SOS 9 Settlement Discussion Alternatives**
SOS 7a Coordination Act Report Operation	**SOS 9a Detailed Fishery Operating Plan**
SOS 7b Incidental Take Statement Flow Targets	**SOS 9b Adaptive Management**
SOS 7c NMFS Conservation Recommendations	**SOS 9c Balance Impacts Operation**
	SOS Preferred Alternative

Bold indicates a new or revised SOS alternative

SOS 4 originally included 5 options in the Draft EIS. They were similar in operation and impact. In SOS 4a and 4b, the primary feature was the use of Biological Rule Curves for Libby and Hungry Horse reservoirs. SOS 4c also included these rule curves but went further by optimizing the operation of the other storage projects, particularly Grand Coulee and Dworshak. For the Final EIS, the SOR agencies have decided to update the alternative by substituting the IRC for the Biological Rule Curves and by eliminating SOS 4a and 4b. The IRCs are a more recent, acceptable version of minimum elevations for Libby and Hungry Horse. Significant public comment in support of this alternative with IRCs was received. Similar to SOS 2 above, SOS 4a and 4b were not different enough in operation or impacts to warrant continued consideration.

The Natural River (SOS 5) and the Spillway Crest Drawdown (SOS 6) alternatives in the Draft EIS originally included options for 2 months of drawdown to the appropriate pool level and 4 1/2 months of drawdown. The practicality of 2–month drawdowns was questioned during public review, particularly for the natural river. It did not appear that the time involved in drawing down the reservoirs and later refilling them provided the needed consideration for other uses. Flows are restricted to refill the reservoirs at a time when juvenile fall chinook are migrating downstream and various adult species are returning upstream. The 2 1/2 month drawdown strategies (SOS 5a, 6a, and 6c) have been dropped from the Final EIS. However, 2 1/2 month spillway crest drawdown at all four lower Snake projects is still an element in SOS 9c, so the impacts associated with this type of operation are assessed in the Final EIS.

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

SOS 7 Federal Resource Agencies Operations, which included 3 options in the Draft EIS, has been dropped from the Final EIS and replaced with an alternative now labeled as SOS 9 that also has 3 options. SOS 7a was suggested by the USFWS and represented the State fishery agencies and tribes' recommended operation. Since the issuance of the Draft EIS, this particular operation has been revised and replaced by the DFOP (SOS 9a). The SOR agencies received comment that the DFOP was not evaluated, but should be. Therefore, we have included this alternative exactly as proposed by these agencies; it is SOS 9a. SOS 7b and 7c were suggested by NMFS through the 1993 Biological Opinion. This opinion suggested two sets of flow targets as a way of increasing flow augmentation levels for anadromous fish. The flow targets came from the Incidental Take Statement and the Conservation Recommendation sections of that Biological Opinion. The opinion was judged as arbitrary and capricious as a result of legal action, and these operational alternatives have been replaced with other alternatives that were developed through settlement discussions among the parties to this lawsuit. SOS 7b and 7c have been dropped, but SOS 9b and 9c have been added to represent operations stemming from NMFS or other fishery agencies. In particular, SOS 9b is like DFOP but has reduced flow levels and forgoes drawdowns. It is a modification to DFOP. SOS 9c incorporates elements of operation supported by the State of Idaho in its "Idaho Plan." It includes a 2 1/2–month spillway crest drawdown on the lower Snake River projects and several other elements that attempt to strike a balance among the needs of anadromous fish, resident fish, wildlife and recreation.

Shortly after the alternatives for the Draft EIS were identified, the Nez Perce Tribe suggested an operation that involved drawdown of Lower Granite, significant additional amounts of upper Snake River water, and full pool operation at Dworshak (i.e., Dworshak remains full year round). It was labeled as SOS 8a. Hydroregulation of that operation was completed and provided to the Nez Perce Tribe. No technical response has been received from the Nez

Perce Tribe regarding the features or results of this alternative. However, the elements of this operation are generally incorporated in one or more of the other alternatives, or impose requirements on the system or specific projects that are outside the range considered reasonable. Therefore, this alternative has not been carried forward into the Final EIS.

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

Table 4–3. System Operation Review – Summary of Operating Elements of Strategies

		SOS 1a	SOS 1b	SOS 2c	SOS 2d	SOS 4c	SOS 5b	SOS 5c	SOS 6b	SOS 6d	SOS 9a	SOS 9b	SOS 9c	SOS PA
Drawdown	Pools	none	none	LSN; JDA	LSN; JDA	LSN	LSN; JDA	LSN; JDA	LSN; JDA	LWG; JDA	LSN; JDA	LSN; JDA	LSN; JDA	LSN; JDA
	Depth	n/a	n/a	MOP; MIP	MOP; MIP	MOP	natural river; MOP	natural river; MOP	spillway crest; MOP	spill-way crest; MOP	spillway crest; MOP	MOP; MIP	spill-way crest; MIP	MOP; MOP
	Time	n/a	n/a	4/16–7/31; 4/16–8/31	4/16–7/31; 4/16–8/31	4/16–7/31	4/16–8/31; 5/1–8/31	all year round	4/16–8/31; 5/1–8/31	all year round	4/1–8/31; 4/16–8/31	4/1–8/31; 4/16–8/31	4/1–6/15; 4/16–8/31	4/10–8/31; all year
Storage for Flow – Columbia	Volume	3.45 MAF	none	3 MAF;	4 MAF	IRCs, etc.	3 MAF	3 MAF	3 MAF	3 MAF	on flood control	on flood control	IRCs, etc.	on flood control
	Time	May	n/a	May–June	May–June	all year	May–June	May–June	May–June	May–June	all year	all year	all year	most of year
Storage for Flow – Dworshak	Volume	600 KAF	none	900; 470 KAF	1 MF or 927 KAF; 470 KAF	fixed elevations	on flood control	on flood control	on flood control	on flood control	on flood control	on flood control	on flood control	on flood control
	Time	4/16–6/30	n/a	4/16–6/15; 6/16–8/31	4/10–6/20; 6/21–7/31	all year	all year	all year	all year	all year	all year	all year	all year	all year
Storage for Flow – Upper Snake	Volume	none	none	427 KAF	927 KAF	none	none	none	none	none	1.927 MAF	927 KAF	927 KAF	427 KAF
	Time	n/a	n/a	4/16–9/30	4/16–8/31	n/a	n/a	n/a	n/a	n/a	4/16–8/31	4/16–8/31	4/16–8/31	4/16–8/31
Storage for Flow – Brownlee	Volume	110 KAF	none	137; 100 KAF	110; 137; 100 KAF	110 KAF	110 KAF	110 KAF	110 KAF	110 KAF	110; 137; 140; 100 KAF	190; 137; 100 KAF	190; 137; 100 KAF	draft to elevations
	Time	n/a	n/a	July; Sept.	May; July; Sept.	n/a	n/a	n/a	n/a	n/a	May; July; Aug.; Sept.	April–May; July; Sept.	April–May; July; Sept.	May; July; Sept.
Flow Targets (spring; summer)	Columbia	none	none	none	200; 160 kcfs	none	none	none	none	none	300–160 kcfs	300; 200 kcfs	200; 160 kcfs	260–220; 200 kcfs
	Snake	none	none	none	85; 50 kcfs	none	none	none	none	none	74; 45; 32 kcfs	140; 85 kcfs	63 kcfs	100–85; 55–50 kcfs
Spill	FPE	Spill Agr.	none	Spill Agr.	Spill Agr.	Spill Agr.	Spill Agr.	Spill Agr.	Spill Agr.	Spill Agr.	80	80	80	80
	Cap		n/a								120%	120%	120%	115%

CHAPTER 5

RESULTS

5.1 QUANTITATIVE RESULTS: INTRODUCTION

The following section presents the output of CRiSP1.5 and SLCM for all modeled stocks in narrative and graphical form. In doing so, the potential effects of hydrosystem operations can be compared across the alternatives. The results are presented in order of: (1) category of alternative hydrosystem operation; (2) stock; and, (3) value measure.

5.1.1 Grouping of Alternatives

The 13 alternatives have been grouped into four categories according to the general approach each takes to hydrosystem operation. The four categories of alternatives are: Flow Control (1a, 1b, 2c [No Action Alternative], 2d, and 4c); Drawdown (6b, 6d); Natural River (5b, 5c); and Combination (9a, 9b, 9c, and the Preferred Alternative). Combination Alternatives are made up of several components from the other categories of alternatives including spill, flow augmentation and drawdown.

The results of the analyses of the Drawdown and Natural River alternatives assume that the alternatives are effective immediately, even though physical modifications to the projects necessary to implement these alternatives may take years.

5.1.2 Results Relative to the No Action Alternative

The following results are relative to the No Action Alternative, alternative 2c. The No Action Alternative generally represents how the hydrosystem was operated in 1992 and 1993. It includes several flow measures aimed at improving the survival of the listed species. Prior to 1992, the hydrosystem operated in a manner similar to alternative 1a. This alternative also includes measures found in the NPPC's Fish and Wildlife Program to protect anadromous fish.

However, the No Action Alternative does not reflect only in-river survival of fish migrating in those years because, in both 1992 and 1993, nearly all juveniles that were collected in the bypass systems at the collector dams (Lower Granite, Little Goose, and McNary) were transported via barge to below Bonneville Dam.

The AFWG uses juvenile survival as the performance measure to examine transport effects associated with three different transport hypotheses as explained in Chapter 3: The Fixed Barge Hypothesis assumes that 98 percent of the juveniles transported survive to below Bonneville Dam; the 1986 TIR Hypothesis assumes that 76 percent of the Snake River and Columbia River spring and summer chinook survive, and 90 percent of the steelhead; and, the 1986 Adjusted TIR Hypothesis assumes that 36 percent survive to below Bonneville Dam.

SLCM analysis is used to provide estimates of the total number of adults, including harvest and spawning escapement, under the various alternative hydrosystem operations. Although SLCM analyses were performed for the same transport hypotheses as CRiSP1.5, this chapter presents only one transport theory for each stock, using the CRiSP1.5 overall survival values. See Technical Exhibit A, Table A-10, for a complete listing of adult production under all transport hypotheses used by CRiSP1.5. For Snake River spring chinook, as well as Snake River summer chinook and Dworshak steelhead, life cycle analysis was performed using estimates of juvenile survival, with transport, derived from the Fixed 1986 TIR. For Snake River fall chinook, Methow summer chinook and Hanford fall chinook, SLCM analysis used the Fixed Barge transport hypothesis. SLCM results for the other transport hypotheses can be found in Technical Exhibit A.

SLCM overstates total harvest for some stocks (e.g. Figure 5-14). In particular, the total adult numbers displayed in this chapter are definitely too high for Dworshak hatchery steelhead and Snake River fall

chinook, and may be too high for the above–Wells–Dam summer chinook. However, this does not affect the ranking of alternatives, nor does it affect the spawning escapement values.

5.2 QUANTITAIVE RESULTS: POTENTIAL EFFECTS OF THE ALTERNATIVES ON SNAKE RIVER STOCKS

5.2.1 Flow Control Alternatives

5.2.1.1 Spring Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Flow Control alternatives show an appreciable change in juvenile travel time from point of release to below Bonneville Dam (see Table 5–1). Regardless of the alternative, Snake River spring chinook smolt travel time is about 20 to 21 days (see table). Similarly, relative to the No Action Alternative, 2c, none of the Flow Control alternatives show an appreciable change in juvenile survival which ranges between 25 percent and 26 percent.

Juvenile Survival with Transport

According to the 1986 TIR and the Fixed Barge Transport hypotheses, estimates of juvenile survival, with transport, exceed in–river survival estimates by more than two–fold. According to the Adjusted 1986 TIR Hypothesis, estimates of juvenile survival with transport are essentially equivalent to in–river survival estimates. For each of the Flow Control alternatives, juvenile survival estimates are equivalent to the No Action Alternative estimates, regardless of the transport hypothesis used (Table 5–1 and Figure 5–1).

Adult Returns with Transport

The number of Snake River spring chinook adults, as predicted by SLCM, shows essentially no difference among the five Flow Control alternatives. Regardless of the alternative, the median number of spawners in 30 to 40 years ranges between 5,700 and 6,300, while the total harvest is between 1,800 and 1,900. The No Action Alternative operation, 2c, predicts 5,900 spawners and 1,800 harvested fish (Figure 5–11).

5.2.1.2 Summer Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Flow Control alternatives show an appreciable change in juvenile travel time from point of release to below Bonneville Dam (Table 5–2). Regardless of the alternative, Snake River summer chinook smolt travel time is about 24 to 25 days. Similarly, relative to the No Action Alternative, 2c, none of the Flow Control alternatives show an appreciable change in juvenile survival, which ranges between 27 percent and 28 percent (Table 5–2).

Juvenile Survival with Transport

According to the 1986 TIR and the Fixed Barge Transport hypotheses, estimates of juvenile survival with transport exceed in–river survival estimates by about two–fold. According to the Adjusted 1986 TIR Hypothesis, estimates of juvenile survival with transport are slightly lower than those predicted for in–river migrants, i.e., 25 percent to 26 percent, and 27 percent to 28 percent, respectively. For each of the Flow Control alternatives, juvenile survival estimates are equivalent to the No Action Alternative estimates, regardless of the transport hypothesis used (Table 5–2 and Figure 5–2).

Adult Returns with Transport

The total number of adults, as predicted by SLCM, shows essentially no difference among the five Flow Control alternatives. Regardless of the alternative, the median number of spawners in 30 to 40 years ranges between 850 and 925. The total harvest is approximately 50 fish. The No Action Alternative operation predicts 850 spawners and 50 harvested fish (Figure 5–12).

Table 5–1. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Snake River Spring Chinook Using CRiSP1.5

SNAKE RIVER SPRING CHINOOK										
Juvenile Passage Survival Using CRiSP1.5										
					Survival with Transport (%)					
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[1]	+/–	1986 TIR[2]	+/–	1986 Adjusted TIR[3]	+/–
1a	25	3	20	2	64	2	51	1	26	1
1b	25	3	21	2	64	2	51	1	26	1
2c	26	3	20	2	65	2	51	1	26	1
2d	25	3	20	2	65	2	51	1	26	1
4c	26	3	20	2	65	2	51	1	26	1
5b[4]	45	2	15	1	52	2	48	1	40	4
5c[5]	44	3	15	1	52	2	47	1	39	4
6b[6]										
6b+	35	4	18	2	41	2	37	3	31	4
6b–	19	2	18	2	22	2	20	2	16	3
6d[7]										
6d+	27	3	20	2	52	5	43	3	26	3
6d–	23	3	20	2	43	4	35	2	20	2
9a										
9a+	37	3	18	2	NO TRANSPORT					
9a–	22	2	18	2	NO TRANSPORT					
9b	27	2	20	2	60	1	48	1	25	2
9c[8]										
9c+	37	3	18	2	42	2	39	2	32	4
9c–	21	1	17	2	24	1	22	1	18	2
PA	27	3	20	2	63	2	50	1	27	2

\+ means optimistic passage conditions are assumed
– means pessimistic passage conditions are assumed
TIR means Transport/In–River Ratio
PA means the Preferred Alternative

1 Assumes 98% Transportation Survival to Below Bonneville Dam
2 Assumes 76% Transportation Survival to Below Bonneville Dam
3 Assumes 36% Transportation Survival to Below Bonneville Dam
4 Transportation from McNary Dam only to Below Bonneville Dam
5 Transportation from McNary Dam only to Below Bonneville Dam
6 Transportation from McNary Dam only to Below Bonneville Dam
7 Transportation from McNary Dam only to Below Bonneville Dam
8 Transportation from McNary Dam only to Below Bonneville Dam

Table 5–2. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Snake River Summer Chinook Using CRiSP1.5

SNAKE RIVER SUMMER CHINOOK										
Juvenile Passage Survival Using CRiSP1.5										
					Survival with Transport (%)					
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[9]	+/–	1986 TIR[10]	+/–	1986 Adjusted TIR[11]	+/–
1a	28	2	25	1	59	8	47	5	26	1
1b	27	2	25	2	59	8	47	5	25	1
2c	28	2	24	1	58	8	47	5	26	1
2d	28	2	24	1	59	8	47	5	26	1
4c	28	2	24	2	59	8	47	5	26	2
5b[12]	46	2	19	1	53	3	48	1	40	5
5c[13]	45	2	19	1	52	3	48	1	40	5
6b[14]										
6b+	36	3	23	2	40	1	38	2	33	5
6b–	19	2	23	2	21	1	20	1	17	3
6d[15]										
6d+	30	2	24	2	52	7	43	3	27	3
6d–	26	2	24	2	42	5	35	3	22	3
9a										
9a+	39	2	22	1	NO TRANSPORT					
9a–	23	1	22	1	NO TRANSPORT					
9b	30	2	24	1	54	7	45	4	26	2
9c[16]										
9c+	39	2	22	2	43	1	40	1	35	3
9c–	22	1	22	2	24	1	23	1	20	2
PA	29	2	24	2	58	9	47	5	27	2

+ means optimistic passage conditions are assumed
– means pessimistic passage conditions are assumed
TIR means Transport/In–River Ratio
PA means the Preferred Alternative

9 Assumes 98% Transportation Survival to Below Bonneville Dam
10 Assumes 76% Transportation Survival to Below Bonneville Dam
11 Assumes 36% Transportation Survival to Below Bonneville Dam
12 Transportation from McNary Dam only to Below Bonneville Dam
13 Transportation from McNary Dam only to Below Bonneville Dam
14 Transportation from McNary Dam only to Below Bonneville Dam
15 Transportation from McNary Dam only to Below Bonneville Dam
16 Transportation from McNary Dam only to Below Bonneville Dam

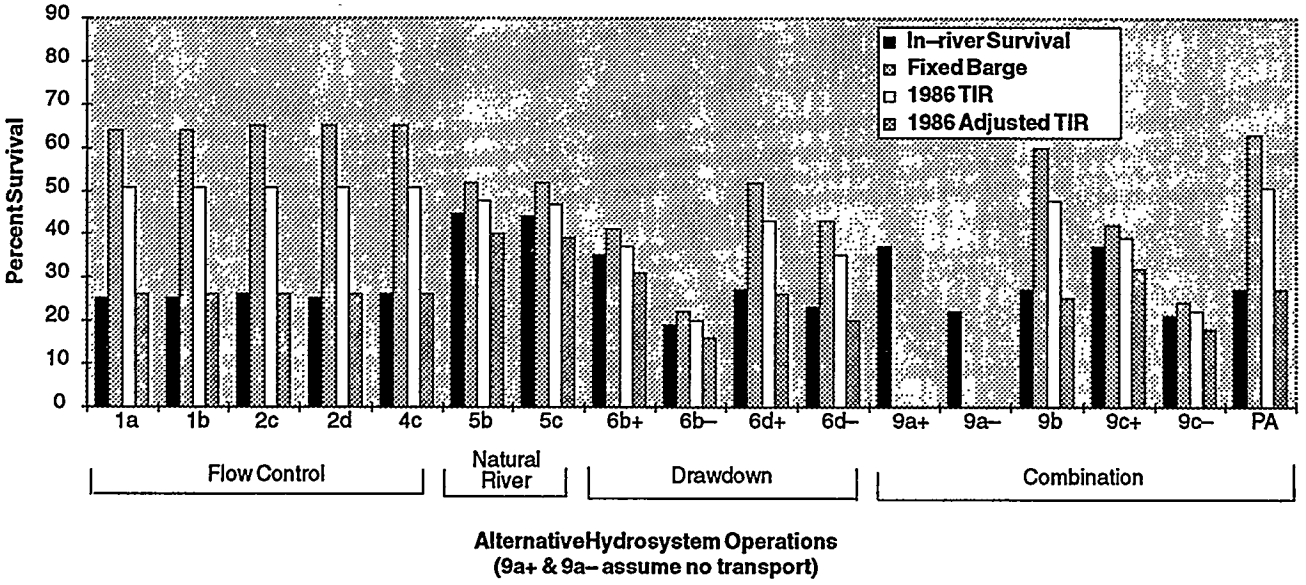


Figure 5–1. Comparison of Overall Juvenile Passage Survival for Snake River Spring Chinook Using CRiSP 1.5 Assuming Average Water

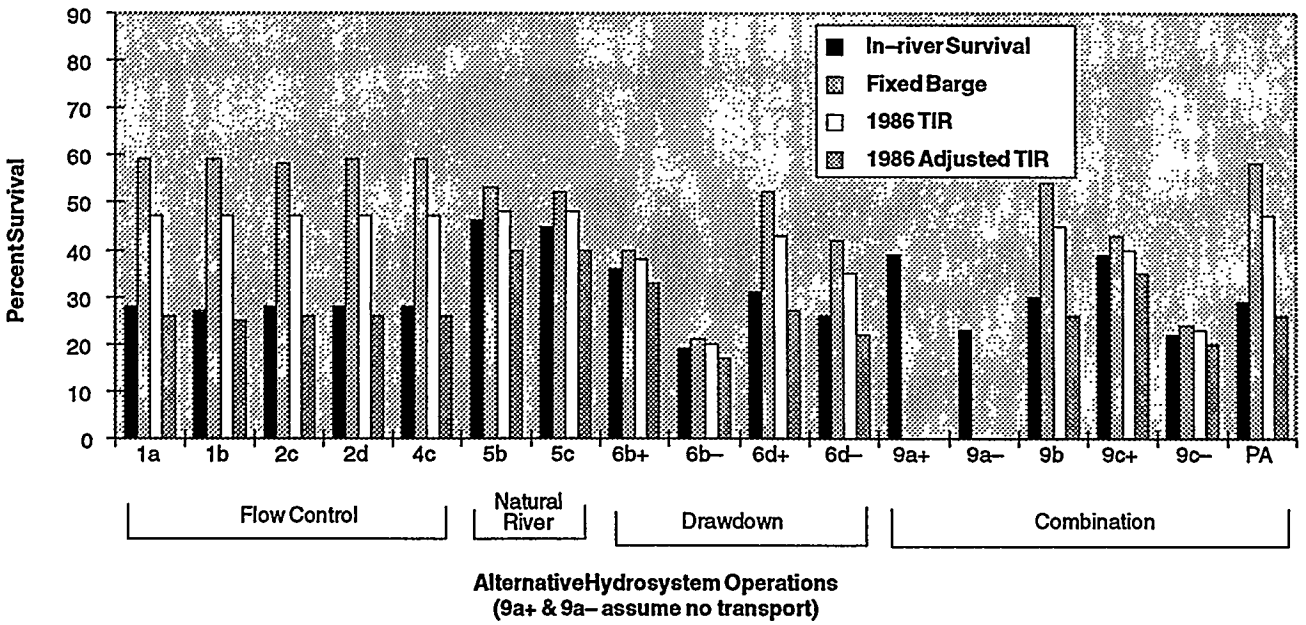


Figure 5–2. Comparison of Overall Juvenile Passage Survival for Snake River Summer Chinook Using CRiSP 1.5 Assuming Average Water

5.2.1.3 Fall Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Flow Control alternatives show an appreciable change in juvenile travel time from point of release to below Bonneville Dam (Table 5–3). Regardless of the alternative, Snake River fall chinook smolt travel time is about 56 to 57 days. Similarly, relative to the No Action Alternative, 2c, survival of Snake River fall chinook in–river migrants is consistently poor and uniform, at about 5 percent, across all Flow Control alternatives, including the No Action Alternative.

Juvenile Survival with Transport

According to the Fixed Barge Transport Hypothesis, estimates of juvenile survival with transport improve markedly relative to in–river migrants, ranging from 45 to 46 percent. For each of the Flow Control alternatives, juvenile survival estimates, with transport are equivalent to the No Action Alternative estimates (Table 5–3 and Figure 5–3).

Adult Returns with Transport

The number of adults, as predicted by SLCM, shows essentially no difference among the five Flow Control alternatives. Regardless of the alternative, the median number of spawners in 30 to 40 years is approximately 5,100, with total harvest of about 40,000. The No Action Alternative operation predicts 5,100 spawners and 40,000 harvested adults (Figure 5–13).

5.2.1.4 Dworshak Hatchery Steelhead

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Flow Control alternatives show an appreciable change in juvenile travel time from point of release to below Bonneville Dam (Table 5–4). Regardless of the alternative, Dworshak Hatchery steelhead smolt travel time is about 22 to 23 days. Similarly, relative to the No Action Alternative, 2c, none of the Flow Control alternatives show an appreciable change in juvenile survival, which CRiSP1.5 estimates at about 17 percent.

Juvenile Survival with Transport

According to the 1986 TIR and the Fixed Barge Transport hypotheses, estimates of juvenile survival with transport exceed in–river survival estimates by more than three–fold. Juvenile survival with transport is virtually constant across the Flow Control alternatives, including the No Action Alternative, 2c, and ranges between 62 percent and 68 percent. (Table 5–4 and Figure 5–4).

Adult Returns with Transport

The number of adults, as predicted by SLCM, shows essentially no difference among the five Flow Control alternatives. Regardless of the alternative, the median number of spawners in 30 to 40 years is approximately 15,000, with total harvest of about 390,000. The No Action Alternative operation predicts 15,000 spawners and 390,000 harvested adults (Figure 5–14).

5.2.2 Natural River Alternatives

5.2.2.1 Spring Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, both of the Natural River alternatives show a marked decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5–1). Under the Natural River alternatives, Snake River spring chinook smolt travel time is about 15 days. Similarly, relative to the No Action Alternative, 2c, both of the Natural River alternatives show higher juvenile survival ranging between 44 and 45 percent compared with 26 percent for the No Action Alternative. This large improvement in survival is primarily due to the removal of all turbine–related mortality, rather than to changes in migration speed.

Juvenile Survival with Transport

According to the 1986 TIR and the Fixed Barge Transport hypotheses, estimates of juvenile survival with transport exceed in–river survival estimates by a modest amount. Survival with transport ranges

between 47 percent and 52 percent, depending on the transport hypothesis assumed. This equates to about a 2 to 8 percentage point increase relative to predicted in–river survival for the two Natural River alternatives. According to the Adjusted 1986 TIR Hypothesis, estimates of juvenile survival with transport are less than the in–river survival estimates, ranging between 39 percent and 40 percent compared with 44 percent to 45 percent, respectively (Table 5–1 and Figure 5–1).

Adult Returns with Transport

Under the 1986 TIR hypothesis, SLCM predicts that adult returns will be approximately 30 percent less than realized under the No Action Alternative operation, 2c, or about 4,000 spawners and 1,200 harvested adults (Figure 5–11).

5.2.2.2 Summer Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, both of the Natural River alternatives show a moderate decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5–2). Under the Natural River alternatives, Snake River summer chinook smolt travel time is about 19 days. Similarly, relative to the No Action Alternative, 2c, both of the Natural River alternatives show higher juvenile survival ranging between 45 and 46 percent compared with 28 percent for the No Action Alternative. As noted for Snake River spring chinook, this large improvement in survival is primarily due to the removal of all turbine–related mortality rather than to changes in migration speed.

Juvenile Survival with Transport

According to the 1986 TIR and the Fixed Barge Transport hypotheses, estimates of juvenile survival, with transport, are similar to those for spring chinook and exceed in–river survival estimates by a modest amount. Survival with transport ranges between 48 percent and 53 percent, depending on the transport hypothesis assumed. This equates to about a 2 to 8 percentage point increase relative to predicted in–river survival for the two Natural River alternatives. According to the Adjusted 1986 TIR Hypothesis, estimates of 40 percent juvenile survival with transport are less than the in–river survival estimates, which are 45 percent to 46 percent, respectively (Table 5–2 and Figure 5–2).

Adult Returns with Transport

Under the 1986 TIR hypothesis, SLCM predicts that adult returns will be approximately 10 percent more than realized under the No Action Alternative operation, 2c, or about 1,000 spawners and 60 harvested adults (Figure 5–12).

5.2.2.3 Fall Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, both of the Natural River alternatives show a dramatic decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5–3). Under the Natural River alternatives, Snake River fall chinook smolt travel time is about 29 days. Similarly, relative to the No Action Alternative, 2c, both of the Natural River alternatives show higher juvenile survival ranging between 15 percent and 16 percent compared with 5 percent for the No Action Alternative. As noted for Snake River spring and summer chinook, this large improvement in survival is primarily due to the removal of all turbine–related mortality, rather than to changes in migration speed.

Juvenile Survival with Transport

According to the Fixed Barge Transport Hypothesis, estimates of juvenile survival with transport exceed in–river survival estimates nearly two–fold. Survival with transport is about 27 percent, compared with about 15 to 16 percent for the in–river migrants. However, compared to survival with transport under the No Action Alternative operation, 2c, the Natural River alternatives show much lower survival, e.g., 46 percent compared with 27 percent (Table 5–3 and Figure 5–3).

Adult Returns with Transport

Both of the Natural River alternatives show a marked decrease in adult abundance relative to the No Action Alternative (2c). Both spawning escape-

ment and total harvest are reduced by about 60 percent, to 2,000 spawners and 16,000 total harvest (Figure 5–13).

5.2.2.4 Dworshak Hatchery Steelhead

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, both of the Natural River alternatives show a moderate decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5–4). Under the Natural River alternatives, Dworshak Hatchery steelhead smolt travel time is about 16 days. Similarly, relative to the No Action Alternative, 2c, both of the Natural River alternatives show higher juvenile survival at 33 percent compared with 17 percent for the No Action Alternative. As noted for Snake River spring, summer and fall chinook, this improvement in survival is primarily due to the removal of all turbine–related mortality rather than to changes in migration speed.

Juvenile Survival with Transport

According to the 1986 TIR and Fixed Barge Transport hypotheses, estimates of juvenile survival with transport exceed in–river survival estimates by between 10 and 12 percentage points. Survival with transport ranges between 43 percent and 45 percent, compared with 33 percent for the in–river migrants. However, compared with survival with transport under the No Action Alternative operation, 2c, the Natural River alternatives show much lower survival, i.e., 63 percent to 68 percent compared with 43 percent to 45 percent, respectively (Table 5–4 and Figure 5–4).

Adult Returns with Transport

Under the 1986 TIR Hypothesis, SLCM predicts that the Natural River alternatives will result in significantly lower adult production compared with the No Action Alternative, 2c. Under operation 2c, with full juvenile transport in place, SLCM predicts adult production in 40 years of about 15,000 spawners and 390,000 harvested adults, but only about 10,000 spawners and 265,000 harvested adults under the Natural River alternatives (Figure 5–14).

5.2.3 Drawdown Alternatives

5.2.3.1 Spring Chinook

In–River Juvenile Survival and Travel Time

Relative to the No Action Alternative, 2c, the Lower Granite drawdown (6d) does not decrease travel time. The four–pool drawdown (6b) decreases travel time from 20 to 18 days (Table 5–1). Since the two drawdown alternatives create a number of unpredictable risks, two sets of survival estimates are reported, i.e., one with optimistic (6b+, 6d+) and one with pessimistic (6b–, 6d–) juvenile passage assumptions, as described in Chapter 3. Optimistically, the one–pool drawdown boosts survival, relative to the No Action Alternative, 2c, only slightly from 26 percent to 27 percent. Pessimistically, survival under the one–pool drawdown would decrease slightly, relative to the No Action Alternative, from 26 percent to 23 percent.

For the four–pool drawdown, optimistically, survival would improve measurably over the No Action Alternative, i.e., from 26 percent to 35 percent. Pessimistically, survival would decrease from 26 percent to 19 percent, relative to the No Action Alternative (Table 5–1).

Juvenile Survival with Transport

For the one–pool drawdown alternative, both the 1986 TIR and Fixed Barge hypotheses predict that survival, with transport, would exceed in–river survival under both optimistic and pessimistic passage assumptions (Figure 5–1). For the four–pool drawdown, in–river survival and survival with transport are very similar, regardless of whether optimistic or pessimistic assumptions are made about passage, or which transport model is used. For all drawdown configurations and perspectives, the 1986 Adjusted TIR Hypothesis predicts survival with transport will be about 3 to 4 percentage points less than in–river survival (Table 5–1 and Figure 5–1).

Adult Returns with Transport

Compared with all other alternatives, SLCM predicts that the drawdown alternatives will result in very poor adult production (Figure 5–11).

Compared with the No Action Alternative, 2c, the optimistic variants of drawdown result in adult production levels that are at best about 20 to 25 percent of those predicted under the No Action Alternative, 2c. The pessimistic assumptions predict that the stock will fail or remain at depressed levels due to the decrease in passage survival.

5.2.3.2 Summer Chinook

In–River Juvenile Survival and Travel Time

Results reported for summer chinook mimic those reported for spring chinook. Relative to the No Action Alternative, 2c, the Lower Granite drawdown (6d) does not decrease travel time. The four–pool drawdown (6b) decreases travel time only slightly, i.e., to 23 days. Optimistically, the one–pool drawdown boosts survival relative to the No Action Alternative, 2c, only slightly from 28 percent to 30 percent. Pessimistically, survival under the one–pool drawdown would decrease slightly, relative to the No Action Alternative, from 28 percent to 26 percent (Table 5–2).

For the four–pool drawdown under optimistic conditions, survival would improve measurably over the No Action Alternative, i.e., from 28 percent to 36 percent. If pessimistic conditions prevail, survival would decrease from 28 percent to 19 percent, relative to the No Action Alternative (Table 5–2 and Figure 5–2).

Juvenile Survival with Transport

For the one–pool drawdown alternative (6d), both the 1986 TIR and Fixed Barge hypotheses predict that survival with transport, would exceed in–river survival under both optimistic and pessimistic passage assumptions (Figure 5–2). For the four–pool drawdown, in–river survival and survival with transport are very similar, regardless of whether optimistic or pessimistic assumptions are made about passage, or which transport model is used. For all drawdown configurations and perspectives, the 1986 Adjusted TIR Hypothesis predicts survival with transport will be only slightly less than in–river survival, i.e., about 2 to 4 percentage points less than the No Action Alternative.

Adult Returns with Transport

Compared with all other alternatives, SLCM predicts that the drawdown alternatives will result in very poor adult production (Figure 5–12). Compared with the No Action Alternative, 2c, the optimistic variants of drawdown result in adult production levels that are at best about 20 to 25 percent of those predicted under the No Action Alternative, 2c. The pessimistic assumptions predict that the stock will fail or remain at depressed levels due to the decrease in passage survival.

5.2.3.3 Fall Chinook

In–River Juvenile Survival and Travel Time

Relative to the No Action Alternative, 2c, the Lower Granite drawdown (6d) and the four–pool drawdown (6b) do not increase or decrease travel time, i.e., travel times are the same at about 56 days. Optimistically, the one–pool drawdown survival is equivalent to the No Action Alternative, 2c, at 5 percent. Pessimistically, survival under the one–pool drawdown would decrease slightly from 5 percent to 4 percent, relative to the No Action Alternative.

For the four–pool drawdown, optimistically, survival would improve slightly over the No Action Alternative, i.e., from 5 percent to 7 percent. Pessimistically, survival would decrease from 5 percent to 3 percent, relative to the No Action Alternative (Table and Figure 5–3).

Juvenile Survival with Transport

For the one–pool drawdown alternative (6d), the Fixed Barge Hypothesis predicts that survival with transport would significantly exceed in–river survival under both optimistic and pessimistic passage assumptions (Figure and Table 5–3). For the four–pool drawdown, in–river survival is about one–half that of survival with transport under optimistic and pessimistic passage assumptions.

Adult Returns with Transport

Under the four–pool drawdown (6b+ and 6b–), Snake River Fall Chinook go extinct due to the reduction in overall system survival. For the one–pool drawdown (6d+ and 6d–) adult abundance decreases by 60 to 75 percent (Figure 5–13).

Table 5–3. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Snake River Fall Chinook Using CRiSP1.5

SNAKE RIVER FALL CHINOOK						
Juvenile Passage Survival Using CRiSP1.5						
					Survival with Transport (%)	
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[17]	+/–
1a	5	1	57	2	45	1
1b	5	1	57	2	45	1
2c	5	1	56	2	46	1
2d	5	1	56	1	46	1
4c	5	1	57	2	45	2
5b[18]	16	2	29	2	27	1
5c[19]	15	2	29	2	27	1
6b[20]						
6b+	7	1	56	2	14	2
6b–	3	1	56	2	6	1
6d[21]						
6d+	5	1	56	2	31	2
6d–	4	1	56	2	25	2
9a						
9a+	8	1	54	1	NO TRANSPORT	
9a–	5	1	54	1	NO TRANSPORT	
9b	4	1	55	2	28	2
9c	3	1	55	2	26	3
PA	6	1	55	2	47	1

+ means optimistic passage conditions are assumed
– means pessimistic passage conditions are assumed
TIR means Transport/In–River Ratio
PA means the Preferred Alternative

17 Assumes 98% Transportation Survival to Below Bonneville Dam
18 Transportation from McNary Dam only to Below Bonneville Dam
19 Transportation from McNary Dam only to Below Bonneville Dam
20 Transportation from McNary Dam only to Below Bonneville Dam
21 Transportation from McNary Dam only to Below Bonneville Dam

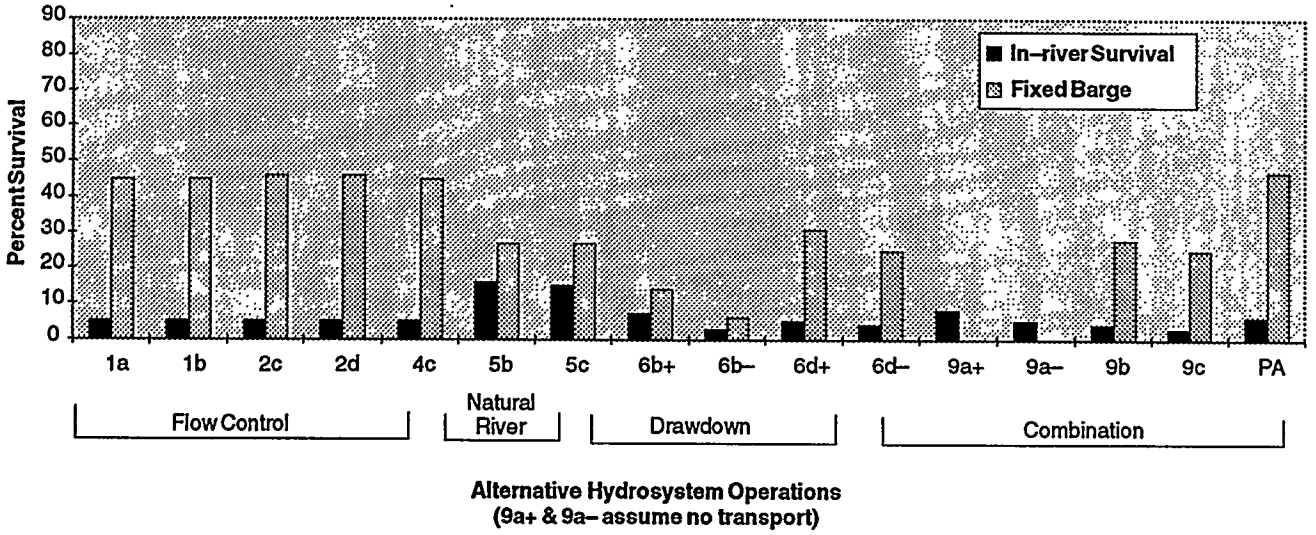


Figure 5–3. Comparison of Overall Juvenile Passage Survival for Snake River Fall Chinook Using CRiSP 1.5 Assuming Average Water

5.2.3.4 Dworshak Hatchery Steelhead

In–River Juvenile Survival and Travel Time

As observed for both Snake River spring and summer chinook, drawdown of the lower Snake reservoirs does little to hasten the migration of steelhead smolts. For the one–pool drawdown (6d), no change in travel time, relative to the No Action Alternative, 2c, is predicted. Similarly, the four–pool drawdown only reduces travel time by about 2 days, requiring a total of 20 days to arrive below Bonneville Dam (Table 5–4).

Based on optimistic assumptions, the one–pool drawdown increases in–river survival slightly as compared with the No Action Alternative, increasing from 17 percent to 20 percent. Under pessimistic assumptions, in–river survival decreases slightly from 17 percent to 16 percent relative to the No Action Alternative. For the four–pool drawdown, optimistic assumptions (6b+) predict that in–river survival will increase to 23 percent, compared with 17 percent for the No Action Alternative. In contrast, pessimistic assumptions predict in–river survival could drop below that predicted for the No Action Alternative (Table 5–4).

Juvenile Survival with Transport

For the one–pool drawdown, both the 1986 TIR and Fixed Barge transport hypotheses predict that survival with transport will substantially exceed that of in–river migrants (Table 5–4). Under the four–pool drawdown, survival with transport still exceeds in–river survival, but to a lesser extent. CRiSP1.5 predicts that net survival is maximized within the drawdown alternatives by transporting smolts under the one–pool drawdown. However, the predicted survival with transport under the one–pool drawdown (51 to 54 percent) does not come close to the survival with transport predicted under the No Action Alternative, 2c, operation (63 to 68 percent) (Table 5–4, Figure 5–4).

Adult Returns with Transport

The optimistic variants of drawdown, 6b+ and 6d+, result in adult production levels that are about 48 percent and 81 percent of the No Action Alternative, 2c, respectively. The pessimistic assumptions result in adult production levels that are about 28 percent and 70 percent of that predicted for the No Action Alternative, respectively (Figure 5–14).

Table 5–4. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Snake River Dworshak Hatchery Steelhead Using CRiSP1.5

SNAKE RIVER DWORSHAK HATCHERY STEELHEAD								
Juvenile Passage Survival Using CRiSP1.5								
					Survival with Transport (%)			
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[23]	+/–	1986 TIR[24]	+/–
1a	17	3	22	2	67	2	62	2
1b	17	3	23	3	67	2	62	2
2c	17	3	22	2	68	2	63	2
2d	17	3	23	2	68	2	63	2
4c	17	4	22	3	68	2	63	2
5b	33	4	16	1	45	1	43	1
5c	33	3	16	1	45	1	43	1
6b								
6b+	23	4	20	2	33	3	32	3
6b–	13	3	20	2	19	2	18	2
6d								
6d+	20	3	21	2	54	2	51	2
6d–	16	3	22	2	48	2	44	2
9a								
9a+	25	3	18	1	NO TRANSPORT			
9a–	15	2	20	2	NO TRANSPORT			
9b	16	4	22	2	61	4	57	4
9c[25]								
9c+	24	4	20	2	33	3	32	3
9c–	15	2	20	2	21	2	20	2
PA	17	3	22	2	66	2	62	1

\+ means optimistic passage conditions are assumed
– means pessimistic passage conditions are assumed
TIR means Transport/In–River Ratio
PA means the Preferred Alternative

[23] Assumes 98% Transportation Survival to Below Bonneville Dam
[24] Assumes 90% Transportation Survival to Below Bonneville Dam
[25] Transportation from McNary Dam only to Below Bonneville Dam

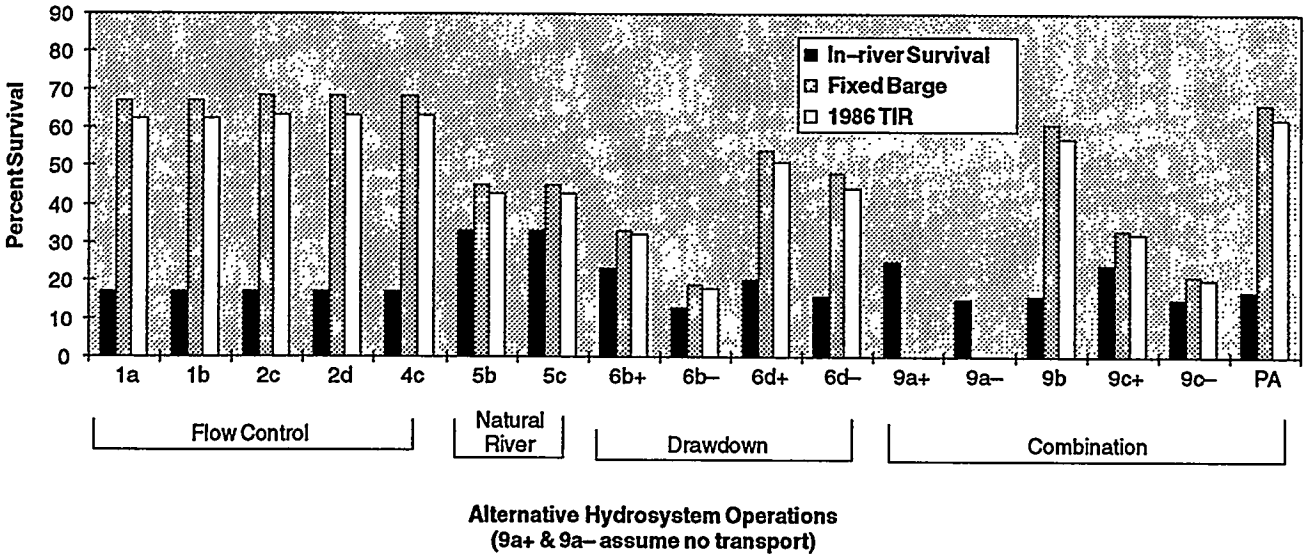


Figure 5–4. Comparison of Overall Juvenile Passage Survival for Snake River Dworshak Hatchery Steelhead Using CRiSP 1.5 Assuming Average Water

5.2.4 Combination Alternatives

5.2.4.1 Spring Chinook

In–River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Combination alternatives show a marked increase or decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5–1). Under the Combination alternatives, Snake River spring chinook smolt travel time ranges between 17 and 20 days compared to 20 days for the No Action Alternative. In–river survival under alternatives 9b and the Preferred Alternative are essentially equivalent to the No Action Alternative, 2c, at 27 percent. In–river survival under 9a+ and 9c+ is similar to survival under 6b+ at about 35 percent to 37 percent. In–river survival under 9a– and 9c– is similar to survival under 6b– at about 19 percent to 22 percent. These similarities in survival are not unexpected since these three Combination alternatives involve a drawdown of all four lower Snake reservoirs.

Juvenile Survival with Transport

Under all transport hypotheses, the predicted survivals with transport for alternatives 9b and the Preferred Alternative are similar to those found for the No Action Alternative, 2c.

Under alternative 9a, there is no transport.

Under all transport hypotheses, juvenile survival for alternatives 9c+ and 9c– is similar to that for alternatives 6b+ and 6b– (Table 5–1 and Figure 5–1).

Adult Returns with Transport

Under the 1986 TIR Hypothesis (Figure 5–11), SLCM predicts: (1) given pessimistic assumptions regarding drawdown (9c–), Snake River spring chinook would become extinct due to decreases in passage survival; (2) even under optimistic assumptions regarding drawdown (9c+), adult production is severely depressed and remains well below levels predicted for the No Action Alternative, 2c; (3) under 9b, adult production increases substantially but still remains well below adult production predicted for the No Action Alternative, 2c; and, (4) adult production under the Preferred Alternative is

equivalent to that predicted for the No Action Alternative.

Even though there is no transport under alternative 9a, results are reported in this section to provide a basis of comparison among the Combination alternatives. Under alternatives 9a+ and 9a−, SLCM predicts adult production to be essentially the same as that predicted for alternatives 6b+ and 6b−. Under optimistic assumptions regarding drawdown, the stock remains at a depressed level, while under pessimistic assumptions, the stock goes extinct due to decreases in passage survival (Figure 5−11).

5.2.4.2 Summer Chinook

In−River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Combination alternatives show a marked increase or decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5−2). Under the Combination alternatives, Snake River summer chinook smolt travel time ranges between 22 and 24 days. In−river survival under alternatives 9b (30 percent) and the Preferred Alternative (29 percent) are similar to the No Action Alternative, 2c (27 percent). In−river survival under 9a+ and 9c+ is slightly higher than survival under 6b+, at about 39 percent. In−river survival under 9a− and 9c− is slightly higher than survival under 6b− and is between 22 percent and 23 percent. These similarities in survival are not unexpected since these three alternatives involve a drawdown of all four lower Snake reservoirs.

Juvenile Survival with Transport

Under all transport hypotheses, the predicted survivals with transport for alternatives 9b and the Preferred Alternative mirror those found for the No Action Alternative, 2c.

Under alternative 9a, there is no transport.

Under all transport hypotheses, survival for alternatives 9c+ and 9c− is slightly higher than that for alternatives 6b+ and 6b− (Table 5−2 and Figure 5−2).

Adult Returns with Transport

Under the 1986 TIR Hypothesis, SLCM predicts (Figure 5−12): (1) given pessimistic assumptions regarding drawdown (9c−), Snake River summer chinook would become extinct due to decreases in passage survival; (2) even under optimistic assumptions regarding drawdown (9c+), adult production is severely depressed and remains well below levels predicted for the No Action Alternative, 2c; (3) under 9b, adult production increases substantially but still remains well below adult production predicted for the No Action Alternative, 2c; (4) adult production under the Preferred Alternative is equivalent to that predicted for the No Action Alternative.

Even though there is no transport under alternative 9a, results are reported in this section to provide a basis of comparison among the Combination alternatives. Under alternatives 9a+ and 9a−, SLCM predicts adult production to be essentially the same as that predicted for alternatives 6b+ and 6b− (Figure 5−12). Under optimistic assumptions regarding drawdown, the stock remains at a depressed level, while under pessimistic assumptions, the stock goes extinct.

5.2.4.3 Fall Chinook

In−River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Combination alternatives show a marked increase or decrease in juvenile travel time from point of release to below Bonneville Dam (Table 5−3). Under the Combination alternatives, Snake River fall chinook smolt travel time ranges between 54 and 55 days. In−river survival under alternative 9b (4 percent) and the Preferred Alternative (6 percent) is similar to the No Action Alternative, 2c (5 percent).

Fall chinook in−river survival under alternative 9c is expected to be about two−thirds of that predicted for the No Action Alternative because fall chinook juvenile migration does not begin, under this alternative, until the Lower Snake reservoirs have all refilled. According to CRiSP1.5, the deleterious

effects of high spill under this alternative result in higher mortality from gas supersaturation for the fall chinook, compared with the other Snake River stocks.

Given optimistic passage assumptions, survival under alternative 9a+ exceeds No Action Alternative survival by three percentage points; given pessimistic assumptions, survival under 9a− is comparable to the No Action Alternative at about 5 percent.

Juvenile Survival with Transport

Under the Fixed Barge Hypothesis, the predicted survival with transport under the Preferred Alternative mirrors those found for the No Action Alternative, 2c, and the other Flow Control alternatives at 45 to 47 percent (Table 5−3 and Figure 5−3).

Under alternative 9a, there is no transport.

Under alternatives 9b and 9c, survival, with transport, is slightly more than one−half of that under the No Action Alternative, 2c, and ranges between 26 and 28 percent for 9c and 9b, respectively.

Adult Returns with Transport

Under the Fixed Barge hypothesis, SLCM predicts: (1) under alternatives 9b and 9c, adult production decreases by about 60 percent relative to adult production predicted for the No Action Alternative, 2c; and (2) adult production under the Preferred Alternative is slightly higher than that predicted for the No Action Alternative.

Even though there is no transport under alternative 9a, results are reported in this section to provide a basis of comparison among the Combination alternatives. Under alternatives 9a+ and 9a−, SLCM predicts that fall chinook will become extinct. Extinction is caused by the marked reduction in downstream survival relative to the No Action Alternative.

5.2.4.4 Dworshak Hatchery Steelhead

In−River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the Combination alternatives show a marked decrease in juvenile travel time from point of release to below Bonneville Dam although moderate decrease from 0 to 4 days may occur (Table 5−4). Under the Combination alternatives, Dworshak Hatchery steelhead smolt travel time ranges between 18 and 22 days. In−river survival under alternative 9b (16 percent) and the Preferred Alternative (17 percent) are similar to the No Action Alternative, 2c (17 percent). In−river survival under 9a+ and 9c+ is slightly higher than survival under 6b+ at about 25 percent. In−river survival under 9a− and 9c− is slightly higher than survival under 6b−, and is 15 percent. These similarities in survival are not unexpected since these three alternatives involve a drawdown of all four lower Snake reservoirs.

Juvenile Survival with Transport

Under all transport hypotheses, the predicted survivals, with transport for alternatives 9b and the Preferred Alternative are only slightly less than those found for the No Action Alternative, 2c (Table 5−4 and Figure 5−4).

Under alternative 9a, there is no transport.

Under both transport hypotheses, survival for alternatives 9c+ and 9c− is nearly the same as that for alternatives 6b+ and 6b−.

Adult Returns with Transport

Under the 1986 TIR Hypothesis, SLCM predicts: (1) alternative 9c− yields only about one−third as many adults as under the No Action Alternative; (2) even under optimistic assumptions regarding drawdown (9c+), adult production is still one−half of that realized under the No Action Alternative, 2c; (3) under 9b and the Preferred Alternative, adult production is nearly equivalent to that predicted under the No Action Alternative, 2c (Figure 5−14).

Even though there is no transport under alternative 9a, results are reported in this section to provide a basis of comparison among the Combination alternatives. Under alternatives 9a+ and 9a−, SLCM predicts that adult production would be slightly less than that predicted for alternatives 6b+ and 6b− and would be between 6,200 and 3,700 spawners,

and 150,000 to 90,000 harvested adult fish, respectively.

5.3 QUANTITATIVE RESULTS: POTENTIAL EFFECTS OF THE ALTERNATIVES ON MID-COLUMBIA RIVER STOCKS

In-River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the alternative operations shows an appreciable increase or decrease in juvenile travel time from point of release to below Bonneville Dam (Tables 5-5, 5-6, 5-7 and 5-8). Across alternatives, Methow spring chinook smolt travel times range between 25 and 27 days; Methow summer chinook smolt travel times range between 33 and 36 days; Wenatchee steelhead smolt travel times range between 32 and 33 days; and, Hanford fall chinook smolt travel times ranged between 22 and 23 days.

In general, in-river survival across all alternatives appears relatively constant for all mid-Columbia stocks. However, for two stocks, the Methow spring chinook and Hanford fall chinook, the Combination alternatives offer slight gains in survival relative to all other alternatives. In the Combination alternatives, increased spill and flow may be working in concert to provide this slight increase in juvenile survival for these stocks (Table 5-5 and 5-8). Across all alternatives, juvenile survival for Methow spring chinook ranges between 23 percent and 27 percent; Hanford fall chinook ranges between 18 percent and 22 percent. In contrast, the ranges in survival for the Methow summer chinook and Wenatchee steelhead are even smaller, i.e., between 3 percent and 4 percent and between 18 percent and 20 percent, respectively (Tables 5-6 and 5-7).

Juvenile Survival with Transport

According to the Fixed Barge and 1986 TIR hypotheses, providing transportation at McNary Dam appreciably increases smolt survival to below Bonneville Dam (Tables 5-5 to 5-8 and Figures 5-5 to 5-8). Under these hypotheses, CRiSP1.5 predicts that transportation increases survival by 3 to 5 percentage points and 1 to 4 percentage points, respectively, over in-river survival for Methow spring chinook and, 5 to 8 percentage points and 4 to 8 percentage points, respectively, for Wenatchee steelhead. Under the Fixed Barge hypothesis, survival, with transport, increases by 2 to 4 percentage points (nearly a 100 percent increase) for Methow summer chinook and 11 to 15 percentage points for Hanford fall chinook.

Adult Returns with Transport

For the Methow summer chinook, assuming the Fixed Barge Hypothesis, SLCM predicts: (1) eliminating transportation under 9a results in near-extinction of the population due to decreases in passage survival; (2) alternatives 9b and 9c produce about one-half the number of adults as all other remaining alternatives; and (3) the remaining alternatives result in comparable numbers of adults, at around 500 to 700 spawners and 9,000 to 11,000 harvested fish (Figure 5-15).

For Hanford fall chinook, assuming the Fixed Barge transport hypothesis, SLCM predicts: (1) eliminating transportation under 9a results in a significant drop in harvest (from approximately 510,000 under the No Action Alternative, 2c, to about 330,000 under 9a); and (2) the remaining alternatives result harvest comparable to the No Action Alternative (Figure 5-16). Spawners remain nearly constant across alternatives, due to the imposition of an escapement cap of 50,000 at McNary Dam (to simulate the effect of US v Oregon harvest regulations).

5.4 QUANTITATIVE RESULTS: POTENTIAL EFFECTS OF THE ALTERNATIVES ON LOWER COLUMBIA RIVER STOCKS

In-River Juvenile Survival and Travel Time

As compared with the No Action Alternative operation, 2c, none of the alternative operations shows an appreciable increase or decrease in either juvenile travel time or smolt survival from point of release to below Bonneville Dam (Table and Figure 5-9). Regardless of the alternative, Deschutes River spring chinook smolt travel time is about 12 days. Similarly, Rock Creek steelhead smolt travel time is uniform across alternatives at about 16 days (Table and Figure 5-10).

Table 5–5. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Methow Spring Chinook Using CRiSP1.5

METHOW SPRING CHINOOK										
Juvenile Passage Survival Using CRiSP1.5										
					Survival with Transport (%)					
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[26]	+/–	1986 TIR[27]	+/–	1986 Adjusted TIR[28]	+/–
1a	24	2	26	1	27	2	25	2	22	3
1b	23	2	26	2	27	2	24	2	20	3
2c	24	2	26	2	27	2	25	2	22	3
2d	23	2	27	1	28	2	27	2	21	3
4c	24	2	26	2	28	2	26	2	22	3
5b	24	2	26	2	28	2	26	2	22	3
5c	24	2	26	1	27	2	25	2	21	3
6b	24	2	26	2	28	2	26	2	22	3
6d	24	2	26	2	28	2	26	2	22	3
9a	27	2	25	1	NO TRANSPORT					
9b	26	2	25	2	29	2	27	2	24	3
9c	25	1	26	1	28	2	26	2	22	3
PA	25	2	26	1	NO TRANSPORT					

\+ means optimistic passage conditions are assumed
– means pessimistic passage conditions are assumed
TIR means Transport/In–River Ratio
PA means the Preferred Alternative

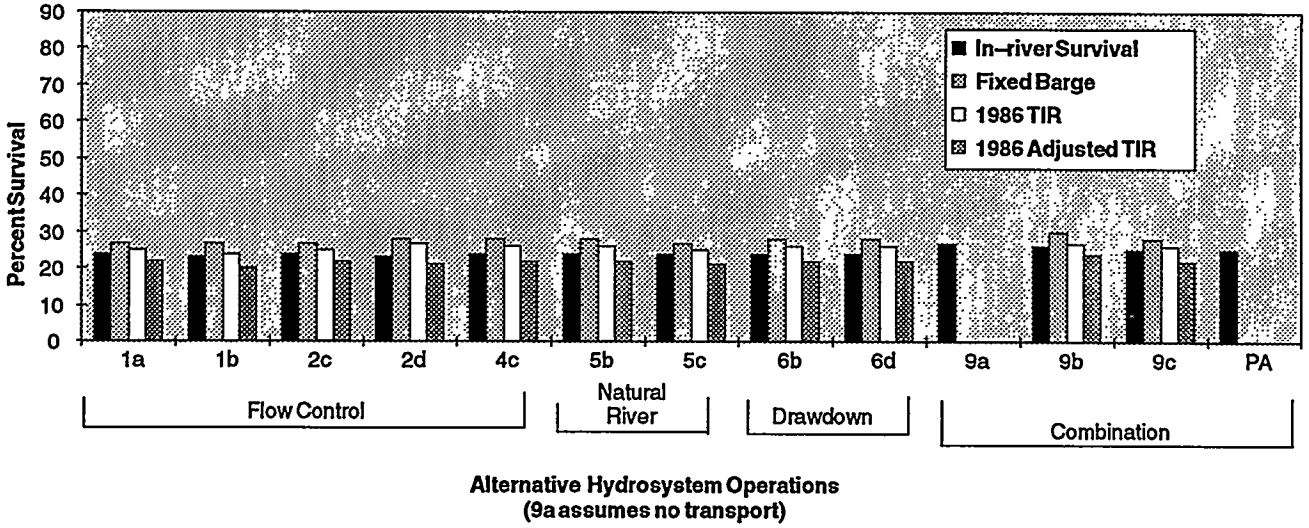


Figure 5–5. Comparison of Overall Juvenile Passage Survival for Methow Spring Chinook Using CRiSP 1.5 Assuming Average Water

[26] Assumes 98% Transport Survival to Below Bonneville Dam and Transport from McNary Dam only to Below Bonneville Dam
[27] Assumes 76% Transport Survival to Below Bonneville Dam and Transport from McNary Dam only to Below Bonneville Dam
[28] Assumes 36% Transport Survival to Below Bonneville Dam and Transport from McNary Dam only to Below Bonneville Dam

Table 5–6. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Methow Summer Chinook Using CRiSP1.5

METHOW SUMMER CHINOOK						
Juvenile Passage Survival Using CRiSP1.5						
					Survival with Transport (%)[29]	
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[30]	+/–
1a	3	1	36	2	7	1
1b	3	1	36	2	7	1
2c	3	1	36	2	7	1
2d	4	1	35	2	7	1
4c	4	1	35	2	7	1
5b	4	1	36	2	7	1
5c	3	1	36	2	7	1
6b	3	1	36	2	7	1
6d	3	1	36	2	7	1
9a	4	1	33	1	NO TRANSPORT	
9b	4	1	34	2	6	1
9c	4	1	34	2	6	1
PA	4	1	35	2	7	1

PA means the Preferred Alternative TIR means Transport/In–River Ratio

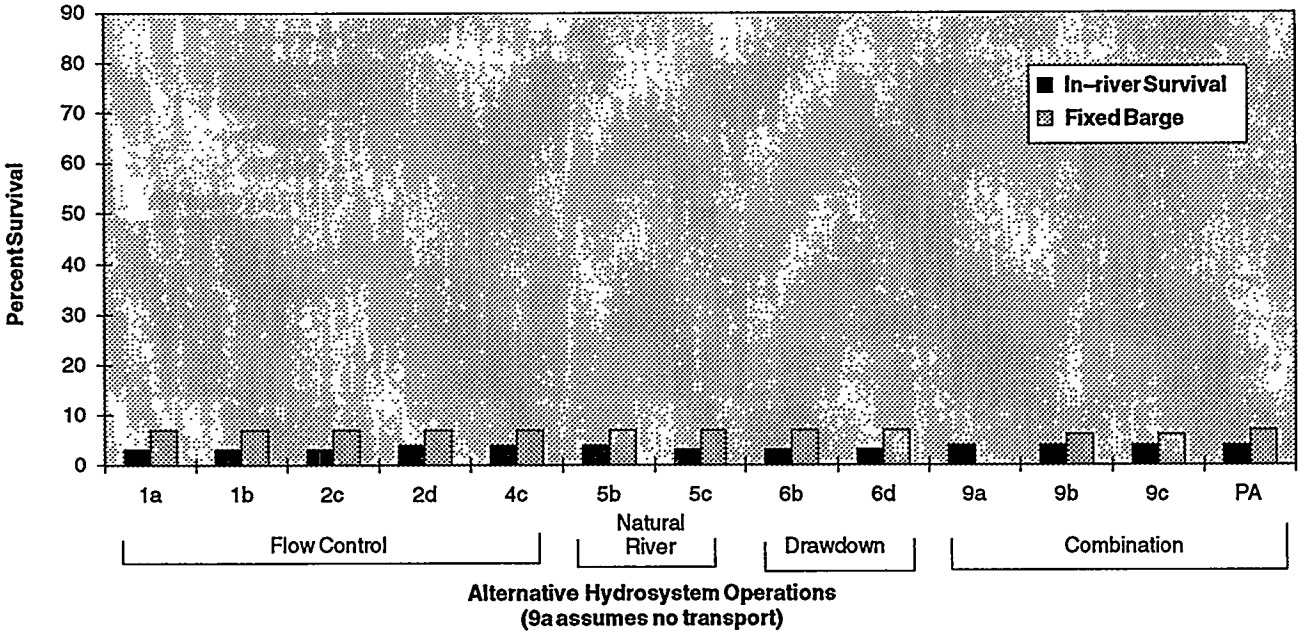


Figure 5–6. Comparison of Overall Juvenile Passage Survival for Methow Summer Chinook Using CRiSP 1.5 Assuming Average Water

[29] Transport from McNary Dam only to Below Bonneville Dam

[30] Assumes 98% Transport Survival to Below Bonneville Dam

Table 5–7. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Wenatchee Steelhead Using CRiSP1.5

WENATCHEE STEELHEAD								
Juvenile Passage Survival Using CRiSP1.5								
					Survival with Transport (%)[31]			
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[32]	+/–	1986 TIR[33]	+/–
1a	18	1	33	1	25	2	24	2
1b	18	1	33	2	25	2	24	2
2c	18	1	33	1	23	2	22	2
2d	18	1	33	1	25	2	24	2
4c	18	2	33	2	24	2	23	2
5b	18	1	32	1	24	2	23	2
5c	20	1	33	1	26	2	25	2
6b	18	1	32	1	26	2	24	2
6d	18	1	32	1	26	2	24	2
9a	20	1	32	1	NO TRANSPORT			
9b	18	1	33	1	23	2	22	2
9c	18	1	33	1	25	2	23	2
PA	18	1	33	1	NO TRANSPORT			

PA means the Preferred Alternative

TIR means Transport/In–River Ratio

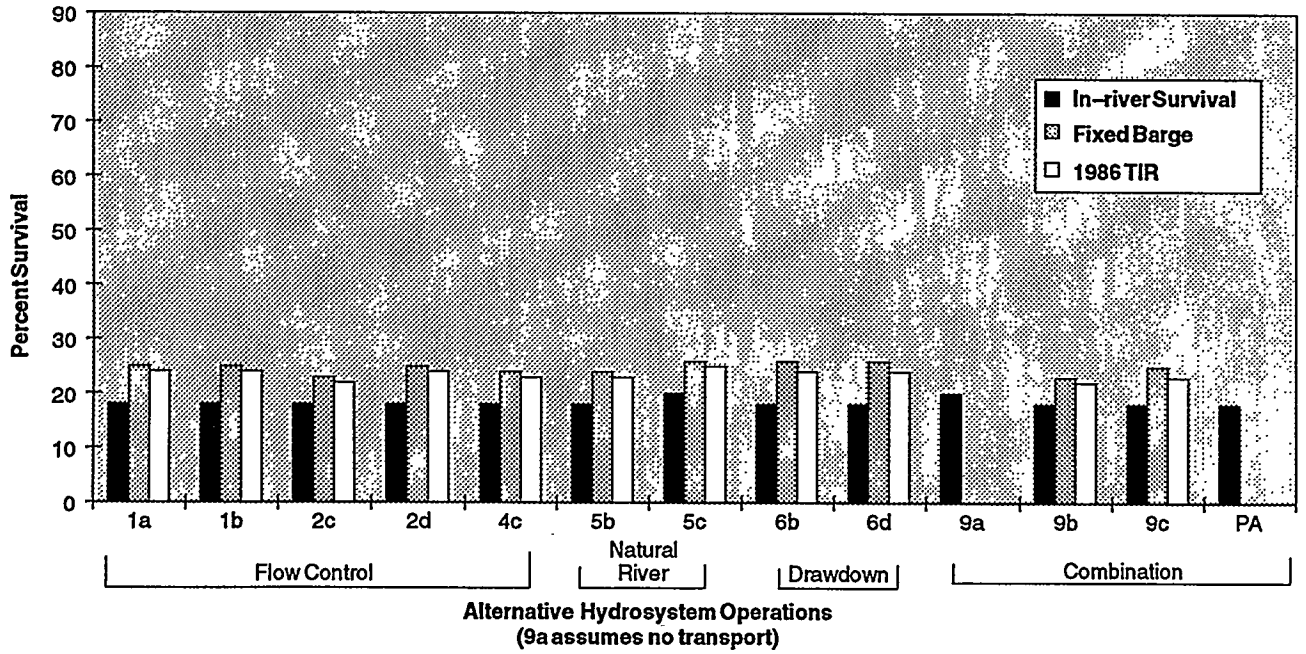


Figure 5–7. Comparison of Overall Juvenile Passage Survival for Wenatchee Steelhead Using CRiSP 1.5 Assuming Average Water

31 Transport from McNary Dam only to Below Bonneville Dam

32 Assumes 98% Transportation Survival to Below Bonneville Dam

33 Assumes 90% Transportation Survival to Below Bonneville Dam

Table 5–8. Estimates of Juvenile Salmonid Survival and Travel Time, with and without Transport, to Below Bonneville Dam for Hanford Fall Chinook Using CRiSP1.5

HANFORD FALL CHINOOK						
Juvenile Passage Survival Using CRiSP1.5						
					Survival with Transport (%)[34]	
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–	Fixed Barge[35]	+/–
1a	18	2	23	1	33	1
1b	18	2	23	1	34	1
2c	19	2	23	1	34	1
2d	19	2	22	1	34	1
4c	19	2	22	1	34	1
5b	19	2	23	1	34	1
5c	18	2	23	1	33	1
6b	19	2	23	1	34	2
6d	19	2	23	1	34	1
9a	22	2	22	1	NO TRANSPORT	
9b	21	2	22	1	32	3
9c	21	2	22	1	32	3
PA	21	2	22	1	35	1

PA means the Preferred Alternative TIR means Transport/In–River Ratio

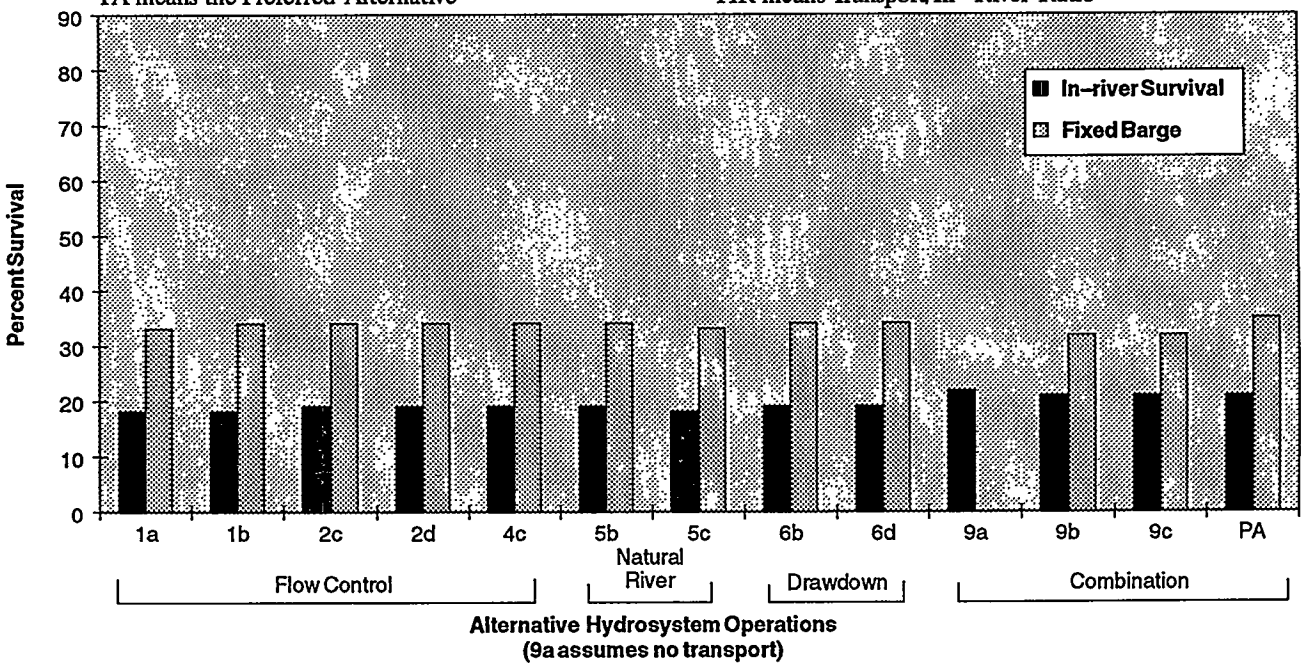


Figure 5–8. Comparison of Overall Juvenile Passage Survival for Hanford Fall Chinook Using CRiSP 1.5 Assuming Average Water

[34] Transport from McNary Dam only to Below Bonneville Dam

[35] Assumes 98% Transport Survival to Below Bonneville Dam

Table 5–9. Juvenile Salmonid Survival Estimates to Below Bonneville Dam for Deschutes River Spring Chinook Using CRiSP1.5

DESCHUTES RIVER SPRING CHINOOK				
Juvenile Passage Survival Using CRiSP1.5				
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–
1a	48	3	12	1
1b	48	3	12	1
2c	48	3	12	1
2d	48	3	12	1
4c	48	3	12	1
5b	48	3	12	1
5c	47	3	12	1
6b	48	3	12	1
6d	48	3	12	1
9a	51	3	12	1
9b	51	3	12	1
9c	50	3	12	1
PA	50	3	12	1

PA means the Preferred Alternative

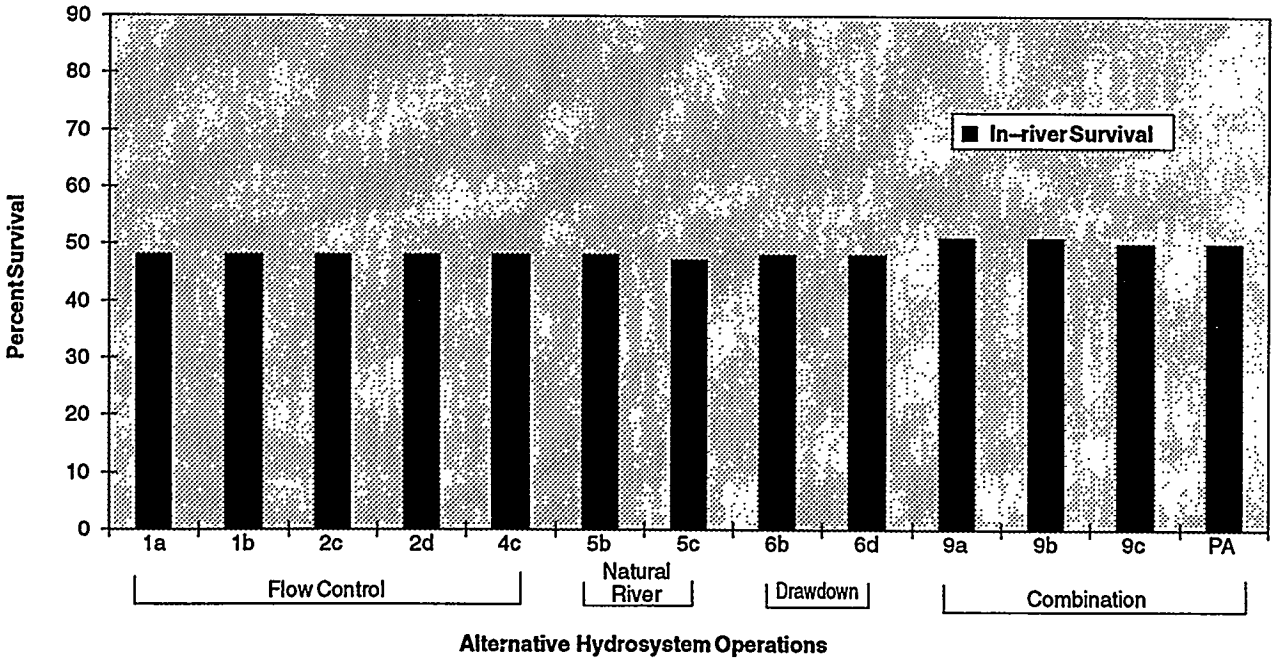


Figure 5–9. Deschutes River Spring Chinook Juvenile Passage Survival Using CRiSP 1.5 Assuming Average Water

Table 5–10. Juvenile Salmonid Survival Estimates to Below Bonneville Dam for Rock Creek Steelhead Using CRiSP1.5

ROCK CREEK STEELHEAD				
Juvenile Passage Survival Using CRiSP1.5				
SOS	In–River Survival (%)	+/–	Travel Time (days)	+/–
1a	36	1	16	1
1b	36	1	16	1
2c	36	1	16	1
2d	35	1	16	1
4c	36	1	16	1
5b	36	1	16	1
5c	37	1	16	1
6b	37	1	16	1
6d	36	1	16	1
9a	37	2	16	1
9b	36	1	16	1
9c	37	1	16	1
PA	36	1	16	1

PA means the Preferred Alternative

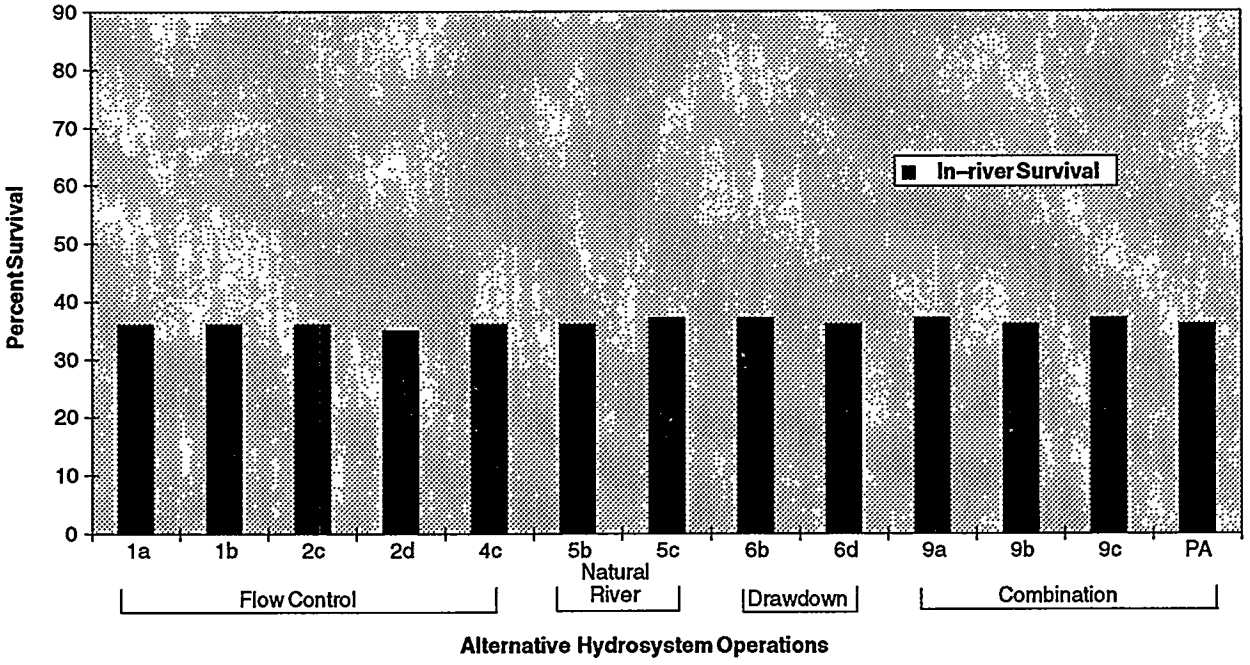


Figure 5–10. Rock Creek Steelhead Juvenile Passage Survival Using CRiSP 1.5 Assuming Average Water

Table 5–11. In–river Survival Estimates to Below Bonneville Dam for Alternatives 9a+AG and the Preferred Alternative AG*, i.e., Assumes Minimal Mortality from Gas Supersaturated Water; Mean Survival Over 50–Year Water Record (Compared with the No Action Alternative 2c.)

	Alternative 9a+		Alternative 9a+ AG		Preferred Alternative		Preferred Alternative AG		No Action Alternative 2c	
Stock	Percent In–river Survival	+/–	Percent In–river Survival	+/–	Percent In–river Survival	+/–	Percent In–river Survival	+/–	Percent In–river Survival	+/–
Snake River Spring Chinook	37	2	37	3	27	3	27	3	26	3
Snake River Summer Chinook	39	2	39	2	29	2	29	2	28	2
Snake River Fall Chinook	8	1	9	1	6	1	6	1	5	1
Dworshak Hatchery Steelhead	25	3	26	4	17	3	19	4	17	3
Methow Spring Chinook	27	2	26	2	25	2	25	2	24	2
Methow Summer Chinook	4	1	4	1	4	1	4	1	3	1
Wenatchee Steelhead	20	2	21	2	18	1	19	2	18	1
Hanford Fall Chinook	22	1	22	1	21	2	20	2	19	2
Deschutes Spring Chinook	51	2	51	3	50	3	50	3	48	3
Rock Creek Steelhead	37	2	41	1	36	1	39	1	36	1

* AG means Adjusted Gas

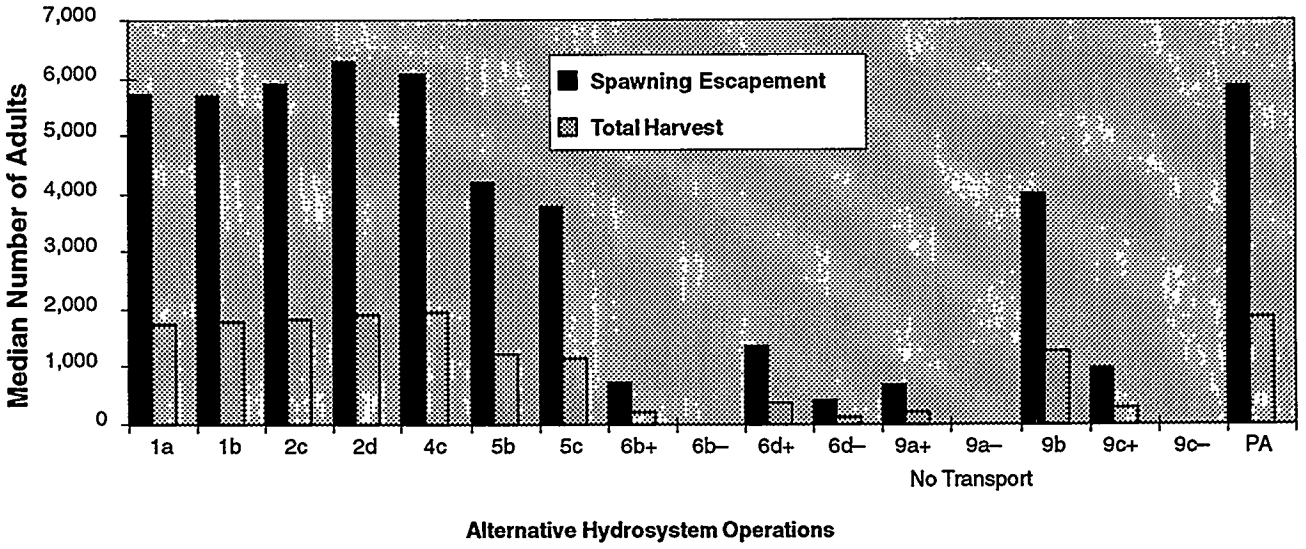


Figure 5–11. Total Harvest and Spawning Escapement, for Snake River Spring Chinook (Projected 30–40 Years Out) Based on 1986 TIR Transport Hypothesis

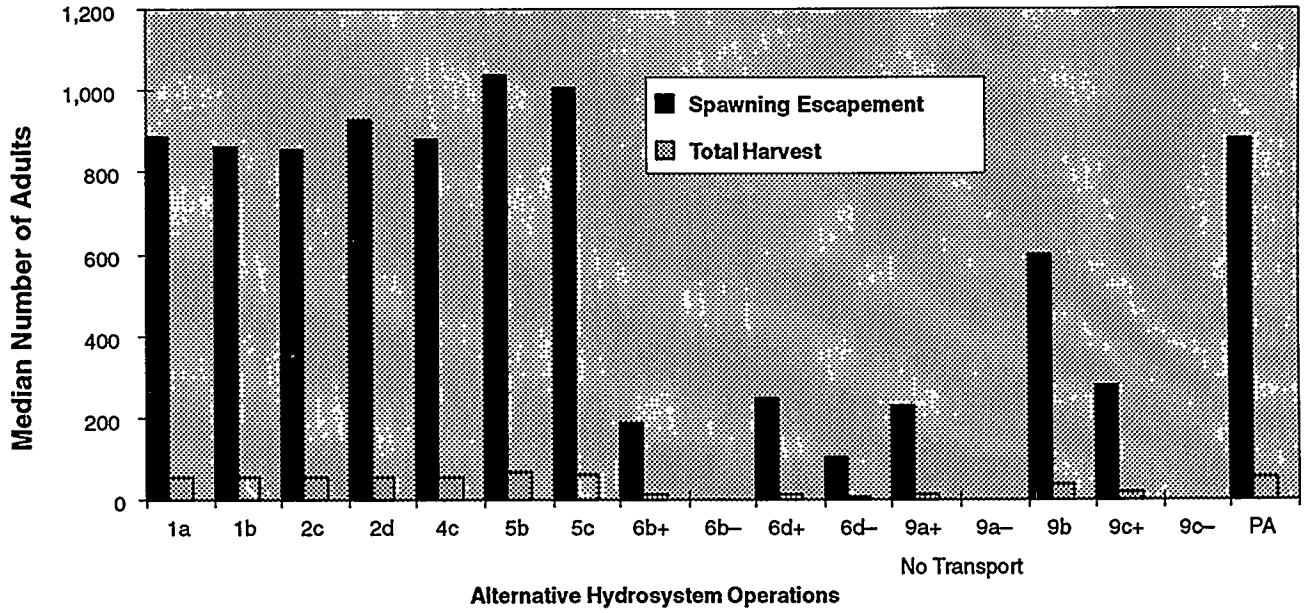


Figure 5–12. Total Harvest and Spawning Escapement, for Snake River Summer Chinook (Projected 30–40 Years Out) Based on 1986 TIR Transport Hypothesis

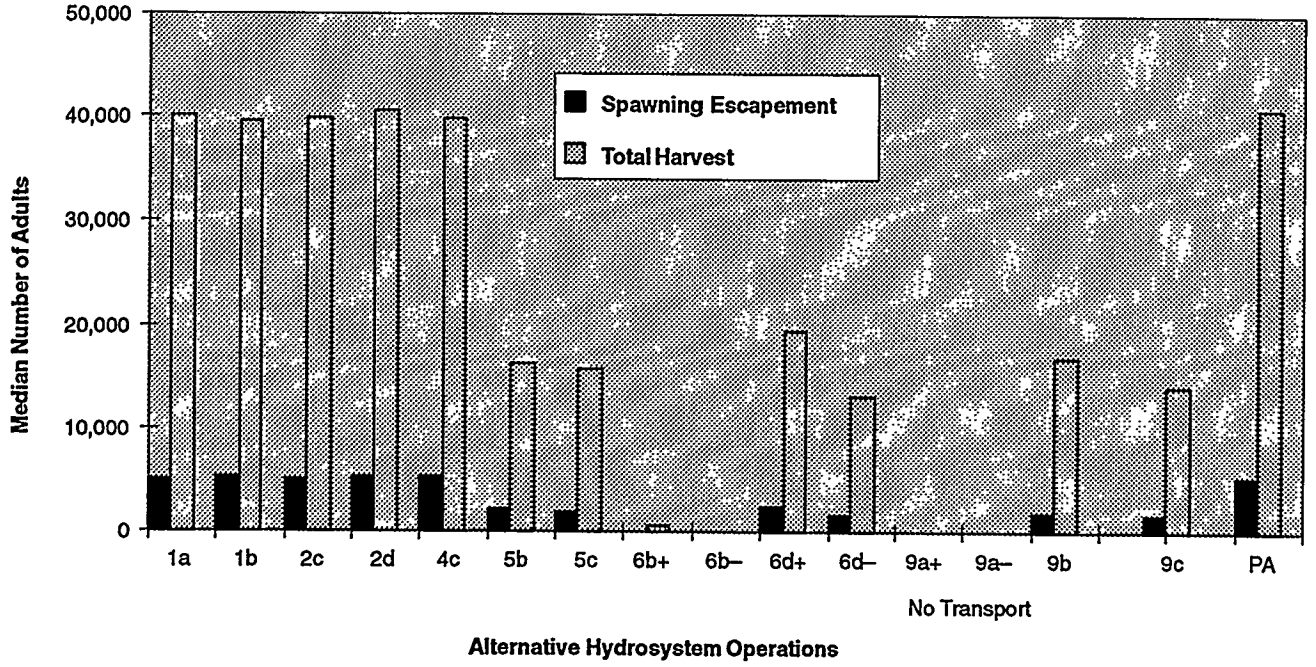


Figure 5–13. Total Harvest and Spawning Escapement, for Snake River Fall Chinook (Projected 30–40 Years Out) Based on Fixed Barge Transport Hypothesis

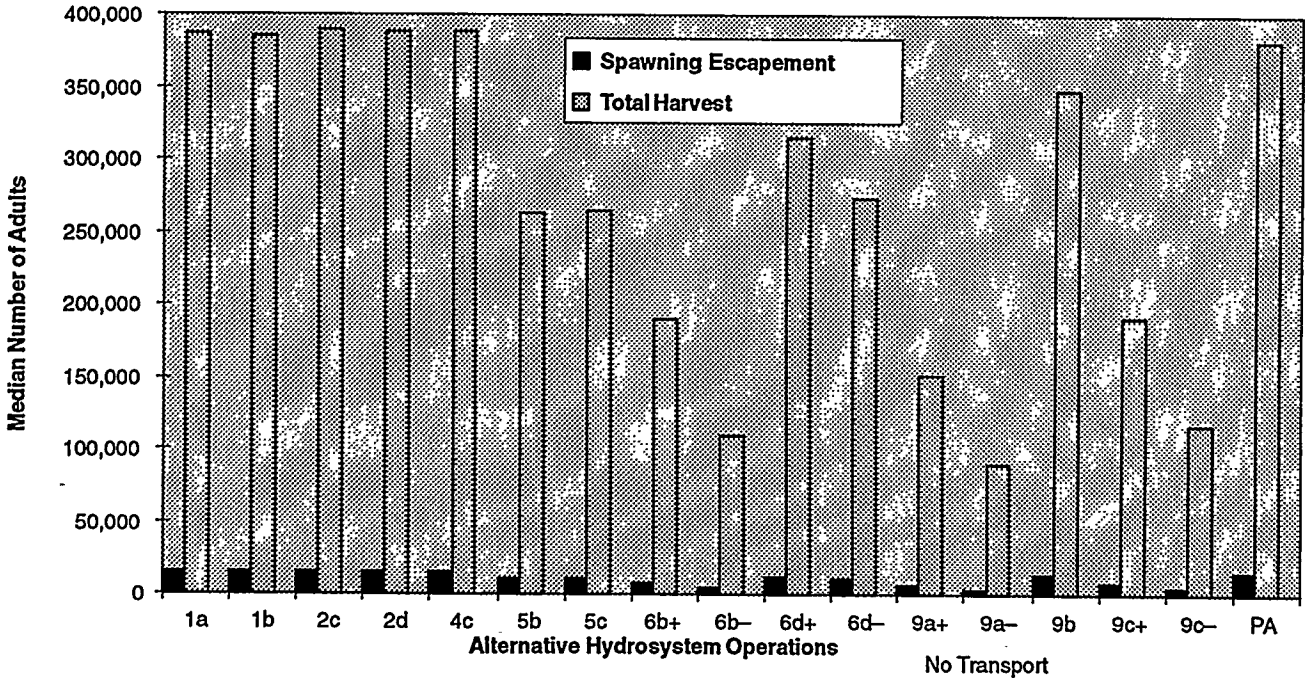


Figure 5–14. Total Harvest and Spawning Escapement, for Dworshak Hatchery Steelhead (Projected 30–40 Years Out) Based on 1986 TIR Transport Hypothesis

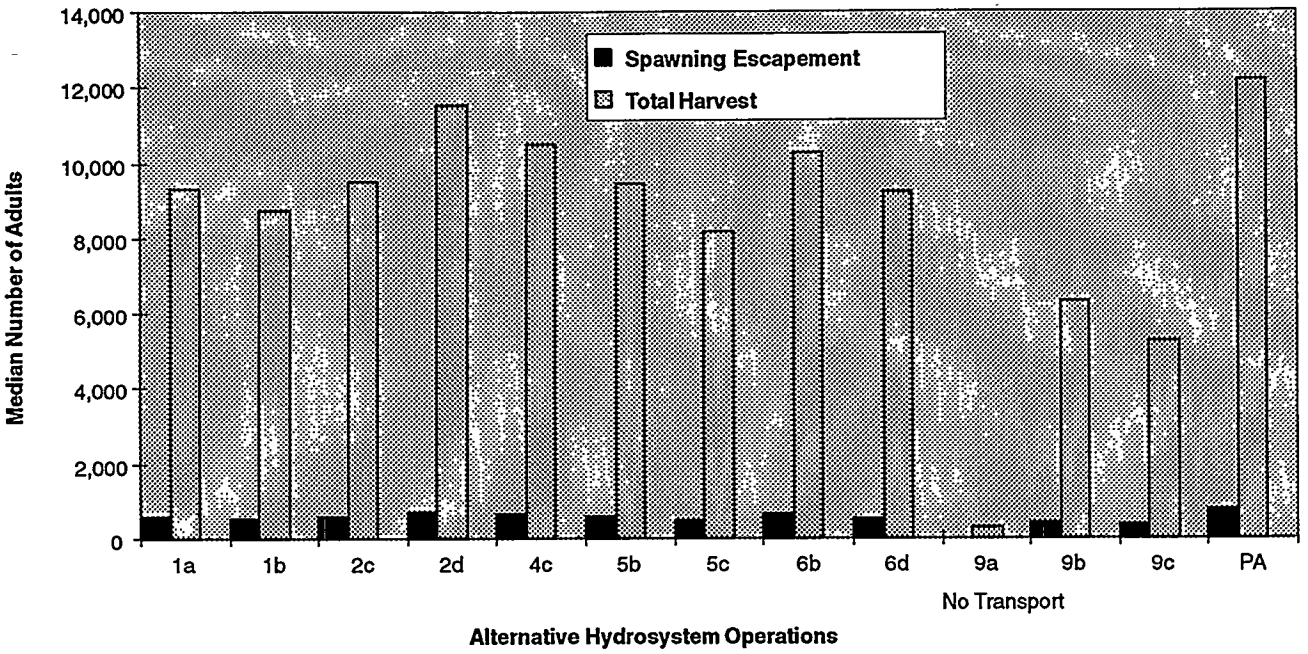


Figure 5–15. Total Harvest and Spawning Escapement, for Methow Summer Chinook (Projected 30–40 Years Out) Based on Fixed Barge Transport Hypothesis

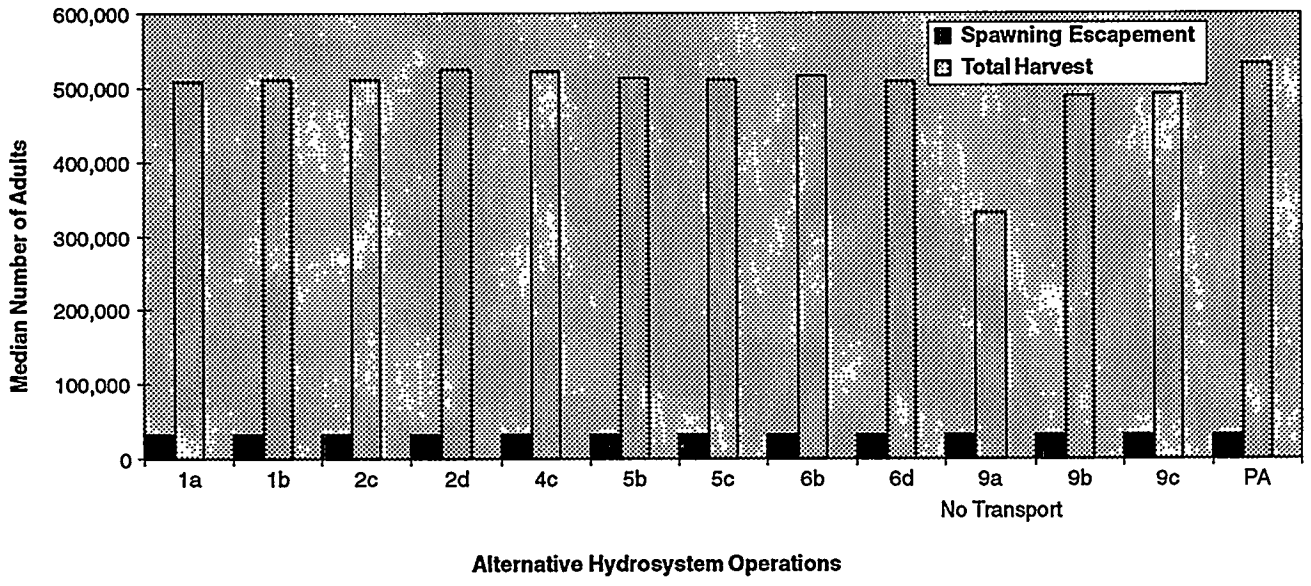


Figure 5–16. Total Harvest and Spawning Escapement, for Hanford Fall Chinook (Projected 30–40 Years Out) Based on Fixed Barge Transport Hypothesis

Juvenile survival for the Deschutes spring chinook ranges between 47 percent and 51 percent across all alternatives. Juvenile survival for the Rock Creek steelhead ranges between 36 percent and 37 percent across all alternatives.

There are two primary reasons that travel time and survival do not vary across alternatives for the Lower Columbia River stocks: (1), mainstem flow levels across alternatives do not vary appreciably (see ROSE Appendix); (2), for those alternatives involving dam reconfiguration, the actions take place at projects in the Snake River only. Therefore, the lower Columbia River stocks are unaffected by them.

Juvenile Survival with Transport

The lower Columbia River stocks reside downstream from smolt collector dams, therefore, they are not transported.

Adult Returns with Transport

These stocks were not modeled under SLCM.

5.5 SENSITIVITY ANALYSIS OF POTENTIAL EFFECTS OF GAS SUPERSATURATION ON JUVENILE SURVIVAL

During public review and comment on the SOR Draft EIS, several reviewers suggested that the CRiSP1.4 model over–estimated the lethal effects of gas supersaturated water on migrating juvenile salmonids. As explained in Chapter 3 of the SOR Final EIS, Anadromous Fish Appendix C, CRiSP1.5 has incorporated a functional change that results in the model being less sensitive to gas supersaturation than the previous version, CRiSP1.4. Table 5–11 presents a comparison between alternatives 9a+ and the Preferred Alternative, with and without the effects of gas supersaturation, relative to survival under the No Action Alternative, 2c. According to this table, CRiSP1.5 does not attribute significant mortality to gas supersaturation, i.e., for most stocks under all three alternatives, in–river survival remains relatively constant. However, there may be some slight benefit to Rock Creek steelhead if gas–related mortality is turned off (Table 5–11).

5.6 QUALITATIVE RESULTS: POTENTIAL EFFECTS OF MAINSTEM RESERVOIR DRAWDOWNS ON ANADROMOUS FISH

CRiSP1.5 attempts to represent many of the effects associated with reservoir drawdown. However, some effects simply can't be depicted in a smolt passage model, since they involve ecological processes within reservoirs, or impacts on adult passage.

Furthermore, some of the smolt passage–related effects associated with drawdown – particularly those involving the performance of structural components at the dam (e.g., FGE, or turbine–related mortality) – are highly uncertain.

As a consequence, model predictions can be quite plastic, depending on the analysts who make judgment calls regarding the direction and magnitude of the effects. For this reason, the AFWG modeled both optimistic and pessimistic scenarios for drawdown alternatives to reflect the range of uncertainty regarding these unmeasured effects.

Since it is apparent that the models cannot reflect all drawdown effects, this section contains a brief discussion of some qualitative aspects that require consideration when evaluating the efficacy or risk associated with drawdown. The reader should note that there are other analytical forums under the auspices of the Corps that are attempting to resolve these uncertainties through reconnaissance field studies, and physical modeling of structurally reconfigured dams.

The drawdowns proposed for implementation are of two general types. (1) One is a deep drawdown from normal pool elevation to the crest of the spillway. Depending on the damsite, the change in elevation could range from 30 to 50 feet. (2) The second type of drawdown – to minimum operating pool (MOP) – amounts to only about a three to five foot drop from normal operating pool elevation. Dams are designed to operate at MOP, although some modifications to facilities may be necessary. Obviously, effects are much more pronounced at a drawdown to spillway crest. The following discussion emphasizes deep drawdowns, except where indicated otherwise.

Ecological considerations. Reservoir drawdown would perturb the existing ecological balance within the reservoirs, perhaps to the detriment of some salmon populations. Reservoir drawdown would constrict the size of existing reservoirs. This may alter rearing and reproductive habitat of predatory fish, as well as their general distribution and that of their prey, including smolts. The outcome in terms of net smolt loss due to predation is uncertain.

Apart from potential changes in predator/prey interaction, the periodic dewatering cycles would perturb the overall trophic structure within the reservoir. Shallow nearshore areas would be exposed. Young, parr–stage ocean–type chinook salmon rear in shallow shoreline flats, relying on that habitat for forage items, and emergent plants for cover from predators. Destruction of this habitat would certainly not be advantageous to this species. This issue has received no analytical treatment to date, but is critically important with regard to subyearling chinook, particularly where they occur in sizable numbers, such as in Lower Granite and John Day reservoirs.

In some reservoirs the resuspension of accumulated sediment may create conditions that are unfavorable to salmonids, at least until some new stasis is reached. With the exposure of sediment covered substrate, wave action, precipitation events or swifter currents can all cause resuspension of sediments. This may be of particular concern at uppermost dams where the greatest volumes of sediment have accumulated. Concern over sediment dispersion and removal has been a key impediment to proceeding with dam removal on the Elwha River in Washington State.

Furthermore, drawdown alternatives and the Natural River alternatives would eliminate transportation. As a result, increased numbers of steelhead would likely remain as residents in the constricted reservoirs, given their proclivity for residualization and the vast numbers of hatchery steelhead currently released in the drainage. Steelhead may in themselves become effective predators on smolts, particularly subyearling Snake River fall chinook. The potential for such a possibility deserves consideration.

System reconfiguration. To accommodate reservoir drawdown, existing dams would have to be reconfigured. Structures of concern include spillways, stilling basins, turbines, smolt bypass systems, and adult passage facilities. The goal of any new dam configuration should be to impose no greater mortality on either smolts or adults than currently exists, and preferably to decrease net mortality associated with the redesigned structure. This would involve balancing several mechanisms that affect mortality including: gas saturation associated with spill; changes in turbine effects under reduced head; the effectiveness of any new smolt collection/bypass system; changes in juvenile mortality associated with spill passage; and, impacts on adult passage in terms of delay of migration and fallback. Dam configurations being considered would create conditions that can affect each of these mechanisms, with unpredictable results.

These passage effects are separate from anticipated benefits associated with decreases in smolt travel time. Furthermore, no party has presented data, analyses, model runs or even subjective assessments that can assure this region that the net outcome of any reconfigured system would result in either neutral or improved passage–related survival. Models cannot help in this regard, because no measures or estimates of resultant effects are available. Even the direction of change is uncertain. With respect to predicting effects on adults, no upstream passage models are available.

The Natural River alternatives (5b & c) are variants of reservoir drawdown. This strategy goes beyond the intent of drawdown, i.e., increased speed of migration, and attempts to eliminate all mortality associated with dam passage by creating an alternate channel around each dam. As envisioned, the floor of the channel would be near riverbed elevation. This strategy could appreciably increase smolt survival through the Snake River as has been seen in AFWG model analyses, since it averts turbine, spill, and bypass mortality by disabling the dams. Reservoir effects would presumably be lessened.

However, the model analyses may not capture all the nuances associated with implementing the natural river alternative. For example, this strategy precludes transportation at reconfigured dams, eliminating one option for passage. All smolts from the Snake River basin would remain in–river to arrive at McNary Dam. Here, smolts would either be bypassed and continue passage downstream, or be transported to below Bonneville Dam. It may be necessary or desirable to transport smolts from McNary Dam under certain flow regimes, as is currently the policy. Under the Natural River alternative this may be impractical or impossible, because the large number of smolts that remain in–river (that could have been transported from LGR, LGO or LMO dams) would likely overwhelm the McNary facility. Furthermore, if the intent were to transport at McNary Dam in low flow years, the logic of dismantling transport facilities at the Snake River dams, as required by the Natural River alternative, is problematic, since transportation from Snake River projects would increase the potential for survival of the Snake River stocks under such conditions.

Preferred Alternative: John Day Reservoir Drawdown. The drawdown of Lower Snake River and John Day reservoirs is proposed under several of the alternative hydrosystem operations. John Day reservoir would be drawn down to Minimum Operating Pool (MOP) under alternatives 5b, 5c, 6b, 6d, 9a, and, most notably, under the PA.

Following is a brief discussion of the potential effects that drawdown of John Day reservoir to MOP would have on anadromous fish. Since the drawdown to MOP is a slight elevation change in comparison to spillway crest, these potential effects would likely not be as pronounced as those occurring under a drawdown to spillway crest.

Loss of shallow water habitat

There would be an appreciable loss of backwaters and shallow water habitat (approximately 6,000 acres) in John Day pool. This habitat is critical for rearing young ocean–type chinook salmon (Zimmerman and Rasmussen 1980, Parente and Smith, 1981) and has good conditions for growth, areas of low predation, and resting areas for migrating salmonids.

Potential effects due to reconfiguration

The amount of dam reconfiguration necessary to accommodate drawdown of John Day reservoir to MOP would be minimal, if any. Thus, passage conditions should remain generally as they are today. It is unlikely that turbine survival, adult passage or FGE would be affected. However, it is possible that orifice passage efficiency (OPE) may decrease somewhat due to the reduced head on the orifice.

Potential Effects on Irrigon and Umatilla Hatcheries

Drawing down John Day reservoir to MOP would severely reduce the water supply at Irrigon and Umatilla Hatcheries (estimated 65 percent loss of available water). The Corps of Engineers, Portland District, has nearly completed a study of alternatives for mitigation of the water loss. A water supply system that combines a river intake with other alternatives may mitigate for the water loss. If this option were chosen, plans and specifications, design, and construction could be completed in approximately four years.

5.7 QUALITATIVE RESULTS: SALMONID RESPONSE TO TRANSPORTATION

This section qualitatively evaluates salmonid response to transportation on a stock by stock basis. Stocks described are Snake River spring/summer chinook, fall chinook, sockeye, and steelhead.

Several reviews (Olney, et al., 1992; Mundy et al., 1994) have questioned the validity of juvenile fish transport studies by NMFS and others. The primary concern has been that 'control' fish are not true controls because they are handled, marked, and, in some cases, transported above or below dams before being released to migrate in–river. Other researchers (Williams and Matthews, 1994) point out that transport and in–river conditions have improved considerably since much of the transport research was done. Therefore, it is recognized that transport research used in the qualitative analysis needs to be redone to reflect current conditions. In their 1995

Biological Opinion, NMFS has recommended such re-evaluation, and studies were initiated by NMFS for the Corps in the spring of 1995.

5.7.1 Spring/Summer Chinook

Juvenile Snake River spring/summer chinook have been lumped together because they migrate downstream at about the same time, and are virtually indistinguishable by external physical characteristics (Waples, *et al.*, 1991c). NMFS has been studying collection and transportation of spring/summer chinook since the late 1960s (Ebel, 1970). Research was continuous through 1980 (Park and Athearn, 1985). Additional research was conducted with juveniles marked in 1986 and 1989 and adult recoveries made through 1992 (Matthews, *et al.*, 1993).

Studies by Sims and Ossiander (1981) provided estimates of in-river survival over various flow years. Survival ranged from a low of 2 percent in 1977 (severe drought year) to approximately 30 percent in higher flow years. In 1973 (a drought year) and 1972 (a high flow year), Sims and Ossiander (1981) and Raymond (1979) estimated that only 5 percent of the juvenile spring/summer chinook survived to The Dalles Dam.

Park and Athearn (1985) reported that in 18 studies conducted from the late 1960s through 1980, eight studies showed statistically higher survivals for transported juvenile spring/summer chinook, eight studies indicated positive, but not statistically significant higher survivals, and one study (1977 – a severe drought year) yielded no results due to generally low adult returns, and 1976 (truck transport only) did not show better results for transportation. Based on these studies, NMFS recommended that the transportation program become operational, and that spring/summer chinook should be transported in all flow years.

In 1985, the fishery agencies and Tribes proposed their "Spread the Risk" policy which called for bypassing spring/summer chinook at Little Goose and McNary dams. The agencies based this recommendation on lower TIRs for spring/summer chinook, even though, as described in the preceding paragraph, results were positive for transportation in the majority of tests. In an interagency agreement signed in 1985, the Corps agreed to follow the "Spread the Risk" policy with additional research to verify that under improved in-river bypass conditions, transport still provided a benefit to spring/summer chinook. Although the study was designed to provide for marking of juvenile fish in 1986, 1987, and 1988, and retrieval of information from adult returns from 1987 through 1991, low flow years allowed marking of juvenile fish only in 1986 and 1989, with retrieval of adult information three years after each marking year, or from 1987 through 1989, and 1990 through 1992. TIRs of 1.6:1 and 2.5:1 were obtained, indicating that with flow years such as 1986 and 1989, transport still provided significant benefit to the survival of spring/summer chinook.

5.7.2 Fall Chinook

Sims and Ossiander (1981), and NMFS research on transportation were not able to estimate in-river survival or TIRs for Snake River fall chinook because there were too few juveniles present in the collection at the dams to provide statistically valid results (Park and Athearn, 1985). However, studies conducted at McNary Dam from 1978 through 1980 were summarized in Park and Athearn (1985), in which Park concluded from TIRs ranging from 1.8:1 to 7.3:1. Subsequent studies in the late 1980s again yielded TIRs averaging 3.5:1 (ranging from 1.7:1 to 7.1:1) (Harmon, et al., 1995). The positive transport benefit ratios in all recovery areas, together with significantly higher numbers of transported fish in all areas, clearly suggests that survival of these fish is enhanced by transportation from McNary Dam. NMFS and others assumed Snake River fall chinook would similarly benefit from transportation, and at Snake River dams measures for spring/summer chinook (turbine intake screens, raised operating gates, revised turbine operations, bypass, collection and transportation) would provide additional protection for fall chinook as well. This has been documented to some extent in Fish Guiding Efficiency studies by NMFS (Krcma, *et al.*, 1980; Swan, *et al.*, 1983) at Snake River dams. Survival of fall chinook has been documented in recent years in FTOT annual reports (Ceballos, *et al.*, 1991, 1992, 1993).

From this information and extrapolation from analyses for spring/summer chinook, some believe a flow/survival relationship also exists for fall chinook. That is, the lower the flow year, the lower in–river survival will be. Transportation survival may be somewhat lower for fall chinook due to collection, handling, and transportation in warmer water temperatures, but TIRs, based on studies from McNary Dam, are still probably higher than they are for spring/summer chinook. However, due to improvements in in–river survival, TIRs for fall chinook (if they could be measured for Snake River fall chinook) could be expected to decrease as improvements in in–river migration conditions continue.

5.7.3 Sockeye

Very little is known about the response of Snake River sockeye to transportation since there have been so few juvenile migrants during studies of flow/survival and transportation. It is assumed (NMFS response to Corps Section 10 Permit application for transport, 1993) that they benefit from improvements in in–river conditions and in collection and transportation similar to the spring/summer chinook. Therefore, it is assumed that similar relationships exist for in–river survival versus transport, and that continued evaluation of survival by both migration routes is needed to establish whether in–river survival will exceed transport survival under some flow conditions.

5.7.4 Steelhead

Sims and Ossiander (1981) developed a flow/survival relationship for steelhead similar to the spring/summer chinook relationship. It is expected that the relationship has changed, just as it has for spring/summer chinook.

Park (Park and Athearn, 1985) reported that steelhead showed significant benefit from transportation in all tests from 1968 through 1980. In the last transport evaluation (Matthews, *et al.,* 1993), NMFS reported similar TIRs for steelhead and spring/summer chinook, whereas in the late 1970s, steelhead TIRs were generally higher than spring/summer chinook TIRs. Rather than reflecting a decline in steelhead survival due to transportation, this pattern probably reflects a concurrent increase in survival of in–river migrants (Matthews and Williams, in publication).

Since steelhead are not an ESA listed species at this writing, most comments and actions taken in the transport program since 1992 have focused on improving conditions for Snake River sockeye and chinook. However, NMFS received a petition requesting listing of Snake River and mid–Columbia River steelhead under the ESA in February 1994, and listing of this species may expand the focus of the transportation program by the summer of 1995 if steelhead are listed.

5.8 QUALITATIVE RESULTS: ALTERNATIVES TO TRANSPORTATION

This section qualitatively evaluates strategic alternatives to transportation as methods for aiding in salmon and steelhead recovery.

5.8.1 In–River Migration (No Juvenile Transport)

Under the ESA, NMFS has the responsibility of determining whether transporting fish benefits endangered species and whether an ESA section 10 permit should be granted, allowing juvenile transportation to continue.

In commenting on the 1993 and 1994 ESA Section 10 Permit applications, many opponents of transportation recommended that the permit be denied, and that the smolts rely solely on in–river migration.

In–river migration contemplates the use of existing and future levels of flow augmentation, spill, and bypass systems to increase the survival of juvenile salmon outmigrating throughout the FCRPS. Current credible scientific information indicates that in–river survival would range from a low of about 30 percent in drought years to a high of 70 percent in a high runoff year (Mathews and Williams in press). Use of flow augmentation from sources that were available in 1994 or additional sources that are recommended in the DFOP or the NMFS Biological Opinion would incrementally increase survival of in–river migrants. Flow augmentation would be

more beneficial in low flow years and less beneficial in high flow years. Therefore, in a drought year, survival of the Snake River outmigration might be increased from 30 to 40 percent with current levels of flow augmentation, or 30 to 50 percent if large quantities of flow augmentation were used. In high flow years, added water might increase survival from 68 percent to 70 percent, although it probably would not be possible to measure the increment of benefit (Mathews and Williams in press).

Many experts believe that spill provides safer passage than turbine/bypass passage. Direct mortality from spill is generally thought to be less than 2 percent, while turbine mortality under current operations is approximately 8 percent, and bypass mortality is less than 2 percent. Without transportation, it would appear that small gains in survival would accrue by using spill. However, spill elevates gas supersaturation in the river, so where this condition becomes detrimental, it must be factored in to estimate overall survival.

NMFS has recommended in their 1995 Biological Opinion on hydro operations that spill and additional flow augmentation be used in 1995 and future years and that survival by in–river and transportation migration routes be thoroughly evaluated. These studies should provide further credible scientific information on which to base future decisions on use of transport, spill and flow augmentation.

Alternative Description

Deny the ESA Section 10 Permit, and require all smolts to migrate in–river. Under this alternative, it would be possible to reinstate transportation if river conditions warranted and NMFS determined it necessary, but not within the current migration season (see below).

Results

The timing and volume of flow that would occur in any given year is difficult to predict, as evidenced in 1993, which appeared to be a drought year until late March. However, heavy spring and summer rains in several parts of the basin turned the expected low runoff into a relatively high runoff year. Additionally, an expected high runoff can be delayed, with relatively low flows occurring during the early part of the migration. Most reviewers of transportation research believe that in a severe drought or low flow years, transportation provides greater survival than in–river migration. According to Raymond (1979), transportation was essential in the severe drought year of 1977, when in–river survival was estimated to be less than 2 percent.

Conversely, prior to each transport season, months of lead time are required to prepare transportation facilities, hire and train temporary personnel, and finalize truck leases and towboat contracts. Denial of an ESA Section 10 Permit by the NMFS would stop the transportation program for an entire season at a minimum. The more years that transportation remains inoperable, the longer it could take to reinstate, due to time required to budget and obtain funding, facility maintenance needs, time required to obtain and train personnel, and time required to prepare and execute contracts.

As a result of the denial of a permit, transportation would not be an option should unanticipated low flows create a critical situation for migrating juveniles.

5.8.2 Removal of Dams

This alternative would involve removing some or all of the eight lower Snake and lower Columbia River dams. Removal of dams, which attempts to return the river in the area of the dams and reservoirs to natural flow and habitat conditions, has been suggested in several forums. It was examined and eliminated in the early round of the Corps' System Configuration Study (SCS). Reasons for its elimination are discussed below.

The Corps decided to move forward with similar alternatives in the SCS: The Natural River options. As described in Chapter 4, under the natural river alternatives, the four lower Snake River reservoirs would be lowered to near streambed levels, while the dams remain in place. The river would be essentially bypassed through a new opening in the dam (not through the turbines or spillways). The original concept by the Corps would have been to construct low level spillways to pass water and fish around the

dams during the outmigration. The dams would have been operational approximately half of each year. This option was estimated to cost $5 billion and take up to 20 years to implement. The revised option would be to cut a channel around the dams, and forego any further operation of the dams. This option was estimated to take 5 years to implement at a cost of $600 million.

Alternative Description

Removal of one to eight of the mainstem Snake and/or Columbia River dams.

Results

Removal of some or all of the eight Snake and Columbia River dams would return the river to the old river channel in the reservoir areas of the dams removed. Proponents believe that this would remove most of the human–induced mortality on the salmon runs. However, this action will not restore the fish runs to pre–dam levels because other human developments upstream of the eight dams will continue to affect the environment. Logging, agriculture, sedimentation, grazing, mining, and other human–caused effects would continue to affect spawning and rearing areas. Upstream storage and irrigation diversions would continue to affect water volumes, flow regimes, water use, and water quality.

Within the areas of the dams and reservoirs removed, habitat recovery could take decades or even centuries, as sediments are redistributed and new riverine habitats develop. During this period, resident and anadromous fish populations would have to adjust to the change. Fall chinook spawning in the reservoir areas would have to find new sites in the riverine habitat. Optimistically, there would be much more suitable habitat, but pessimistically, it may be of reduced quality due to sediment redistribution as the river channel stabilizes.

During dewatering of reservoir areas, many resident fish and some anadromous fish would be stranded and lost (Corps, 1993). Squawfish and exotic species, e.g., predators such as smallmouth bass (*Micropterus dolomieui*) and channel catfish (*Ictalurus punctatus*), and habitat degraders such as carp (*Cyprinus carpio)* would still be present. Reduction of habitat from reservoirs to the river channel would redistribute and possibly concentrate predacious fish. Until equilibrium of the predator population with the reduced habitat and higher flow velocity is reached, predation could be higher than at present on juvenile salmonids.

Avian and other predators would also be attracted to, and concentrate on, stranded and more accessible fish and other aquatic organisms. Until riparian habitat is restored at the new river's edge, there would be a reduction of food from terrestrial sources. Rearing areas for fall chinook and Columbia River summer chinook will be reduced, depending on which reservoirs are removed.

Although many assume that returning the river to the old river channel would restore historic survival levels for juvenile salmon and steelhead, many factors (as described above) have changed over the years. Therefore, there is no guarantee that significant improvement in survival would occur.

Adult salmonids would face many riffles, pools, and in some cases, waterfalls in the old river channel. Compared with travel times in reservoirs, the time required for upstream migration through the natural river would be higher (Bjornn, *et al.* 1993). Unless all upstream storage dams are also removed, the annual hydrograph would be similar to what it is now, with the spring freshet being reduced, and flows being spread out over the lower flow periods of the fall and winter.

While in the long run it is assumed that removal of the dams could restore fish runs to more natural timing and survival rates, short term losses would accompany re–adjustment of the system to the more natural river condition.

Removal of any of the collector dams would eliminate collection and transportation of juvenile fish at those dams. While collection and transportation may still be possible from other sites, depending on the dams removed, river navigation for transportation purposes may be eliminated.

5.8.3 Canal/Pipeline Alternatives

One of the alternatives that has received attention in the System Configuration Study is the idea of an alternative river system for moving fish from the head of Lower Granite pool to the ocean. Several canal and pipeline alternatives have been suggested. They are described and discussed below.

Alternative Descriptions

Option One: Canals. Build a canal from the Lewiston–Clarkston area to the river below Bonneville Dam.

Option Two: Pipeline. Build a pipeline along the shore, floating in the reservoir, or laid along the bottom of the river from the Lewiston–Clarkston area to below Bonneville Dam.

Results

There are a great number of biological, engineering, and financial issues to address before any of these options could be practically considered. Many of the biological issues apply to all of the alternatives. Biological issues arise in part from the sheer tonnage of fish that the system must support, including whether and how to accommodate smolts entering the river downstream of the first collection site, how to mix tributary and river water so as not to interfere with the homing response in adults, and how to keep the canal or pipeline free of debris that can build up and injure smolts during passage.

Pumps required to keep the water flowing through such a long structure are known to cause stress and injury to the fish, particularly with repeated pumping that would be necessary. Some smolts grow and rear during their migration to the ocean. A conduit or pipeline system does not provide for this need. Additionally, there is always concern about vandalism, poaching, predation, and water quality.

Canal Option: This option would require construction of a collection facility to screen the majority or all juvenile fish from the Snake River above Lower Granite Dam, and divert them into a canal constructed from the facility to the river below Bonneville Dam. Over 350 miles of canal would be required, including tunnels through some areas, construction along cliffs in many areas, river crossings over major tributaries, and facilities for introducing more fish collected at downstream dams. Resting pools with semi–natural habitat, aeration equipment to freshen the water, and fences or screen covers to keep out wildlife and predators have been suggested. Again, with the 50 to 60 million fish anticipated to be handled, a great deal of biological uncertainty is associated with this alternative.

The Corps estimates that a migratory canal would cost $5.4 billion, $9.5 million per year to operate, and 11 1/2 years to make operational (Corps SCS Appendix D, 1994).

During the SCS evaluation, agency, Tribal, and other concerned interests in the Technical Advisory Group (TAG) agreed that the technology was uncertain, and that the biological risks associated with the canal option were too great to continue to pursue this option.

Pipeline Options: Two pipeline concepts were proposed as alternatives to the canal described above. One was a pipeline along the shore, and the other was a pipeline floating in the reservoirs with siphons over the dams. Again, these pipelines would require methods for introducing fish into them at downstream dams. Aeration equipment would be required to maintain water quality, and pumps would be required to maintain transport velocities.

It has been previously identified (Park, *et at.*, 1979; Congleton, 1983) that a 2,500 foot long pipeline at Lower Granite Dam – a pipeline in which pressures change two atmospheres – has caused enough stress that the system should be replaced with the more modern and more benign flume system now in use at Little Goose, Lower Monumental, and McNary dams. Given this, a 350 mile long pipeline – with pressure changes of 3 atmospheres at each of eight dams; with associated propellers to keep the water moving; and with the necessity to add fish and water at downstream locations – was determined to be fraught with biological problems by the SCS TAG.

For the two pipeline options analyzed in detail in the SCS Phase I report, it was concluded that a pressurized pipeline would cost $5.1 billion, $9.5 million per year to operate, and take 11 1/2 years to make operational. The floating pipeline would cost approximately $1 billion, $31.8 million per year to operate, and would take 11 1/2 years to make operational.

Again, risks to juvenile salmon evaluated in the SCS process were determined to be too great to merit further study of this idea.

5.9 QUALITATIVE RESULTS: ALTERNATE METHODS OF TRANSPORTATION

This section qualitatively analyzes alternative methods of transportation. In other words, the analysis assumes that the transportation of juvenile salmonids would continue, and evaluates changing transportation tactics and technologies.

5.9.1 Means of Conveyance

5.9.1.1 Net Pens

It has been suggested that net pens could be used instead of barges on the Snake and Columbia Rivers. The net pen concept will be further evaluated in the SCS Phase II.

Net pens are floating frameworks in which a pen constructed of netting material is suspended. The biological advantage of net pens is that fish are transported in more natural conditions than in barges – that they are able to see out into the river, and river water flows freely through the pens.

A net pen design was considered in the mid–Columbia River to collect smolts at Wanapum Dam and transport them down to Priest Rapids Dam where they would be discharged through the bypass system for return to the river.

Alternative Description

Transport migrating salmonids downstream via net pens, rather than in trucks or barges.

Results

In reviewing the structural design for the net pens proposed for the mid–Columbia, Corps engineers determined that the net pens, as proposed, would have to be strengthened substantially to deal with wind/wave action routinely encountered in the transportation route (especially in John Day Reservoir where fish barges and commercial tows often have to pull over until adverse weather conditions subside). Under severe weather conditions, or if net pens were transported at higher speeds, there is concern that fish would be swept against the netting and stressed or injured. Under normal or severe debris conditions, there is concern that logs or other debris could tear the net pens. Perhaps the most crucial concern is that in net pens, fish are held near the surface with free circulation from the reservoirs. In situations with gas supersaturation or other pollution, fish could be subjected to, and even held in, lethal conditions.

The net pen concept involves large numbers of pens that would be transported at considerably slower speeds down the reservoir than the existing barges. Converting to net pens would require more vessels and more towboats than are currently used in transportation. In the SCS, an analysis was made comparing the existing barge fleet (six barges) with a replacement fleet of 24 net pens that would be required to continue a comparable transport program. The cost of acquiring the net pens is estimated at $26.6 million, with an annual operating cost of $6.8 million per year. This compares with $5.4 million spent on the existing barges, and annual operating costs of $1.4 million (for barging alone).

5.9.1.2 Aircraft

Proposals have been submitted by two helicopter companies for transportation of fish. One company provided a video tape of fish–stocking operations used in Scotland in which fish and water were loaded into an approximately 500 gal transport container, flown to a new destination, and released. The other company proposed the use of Sykorsky Sky Cranes (large helicopters commonly used for helicopter logging and other heavy lifting jobs) to transport

fish, stating that they could develop larger containers (several thousand gallons) for the purpose.

Alternative Description

Transport migrating salmonids from the collector site dam to a release site via aircraft.

Results

NMFS tested the use of an airplane to transport fish in 1976 (Park, *et al.*, 1979). Some of the most valuable information gathered was that aircraft have limited capacity, and that flying conditions during the transportation season can be hazardous. Although it was not a great concern in the 1970s, more recent research has identified stress and perhaps subsequent mortality from transferring fish from raceway to vehicle (Park, *et al.*, 1984; Congleton, 1986). To load the plane requires additional transfer from the truck to the plane.

In the videotape presented by a helicopter proponent, it was apparent that fish were being transported at very high densities, generally over distances that could be covered in less than one hour. In applying this concept to the existing transport program, it was apparent that even the largest helicopters would have great difficulty in dealing with the numbers of fish being transported. Also, the helicopter companies agreed that it will not be possible to fly in the adverse conditions that can occur from the lower Snake River dams to the lower Columbia River Gorge where transported fish are typically released. Although cost was not discussed, judging from commercial helicopter rates, the cost per pound of fish transported would be substantially higher than existing trucking and barging costs.

5.9.1.3 Polymer Bags

A company presently transporting fresh water across oceans to arid countries via 700,000 gal. polymer bags proposed that the technology could be expanded into the fish transport program. The polymer bags, are cigar–shaped bags adapted from the skin material used in blimps. A videotape showing the capabilities of their product was transmitted to the Corps.

The proponent proposed that fish and water would be loaded into the polymer bags at the dams, and that the bags would be towed downstream by towboats to the release area below Bonneville Dam.

Alternative Description

Transport fish from the collector site to a downstream release site via 700,000 gal polymer cigar–shaped bags adapted from the skin material used in blimps bags.

Results

After viewing the videotape provided by the proponent, several questions arose concerning use of polymer bags for fish transportation. Filling the bags, and loading fish, appeared to require pumping through pressurized pipes. Stress studies at JFTP facilities have raised considerable concern about the stress of such activities. As presented, the concept included no mechanisms for controlling water quality within the bags. With the knowledge that over 910,000 fish have been collected within a 24 hour period at Lower Granite Dam, there is concern that large loads of fish might deplete oxygen levels within the bags. Therefore, substantial design aspects would have to be developed to make the bags acceptable.

5.9.2 Operating Tactics and Technology

5.9.2.1 Size Separation

Concern has developed that collecting smaller salmon with larger salmon and steelhead subjects the smaller fish to stress from species interaction.

The concern about size separation was investigated by NMFS (Park, *et al.*, 1983). Direct predation was not observed, but, Park *et al.*, (1983) did report higher stress levels in chinook transported with larger steelhead than in chinook transported only with other smaller chinook. In later tests by Congleton (1986), evidence of stress was also observed. In the transition from "dry separators" developed in the early 1970s by NMFS to the "wet separators" first tested in 1978, size separation during transport was developed.

Size separation has been provided at Little Goose and McNary dams since late 1978 and 1979. Fish transported from these dams are kept separated by size in transport vehicles to avoid stress and predation.

New state of the art separators have been installed at Little Goose (1990), Lower Monumental (1992), and McNary (1994) dams to continue separating larger salmon and steelhead from smaller ones. NMFS and NPPC have asked that installation of size separation at Lower Granite Dam be expedited. The Corps is proceeding with development of size separation at Lower Granite Dam.

Alternative Description

Improve size separation capabilities in the JFTP to reduce stress in transported fish.

Results

In the most recent evaluation at Little Goose Dam, approximately 80 percent of the spring/summer chinook were separated from the larger hatchery steelhead, and about 20 percent of the hatchery steelhead went through the small fish side of the separator. However, for wild steelhead, which are smaller, the separator was only about 50 percent efficient (Ceballos, *et al.*, 1992).

The separator design was improved from the Little Goose installation (1990) to the Lower Monumental (1992) and McNary (1994) designs. Evaluation results are pending on how effective the new design is at separating fish by size.

5.9.2.2 Stock or Species Separation

Alternative Description

Separate ESA–listed species from unlisted species during transportation.

Results

With existing technology, it is not possible to distinguish individual stocks within a species, nor is it practical to separate individual species. The difficulty arises in finding a method for separating smolts which does not require additional handling.

Currently, every effort is made to minimize the handling of fish in accordance with criteria provided by the fishery agencies and tribes. Small samples (typically less than 3 percent of the spring/summer chinook outmigration) are taken for species, size, and condition evaluation. These fish are pre–anesthetized and anesthetized to minimize stress during handling. To manually separate listed species would require that all fish be anesthetized and handled. As stated earlier, up to 890,000 fish have been collected in a 24–hour period at Lower Granite Dam, and collections of hundreds of thousands per day are common at Lower Granite and McNary dams. Manually handling such large numbers of fish for species separation would not be in the best interest of the fish.

NMFS considers all of the Snake River fall chinook, wild and hatchery, as representative of one Evolutionary Significant Unit (ESU). Most of the Snake River fall chinook migrate in the summer and fall when fish numbers are very low. When fish numbers are below 200 per day, all of the fish are passed through the laboratory. While this subjects them to anesthetization and handling, it does afford the opportunity to separate the fall chinook from the larger spring/summer chinook and steelhead that are present in small numbers at that time. Any sockeye that are present can be separated as well.

All of the Snake River sockeye are wild fish. Kokanee (land–locked sockeye) in the Snake River basin are typically naturally produced. Adult kokanee are distinguishable from adult sockeye generally by their size. However, juvenile kokanee cannot be distinguished from juvenile sockeye with reliability. Combined Snake River sockeye and kokanee (referred to collectively as *O. nerka* by the agencies) migrate at the same time as spring/summer chinook and steelhead.

Aside from manually inspecting each fish and separating them by hand, there is no reliable method at this time to separate ESA listed from unlisted stocks.

5.9.2.3 Hatchery/Wild Separation

Proponents of separating hatchery from wild fish have expressed concern that hatchery fish harbor and transmit diseases to wild fish. Other concerns are that sheer numbers of hatchery fish may cause stress in the collection and transportation process, or that after release, hatchery fish may deplete food supplies in the lower river that wild fish need.

Alternative Description

Separate hatchery fish from wild fish to avoid wild fish being exposed to diseases carried by hatchery fish.

Results

For several years, the state fishery agencies have been fin–clipping all hatchery steelhead. Until 1993, the joint fish marking committee of fishery agencies would not allow adipose fin clipping of all chinook. However, this was changed in 1993, and most hatchery chinook were marked with adipose fin clips. It is now possible to distinguish between most hatchery and wild fish. However, in some of the ESUs, hatchery fish are included (Snake River fall chinook, and some of the spring chinook populations derived from wild stocks). These fish could not, if adipose fin clipped, be separated from non–ESU hatchery fish.

If a mechanized system (holographic imagery for example) could be developed to detect fish with adipose fins versus those without, this would allow separation of hatchery and wild fish. However, given the numbers of fish handled at the collection facilities during peak migrations, no technology has been developed to date for that purpose.

The fishery agencies have made efforts to separate hatchery chinook from hatchery steelhead by varying release dates at the hatcheries. These efforts have been successful to some degree, but they also have risks. In 1992, a drought year, chinook that were released early faired well, but the steelhead released after the peak outflow residualized in large numbers in Lower Granite and the other lower Snake River reservoirs (Ceballos, *et al.*, 1993).

Concepts have been proposed such as the use of net pens to hold hatchery fish for acclimation and separate transportation. These fish could home and return to the areas where they are held, without migrating freely in–river with wild migrants. If this or a similar concept were developed, it would be possible to transport most hatchery fish separately from wild fish.

5.9.2.4 Barge Fish Only (No Truck Transport)

In the late 1970s when barges were coming into use, there was concern whether trucks were equal to barges as transport vehicles. Presently, both trucks and barges are used as transport conveyances; trucks when fish numbers are low, and barges when more fish are transported. Some reviewers of the transport program feel that trucks are more stressful and cause more mortality than barges. They recommend that all transport should be accomplished by barges. This concept was carried forward by the NPPC in its 1991 Amendments to the Fish and Wildlife Program.

Alternative Description

Discontinue the use of trucks as transport conveyances, and use only barges to transport fish.

Results

NMFS evaluated the two types of vehicles in 1978 and found the transport conditions to be equivalent in terms of water quality (Park, *et al.*, 1980). Delayed mortality ranged from 10.4 to 20.4 percent for yearling chinook in trucks, and averaged 7.2 in barges. For steelhead, delayed mortality from trucking was 3.8 percent, and no delayed mortality was observed from barging. Later evaluations found that trucks produced slightly higher stress levels than barges, but the difference was not considered substantial enough to abandon the use of trucks (Park, *et al.*, 1978; Congleton, 1984). Because the two modes of transportation are similar in their biological impacts on smolts, the deciding factors became ones of cost and efficiency.

The cost of using barges would be roughly 10 times higher than for trucks moving the same number of fish. The 3,500 gal tankers can transport up to 1,750 lbs of fish (17,500 at 10 fish/lb). It costs roughly

$350 per round trip for a large tanker, and takes two days (including an overnight stay downriver) for one driver. On the barge, a round trip costs approximately $15,000, but at similar fish size, 750,000 fish can be transported.

During low collection periods, trucking costs are further reduced by piggybacking fish from more than one project. For example, a lightly loaded truck from Lower Granite Dam may stop at Little Goose Dam and take on additional fish. Trucking and operator costs are reduced in this manner. Piggybacking two projects has been approved by the fishery agencies and tribes, and is permitted under the ESA Section 10 Permit. During extremely low fish numbers (less than 200 per day), mini–tankers (tank units that fit in the bed of a 1–ton pickup) are used. The smallest load thus far was hauled in 1992, when a two–day collection of six fish was transported from Lower Granite Dam. Piggybacking is also allowed for mini–tankers. The cost per trip on mini–tankers is somewhat less than for a large tanker due to fuel savings and reduced equipment costs.

If barging of all fish were required, the cost of operation would more than double the current level of approximately $2.5 million to well over $5 million per year.

Most of the concern between barging and trucking is offset by the fact that a vast majority of the transported fish are barged. Over the past several years, over 95 percent of the Snake River yearling (spring/summer chinook, sockeye, and steelhead) fish transported have been barged downstream. Conversely, the majority of subyearling fish from the Snake River have been trucked because they migrate after the spring barging has concluded. Summer barging from McNary Dam is required to keep pace with the subyearling outmigration from the mid–Columbia River.

5.9.2.5 Reduced Collection/Transportation Densities

During the research of the late 1960s and 1970s, NMFS transported fish in trucks at normal hatchery loading densities (1.5 to 2.0 lbs/gal). At the concern of the fishery agencies and Tribes, the loading densities were reduced to 1.0 lb/gal for the 1980 transition from research to an operational program. From 1981 to the present, loading densities prescribed by the fishery agencies, Tribes, and Corps are 0.5 lb/gal. This criterion is used for raceways at the collector dams, and for the transport trucks. Hauling at maximum density occurs only during peak fish migration periods. The majority of barge loads (95+ percent of the fish are barged) are at densities as low as a few thousandths of a lb/gal, and most truck loads are below the maximum density.

Alternative Description

Reduce the density at which fish are held in collection facilities and in transportation equipment by increasing the number and use of fish barges.

Results

Due to the concern about loading densities, NMFS conducted studies in 1982 (Park, *et al.,* 1983). Densities of 0.25 to 1.5 were tested by Park, *et al.* Congleton (1986) conducted studies in the mid–1980s on holding and transport densities of 0.25 to 0.125 lbs/gal, as compared to higher loading densities. Basically, the findings were that stress levels in fish are reduced from higher densities down to the 0.5 lb/gal rate, but that no appreciable improvement is observed at 0.25 or 0.125 lb/gal.

By doubling barge capacity for a given trip, the loading density can be reduced to 1/2 the current rate (approximately 0.25 lb/gal at maximum loading). Since the ESA listing of Snake River salmon, there has been so much controversy about alternatives to transportation that there has been no unified support in the region for expansion of the transport facilities or equipment to reduce loading densities. However, based upon NMFS' request, the Corps has decided to withdraw the extra barge concept from the SCS Phase II and proceed immediately with this option.

Given expected approval times, time for budgeting funds, time for revising designs, and construction times, it is doubtful that the first new barge could be available before 1997. NMFS, the Corps, and the

Recovery Team have recommended that additional barges be acquired. Acquisition of additional barges is proceeding.

5.9.2.6 Add Temperature Control to Existing Barges

At the lower Snake River collector dams, the normal transport season customarily extended from the last week of March through July, and at McNary Dam until about the end of September. To protect Snake River fall chinook following ESA listing, the season was extended through October at the Snake River dams, and December at McNary Dam. This means that in July and August, when Snake River water temperatures usually reach or exceed 75° F, rather than bypass fish back to the river, they are now transported. At this time of year, Snake River fish are trucked. Both the large and mini–tankers are equipped with refrigeration units for temperature control. At the same time, barging is occurring from McNary Dam. Concern has been expressed that fish barged during higher water temperatures may be stressed.

Alternative Description

Add refrigeration units to barges.

Results

Investigation of barge mortality records during summer transport revealed no significant increase over spring transportation (Eby, pers. comm.; Wik, pers. comm.).

Meanwhile, adding refrigeration units to barges is considered in the SCS evaluation, Appendix E. Engineering evaluation has been conducted to determine what it will cost to provide temperature control to the existing barges. It is determined that to lower the temperature of the pumped flow 8° F (up to 15,000 gpm inflow) will require chilling equipment of such magnitude that it will have to be located on a separate barge. To provide six temperature control barges to accompany the existing barges will cost $63.5 million and $7 million a year to operate.

Since increased river temperatures do not appear to be causing a problem for barged fish, further study of temperature control in barges has been curtailed.

5.9.2.7 Modify Barge Release Mechanisms/ Designs

Some observers of the release of fish from the barges have expressed concern that release, especially the delay of the last few fish, causes stress to the fish. To meet this concern, the Corps contracted with OSU/U of I (Schreck and Congleton) to evaluate mortality within the barges, fish exiting through the release mechanisms, and to track fish after release, and monitor post–release stress if possible. The NPPC included investigation of new release mechanisms in their 1991 Amendments to their Fish and Wildlife Program, and the Corps included this topic in the SCS.

Alternative Description

Option one: Increase the size of release systems on medium and large barges to improve release conditions.

Option two: Make major modification of barge design, including split–hulled barges, and hinged–bow barges so fish could be released more quickly, presumably to reduce stress of release.

Results

Improving release mechanisms on barges is considered in Appendix E of the SCS (Corps, 1994). The Biological Opinion (RPA 9, p. 115) calls for enlarging exits on existing barges starting in 1996 and completed by 1997.

The current release mechanisms were designed to minimize stress and injury to fish. The compartments slope toward a round 18–inch diameter hole that is closed with a rubber stopper. The edges of the hole are rounded and smooth. At release, the stopper is quickly raised, and the water and fish drain out through the bottom of the barge. Evaluation of the release mechanisms shows that some fish swim hard to resist being unloaded, and that the last fish to leave are momentarily unwatered at release. The release process, from the time the water level starts to recede until the last fish leaves the compart-

ment on the barge, takes less than five minutes. Stress measurements have not shown conclusively that the release mechanisms or the short term exertion and unwatering of a few fish are harmful (Schreck and Congleton, 1994).

The Corps is designing modifications to enlarge exits on the six existing barges. The fist barge would be modified in 1996, and stress would be monitored to assure that the modification achieves the desired result. The remaining barges would be modified between the 1996 and 1997 transport seasons. For any new barges that will be acquired, modification of release mechanisms will be considered in redesign or updating of existing designs.

5.9.2.8 Sound/Vibration Effect in Barges

The existing barges use diesel engines to drive pumps for the water supply. Observers have expressed concern that the pumps may cause noise or vibrations that are deleterious to the fish. As a result, the Corps contracted with Schreck and Congleton to evaluate stress in the barges.

A second concern has been voiced by a private company with years of experience quieting submarines. This company was commissioned to evaluate noise levels in fish hatcheries (Dworshak and Clearwater, for example). When they reported much higher noise levels in the hatcheries than in natural waters to the NPPC, the NPPC recommended they contact the Corps concerning noise levels in fish barges.

Alternative Description

Modify existing barges if sound/vibration analyses find levels deleterious to fish and/or consider sound effect in the design of any new barges.

Results

Congleton (1993) found little difference in stress levels between fish held in barges with engines on and fish held in barges with engines off. He did find that there is elevated stress for the first hour after fish were loaded into the barge. However, he could not determine whether the stress is caused by noise in the barge, or loading from the raceways into the barge. Stress levels returned to normal an hour or so after loading into the barge.

The noise control proponent first contacted the Corps in December of 1993, demonstrating with audio equipment the marked difference in noise levels in hatcheries versus natural noise levels. It is likely that similar high noise levels are occurring in barges. The proponent has submitted a proposal to the Corps for evaluation of noise levels in the barges compared with background (natural river) noise levels. At this time, the proposal is being considered.

If noise levels turn out to be a major concern in the barges, steps will be taken to retrofit noise suppression equipment in existing barges. If new barges are constructed, noise suppression will be included in any new designs or modification of existing designs.

5.9.2.9 Increase Direct Loading

Studies of stress levels in the collection/transportation process have identified that stress levels are highest as fish come over the separator, reduce as fish recover in raceways, are elevated as fish are loaded into trucks or barges, and reduce again as fish recover in the transport vehicle (Park, *et al*, 1983; Congleton, 1986). Based on this information, the fishery agencies, tribes, NPPC, and NMFS have recommended that direct loading of barges be increased. NMFS' 1995 B.O. (RPA 25, p. 127) calls for the Corps to determine how many additional barges would be needed to maximize direct loading, to acquire two new barges by 1997, and the remainder by 1999.

Alternative Description

Facilitate direct loading of juveniles into barges, thus reducing stress. This would require the acquisition of more barges.

Results

The Corps has conducted preliminary analysis on the requirements for additional barges to maximize direct loading. Preliminary indications are that up to 12 new 150,000 or 100,000 gal barges will be a sufficient number of barges so that a barge could be parked at each facility and loading while other barges were in transit downstream.

Based on the cost of the most recently acquired barges, new barges will cost between $2.5 and $3.0 million apiece, or $27.5 to $33 million. Assuming acquisition were approved and funds provided, with design and contracting time, the two new barges could be available by 1997 and the remaining barges by 1999 (Biological Opinion, RPA 25, p.127).

Expanding the barge fleet from six barges up to 18 barges would require additional barge moorage areas and fueling facilities. Individual barges would be leaving each collector dam daily whereas under current operations, a barge from Lower Granite Dam stops at Little Goose, Lower Monumental, and McNary dams to take on additional fish. Therefore, additional towboats would be required, and fish barge traffic would increase. By dividing towboat operations between Granite/Goose and Monumental/McNary dams, it is anticipated that the number of towboats would increase from the current level of four per season to eight per season.

The environmental effects from use of resources to construct the additional barges, and from increased traffic and use of fuel associated with the operation of the barges and towboats should be minimal. Positive environmental effects would accrue from the reduction in handling and stress, and the reduced transport densities of the fish transported.

5.9.2.10 Partial Transport of Some Species ("Spread the Risk")

The "Spread the Risk" policy used through 1994 call for returning approximately 80 percent of the collected spring chinook to the river when Snake River flows exceed a five day average of 100 kcfs, and approximately 80 percent of the spring chinook to the river at McNary when flows exceed 220 kcfs. At flow levels below these, all collected smolts are transported. The policy is based on the concept that yearlings survive in-river at certain flow levels as well or better than they do in the collection and transportation program. Thus, by transporting or not transporting depending on flows, the risk to the population is spread between transportation and in-river migration. The policy was formalized in an agreement signed in March of 1985 and was effective through the 1993 transport season. Recently, proposals have been made through the Salmon Summit, SCS, NPPC, commenters on transport permits, and others, that this partial transport concept be re-evaluated.

Spreading the risk was modified in NMFS' 1995 Biological Opinion. Collection was to be maximized at the Snake River collector dams, but no spring transportation was to occur at McNary Dam. With flows above 85 kcfs at Little Goose and Lower Monumental Dams, and above 100 kcfs at Lower Granite Dam, spill was to be provided to increase in-river passage (Biological Opinion, pp 102 through 112). Thus, NMFS intended that maximum numbers of fish be transported from the Snake River, but that those fish that were not collected would be afforded the best possible in-river survival conditions.

Alternative Description

Manage the collection process to release selected species back to the river for in-river migration at certain flow levels.

Results

There are currently no reliable in-river survival estimates or transport survival estimates that clearly demonstrate the relative benefits of one strategy over the other for certain flow conditions. Section 5.1 attempts to quantitatively evaluate several in-river survival estimates at various flow levels with several transportation survival theories in order to determine if a trigger flow exists at which smolts should be returned to the river.

Accompanying the revised "Spread the Risk" approach in the Biological Opinion, NMFS called for a complete re-evaluation of transport and in-river survival. This re-evaluation was intended to resolve the controversy over intepretation of previous fish transportation research, and verify whether in-river passage has been improved to the extent where transport is no longer needed to protect spring migrating fish.

5.9.2.11 Varied Timing

Before the eight dams and reservoirs were constructed, NMFS estimated that it took juvenile salmon 20 to 30 days, depending on flow levels, to migrate from the Salmon River to the estuary (Raymond, 1979). With the dams and reservoirs, the trip takes 50 to 90 days, and in severe drought years such as 1977, it may never have been completed.

As described earlier, smolts have a limited time to migrate or they revert to resident form and cannot enter saltwater. Transportation, including time to migrate from the Salmon River to the collector dams, probably gets the smolts to the estuary in 12 to 15 days. This raises the question of whether transport gets some fish there too soon. Some options, such as the use of net pens, would more closely approximate historic migration rates. By varying transport equipment or transport equipment travel times, it would be possible to more closely approximate natural migration timing.

Alternative Description

Vary transport timing to more closely approximate natural migration timing.

Results

Transportation may get the fish downriver before they are adapted for saltwater life. However, research by NMFS (Matthews *et al.*, 1989) shows that fish can enter saltwater earlier than they would have naturally, without detrimental effects. Research by Bjornn earlier than they would have naturally, (1992) verified this finding.

Currently, the length of time for which fish can be held in collection facilities (two days) or in transport vehicles (two days) is set by the CBFWA/FPAC in coordination with the Corps. Those criteria have worked well for over a decade. No scientific data has been generated that shows that transportation gets fish to the ocean too fast.

If revisions were made in the transportation criteria to allow for longer migration times in the trucks and barges, more transport vehicles would be required to keep up with collection at the dams. NMFS' 1995 Biological Opinion does not call for changes to the transport program to increase migration time. To the contrary, NMFS calls for additional barges and increased direct loading which would tend to decrease the migration time by about one day over current conditions.

5.9.2.12 Transport Further Downstream/Revise Release Areas

Transported juvenile salmon and steelhead are currently released below Bonneville Dam. Early season trucked fish are released approximately 300 feet below the Bonneville Dam First Powerhouse through a fixed release pipe on Bradford Island. Barged fish are released between lighted buoy No 92 (RM 144) and Warrendale, Oregon (RM 141). Mid– and late–season trucks are transported mid–river from the boat ramps at Dalton Point or Dodson on the Oregon shore, and fish are released at random locations in higher velocity flows near mid–river.

Predation studies have shown areas of concentration of squawfish in slower moving areas and in eddies along the shore and below islands or gravel bars below Bonneville Dam. Commenters have recommended that fish be transported further downstream to avoid predation from Bonneville Dam to the ocean, and some commenters have suggested transporting fish into the Columbia River plume where it extends into the ocean.

Alternative Description

Modify the release areas for trucks and barges to minimize predation on transported fish.

Option One: Modify release areas below Bonneville Dam, moving them but keeping them near to Bonneville Dam.

Option Two: Transport fish further downstream nearer the estuary to avoid predation in the lower river.

Results

In 1993, based on tests conducted with Bonneville Hatchery fish which showed better survival of fish released mid–river, the Corps revised the release for mid– and late–season truck transported fish. A towboat and barge were retained to transport trucks to mid–river for release. Early in the summer when flows allowed access to the boat ramp, trucks were loaded on the barge at Dalton Point Boat Ramp. Later in the season after the river level got too low for access to Dalton Point, the barge picked up trucks at Dodson Boat Ramp. In either case, trucks were transported mid–stream to good flow areas where the fish were released. For safety reasons, and to minimize the time fish were held in trucks, these releases were made during afternoon and evening hours, shortly after the trucks reached the boat ramp.

The Corps and NMFS have investigated transporting fish further downstream. In seeking ways to release trucked fish mid–river, Corps biologists from the Portland District suggested that trucks be loaded on the Cathlamet Ferry at Cathlamet, Washington. As the ferry crossed the river, fish could be released. This idea was opposed by several fishery agencies because no research had been done on transporting fish further downstream. The idea was dropped when the mid–river barging program was developed.

In 1992, the Corps and NMFS began investigation of barging fish to the mouth of the Columbia River. Marked groups of steelhead with incidental numbers of chinook and sockeye were transported to the river off Tongue Point, Oregon (approximately RM 18). Groups of steelhead marked at Lower Granite Dam were transported and released below Bonneville Dam, and groups were marked and transported on to Tongue Point. The study plan called for marking in 1992, 1993, and 1994, and monitoring of returns through 1995, 1996, and 1997. The Corps and NMFS have decided to continue this study through completion.

If barging steelhead to Tongue Point substantially increases adult returns, the research will probably have to be repeated with salmon before this method can be used to increase the survival of listed species. To incorporate the extended transport distance into the existing program, the number of barges would have to be increased 20 percent, as would the number of towboats used. Preliminary results for 1995 indicate the worst adult returns from the ocean in years (Harmon, et al., 1995). Therefore, this research may be compromised by poor ocean conditions, masking whether there are benefits from extending transportation to the estuary.

5.9.3 New Facilities

5.9.3.1 Upstream Collection Facility

Past estimates of mortality in Lower Granite pool are near 15 percent, although Iwamoto, 1993, suggests much lower reservoir mortality. In low flow years, such as 1992, segments of the outmigration may be residualizing in Lower Granite Reservoir (Ceballos, *et al.*, 1993), resulting in loss of fish through residualism, harvest, or mortality from predators.

The NPPC recommended investigation of an upstream collection system, and the NMFS Recovery Team recommended further investigation in its draft Recovery Plan (Bevan, *et al.*, 1993). Upstream collectors are being evaluated in the SCS.

Alternative Description

Construct a collection facility upstream of Lower Granite Reservoir.

Option One: Build a low–height facility downstream of the Snake/Clearwater confluence. This facility, located at Silcott Island, would require massive screen structures in the main river channel to divert juvenile fish into collection facilities. In the secondary channel, adult fish would be guided into a small fish ladder, and navigation traffic would be passed through a low level navigation lock. In this concept, new barges, capable of being loaded through the bow, would be moored in locks where they could be lowered below the collection structure to allow gravity loading.

Option Two: Build a structure of just enough height to allow gravity loading into barges. This structure would be a low level dam with trash racks to protect the fish screens, and possibly with a spillway to pass high flows and debris.

Option Three: Develop a partial screening system extending to mid–river from either shore where collection and barge loading facilities would be located. In the center of the river, an open area would be provided for navigation traffic and for passing debris. Based on the assumption that more fish would be collected, additional barges would be required. Also, the round trip to the release area below Bonneville Dam would be five days rather than the current four day round trip from Lower Granite Dam. If trucks were used when fish numbers are low as they are in the current program, the study would require re–evaluation of vehicle and driver requirements.

Results

Before moving ahead with the upstream collector idea, it will be necessary to test the effect of collecting fish further upstream for impacts on the homing ability of anadromous salmonids. This was extensively tested during the development of the current transportation program, primarily with steelhead (Ebel, 1975). Steelhead were studied in a test of direct truck transport from Dworshak National Fish Hatchery to the mouth of the Clearwater River, and then in barges to below Bonneville Dam in 1978. This resulted in unacceptable straying (Park, *et al.*, 1979). Test results again proved unacceptable in 1980 and 1981 (Sims, *et al.*, 1983). Therefore, before an upstream collector is constructed, it is essential to know that it would work effectively.

In recent years, 25 to 28 million hatchery and wild salmon and steelhead have been produced above Lower Granite Dam. Approximately half of these fish have survived to Lower Granite Dam. If collected at the head of the reservoir (eliminating the perceived 15 percent mortality), 65 percent of the outmigration – roughly 16 to 18 million fish – could be transported. Based on 890,000+ per 24 hour period collected at Lower Granite Dam, up to 1.8 million fish could be collected in 24 hours. Given current barge capacities, it will take four 150,000 gal barges per day to keep pace with peak collection. It may be more efficient to double the size of the barges to 300,000 gals, reducing the number of barges needed per day. Tows of up to four barges equivalent in size to the 300,000 gal capacity can be accommodated in the navigation locks at the dams, and the larger towboats on the river are sized to handle four barge tows.

If the barges have to be redesigned to work in a low–height facility, ten to 20 new barges will be required, depending on their size. Depending on whether barges are pushed individually by towboats, or organized into tows, five to 20 towboats will be required. At $3 to $5 million per barge, $30 to $100 million will be required for barges. Annual costs for towboats will run $2.5 to $10 million. If highly successful, the upstream collection could reduce the need for collection and transportation from the Snake River collector dams. This will ease personnel requirements in the program. Still, although fewer fish will be collected at the facilities, they require 24–hour per day, 7–day per week attention for the protection of the fish.

Round trips for barges from the collection facility will take five days to a release site below Bonneville Dam. Barging now occurs from about 15 April through 15 July at Lower Granite Dam. Due to earlier arrival and higher collection percentages at the upstream collector, barging will probably occur from 1 April through 1 August.

Assuming that trucks were used when collection was less than 20,000 fish or less than 1,750 lbs per day, two 3,500 gal tankers could keep pace with collection in the Lewiston/Clarkston area similar to the schedule at Lower Granite Dam. Operating from the Lewiston/Clarkston area would only add 20 miles to the truck trip.

The concept of an upstream collector has been overtaken by emphasis on surface collectors. In their 1995 Biological Opinion, NMFS has encouraged further investigation and development of surface collection technology (RPA 11, p. 118).

5.9.3.2 Surface–Oriented Juvenile Fish Collection and Bypass Systems

The Recovery Team and other commenters identified the fact that in current collection systems, fish are forced to sound 60 to 80 feet into the turbine intake (Figure 2–2), where they are guided into the bulkhead slot, and must rise to within a few feet of the surface to exit through the orifice. This concept is patterned off the Wells Dam (Douglas County Public Utility District) hydro–combine design, which provides 90+ percent fish guidance. The surface–oriented fish collection and bypass system concept has been included in the SCS Phase II study in response to its inclusion in NMFS' 1995 Biological Opinion.

Alternative Description

Redesign collection and bypass systems at the dams so that juvenile fish do not have to sound and enter the turbine intakes.

Results

The current system requires that juvenile fish undergo an increase in hydrostatic pressure from just over 1 atmosphere to 3 to 4 atmospheres as they dive to enter turbine intakes, then undergo a fairly rapid decrease to just over 1 atmosphere again while reaching the exit from the bulkhead slot.

At Wells Dam, spillways are located over the turbine units. Baffles with vertical slots have been used to create a juvenile bypass system in which the fish are not required to dive down into the intakes. This system has exhibited 90 percent FGE without the use of screening devices (Klinge, 1993).

The Corps is investigating the possibility of constructing a similar type of bypass on the face of the powerhouse of its dams. While this concept has definite promise for reducing stress and increasing FGE, the SCS concluded: "This surface–oriented collection concept is considered to be a new generation of fish passage facility with high biological effectiveness expected. Therefore, a significant amount of research and study will be required before implementation. As a result, this action is considered to be a long–term activity."

The Corps is considering surface collection in the SCS Phase II. Two prototype surface collector slots were constructed and are being tested at Ice Harbor Dam in 1995. Similar surface collector slots are being designed for testing at The Dalles Dam in 1996. A prototype surface collection facility is being designed for testing at Lower Granite Dam in 1996. A similar surface collection system is being considered by Grant County PUD for Wanapum Dam on the Columbia River in 1995.

5.10 QUALITATIVE RESULTS: LITERATURE REVIEW AND EVALUATION

5.10.1 Stress Evaluations

The evaluations of stress response and performance have been used primarily to identify problem areas within the fish conveyance systems at a project, and during actual transportation operations. The results of these studies have helped to focus effort on correcting known sources of stress or injury, and to provide more effective stress control measures, such as shading. Some response to stress is good, in the sense that a response shows the fish to be positively reacting to its environment, much as a human would elicit a startle response or an adrenaline rush. The limiting factor to consider in these studies has been the lack of a control group, i.e., information on natural stress and the condition of in–river migrants and their response to passage conditions. Until that type of information can be collected, the information on transported fish is useful to continue to evaluate ways to improve the system for collected fish.

The stress response of spring chinook salmon to the collection and transport system at Lower Granite Dam was first evaluated by NMFS in 1980 (Park *et al.* 1981) using the seawater challenge test. In 1982 these tests were expanded to further isolate areas of stress at Lower Granite and McNary dams, and included transport density and separation tests (Park *et al.* 1983). Further tests were conducted in 1983 at Little Goose Dam to determine stress of spring chinook salmon as influenced by steelhead during transportation (Park *et al.* 1984). The Idaho Cooperative Fish Research Unit (ICFRU) began a 2–year study in 1982 to evaluate the effects of stress

on the viability of chinook salmon smolts at Lower Granite Dam (Congleton *et al.* 1983, 1984). The collection and transport system (including gatewells, raceways, truck and barge) and confinement tests were evaluated. The Oregon Cooperative Fish Research Unit (OCFRU) conducted a similar system and transport evaluation study in 1982–1984 at McNary Dam (Schreck *et al.* 1984 and 1985). Bjornn *et al.* have evaluated the effect of stress on survival of juvenile outmigrants (Bjornn *et al.* 1985,1986,1987,1988).

The 1982 seawater challenge tests at Lower Granite Dam suggested that the stress level of spring chinook salmon smolts was influenced by holding or transporting them in the presence of steelhead smolts (Park *et al.* 1983). Additional tests scheduled for Little Goose Dam in 1983 were hampered by low numbers of available test fish resulting in limited testing. Further research was recommended to define potential benefits of separation (Park *et al.* 1984). As acknowledged by the researchers, the test design and methodology used to assess the question of species interaction most likely biased the test and the resulting data (Matthews, pers. comm.).

ICFRU tests in 1983 at Lower Granite Dam showed elevated cortisol concentration in chinook salmon smolts in four of eleven tests with steelhead, but at concentrations indicating that chinook were not significantly stressed by confinement with steelhead (Congleton *et al.* 1984). Cortisol is an immediate response ("fright" response equivalent to adrenaline rush) while glucose is a longer term response. For the Little Goose tests, run in conjunction with the NMFS testing, cortisol concentrations were significantly elevated above control concentrations in only one of nine groups of chinook confined with steelhead. However, tests may have been compromised by elevated cortisol levels in all groups resulting from handling and anesthetization (Congleton *et al.* 1984). The benefit of separation is not clear (Congleton, pers. comm.)

Truck, barge, and raceway loading densities have been studied by ICFRU, OCFRU, and NMFS. Densities of 0.5 pound/gal do not appear to affect initial post–loading or final cortisol concentrations in fish (arriving at Bonneville Dam). Overall, cortisol concentrations were lower in fish transported by barge than by truck. Raceway loading density did not affect cortisol levels in chinook salmon held with steelhead trout at 0.5 pound/gal, suggesting that chinook salmon are not stressed by confinement with steelhead trout.

Other objectives of the ICFRU effort included evaluation of direct loading from the separator into the barge. Higher plasma cortisol levels were noted in direct load fish versus fish held overnight in raceways. Plasma glucose concentrations, however, were relatively low in all groups of chinook, whether direct load or raceway. The higher cortisol levels may be a result of bypass passage rather than the direct–load process itself.

As a result of recent regional actions (ESA petitions, Salmon Summit, SOR, and CRSMA (SCS), questions have been raised pertaining to stress response of small fish and large fish to separation by size, holding and transport density, direct load, facility performance, and stock separation (wild vs. hatchery). Information on these topics is either not available (stock separation, densities at less than 0.5 pound/gal) or is not clearly definitive (size separation).

Because of changes in design methodology and procedures for stress evaluation, changes in system evaluation, and questions on future direction of ways to handle, hold and transport fish, a new cooperative study was initiated by OSU and ICFWRU in 1992 to evaluate current transportation techniques. This effort included a literature review which summarized the state of knowledge of interspecific behavior (related to separation), beyond the Corps–funded studies summarized above. The first year of evaluation (Schreck *et al.* 1993.) confirmed that stress responses in spring/summer chinook return to pre–collection levels by the time of release from barges. Video monitoring within the barge compartments, and monitoring of radio–tagged fish after barge release, suggested generally appropriate behavior (i.e., fish moved downstream after rapid exit from release site). Work in 1993 focused on separator performance at Lower Monumental, continued

evaluation of collection and transport performance, response to noise on transport barges, and tracking of radio–tagged fish post release (Schreck *et al* 1994).

The new juvenile facility at Lower Monumental was also evaluated by NMFS in 1993 (Marsh *et al.* in prep). Marked groups of spring/summer chinook and steelhead were released into selected locations, and were recaptured and evaluated for descaling, injury, and mortality. Due to construction and mechanical problems, some of the tests for 1993 were not completed, and are re–scheduled for 1994. The portions of the facility that were tested performed very well. Stress levels were also measured during passage through the facility for chinook salmon and steelhead. Results are not yet available from NMFS.

The new juvenile facility completed at McNary Dam in 1994 was evaluated by NMFS. Objectives similar to those conducted at Lower Monumental, including stress evaluation, were performed, but the results, which showed minimal stress, have not been published yet.

Menke (1994) pointed out that stress likely decreases the survival of fish upon entry into the ocean, linking stress to disease. Menke (1994) states that disease transmission in collection and transportation facilities is a serious problem. Experts working with stress and disease related to the transportation program have not raised a serious alarm or concluded that the transportation process should be discontinued. Further research is needed to understand the stress in transportation, and in the in–river migration route before a conclusion can be drawn as to which provides the safest passage under various flow conditions.

Research supports the contention that collection and transportation facilities have improved since the Corps' transport program began. Maule et al., (1988) reported that improvements to facilities at McNary Dam decreased stress levels from 1982 to those measured in 1983 and 1984. Harmon, et al. (1988) reported that, "Delayed mortality was virtually nil ... nearly identical to the level reported for 1987 (Matthews et al. 1988) and substantially lower than reported for 1986 (Matthews et al. 1987). These data continue to indicate that incorporation of the pre–anesthesia handling/marking technique greatly enhance post–handling/marking survival of juvenile salmonids." While Harmon and Matthews were referring to fish handled for research purposes, the pre–anesthesia technique was adopted for all smolt handling in the transportation program, and the percentage of fish handled was reduced to approximately 3 percent of the total collection to minimize handling effects."

Schreck et al. (1993 and 1994) measured stress in the collection and transportation process. They found that stress increased cumulatively in the collection process and through loading into transport vehicles. Stress decreased during transport. Extended transport to Tongue Point did not increase stress in steelhead compared to normal transport. Swimming performance of juvenile chinook was not impaired by transport. Loading additional fish at lower dams did not increase stress of fish loaded at Lower Granite Dam. Radio equipped juvenile salmonids were tracked downstream after release from the barges. Schreck et al (1994) said, "Of all radio-tagged fish released, 55 –65 percent were observed at the monitoring station near the upstream end of the Columbia Estuary, 86 miles downstream.... This is the first direct measurement of absolute survival of migrating juvenile salmonids in the lower Columbia River." Accounting for other fish observed into the lower river, Schreck et al. said, "It is likely that as many as 72.5 to 77.5 percent of the tagged fish survived to reach the estuary..."

Compared with delayed mortalities of 20 to 30 percent in the 1970s (Park and Athearn, 1985), Williams and Matthews (1995) attribute increased survival to improved collection and transport systems at the projects, and attribute improved survival of handled fish to use of pre–anesthesia and other improvements in collection systems and operations.

5.10.2 Disease Evaluations (BKD)

Bacterial kidney disease (BKD) may be a significant factor in the poor survival of spring chinook salmon smolts (Matthews *et al.* 1985; Park 1985; Raymond

1988). Evidence exists that salmonids infected with BKD while in fresh water may die of BKD upon entry into salt water (Banner *et al.* 1986), and that stress associated with the transition from fresh water to salt water may accelerate the mortality (Fryer and Sanders 1981; Banner *et al.* 1983). To evaluate the effect of BKD on transported fish, the National Fisheries Research Center, USFWS, began a multi–year investigation in 1988 to monitor the presence and levels of BKD in: (1) spring/summer chinook salmon and other salmonid smolts arriving at collection facilities on the Columbia and Snake Rivers; (2) and in spring/summer chinook salmon parr at selected natural/wild production areas of the Snake River. The investigation was done to determine if horizontal transmission of BKD can occur among transported salmonid fishes and to monitor downstream movement and adult returns of transported and nontransported spring chinook salmon originating from parents with either high or low BKD infection levels.

Study results to date (Pascho and Elliott, 1989; Elliott and Pascho 1991; 1992; and 1993) have been helpful in beginning to provide needed information on how BKD affects hatchery and wild parr, and how the disease is expressed as fish begin to outmigrate. The Elliott/Pascho work has shown that the prevalence of BKD infection is often very high in all species of salmonid smolts leaving the Snake and mid–Columbia river basins. Sampling of spring and summer chinook salmon parr in natural and wild production areas of the Snake River Basin has suggested that the prevalence of infection in fish from those stocks may exceed 80 percent (Pascho and Elliott, letter to K. Menke, September 1993). Upwards of 96 percent of spring/summer chinook salmon sampled from the Columbia and Snake Rivers were infected with BKD. Although the prevalence was high, infection levels were generally low, although variable. However, results from wild/natural parr samples cannot be directly compared to those obtained by sampling hatchery smolts at dams because of age differences and because prevalence and levels of infection can change during life stages. Elliott and Pascho have shown that certain factors important for successful transmission of *Renibacterium salmoninarum* (causative agent of BKD) are present in the migratory route of Snake River salmonids. Additional research with livebox trials suggest that horizontal transmission among salmonids could occur in the river as well as in the collection raceways at the dams or in the transportation barges. Elliott and Pascho are continuing their research efforts to determine if the collection and transportation process actually increases the risk of horizontal transmission of *R. salmoninarum* over that which would occur with in–river passage, with its longer duration of exposure time due to longer time spent in the river.

Pascho and Elliott (1989) have not been able to evaluate adult returns of transported and nontransported groups, and corresponding impact of BKD levels of these groups, because required numbers of fish to conduct such a study have not been available. A joint pilot study with NMFS began in 1988 to assess the capability of PIT tagging known natural/wild stocks, and hatchery fish from selected hatcheries, to determine recovery rates of all tagged fish at the three collector dams. Since smolt to adult survival of wild fish has been estimated to be from two to 15 times higher than hatchery fish (Raymond 1988), this proposed study would have included known wild stocks and the resulting return rate, paired to hatchery stocks; the hatchery stocks would be segregated by low and high BKD profiles to assess BKD effect on adult returns. Three years of pilot studies were conducted (Matthews *et al.* 1990; Matthews *et al.* 1992; Achord *et al.* 1992; Pascho and Elliott 1989; Elliott and Pascho 1991; 1992; 1993). Surprisingly, over winter survival of wild fish marked in tributary streams was much lower than expected. Based on low recovery rates of both natural/wild stocks and hatchery stocks at the collector projects, a full scale study was determined to be infeasible. For example, 4.5 percent of the natural/wild fish tagged were recovered at Lower Granite Dam (7.6 percent total at three collector dams) in 1989; 5.9 percent at Lower Granite Dam (9.2 percent overall) in 1990; 7.8 percent at Lower Granite Dam (12.1 percent overall). For the hatchery PIT tagged fish, recoveries in 1990 were 31 and 28 percent for the low and

high–BKD groups, respectively, from Dworshak National Fish Hatchery at Lower Granite Dam. Recoveries were 8 percent at Lower Granite for Sawtooth State Fish Hatchery in 1990; and in 1991, recoveries were 24 percent at Lower Granite Dam. Based on such low recoveries, a full–scale study was not practical. The low recoveries of natural/wild production stocks is probably due to high over winter mortality, which is believed to be particularly severe during low snow pack years such as those experienced during the recent drought years. The low recoveries of hatchery stocks from Dworshak (70 miles upstream of Lower Granite, about half of which is free–flowing) is presumed due to the significant transition loss from hatchery to riverine system, and the condition factor of fish when released.

Menke (Crystal Images, 1994) reviewed literature and interviewed experts on bacterial kidney disease and stress for the NRIC. Copies of her draft and final reports were provided to the Corps over the past year for review, and as comments on the transport Section 10 Permit applications. The final report was submitted to the SOR team in comment on this document.

Her stated purpose was, "This document is intended to be a collection of data which indicates that barging threatened and endangered Snake River salmon stocks may not be beneficial, and to emphasize particularly the role of BKD as one reason for serious concern." Menke (1994) concludes that:

- *Current evidence strongly suggests that barging may jeopardize listed wild salmon stocks, that a possible, though not all inclusive, reason is that lateral transmission of BKD can be accelerated by stress in the collection and transportation process.*
- *The hypothesis that barging contributes to increased mortality from BKD offers a reasonable explanation why so few adult salmon return when so many juveniles are barged and known to survive below Bonneville Dam.*
- *The agencies in charge of listed stocks should address the real risks associated with the collection and transportation process and compare them against the risks of spilling fish and allowing them to migrate in–river with improved velocities.*
- *Salmon should be spilled over the dams and be allowed to migrate in–river. Steps should be taken immediately to implement dam modifications which allow safe passage of adult and juvenile salmon during high and low flow years, and in various modes of operation designed to facilitate juvenile salmon migration, including drawdown to spillway crest in low flow years.*
- *Drawdown should be implemented without scientific testing because transportation has been implemented for 15 years with no valid proof of success.*

5.10.3 Ocean Survival

One of the least known factors in the survival of the Columbia River salmon is what happens in the ocean. Richards and Olsen (1993) compared trends for spring/summer chinook adults passing Lower Granite Dam with trends in coastal rivers from California to British Columbia, and with the Pacific Marine Fisheries Commission production index. They found that runs along the coast and in the production index area were in general decline, and that the runs at Lower Granite Dam showed similar decline. However, the rate of decline was less for the Snake River fish, indicating that mitigation measures (including transportation) may be slowing the rate for Snake River fish.

Other studies (Cooper and Johnson, 1992) show declines of steelhead in coastal rivers, and that region–wide low flows have impacted run sizes (Hilborn, *et al.*, 1993). Pearcy (1992), and Beamish and Bouillion (1993) have documented the decline in ocean productivity as it relates to salmon production, and ecological trends as they relate to climatic changes. The Recovery Team (Bevan, *et al.*, 1993) addressed this issue in their draft Recovery Plan prepared for NMFS.

Most literature reviews concur that the best measure of whether transport or in–river passage provides

the best survival must depend on "gravel to gravel" or egg to adult evaluations. In other words, adult returns and reproductive viability are essential in the effort to restore the fish runs.

5.10.4 Transport Evaluation

For spring/summer chinook salmon, in nearly all studies, more, or significantly more, adults returned from groups transported as smolts than from those that migrated downstream through the hydropower complex. The most recent studies continue to strongly support transportation of this species (Matthews 1992). Matthews cites two major factors that affected transport studies; the first was the level of physical injury suffered by smolts in the early research studies that compromised both experimental treatment groups. He attributes significant improvement in debris removal programs and improvements made to the physical components of the collection and transportation system in recent years (orifices, separators, plumbing, and fish handling technology) resulted in major improvements in observed adult return rates of marked and transported fish. Compared to earlier study years, observed adult returns back to the dam were four to seven times higher for the 1983 through 1985 study years. This was in spite of the fact that the smolt populations of the most recent years were comprised of higher percentages of the poorer surviving hatchery component. This is the second factor Matthews cites in earlier transport studies, the decline in the ratio of wild to hatchery smolts as hatchery fish began to predominate the outmigrant population. Matthews (1992) reviews the transition from nearly equal numbers of wild and hatchery–reared fish to outmigrations now predominated by poorly surviving hatchery component.

For fall chinook and steelhead, Matthews (1992) notes that past research has demonstrated conclusively that these stocks have benefited from transportation as juveniles, and current studies continue to support these earlier findings. For fall chinook, the TIR ranged from 1.8:1 to 8.0:1 for the 1978–1983 period. For the 1986 study, 444 transports and 165 controls were recovered from all sites combined. The data showed significant transport benefits and similar TIRs at all recovery sites except the combined hatcheries (Harmon *et al.* 1993). Adult recoveries of fall chinook salmon released in 1987 total 371 transports (0.5% of the release) and 101 controls (0.2%). These preliminary data indicate a substantial survival benefit for transported fish (Harmon *et al.* 1993). Only a few returns from the 1988 study year are in, with 52 transport and 12 control fish recaptured; recoveries will continue for the next few years. For steelhead in the earlier Snake River studies, TIRs ranged from 1.3:1 to 17.5:1. The 1986 study showed a TIR of 2.0:1 (CI=1.4, 2.7); the 1989 study resulted in a preliminary TIR of 2.1:1. For McNary studies from 1978–80, the TIR ranged from 1.3:1 to 3.0:1 (with the exception of one trucked group showing a slightly lower rate).

The questions of straying or homing impairment, and size or age differences between transported and non–transported fish, are often raised. Matthews (1992) reviewed the research history on homing behavior, and suggests no loss of homing ability for steelhead, spring/summer or fall chinook salmon.

Matthews (1992) also reviewed the question of excessive straying from groups transported as juveniles. The levels of straying noted (e.g., 2 of 2,205 recovered adult steelhead for the 1984–1989 Lower Granite studies; 13 (10 were recovered from the Deschutes River) of 824 recovered adult spring/summer chinook salmon for the 1983–1989 Lower Granite studies) are below the levels reported elsewhere (Chapman *et al.* 1991). Matthews also noted that of the millions of juvenile steelhead tagged with coded wire tags (CWTs) at hatcheries in the Snake River Basin during the past 15 years, there was no evidence that these fish returned to inappropriate locations above the dams, even though the majority were transported as smolts to below Bonneville Dam during that time. Similar results were reported for the millions of spring/summer chinook salmon juveniles tagged with CWTs in the Snake River drainage. No fall chinook strays were recovered during any studies to date.

Matthews (1992) discussed delay versus later timing of adults returning. He summarized that the slight difference in run– timing, if in fact it is even real, does not appear to affect the ability of steelhead to return to the hatcheries in time to spawn successfully. Data for other salmonid species suggested that a significant delay during adult migrations was not likely to be an effect attributable to transportation of juvenile anadromous salmonids.

Other recent evaluations include the feasibility of PIT tagging known natural/wild chinook parr to directly evaluate transport benefit for wild vs. hatchery stocks (Matthews *et al.* 1990; Matthews *et al.* 1992; Achord *et al.* 1992; Mundy, *et al.* 1994) emphasized that expediting the PIT tag monitoring systems is imperative to provide the information on when transport is needed, and when it is not necessary.

The region must continue to work toward the best solutions for recovering and rebuilding the wild salmon runs of the Columbia and Snake rivers. Additional studies are needed to determine the best operation of the FRCPS for maximizing salmon survival. Studies are needed to determine, (1) if spill increases overall salmon survival; (2) if flow augmentation increases overall salmon survival; (3) if spill, flow augmentation, and improved bypass systems can produce survival levels equal to or greater than those afforded by transportation; and, (4) under what conditions and operational scenarios transportation will not be necessary. Additional studies are needed to determine what the carrying capacities are for spawning and rearing areas, and every effort should be made to rebuild wild and natural spawning populations. Hatcheries should be utilized for supplementation during the restoration process, and phased out unless they are used for production of fish where wild production has been lost or cannot occur. Domestic fisheries need to be regulated to protect wild stocks, and foreign fisheries need to be curtailed to allow escapement adequate to rebuild the runs. Studies are needed to analyze ocean conditions affecting salmon survival, and international management is needed to ensure that the productivity of the oceans for target and interrelated fisheries and other ecosystems are protected.

5.10.4.1 Public Utility District Transport Evaluations

Transportation of sockeye salmon smolts from Priest Rapids Dam to below Bonneville Dam was evaluated from 1984 through 1988 by the Public Utility Districts (PUD) of the mid–Columbia River. Transport by truck was tested in all years; for two years, a combination of trucking and barging was also tested. In these tests, smolts were trucked to McNary Dam and then transferred to a barge for subsequent transport to below Bonneville Dam. Statistical analysis of the adult return data has not been reported, therefore information from these studies must be viewed with caution (Matthews 1992). Preliminary data indicates mixed results. TIRs for truck transport (1984 and 1986) were less than 1.0, with return rates of both test and control groups being poor. In the other years, return rates were improved and TIRs were equal to or greater than 1.0 (range 1.0 to 2.9). TIRs for the trucked and barged groups (1987,1988) were lower than for trucked only groups. Matthews notes mechanical flaws and poor truck release sites as possible factors. Matthews notes a potential difference in stock performance reflected in temporal differences in the adult return rates. Homing behavior was discussed, but due to lack of statistical analysis, results are inconclusive. Matthews suggests that a statistical analysis will likely prove the data to be inconclusive overall, primarily because adult recoveries are so low.

5.10.4.2 Lower River Transport Evaluations

The question of whether survival of juvenile salmonids can be enhanced by releasing them closer to the estuary has been raised by the NPPC. After release below Bonneville Dam, smolts must still traverse 150 km before arriving at the estuary. Although free–flowing below Bonneville Dam, the area is known to harbor large numbers of predators, primarily northern squawfish, seals, sea lions, and various avian predators. Available data from Scandinavian studies show that Atlantic salmon smolts (*Salmo salar*) released directly into estuarine waters have resulted in increased survival (Gunnerod *et al.* 1988). Macdonald *et al.* (1988) and Levings *et al.* (1989) suggested reduced predation and stress, and increased food

availability, as factors in increased survival. Solazzi *et al.* (1991) reported a 1.6 times higher survival rate for coho salmon released near estuary. NMFS' March 1995 Proposed Recovery Plan for Snake River Salmon recommends development of strategies for transporting juvenile salmonids to a variety of release points below Bonneville Dam including the Columbia River estuary.

Beginning in 1992, and scheduled for three years, NMFS has been evaluating whether steelhead smolts transported by barge and released in the upper estuary at Tongue Point will return as adults to Lower Granite Dam in significantly greater numbers than those transported by barge and released at the traditional sites below Bonneville Dam. Depending on the results of the study for steelhead, spring/summer and/or fall chinook salmon may be tested in the future. Preliminary results of the 1992 releases, based on jack returns in 1993, is 1.1:1 (Matthews, personal communication, 1994).

5.10.4.3 Lyons Ferry State Hatchery Transport Evaluation

Lyons Ferry State Hatchery rears and releases Snake River fall chinook under the Lower Snake River Fish and Wildlife Compensation Plan. In recent years, 100 percent of the releases have been marked or tagged to ensure the genetic purity of the stock. The hatchery generally releases four groups of fall chinook, both yearling and subyearlings, which are released at the hatchery or loaded on barges to bypass Lower Monumental and Ice Harbor dams. Survivals of subyearling fish (range 0.02 to 0.6 percent) have been much lower than survivals of yearling fish (0.3 to 7.3 percent). Survivals of barged fish, regardless of age, have been equal to or greater than survivals of fish released at the hatchery. Contribution of subyearling fish has been primarily to the Columbia River gillnetters, Canadian commercial fishers, and escapement. Escapement of tagged fish released from barges appears to be slightly higher than those released at the hatchery, perhaps because the latter group had higher contribution to the in–river net fishery. Contribution of yearling fish has been mainly to Canadian, Columbia River gillnet, and Washington coastal troll fisheries. Escapement amounted to approximately 21.3 percent of the survival, however the estimated escapement was an underestimate because expanded data from trapping operations at the dams was not available. Contribution rates to various fisheries did not appear to differ between barged or hatchery releases (Fuss, *et al., 1994).*

5.10.4.4 CBFWA Ad Hoc Transportation Review

In response to a request from NMFS to the CBFWA Liaison Group, an Ad–Hoc Transportation Review Group (TRG) comprised of representatives of the USFWS, WDF, CRITFC, IDFG, and the FPC was convened to review juvenile fish transportation studies (Olney, *et al.*, December 31, 1992). They reviewed studies conducted of spring/summer chinook salmon at Lower Granite Dam in 1986 and 1989, spring chinook salmon at Priest Rapids Dam from 1984–86 and at McNary Dam in 1987 and 1988, sockeye salmon at Priest Rapids Dam from 1984–88, fall chinook salmon at McNary Dam for 1986–88, and steelhead at Lower Granite Dam for 1986 and 1989. Conclusions stated in their cover memorandum are:

1. *TIR ratios have been reported for some studies (e.g. 1989 spring/summer chinook at Lower Granite Dam) without a thorough review of the basic data and without statistical analyses to validate the results.*

2. *Return rates and TIR ratios at the dams for the studies examined were not calculated separately for wild and hatchery spring, summer, and fall chinook salmon because hatchery and wild chinook smolts were indistinguishable when they were marked at the dams.*

3. *The 1986 and 1989 spring/summer chinook transportation studies at Lower Granite Dam are weighted heavily to the earlier migrating hatchery fish. Due to this situation and the high abundance of hatchery fish in the migration, TIR ratios at Lower Granite Dam primarily reflect how well hatchery fish responded to transportation and in–river migration (combined with short haul*

transport). The recoveries from the spring chinook studies at McNary Dam also are heavily weighted to hatchery returns.

4. *TIR ratios based on return rates of marked fish at mainstem dams do not measure the effect of transportation on fish survival back to the spawning grounds. The only information available from the spring/summer chinook and sockeye salmon studies on the effect of transportation to the spawning grounds and hatcheries is the upstream coded wire tag data.*

5. *None of the transportation studies have provided estimates of the potential error associated with reading the brands on adult fish sampled at the dams. In response to a request from the Review Group, NMFS examined their raw data to determine brand reading errors for the 1986 and 1989 spring/summer chinook studies at Lower Granite Dam and sampled upstream for the coded wire tag were either assigned to the wrong release group, the wrong treatment group, or not recorded as a brand recovery at Lower Granite. For the 1989 study one of the 11 jaw tagged fish recovered upstream was a control fish assigned to the wrong release group. While the sample sizes are small, the magnitude of the errors indicated that brand reading error should be assessed for all the transportation studies.*

6. *TIR ratios based on upstream coded wire tag recoveries for the sockeye salmon studies at Priest Rapids Dam and the spring chinook salmon studies at Priest Rapids and Lower Granite dams in most cases are much lower than the TIRs based on brand recoveries at the dams.*

7. *None of the upstream tributary recovery information for any of the spring and summer chinook transportation studies indicates that transportation was beneficial to the survival of wild fish back to the spawning grounds. Rapid River Hatchery was the only upstream location that showed possible benefits from transportation for the 1986 and 1989 Lower Granite studies.*

8. *For sockeye salmon at Priest Rapids Dam, two of the nine transportation studies showed possible benefits back to the spawning grounds based on coded wire tag recoveries, two showed no benefits, and five indicated that transportation may have negatively impacted survival back to the spawning grounds.*

9. *Several of the studies show major differences between earlier and later migrating fish for both the transports and the controls. Combining the data for many of the studies and calculating a combined TIR ratio for the entire study is an over simplification of a complex interaction of several factors that change over time and that may affect the survival of the treatment and control groups.*

10. *It is apparent that transportation is not a substitute for provision of good in–river migration conditions for many of the salmon stocks evaluated in the studies. For some stocks it appears that transportation may have been detrimental to fish survival.*

From the main report, the Results and Discussion sections state:

"This review represent only a cursory look at the transport data. Because of the reliance on adult return information, and the time delay associated with obtaining that data, most of the conclusions drawn regarding T/Cs must be considered preliminary. There is sufficient data to show that groups migrating later in the season appear to benefit more from transportation. The migration conditions from late July to early August, decreased flow and increased temperature, are circumvented by transporting fish and having transported fish survive at a higher rate.

"There appears to be sufficient evidence to suggest that for fall chinook, transported late in the season from McNary Dam, return at a higher rate than those that migrate in–river. The data for fish transported earlier in the season, late June to early July, is not as convincing. Of par-

ticular concern is the impression that the transportation program is a substitute for good migration conditions. The overall trend in decreasing recovery rates seen from the 1986 to 1988 studies would suggest otherwise. If transportation is to be considered as a long–term mitigation measure, then it must be recognized as only part of the solution to the problem and more emphasis should be placed on when and how transportation as 'part' of a mitigation package is applied."

From the main report, potential problems identified with the transport studies are:

"The control releases for the McNary transport studies are released directly below the project. Problems similar to those that exist for transport controls for the Lower Granite experiments might be confounding the results, i.e. the control fish may be more susceptible to predation upon release because of their short recovery time and release location."

The McNary studies primarily rely on ocean recoveries to develop the Transport/In–River ratios. The ocean recoveries are used as raw recoveries for a group and are not expanded. According to some individuals regularly using the CWT data for ocean fisheries (H. Schaller – ODFW, personal communication), small differences in timing, (as small as two week differences) or slightly different migration patterns can make a comparison of unexpanded tag recaptures meaningless. The probability that small differences may occur in timing is highly likely given the potentially different entry time to the ocean dependent on whether the recovery is a transport or control marked fish. A better evaluation of the ocean recoveries would be based on expanded recapture data from the CWT database. If an analysis of ocean recovery data is conducted, the results should be evaluated independent of the in–river recoveries.

The CBFWA Ad Hoc Review was used by the plaintiffs in NRIC v. NMFS, Case No. 093–469–MA. Elements of the TRG report used are:

[From the TRG report]: 'None of the upstream tributary recovery information for any of the spring and summer chinook transportation studies indicates that transportation was beneficial to the survival of wild fish back to the spawning grounds. [item 7 p 3 cover memo]

For sockeye salmon at Priest Rapids Dam [this dam is on the Columbia River] 2 of the 9 transportation studies showed positive benefits back to the spawning grounds...2 showed no benefits, and 5 indicated that transportation may have negatively impacted survival back to the spawning grounds. [item 8 p 3 cover memo]

'It is apparent that transportation is not a substitute for provision of good in–river migration conditions for many of the salmon stocks evaluated in the studies. For some stocks it appears that transportation may even have been detrimental to fish survival. [item 10 p 4 cover memo]'

"Regarding the 1986 Transportation/Control ratio of 1.6:1 touted by the Corps, Bonneville Power Administration and others as proving transportation works, when the hatchery fish are backed out, the data show a 0.6:1 T/C, i.e., that the nontransported wild fish listed under the ESA returned at a greater rate than the transported fish.

[From the TRG report]: 'The T/C from these recoveries (0.6) suggests that under relatively good migration conditions, transportation may have been detrimental to fish survival.... [p 4 body of document]'"

"Advocates of transportation trumpeted a 2.5:1 T/C for 1989. Reality check:

[From the TRG report]: 'It appears that the 1989 study results primarily reflect how hatchery fish survived transportation and in–river migration combined with short haul transport. [p 8 body of document]

'The poor recovery rates, wide variation in return rates, and heavy influence of hatchery fish on the results raises serious questions about how effective transportation was in mitigating for the

poor in–river migration conditions in 1989. The usefulness of this data in making decisions effecting the recovery of Snake River spring/.summer chinook is also in question. [p 9 body of document]'"

"Regarding other problems with the 1986 and 1989 study designs.' These other problems include the fact that the so–called 'controls' are actually collected and transported part of the way, some are subjected to this twice. Some 'controls!

[From the TRG report]: 'The controls are [collected] marked and loaded into a truck and transported to alternative release sites below little (sic) Goose Dam. [p 9 body of document]

'Another problem in the study design... is that the control releases do not represent true controls. The study is actually a comparison of short haul transport (from Lower Granite Dam to below Little Goose Dam) to a long haul transport (Lower Granite Dam to below Bonneville Dam). Controls [sic] can also be collected and transported from McNary Dam. [p 10 body of document]'"

"The agencies analyze transport of sockeye salmon from the upper Columbia River. Their findings may provide insight as to why National Marine Fisheries Service had so little confidence that transportation 'works' that all Snake River sockeye were removed from the river and put in a condor–style captive breeding program.

'[From the TRG report]: '...the results of coded wire tag recoveries on the spawning grounds indicate that transportation in most years may not have benefited or may have negatively impacted [Col. R. sockeye] returns to the spawning grounds. [p 22 body of document]'"

"Fall chinook are collected and transported from McNary Dam which is on the Columbia River below its confluence with the Snake. The agencies' analysis of the fall chinook data is more obscure than for spring/summer chinook. The situation is more complicated because the fish are transported from McNary after migrating out of the Snake which historically they did mainly late May–early July. Basically the analysis says transporting Snake River fall chinook from McNary in late July and August appears to be better than letting them migrate in–river when migration conditions range from poor to lethal. Here too, however, the data are heavily influenced by the preponderance of hatchery fish which all data suggest transport better than wild fish; probably because they are used to being manhandled, and don't survive as well on their own in–river, and other things we don't know.

[From the TRG report] 'There is sufficient data to show that groups migrating late in the season appear to benefit more from transportation. The migration conditions from late July to early August [which generally are lethal in the lower Snake River for juvenile fall chinook], decreased flow and increased temperature, are circumvented by transporting fish and having fish transported at a higher rate. [35 body of document]

'The data for fish transported earlier in the season, late June or early July, is not as convincing. Of particular concern is the impression that the transportation program is a substitute for good migration conditions. The overall trend in decreasing recovery rates seen from the 1986 to 1988 studies would suggest otherwise. [emphasis added][pg. 35, body of document]'"

5.10.4.5 US Fish and Wildlife Service Staff Review of Transportation

In a review similar to the Ad Hoc Review of the 1984 to 1989 literature, the USFWS staff reviewed research from 1968 to 1990 (Review of Transportation of Spring/Summer Chinook in the Snake River (1968–90) for the Recovery Team, USFWS Technical Staff, 1993).

The USFWS staff reviewed over 30 published research reports and concluded:

- *Differential treatment of marked in–river migrants (controls) violate the assumption that they accurately represent survival of in–river*

migrating fish and that their treatment in the test does not cause significant mortality above the level sustained by the in–river migrating population.

- *Delayed mortality was substantial in most transport experiments.*
- *The studies did not account for stress in the hauling of control fish. Adjustments for stress reduced TIRs and indicated that many more tests than previously reported showed negative impact from transport.*
- *Because of serious flaws in the experimental design, the TIRs are not a valid measure of transport survival versus in–river survival.*
- *Comparison of smolt to adult returns showed that collection, marking, and handling had a major negative impact on Snake River spring/summer chinook, and transportation may also have had a negative impact.*
- *There is no evidence that transportation has significantly increased the number of adult spring/summer chinook spawning in the Snake River. Transportation may have reduced the number of spawners.*
- *Losses from stress associated with fish handling for the transport program contributed significantly to the decline of spring/summer chinook in the Snake River.*
- *The Corps needs to re–calculate the range of impacts from transport by including TIRs of less than 1.0 for spring/summer chinook.*

Dr. Lyle Calvin (OSU Dean of Statistics, retired) was asked to review the USFWS Staff Review. He found:

"Most of this document is concerned with the failure of the transportation research to deal with what has been termed a 'key assumption' ... that the survival of the control fish, which are collected, handled, and in most studies transported to their release site, accurately represents survival of in–river migrating fish and that their treatment during the test does not cause significant additional mortality above the level sustained by the in–river migrating population. This assumption is not needed in the transportation program and is a much stronger assumption than the assumptions that are needed. The related assumptions that are made in the program are:

1. *The effect of handling and marking of the control fish is the same as for the transported fish. If the effect is the same, it will cancel out in the TIR ratio.*
2. *There is no effect of collecting and transporting control fish from their point of collection to their release point.*

"Even if the assumption stated by the USFWS were valid, the two assumptions listed above would still be required. Their assumption is a far stronger one than is required, and as they correctly state, is unlikely to be true. However, assumption 1 is a realistic assumption that seems likely to be true, although it has not been investigated in depth. Assumption 2 is a more difficult one to accept and might have either a positive or negative effect on the T/C ratio. NMFS has assumed that the trucking from Lower Granite Dam to below Little Goose is likely to be beneficial to the control fish and hence would result in T/C ratios that are more conservative than if trucking had not taken place. The USFWS, on the other hand, has assumed that the trucking would result in higher mortalities than would be found in in–river fish, and hence, would result in T/C ratios that are too high. Unfortunately, it is not an assumption that is easy to test. It would be helpful to have informed biologists discuss this assumption and to have the benefit of their thought....

"At other points ... reference is made to the identification of major problems in the transportation studies by the Ad Hoc Transportation Review Group. In particular, ... flaws in the experimental design ... were listed as 1) hatchery and wild

fish were not distinguished and the study was weighted heavily to the more abundant hatchery fish; 2) the studies did not evaluate the effect of transportation on survival to the spawning grounds; and 3) the control fish were transported by truck and the test fish by barge.

"All three of these conditions are true and are limitations in the research program. The first one, regarding the relative use of hatchery and wild fish, was discussed at length and the decision made on the basis of what was practical and, in fact, possible at that time. One attempt to separate the ... T/C ratios for hatchery and wild fish ... by using scale samples ... could not be made ... because of the failure to mark control fish in low flow years.

"There was never any intent to attempt to capture enough fish to determine if a different in T/C ratios existed at different points of recapture. The numbers of fish were set to provide a number of returning fish that would enable satisfactory estimates of the T/C ratio to be made for the total pooled population. Any subdivision of this number would yield return rates at too low a level to detect statistically significant effects.

"The fact that the control fish were transported by truck and the test fish by barge should not be a factor. Each group should be transported by the method that would cause the least mortality. This comparison serves to point out that the so-called control group is not an absolute control, only a comparison group to which the transported fish can be compared. The control fish ... were trucked to below Little Goose to avoid capturing many of them in the collection system. Trucking the control fish seemed at the time to provide the best method of getting them to a release point that seemed to be the closest possible to make them a meaningful comparison group. The T/C ratio is, therefore, a ratio comparing survival of fish transported around (seven) dams to fish migrating through six dams...."

5.10.4.6 Juvenile Salmonid Transportation from Hydroelectric Projects in the Columbia River Basin – An Independent Peer Review

Because of the regional controversy between opponents and proponents of transportation evidenced by the CBFWA Ad Hoc TRG and the USFWS reviews, and the actions of the Federal action agencies and NMFS in implementing transportation and dam operations, Mundy *et al.*(1994) were retained by the USFWS to conduct an independent peer review of the literature and research pertaining to the transportation program. A panel of experts was assembled to review research to date on the transportation program and related research. The final draft report completed on April 18, 1994, was used in this analysis.

Conclusions reached by the independent group regarding the primary effects of transportation:

"...it is more probable than not that transportation acts to improve relative survival, as measured by recaptures of transported and untransported adults at the point of transportation, of certain species and life history types of juvenile salmon originating in the Snake River Basin under certain hydroelectric operational scenarios and flow regimes".... The species and life history types ... are the steelhead ..., and to a lesser degree the stream type chinook salmon designated as 'spring/summer chinook'.... There is insufficient information to determine whether transportation is, or is not, likely to improve the survivals of subyearling migrant fall chinook and sockeye salmon originating in the Snake River Basin. The flow and operational scenarios that often provide positive effects ... are those associated with below average flow years with little or no spill...on occasions when river flow conditions have been very unfavorable ..., survivals ... of both transported and untransported salmon have been too low to measure.... Stock-specific assessments of survivals of transported salmon relative to survival of untransported salmon are not possible from studies so far conducted. The ability of transportation ... to increase the numbers of any listed species returning to the spawning grounds remains unclear because

recoveries at these sites should not be used to estimate the T/C ratio under the past marking and release strategies...."

Conclusions regarding salmon recovery potential:

"As presently conceived and implemented, transportation is unlikely to halt or prevent the continued decline and extirpation of listed species in the Snake River Basin. If the risks of mortality ... in transportation are more substantial than risks posed by other routes of passage, then transportation would not be employed. With respect to Snake Basin fall chinook, ...fish quality and state of maturation with respect to smoltification ... may not be conducive to transportation from a locality such as Lower Granite Dam. Facts are not in evidence to permit the assessment of the utility of transportation from the Snake River dams for sockeye salmon. Steelhead appear to have a positive relative survival under transportation ... however facts regarding the role of transportation in returning steelhead to spawning grounds are limited. Snake Basin spring/summer chinook have shown a response ... best explained in terms of conditions within the hydroelectric system at the time of transportation. Adverse conditions associated with low flows ... have shown clearly positive rates of adult returns ... to the point of transportation .... In ... 1977, the effects ... could not be measured because nearly all of the marked juvenile salmon, both transported and untransported, died...."....with higher river flows ... the ... relative survivals of spring/summer chinook to transportation may be equivocal, and possible negative, with overall higher survival for both transported and untransported salmon.... ..without estimates or measures of the effects of alternative means of reducing hydroelectric system mortalities, the utility of transportation for ESA listed salmon populations can not be objectively judged. While juvenile salmon transportation may not be discounted as a recovery measure, the factual basis is insufficient to determine the relative efficacy of transportation as a mitigative measure for recovery of (the listed) salmon populations.... When the transportation option is exercised, it must be recognized as an experimental measure with all due care to design operations so that the maximum information is derived from each experiment...."

Conclusions regarding spreading the risk:

"...the sum of all hydroelectric mitigative measures..., including transportation, may not be sufficient to ... permit persistence of listed salmon species because other factors, such as freshwater habitat degradation, and agricultural, industrial, and municipal water diversions, among others, contribute substantially to the mortality load on these species..... Should it happen that the hydroelectric system cannot provide sufficient reduction in mortality to permit persistence of the threatened and endangered species, then mortality reductions from other sources would need to be acquired. The question of whether or not to put the juvenile emigrants into the barge ... is actually part of the larger question of allocating the conservation burden across all controllable sources of mortality.... Without measures of the relative magnitudes of the principal mortality factors, both in and out of the hydroelectric system, an optimum strategy for salmon recovery will never be found, nor is it likely that any effective salmon recovery strategy will be found without a highly focused effort that considers all the alternatives...."

Recommendations from the Peer Review regarding recovery of listed salmon species:

"In summary, to understand the effects of mitigative measures such as transportation, it is essential to carefully measure the survivals of populations of listed species during all key life history stages; by routes of passage within the hydroelectric system, during the life history stanzas prior to initial entry into the hydroelectric system, after exit from the hydroelectric system, and through return to the hydroelectric system and the spawning grounds. ... it is essential to have hydroelectric system operational plans in place that act on the information so obtained...."

Recommendations regarding spreading the risk:

> *"Before a 'spreading the risks' policy can be implemented, the risks need to be known. Without information on relative mortalities within the hydroelectric system, it will be impossible to design salmon recovery plans that have a reasonable chance of meeting their goals.... The need for information on survival rate of smolts that transit the hydroelectric system ... without being transported ... has been described.... When T/C decreases toward unity..., transportation would lose its attractiveness.... ...in order to choose an alternative to transportation, one must be willing to incur the risks of employing and evaluating the alternatives...."*

In summary, the comprehesive analysis of transportation reviews can be found in NMFS' 1995 Biological Opinion. In that document, NMFS has recommended the continuation of the transportation program, improvement and increase of transportation facilities and equipment, and continuing investigation of means of improving in–river survival.

5.11 QUALITATIVE RESULTS: POTENTIAL EFFECTS OF THE ALTERNATIVES ON NON–SALMONID ANADROMOUS FISH

5.11.1 American Shad

5.11.1.1 Rearing

Juveniles rear in the productive shallow–water zones of reservoirs, feeding on plankton until they reach four to five inches in length and begin outmigrating. The greatest effect on shad rearing habitat would occur from reservoir drawdown during the rearing period July through October.

Flow Control Alternatives

There are no major drawdowns of any lower Snake or lower Columbia river reservoirs for any of the Flow Control alternatives; therefore, adverse effects on shad rearing habitat should be minimal.

Drawdown Alternatives

In six drawdown alternatives (5b, 5c, 6b, 6d, 9a, and the PA), John Day Pool would be drawn down near Minimum Operating Pool during the early portion of the shad rearing period. This may cause a major loss of shallow rearing areas in this reservoir.

Little impact would occur to shad rearing areas in the lower Snake River for Alternatives 9b and 9c since reservoir levels would return to nearly full by July.

Significant loss of shad rearing areas would occur in all four lower Snake River pools under alternative 6b. Pools would remain fully drawn down through August. Alternative 6d would result in the drawdown of the Lower Granite Pool from mid–April through August, causing significant loss of shad rearing areas in this reservoir.

Natural River Alternatives

Significant amounts of rearing habitat may be lost in alternatives 5b and 5c. In both alternatives, John Day Pool is drawn down to MOP from May through August which could result in significant shad rearing habitat losses. Both alternatives would result in loss of rearing habitat associated with the Lower Snake reservoirs since all four pools would be drawn down through August under Alternative 5b and year–round under Alternative 5c.

Combination Alternatives (Includes Preferred Alternative)

Loss of shad rearing habitat behind the Lower Snake dams would occur under alternatives 9a and 9b; additional loss of habitat would occur behind John Day dam under Alternative 9a and the Preferred Alternative. Under 9c, the Lower Snake reservoirs refill by June 30 and John Day is drawn down only to MIP, so no rearing habitat loss is expected.

5.11.1.2 Juvenile Migration

Juveniles outmigrate as subyearlings with the majority passing mainstem Columbia River dams in late October and early November. Migrating juveniles have been collected at lower Snake River dams as early as August.

It is unlikely that any of the alternatives would significantly impact juvenile shad migration. Shad numbers have increased dramatically in the Snake and Columbia rivers under a wide range of water years and flow operation strategies.

Shad do not appear to be as susceptible to gas bubble disease (Backman et al. 1991) as anadromous salmonids. Therefore, the Combination Alternatives, which may elevate high total dissolved gas supersaturation conditions are unlikely to significantly affect juvenile shad.

5.11.1.3 Adult Migration

The majority of upstream passage occurs from mid–May through July at Bonneville Dam.

American shad numbers have increased dramatically in the Columbia and Snake Rivers, with rapid colonization following dam construction. It is unlikely that any of the alternatives would significantly affect adult shad passage. A wide variety of water years and different river operation strategies have had little overall negative affect on shad in recent decades, as evidenced by the rapidly increasing population.

5.11.1.4 Spawning

Peak spawning occurs from July 20 to August 5 at Bonneville Dam and upstream. Shad spawn in shallow, gently sloping areas with clean sand or gravel substrates in the open water of mainstem reservoirs. Eggs are semibuoyant and float downstream near the bottom in slow currents as they develop. Fry hatch in 7 to 10 days.

Changes in velocity should not affect shad spawning because shad adapt to and spawn in a wide range of flows.

5.11.2 Pacific Lamprey

5.11.2.1 Rearing

Juvenile lampreys emerge from nests placed in tributary streams and then drift down stream until they reach silty areas near banks or backwaters. There they burrow in and remain as filter feeders for 5 to 6 years. As they grow they may relocate to areas with coarser material (Kan 1975).

Flow Control Alternatives

The bulk of the rearing lamprey (ammocoetes) would likely remain in their spawning tributaries. However some ammocoetes have been found in the mainstem Snake and Columbia rivers, indicating that rearing does occur there as well.

Ammocoetes tend to remain near banks and backwaters and are vulnerable to dewatering. It is unlikely that an ammocoete in a dewatered area would be able to successfully relocate.

Drawdown/Natural River/Combination Alternatives

Ammocoetes emerge from their nests and settle into silty banks in July and August. Under those alternatives where drawdown is complete prior to July, i.e., 6b, 6d, 5b, 5c, 9a, 9b, 9c and the PA, no stranding of ammocoetes should occur.

5.11.2.2 Seaward Migration

Outmigration of newly metamorphosed juveniles into the adult form peaks from April through June. Due to its small size and poor swimming ability (Beamish 1974), downstream migration appears to be mainly passive, involving high spring flood flows (Kan 1975).

Flow Control Alternatives

Migrating lampreys pass dam structures like other anadromous fish – through juvenile bypass facilities, turbines, and by spill. Assisted transport with barge or truck is unlikely, however. Little information exists on the relative survival rates for lampreys of the various routes of passage. Survival rates are anticipated to be proportional to those of anadromous fish.

Drawdown Alternatives

The drawdown operations would be in effect during the seaward migration period for lampreys. CRiSP1.5 model results for the drawdown alternatives indicate a slight decrease in travel time for out

migrating Snake River juvenile salmonids, compared to the Flow Control alternatives. There is no data to indicate what effect such a travel time decrease would have on migrating lamprey.

Natural River Alternatives

The Natural River operations would be in effect during the seaward migration period for lampreys. Flows, fish and lampreys would be bypassed around the dam, thus dam passage mortality should be reduced or eliminated.

Combination Alternatives (Includes Preferred Alternative

Under these alternatives, high spills would be occurring during the peak of the juvenile migration. These spill levels may aid migrating lamprey past dams. These spill levels also result in the highest levels of total dissolved gas supersaturation of any of the alternatives. Lamprey susceptibility to gas bubble trauma is unknown.

5.11.2.3 Adult Migration

Pacific lampreys migrate up the Columbia and Snake rivers from April through August. Passage at Bonneville Dam peaks in July. Lampreys are able to surmount nearly vertical barriers of 5 or 6 feet over which the current is not excessive by creeping up the face with the suctorial disc (Scott & Crossman 1973). They are also able to swim upstream past rapids by alternately swimming and attaching to stones. However lampreys can be blocked by excessive velocity (Farlinger and Beamish 1983) and by physical barriers (Beamish and Northcote 1988; and Hunn and Youngs 1980). Beamish (1974) notes that lampreys are poor swimmers compared with teleost fish, particularly against strong currents.

Adults remain in the rivers, hiding under stones, until the following spring when they become sexually mature. They do not feed during this period.

Flow Control Alternatives

Under the flow control alternatives all ladders, fish bypass systems and navigational locks, through which lampreys regularly pass, would be fully operational. Therefore no adverse impacts to upstream adult migration is anticipated.

River levels would drop fairly rapidly in June and July in the flow control alternatives, possibly exposing hiding adults. However since adults are mobile they should be able to relocate to deeper water without harm.

Drawdown Alternatives

It is felt that lamprey rely heavily on the navigation locks for passage through the Lower Snake River dams (Chris Pinney, COE, Personal Communication). Under drawdown alternative 6b, navigational locks at all four lower Snake River dams would become inoperative. Only the lock at Lower Granite would become inoperative under alternative 6d. Adult fish ladders and juvenile fish bypass systems would be modified to be operational with drawdown alternatives. Thus lampreys should be able to migrate past dams using these ladders and fish bypass systems. However the migration route through navigational locks would become blocked. It is unknown whether those lamprey that would have traveled through the navigational lock would find the fish ladder or juvenile fish bypass entrances and successfully pass through, or what the effects of delay and extra energy expended in searching for suitable passage would ultimately be on adult overwinter survival and spawning success.

Dropping reservoir levels could expose hiding adults; however, they should be able to relocate without harm.

Natural River Alternatives

With the Natural River alternatives, no fish ladders or fish bypass systems would be operational. It is possible that the velocities in the dam openings would be too high to allow successful lamprey passage during the period of time of Natural River operation. Alternative 5a includes Natural River operation for the four Snake River projects for two and 1/2 months, mid–April through June. This may delay adult lamprey passage during that period. Natural River operation would occur in Alternative

5b for 4 and 1/2 months from mid–April through August. This may cause a greater delay in adult migration. As with the drawdown alternatives, it is unknown what effect such delays would have on ultimate spawning success.

Drawdown may expose hiding adults, but again they should be able to relocate without harm.

Combination Alternatives (Includes Preferred Alternative)

Drawing down reservoir levels under these alternatives could expose hiding adults; however, they should be able to relocate without harm.

5.11.2.4 Spawning

Lamprey spawning occurs during June and July mostly in tributaries to the Snake River. Some spawning may also occur in the mainstem Snake and Columbia rivers. Eggs incubate 2 to 3 weeks.

Flow Control Alternatives

It is unlikely that adult passage from the mainstem to the spawning tributaries would be blocked due to any flow fluctuations under these alternatives. Adults should be able to migrate into these areas unimpeded. Conditions in the small tributaries where the bulk of lamprey spawning occurs would be unaffected by any flow control alternative.

A small percentage of lamprey spawn in the mainstem Snake and Columbia rivers. It is possible that a few nests could become stranded during daily fluctuations.

Natural Snake and Columbia river flows begin to drop significantly from June through August 15. It is possible that some nests could become exposed due to seasonal river level drops.

Drawdown Alternatives

The bulk of adults spawning in the tributaries should be able to reach the spawning tributaries with little difficulty under any of the drawdown alternatives. Similarly, tributary spawning habitat should not be affected. For the small percentage of lampreys spawning in the mainstem rivers, reservoirs have already reached their lowest levels by the time lampreys begin to spawn. This should prevent lampreys from spawning in areas that would later become dewatered. Reservoirs will then begin to refill in late August. Thus, some nests may become immersed in deeper water and the rate of water percolation through the gravel covering the nest may be reduced somewhat. This may result in a somewhat higher egg mortality as the rate of dissolved oxygen exchange and removal of metabolic waste is slowed.

Natural River Alternatives

The bulk of adults spawning in the tributaries should be able to reach spawning tributaries without difficulty under alternatives 5b and 5c. Spawning habitat in these tributaries should not be affected.

Under alternative 5b reservoir levels would remain stable from mid– April through August, and, under 5c, year–round. Thus, river conditions for nests made during June and July would remain constant until larval emergence.

Combination Alternatives (Includes Preferred Alternative)

Nests made in June and July may be submerged under deeper water layers as the reservoirs refill at the end of the drawdown period. Rates of water percolation through the gravel in the nests may be reduced as velocity in the reservoir reach slows. Egg mortality may increase slightly as the rate of dissolved oxygen exchange and metabolic waste removal is decreased.

5.11.3 Sturgeon

The Resident Fish Work Group is evaluating landlocked sturgeon upstream of Bonneville Dam. For the effects of the System Operating Strategies, see the Resident Fish Work Group technical appendix.

The Anadromous Fish Work Group examined the predicted flows below Bonneville Dam for all the alternatives. The analysis suggests that, even with the range of predicted water/flow conditions that

would occur in the mid–Columbia and Lower Snake rivers under alternative hydro operations, water/flow conditions below Bonneville Dam would not change measurably. Therefore, effects on sturgeon below Bonneville Dam are expected to be minimal.

CHAPTER 6

CONCLUSIONS

6.1 SALMON AND STEELHEAD

Quantitative Results

6.1.1 Travel Time

- The Natural River alternatives are the only alternatives that significantly reduce migration travel time of juvenile salmon and steelhead, and then only for the Snake River stocks. Travel times are predicted to be reduced about five days for spring migrants, and as much as 28 days for fall chinook.
- None of the alternatives significantly alter the travel time for mid–Columbia and lower–Columbia River stocks.

6.1.2 In–River Juvenile Survival

- The Natural River alternatives produce the highest in–river survival values for yearling migrants in the Snake River basin, with nearly 100 percent or greater increase in survival relative to the No Action Alternative for all Snake River stocks. The Natural River alternatives have no effect on mid– and lower–Columbia River stocks.
- For spring migrating species in the Snake River, several additional alternatives predict slight to moderate improvements in in–river survival relative to the No Action Alternative operation, 2c. These include the one– and four–pool drawdown, but only with optimistic passage assumptions, and Combination alternatives 9a+ and 9c+ with optimistic passage assumptions. However, it is important to recognize that, apart from functional decommissioning of dams (Natural River alternatives), only those drawdown alternatives with very optimistic passage assumptions result in appreciable increases in in–river survival relative to the No Action Alternative. Alternatives modeled with pessimistic passage assumptions show negative benefits relative to the No Action Alternative.
- Flow Control alternatives produce similar results in all three drainages, providing negligible survival benefits for in–river migrants.
- The Preferred Alternative results in smolt survivals generally equivalent to the No Action Alternative and all other Flow Control alternatives and the Combination alternative 9b.

6.1.3 Juvenile Survival with Transport

- For all transportation survival hypotheses, except the Adjusted 1986 TIR, juvenile survival, with transport, exceeds in–river survival under all alternatives when averaged across the 49–year water record.
- All transport hypotheses, except the Adjusted 1986 TIR, consistently yield survivals that exceed those predicted for in–river migrants only. Those alternatives that include transport have the greatest opportunity for intercepting smolts at the collector projects and, thus, providing the greatest overall survival.
- The Adjusted 1986 TIR transport hypothesis yields survivals equivalent to or slightly less than in–river survivals regardless of the alternative. It is the opinion of the AFWG that this transport hypothesis has the weakest empirical foundation.
- Only the Natural River alternatives predict improvements in in–river survival that approach the maximum survival predicted under any of the transport hypotheses. The predicted improvement in smolt survival is likely attributable to the elimination of all

turbine–related mortality at the four lower Snake River dams.

- None of the alternatives have a substantive effect on any lower or mid–Columbia River stock.

6.1.4 Adult Returns

- Under the Fixed Barge Transport Hypothesis, SLCM predicts that Snake River fall chinook go extinct or remain at very depressed levels under the four–pool drawdown alternative (6b+ and 6b–). This is likely due to the fact that under the four–pool drawdown alternative (6b), transport can only occur at McNary Dam. Under those alternatives where fall chinook are transported from the lower Snake dams, i.e., all Flow Control alternatives, one–pool drawdown alternative (6d), Combination alternatives 9b, 9c and the Preferred Alternative, and under the Natural River alternatives 5b and 5c, adult production remains relatively stable ranging between about 15,000 and 40,000 fish. Adult production under the Preferred Alternative is slightly higher than that predicted for the No Action Alternative. Under alternative 9a, where no transport occurs, SLCM predicts that Snake River fall chinook would go extinct.

- Under the four–pool drawdown alternative (6b–), and four–pool spillway crest drawdown (9a– and 9c–), assuming pessimistic passage conditions, Snake River spring chinook and summer chinook go extinct.

- Under the four–pool drawdown alternative (6b+), assuming optimistic passage conditions, and one–pool drawdown (6d–), assuming pessimistic passage conditions, Snake River summer chinook stocks remain very depressed.

- Under alternative 9a, which has no transport element, adult production of mid–Columbia stocks drops to its lowest, with Methow summer chinook going extinct. Also, under this alternative, Snake River spring and summer chinook adult populations remain at depressed levels. Dworshak steelhead adult numbers are sharply reduced relative to the No Action Alternative, 2c, which has transport.

Qualitative Results

- Stress and disease transmission in transported smolts continue to be of concern. Research in these areas should continue.

- Evaluation of transportation survival compared with in–river survival should continue. If in–river conditions can be improved to the extent that in–river survival exceeds survival with transport, then transportation could be eliminated.

Mitigation

Section 1502.14(f) of the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act of 1969, requires that agencies preparing an environmental impact statement include in the alternatives section appropriate mitigation measures not already included in the proposed action or alternatives themselves. A major focus of the SOR EIS has been to identify and evaluate alternative hydrosystem operations that themselves are intended, in part, as mitigation for the adverse effects on anadromous fish of previous hydrosystem operations.

Several mitigation actions have been taken since the construction of the hydrosystem began back in the early 1930's. Such mitigation actions include: installation of adult fish ladders; construction and operation of salmon and steelhead hatcheries; turbine intake screening and installation of bypass systems for juvenile salmonids; implementation of a Water Budget and Spill Agreement, etc. A more detailed list of mitigation and mitigation–related activities can be found in Technical Exhibit B of this document.

The Preferred Alternative identified in the SOR Final EIS is intended to balance the effects on various resources that the hydrosystem operation

would have. However, the Preferred Alternative is designed to favor anadromous fish above other resources and uses associated with the hydrosystem. The PA includes mitigation such as spill, total dissolved gas caps, drawdown and increased flows in the mainstem Columbia and Snake rivers to aid the migration of juvenile salmonids. In conclusion, the PA is intended to be a hydrosystem operation that mitigates for the adverse effects that previous hydrosystem operations have had on anadromous fish.

6.2 NON–SALMONID ANADROMOUS FISH

6.2.1 Lamprey

- **Flow Control Alternatives:** Since a small percentage of lamprey spawn in the mainstem river, a small number of nests and some ammocoetes may be exposed due to seasonal flow fluctuations, resulting in some mortality. It is expected that juvenile migration survival rates would be proportional to those of anadromous fish.
- **Drawdown:** Drawdown may significantly affect adult migration by dewatering navigation locks. A small percentage of nests in the mainstem may become immersed in deeper water as the lower Snake River reservoirs are refilled after the drawdown period, reducing the rate of water percolation. This may cause somewhat higher egg mortality. Seaward migration of juveniles would probably benefit.
- **Natural River:** Adults may be adversely affected by causing some migration delays due to increased velocities at dam openings. As with drawdown, upon reservoir refill, those nests existing in the mainstem may become immersed in deeper water, which could result in somewhat higher egg mortality. Seaward migration of juveniles would probably benefit.
- **Combination (Includes Preferred Alternative):** High spill levels may aid the juvenile lamprey in migrating past dams. The effects of increased gas supersaturation on lamprey that these alternatives may cause is unknown.

Mitigation

Because the effects of gas supersaturated water on lamprey are unknown, there is no mitigation action plan.

6.2.2 Shad

- **Flow Control:** No adverse effects on any of the shad life stages are expected from implementation of the hydrosystem alternatives.
- **Drawdown:** There would be a significant loss of shad rearing habitat behind the four lower Snake River dams under alternatives 6b. Alternative 6d would cause a significant loss of shad rearing habitat in the pool behind Lower Granite Dam.
- **Natural River:** Significant amounts of shad rearing habitat would be lost under alternatives 5b and 5c.
- **Combination (Includes Preferred Alternative):** There would be a significant loss of shad rearing areas behind the four lower Snake River dams under alternatives 9a and 9c. Shad do not appear to be susceptible to gas bubble disease as are anadromous salmonids.

There would be no measurable loss of shad rearing habitat under alternative 9b or the Preferred Alternative.

Mitigation

Since there is no measurable loss of shad rearing habitat under the Preferred Alternative, there is no need for mitigation. However, even if there were a significant loss of shad rearing habitat, mitigation would be unlikely, since NMFS' Draft Recovery Plan identifies shad as a non–native species that competes with juvenile salmonids for food. The Draft Recovery Plan recommends developing methods for removing American shad from the lower Columbia River.

6.2.3 Sturgeon

None of the alternatives would likely have a significant effect on white sturgeon below Bonneville Dam.

Mitigation

No mitigation is required for this species below Bonneville Dam.

6.3 ALTERNATIVES TO TRANSPORTATION

In–River Migration

Denial of an ESA Section 10 permit would preclude the option of transporting any smolts at any time during the migration season. If an occasion such as extremely low flow or high levels of dissolved gas should arise, and it is determined that transportation is a better passage option, it will not be possible to get the program up and running in time to avoid the poor in–river migration conditions. Most experts agree that some transportation would be beneficial every year, at least for fall chinook salmon and steelhead. Therefore denial of the permit is not recommended.

Removal of Dams

Removal of dams is not a near–term alternative to transportation. While removal of the dams may eventually increase smolt survival, it will not restore the river system to its original ecosystem. It could take decades or centuries for the habitat to recover and for the river to reach equilibrium.

Drawdown of Reservoirs

Reservoir drawdown is not a near–term alternative to transportation. This alternative is likely to have near–term and prolonged negative effects on salmonid survival. It may cause periods of blocked migrations for adult fish, and increased mortality for juvenile fish. There is currently no evidence that the various drawdown alternatives increase salmon survival over current levels.

Increased Spill and In–River Passage

The DFOP calls for increased spill and flow augmentation as an alternative to transportation. Dissolved gas effects are of particular concern in this alternative. This alternative has the potential to expose greater numbers of fish to potential lethal levels of dissolved gas, as demonstrated by the 1994 emergency spill operation as called for by NMFS.

If an alternative such as this were to be adopted, these flow provisions would need to be incorporated:

- Spill should be controlled to regulate gas supersaturation within acceptable standards;
- The gas monitoring program should be expanded and improved to give thorough evaluation of impacts to juvenile and adult salmonids in the area from Lower Granite Dam to the estuary, and in the mid–Columbia River area;
- Flow/survival studies should be continued and expanded to verify whether use of controlled spill and increased flow does increase in–river survival. These studies should be incorporated with transport evaluation studies for direct comparison.

Pipelines and Canals

Pipelines and canals are not near–term alternatives to transportation because of biological concerns and construction requirements. If any such alternative were to prove feasible, transportation would have to continue until the pipeline and/or canal was constructed, evaluated and proven to be a biologically safe and superior method of artificially passing fish down the river.

6.4 ALTERNATE METHODS OF TRANSPORTATION

6.4.1 Means of Conveyance

Net Pens

Some believe that net pens allow smolts to navigate by magnetic and other cues as they are moved down river, perhaps improving their homing ability as adults. Such cues may not be available to the barged or trucked fish. However, research on the effects of homing on transported fish indicates that the effect is minimal, since barged fish home at about the same level as naturally migrating fish.

Net pens cannot control gas supersaturation levels, and could expose smolts to lethal levels of dissolved

gas during periods of spill. Because of the regional interest in this concept, it will be carried forward in the SCS Phase II.

Aircraft

Helicopters are not able to make the journey during hazardous weather conditions. They would require that smolts be transported at higher densities, and cost more than the existing transportation system. They have been eliminated from further study.

Polymer Bags

Polymer bags require that smolts be pumped through pressurized pipes during loading. This action is known to cause stress. There is also concern that with no way to control water quality, smolts may deplete the oxygen levels within the bag. Because of these effects, polymer bags have been eliminated from further study.

6.4.2 Operating Tactics and Technology

Size, Stock, and Hatchery/Wild Separation

Size separation is practiced at all transportation projects except the Lower Granite Dam, where the physical facilities to separate by size are scheduled to be completed 1997. Research should continue to examine ways to improve size separation.

It is not possible to distinguish individual stocks, and therefore separation by stock is not feasible.

It is possible to distinguish hatchery from wild fish, since all hatchery fish are now being fin–clipped. However, the only reliable method for sorting and separating smolts is by hand. The added stress of additional handling makes hatchery/wild separation undesirable, given current methodology. Also, the sheer volume of smolts collected for transportation makes it impossible to hand sort fish.

The potential for keeping hatchery fish separate from wild fish by transporting and holding them in separate containers has been identified, and it will be further considered in SCS Phase II.

Barge all Fish

Available information does not indicate substantially higher stress or mortality in truck transport than in barges. Further research is necessary to demonstrate that increased survival from barging all fish offsets the increased costs incurred by dropping trucking as a tactic.

Reduced Collection Densities

Stress and survival studies show existing transport densities to be acceptable. However, to eliminate stress, expansion of the barge fleet has been recommended. With added barges, direct loading can occur at the collector dams, which would reduce densities as fish will not be added dam–by–dam as they are now.

Barge Modifications (Temperature Controls, Release Mechanisms, Sound Dampening)

Refrigeration units have been recommended for barges. The size and costs of such units have proven to be prohibitive, as revealed in the SCS Phase I.

Modification of barge release mechanisms could easily be incorporated into designs for new barges, and could be retrofitted on existing barges as new mechanisms prove effective.

Modification of barges to control sound and vibrations would best be incorporated in new designs. The Corps is presently evaluating sound levels in the existing barges. If this proves to be a problem, design changes will be made for new barges, and existing barges will be modified to reduce the problem.

Increase Direct Loading

In their 1995 Biological Opinion for operation of the FCRPS from 1995 through future years, NMFS recommended maximization of direct loading of fish for transportation. Research by Congleton et al. 1988, and Schreck, et al. 1993 and 1994, indicates that cumulative stress can be reduced by directly loading fish collected at the dams into barges moored at the collection facilities. Preliminary results of studies by the Corps indicate that five to 12 additional barges would be required. These barges would be a combination of 75,000 and 50,000

pound capacity barges. With the addition of these barges, it would be possible to have a barge moored at Lower Granite, Little Goose, Lower Monumental, and McNary dams, while other barges were in transit downstream with fish or upstream empty on their return trip.

Added environmental impacts would result from the use of resources to build the new barges, and from increased towboat and fuel use from pushing the additional barges. Local environmental impacts would occur at Lower Granite, Lower Monumental and McNary dams where barge moorage facilities would be required for storage of the barges when they were not in use.

Partial Transport of Some Species (Spread the Risk)

Partial transport of some species is practiced at this time according to the "Spread the Risk" policy. Installation of size separation at Lower Granite Dam would facilitate in–river passage of selected fish, should research prove that to be a superior migration route. The concept would provide many possibilities for transporting all hatchery fish, separating hatchery from wild fish, and separating wild salmon from steelhead.

Addition of more barges would also increase the options for keeping fish separated by size, species, or stock, since the barges have separate compartments in which groups of fish can be transported.

Varied Timing

No scientific data has been generated that shows that transportation gets fish to the ocean too fast. Before major efforts are undertaken to change the length of time in transit, research is needed to show that it is necessary.

Transport Further Downstream

Transporting fish further downstream is being studied at this time. If this concept increases adult returns, it could be implemented with the addition of more barges and additional towboats. Returns from the first year of study will be available in 1996, and complete returns will be available in 1998.

Truck release areas were changed in 1993. Mid– and late–season trucks were loaded on a barge and fish were released mid–river in higher current areas. This practice will continue. Barges will continue to release over a four mile reach of river, at a different location each night, and all releases will be made in darkness to reduce predation. These release strategies should not be changed at this time.

6.4.3 New Facilities

Upstream Collection Facility

An upstream collector for the purpose of transporting fish would have the advantage of new and better collection facilities, and of eliminating the mortality that occurs in Lower Granite reservoir. At the same time, there is uncertainty as to the effects on homing from collection farther upstream. Further study of an upstream collection facility is planned under SCS Phase II.

Surface–Oriented Juvenile Fish Collection and Bypass Systems

While this concept has definite promise for reducing stress and increasing FGE, it is considered to be a new generation of fish passage facility. Therefore, a significant amount of research and study will be required before implementation.

6.5 LITERATURE REVIEW AND EVALUATION

Transport/In–River Ratio Research

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

However, given changes in the migration corridor since 1968, the 1986 and 1989 TIRs are considered to be most (although by no means totally) representative of current in–river conditions. These tests yielded TIRs of 1.6:1 (1986) and 2.46:1 (1989).

TIR studies should continue under all flow conditions, with emphasis on:

- Completion of PIT tag facilities, including adult facilities, such that tagged fish can be used to evaluate the program without introducing handling effects; and,
- Further evaluation of fall chinook and sockeye, particularly in the Snake River.

Species–specific in–river survival elements also need further study, including, but not limited to:

- Site–specific survival through turbines, bypass, and spillways;
- The effects of spill and gas supersaturation; and;
- In–river survival estimates for the various river reaches.

Stress Research

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

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

Since the beginning of the transportation program, stress research has led to modifications in facilities or operations that have resulted in minimizing stress and reducing mortality in the collection and transportation program. Efforts to reduce stress in the collection and transportation systems and operations should continue. These efforts include:

- Modifications at the Lower Granite juvenile fish facility to reduce stress caused by the buried pipeline by replacing it with a non–pressurized flume;
- Installation of a size separator at Lower Granite to provide size– and (to the degree that different species migrate at different sizes) species–separation to reduce stress in collection and transportation;
- Modifications of the remaining facilities to bring them up to current criteria to minimize stress and mortality in the system;
- Increasing the number of barges used in transportation to maximize direct loading to barges;
- Additional research on the research on stress and mortality in the two modes of transportation (truck and barge).

Disease Research

Pascho and Elliott (1993) have demonstrated that BKD disease organisms are prevalent in the river as well as in the collection and transportation system, and that the majority of fish, hatchery and wild, are infected by the time they reach Lower Granite Dam. BKD research should continue. Additionally research should expanded to determine whether other diseases are a contributing to smolt mortality.

6.6 ROLE OF TRANSPORTATION IN THE RECOVERY PROCESS

Two ESA processes have a major bearing on the outcome of the SOR EIS. These are the NMFS 1995 Biological Opinion on operation of the FCRPS, and NMFS' Recovery Plan. The Biological Opinion directly affects operation of the FCRPS, while the Recovery Plan affects the entire habitat and range of the listed species.

The 1995 Biological Opinion contains a list of reasonable and prudent alternatives which the SOR agencies are recommended to implement. In the near term, measures are in progress to replace the juvenile

fish collection facilities at Lower Granite Dam and install extended length screens at Lower Granite, Little Goose, and McNary dams. New concepts, principally the surface collection concept, are being tested at Ice Harbor Dam in 1995 and Lower Granite and The Dalles dams in 1996. Additional barges have been requested by NMFS to maximize direct loading at all collector dams, and to reduce stress on, and loading densities of, transported fish.

In addition, NMFS has recommended that additional storage be acquired for flow augmentation, and devised a spill plan to increase in–river passage survival. NMFS has set goals of 80 percent FPE and 95 percent survival at each dam. The cumulative improvements recommended by NMFS are expected to significantly improve Snake River salmon survival.

The juvenile fish transportation program affects the lives of Columbia and Snake river salmon for 2 to 4 days of their 2 to 7 year life. Survival and stress reduction measures since the program began have minimized the impacts to the fish. During the 2 to 4 days fish are in the collection/transport process, 98 to 99 percent survival has been documented for a number of years. Survival from egg to smolt for wild chinook spawning in the Salmon River basin ranges from 2.5 to 5 percent. Survival of smolts from Bonneville Dam to return as adults is less than 5 percent. It should be readily apparent that little can be done to increase transport survival, while there is lots of room to improve spawning and rearing survival and ocean survival.

In their 1995 Biological Opinion, NMFS recognized transportation as a life support system that stands between the salmon and extinction. They have recognized that much needs to be done to increase the survival of the listed species before the life support system can be removed. For the interim, they recommend that transport continue in low flow years, and that the decision to continue in normal and high flow years be made after review of conditions at the time. NMFS has recognized the need for additional information on which to base decisions, and has recommended research and actions intended to improve survival above and below the FCRPS as well as measures to improve survival through the FCRPS. Therefore, a concerted effort by the SOR agencies, state and Tribal fishery management agencies, the public, and other nations is necessary before recovery of the listed stocks is possible.

CHAPTER 7

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CHAPTER 8

GLOSSARY OF ANADROMOUS FISH TERMS

Acre–foot: The volume of water that will cover an area of 1 acre to a depth of 1 foot.

AFWG: Anadromous Fish Work Group, the work group dealing with anadromous fish under the SOR process.

Alevin: Life stage of salmonids between hatching and feeding when the yolk sac is still present. Generally equivalent to sac fry or larval stage.

Allozymes: Two enzymes that cause/effect the same reaction.

Ammocoetes: Larval life stage of lamprey.

Amphodids: Small crustaceans belonging to the group Amphipoda. Many are a good food source for fish.

Anadromous fish: Fish, such as salmon or steelhead trout, that hatch in freshwater, migrate to and mature in the ocean, and return to fresh water as adults to spawn.

ANCOOR: The Analytical Coordination Group, an interagency group including NMFS, STFA, BPA, Corps, and others to establish assumptions and review data used in computer models.

Augment: Increase; in this application, increasing river flows above levels that would occur under normal operation by releasing water from storage reservoirs.

BCF: Bureau of Commercial Fisheries. The old name of the National Marine Fisheries Service when it was in the USFWS in the Department of the Interior. The BCF became the NMFS when it was transferred to the Department of Commerce in 1973.

BKD: Bacterial kidney disease. A disease of fish caused by *Rhinebacterium salmoninarum,* particularly damaging to chinook salmon in the Snake River Basin.

BON: Bonneville Dam.

BOR: Bureau of Reclamation, U.S. Department of the Interior.

BPA: Bonneville Power Administration, U.S. Department of Energy.

Bypass system: Structure in a dam that provides a route for fish to move through or around the dam without going through the turbines.

CAR: Coordination Act Report. The report prepared by the USFWS/NMFS to accompany the Federal water resource development agency Environmental Impact Statement and Feasibility Report to Congress for authorization.

Caudal peduncle: The posterior trunk of a fish where the tailfin attaches to the body of the fish.

CBFTC: Columbia Basin Fisheries Technical Committee, later combined with the CRITFC to form the CBFWA.

CBFWA: Columbia Basin Fish and Wildlife Authority. A combined organization of the regional fishery agencies and the CRITFC.

CBFWA FPAC: The Fish Passage Advisory Committee. A technical committee of the Columbia Basin Fish and Wildlife Authority.

Cladocera: A group of zooplankton; a good food source for juvenile salmon.

COE: U.S. Army Corps of Engineers, U.S. Dept. of Defense

COFO: Committee on Fishery Operations. A committee active in the 1970s and early 1980s to establish river operations for the protection of anadromous fish.

Corps: U.S. Army Corps of Engineers, U.S. Department of Defense.

Council: Northwest Power Planning Council

CQS: Center for Quatitative Science at the University of Washington. Developers of the CRiSP models.

CRiSP: Columbia River Salmon Passage model developed by the University of Washington to model fish survival in the Columbia River. Several versions (CRiSP.0, CRiSP.1, etc. of this model exist).

CRITFC: Columbia River Inter–Tribal Fish Commission.

CRJFMP: Columbia River Juvenile Fish Mitigation Program. A program of the Corps to bring all juvenile fish bypass/collection systems up to state–of–the–art performance.

CRSMA: Columbia River Salmon Mitigation Analysis. A program of the Corps to evaluate salmon mitigation measures including the System Configuration Study (SCS).

Crustacean: Any chiefly aquatic anthropod of the class Crustacea. This includes many plankton, crabs, etc. Many are a preferred food for fish.

Cubic feet per second (cfs): A unit of measurement pertaining to flow or discharge of water. One cfs is equal to 449 gallons per minute.

DEIS: Draft Environmental Impact Statement

Depletions: Withdrawals of water from a stream, thereby reducing the volume of instream flow.

DFOP: Detailed Fishery Operating Plan. The operational plan of the CBFWA as recommended to the Corps and BOR.

Dissolved gas concentrations: The amount of chemicals normally occurring as gases, such as nitrogen and oxygen, which are held in solution in water, expressed in units such as milligrams of the gas per liter of liquid.

Draft: Release of water from a storage reservoir.

Drawdown: The distance that the water surface of a reservoir is lowered from a given elevation as water is released from the reservoir. Also refers to the act of lowering reservoir levels.

ELCM: Emperical Life Cycle Model. A computer model developed by the fisheries agencies and tribes to evaluate fish survival for Columbia Basin salmon populations.

Emergence: Process of larval salmonids coming out of the gravel redds after adsorbtion of the yolk sac.

Endangered: Legal status afforded to plant or animal species which is in danger of extinction throughout all or a significant portion of its range because its habitat is threatened with destruction, drastic modification, or severe curtailment, or because of overexploitation, disease, predation, or other factors. Federally–listed endangered species are officially designated by the U.S. Fish and Wildlife Service or NMFS and published in the *Federal Register*.

EPA: Environmental Protection Agency, U.S. Department of the Interior.

Ephemeral: Short lived

ESA: Endangered Species Act of 1973.

Escapement: Number of salmon or steelhead that actually return to a stream to spawn.

Eurahaline: Having a wide salinity tolerence.

FCRPS: Federal Columbia River Power System, Dams operated by the BOR and Corps in the Columbia River Basin.

FEIS: Final Environmental Impact Statement

Feral hatchery fish: Adults from hatchery reared juveniles that are not expected to spawn.

FERC: Federal Energy Regulatory Commission, U.S. Department of Energy.

FERP: Fisheries Engineering Research Program. The Corps' fishery research and coordination program (now FPDEP).

Fingerlings: Juvenile fish about finger size; generally a hatchery term.

Fish hatchery: A facility in which fish eggs are incubated and hatched and juvenile fish are reared for release to rivers or lakes.

Fish ladders: A series of ascending pools constructed to enable salmon or other fish to swim upstream around or over a dam.

FISHPASS: A fish passage model developed by the Corps of Engineers to evaluate fish survival under various operational conditions.

Fish passage facilities: Features of a dam that are intended to move fish around, through, or over the dam without harm. Generally an upstream fish ladder or a downstream bypass system.

Flip lips: Also known as spill deflectors. Structural modifications made to the spillways of some Columbia–Snake River projects to deflect flows and reduce the deep plunging flows that create high dissolved gas levels.

FLUSH: Fish Leaving Under Several Hypotheses. Computer model developed by the fishery agencies to evaluate fish survival in the Columbia Basin.

Forebay: The portion of the reservoir at a hydroelectric plant which is immediately upstream of the generating station.

FPC: Fish Passage Center.

FPAC: Fish Passage Advisory Committee, a subcommittee of the CBFWA that coordinates Columbia River fish passage activities.

FPDEP: Fish Passage Development and Evaluation Program. The fishery research and coordination program of the Corps for coordination with the regional fishery agencies, tribes, NPPC, etc.

FPP: Fish Passage Plan. The plan of the Corps for operation of fish facilities and dams for the protection of fish. The FPP is the basis for consultation between the Corps and NMFS under the ESA Section 7, and it is the basis for the Biological Opinion by NMFS for operation of the FCRPS Corps dams.

fps: Feet per second

Freshet: A rapid temporary rise in streamflow caused by heavy rains or rapid snowmelt.

Fry: Life stage of juvenile salmonid commencing with the shedding of the yoke sac, when the fish begins to feed on its own.

FTOT: Fish Transportation Oversight Team. An interagency team established to oversee the Juvenile Fish Transportation Program comprised of representatives of the NMFS, IDFG, ODFW, CRITFC, and the Corps; disbanded in the spring of 1993.

Full pool: The maximum level of a reservoir under its established normal operating range.

FWCA: Fish and Wildlife Coordination Act (PL 85–624). The law requiring coordination between Federal water resource development agencies and the USFWS, NMFS, and state fish and wildlife agencies.

GAO: U.S. General Accounting Office.

Gas supersaturation: Concentrations of dissolved gas in water that are above the saturation (100 percent capacity) level of the water.

Generation: Act or process of producing electric energy from other forms of energy. Also refers to the amount of electric energy so produced.

Historical streamflow record: The unregulated streamflow data base of the 50 years beginning in July 1928. Data are modified to adjust for factors such as irrigation depletions and evaporations for the particular operating year being studied.

Hydraulic head: The vertical distance between the surface of the reservoir and the surface of the river immediately downstream from the turbine and dam.

Hydroelectric generation: The production of electric power through use of the gravitational force of falling water.

Hydrology: The science of dealing with the continuous cycle of evapotranspiration, precipitation, and runoff.

Hydroregulation model: A computer–based mathematical model that simulates the regulation of water in the coordinated operation of a river system.

ICFWRU: Idaho Cooperative Fish and Wildlife Research Unit at the University of Idaho.

IDFG: Idaho Department of Fish and Game

IHR: Ice Harbor Dam.

Inflow: Water that flows into a reservoir or forebay during a specified period.

Intake: The entrance to a conduit through a dam or water facility.

Interspecific competition: Competition between individuals of different species.

Intraspecific competition: Competition between organisms of the same species.

Invertebrates: A group of animals that do not have a backbone. These are generally small and many are a good food source for many fish.

Isobath: A line on a map connecting all areas of equal depth, also called a contour line.

Jack: Salmon that returns to natal stream to spawn following a single year of ocean–rearing.

JDA: John Day Dam.

JFTP: The Juvenile Fish Transportation Program operated by the Corps.

Juvenile: The early stage in the life cycle of anadromous fish when they migrate downstream to the ocean.

KAF: Thousand acre–feet (of water).

kcfs: A measurement of water flow equivalent to 1,000 cubic feet of water passing a given point for one second.

Larval – An immature form, generally referred to as the life stage between hatching and adsorption of the egg sac.

LGR: Lower Granite Dam.

LGS: Little Goose Dam.

Littoral zone: The shallower waters near the shore of a reservoir or lake.

LMO: Lower Monumental Dam

Low pool: At or near the minimum level of a reservoir under its established normal operating range.

LTSA: Long–Term Spill Agreement

Macrophytes: Aquatic plants that are macroscopic, or large enough to be seen with the naked eye.

MAF: million acre–feet (of water)

Mainstem: The principal river in a basin, as opposed to the tributary streams and smaller rivers that feed into it.

MCN: McNary Dam.

MDFWP: Montana Department of Fish, Wildlife and Parks

Megawatt (MW): A megawatt is one million watts, a measure of electrical power.

Mid–Columbia: The section of the Columbia River from the Canadian border to its junction with the Snake River.

Model: A mathematical function with parameters that can be adjusted so that the function closely describes a set of empirical data. A "mathematical" or "mechanistic" model is usually based on biological or physical mechanisms, and has model parameters that have real–world interpretation. In contrast, "statistical" or "empirical" models are curve–fitting to data where the math function used is selected for its numerical properties. Extrapolation from mechanistic models (e.g., pharmacokinetic equations) usually carries higher confidence than extrapolation using empirical models (e.g., logic).

MOP: Minimum operating pool. The minimum elevation of the established normal operating range of a reservoir.

Morphological: Form and structure of animals or plants

MSL: Mean sea level. Reservoir levels are measured in elevation above MSL.

NBS: National Biological Survey. A new Department of Interior organization combining the researchers of the USFWS, BOR, and Bureau of Land Management.

NEPA: The National Environmental Policy Act of 1969.

Nitrogen supersaturation: A condition of water in which the concentration of dissolved nitrogen exceeds the saturation level of water. Excess nitrogen can harm the circulatory systems of fish.

NMFS: National Marine Fisheries Service, U.S. Department of Commerce.

Non–power operating requirements: Operating requirements at hydroelectric projects that pertain to

navigation, flood control, recreation, irrigation, and other non–power uses of the river.

NPPC: Northwest Power Planning Council. A regional council established by the Northwest Electric Power Planning and Conservation Act of 1980 (PL 96–501), composed of two representatives each from Idaho, Oregon, Montana, and Washington.

NPT: The Nez Perce Tribe

NRIC: Northwest Resource Information Center. The conservation group that initiated the lawsuit to stop the JFTP.

NTF: Nitrogen Task Force. A committee active in the 1970s to resolve the gas supersaturation problems caused by the FCRPS.

NTU: Nephelometric turbidity units. A measure of the amount of suspended sediment in the water.

NWPPC: Northwest Power Planning Council.

OA/EIS: 1992 Options Analysis/Environmental Impact Statement.

OCFWRU: Oregon Cooperative Fish and Wildlife Research Unit.

ODFW: Oregon Department of Fish and Wildlife

OFC: Oregon Fish Commission. Combined with the Oregon Game Commission in 1976 to become the Oregon Department of Fish and Wildlife.

OGC: Oregon Game Commission. Combined with the Oregon Fish Commission in 1976 to become the Oregon Department of Fish and Wildlife.

Osmoregulation: Process by which organisms maintain stable osmotic pressures in their blood, tissues, and cells, in the face of differing chemical properties among tissues and cell, and between the organism and their environment.

Outflow: The volume of water per unit of time discharged at a hydroelectric project.

PAM: Passage Analysis Model developed by the NPPC to predict survival of Columbia River salmonids.

Parasitic: Process of one animal living in or on another animal and depending on that animal as a primary food source.

Parr: Life stage of juvenile salmonids just prior to smoltification.

Pelagic: Living or growing near the surface of the water; open water organisms.

Photoperiod: Number of daylight hours best suited to the growth and maturation of an organism.

Photosynthesis: Process of plants to change sunlight into a useable energy source.

Phototaxis: Movement of an organism in response to light.

Physiological: Pertaining to the function of an organism or its parts.

Phytoplankton: The plant portion of the floating or weakly swimming organisms, often microscopic in size, in a body of water.

Piscivorous: Fish eating

PIT: Passive integrated transponder. A new fish tag that incorporates a crystal, a computer chip, and an antenna that performs like a radio without a battery. When energized by a strong radio signal from a PIT tag detector, the PIT tag sends back a 10 digit alpha–numeric code number specific to each fish.

Pituitary: A hormone producing gland.

Planktivorous: Plankton eating

Pool: Reservoir; a body of water impounded by a dam.

PSC: Pacific Salmon Commission

PSMFC: Pacific States Marine Fisheries Commission. An inter–agency organization established to facilitate fisheries management by the various agencies.

PUD: Public Utility District

Reclamation: U.S. Bureau of Reclamation

Record of Decision: ROD. A document notifying the public of a Federal decision, together with the reasons for that decision. The Record of Decision is published in the *Federal Register.*

Redds: Salmon spawning nests in gravel.

Refill: The point at which the hydro system is considered "full" from the seasonal snowmelt runoff. Also, refers to the annual process of filling a reservoir.

Relative change in survival: The difference in survival between the two alternatives divided by the base case survival value. The change in survival in relation to the base case survival.

Reregulation: Storing erratic discharges of water from an upstream hydroelectric plant and releasing them uniformly from a downstream storage plant.

Reservoir draft rate: The rate at which water, released from storage behind a dam, reduces the elevation of the reservoir.

Reservoir elevations: The levels of the water stored behind dams, relative to MSL.

Reservoir storage: The volume of water in a reservoir at a given time.

Resident fish: Fish species that reside in freshwater throughout their lives.

Residualism: A condition in which migrating juvenile salmonid smolts lose their urge to migrate, physiologically revert to their freshwater life form, and remain in fresh water rather than migrate to sea.

Riprap: Broken rock, cobbles, or boulders placed on the bank of a stream or river for protection against the erosive action of water.

Rheotaxis: Movement of an organism in response to current of a fluid (water).

Riparian: Areas along the bank/shore of a stream or lake.

RM: River Mile; measured upstream from the river mouth.

Run–of–river dams: Hydroelectric generating plants that operate based only on available streamflow and some short–term storage (hourly, daily, or weekly).

Run–of–river reservoirs: The pools or impoundments formed behind run–of–river dams.

Salmonids: Fish of the family Salmonidae, such as salmon, trout (including steelhead), char, and whitefish.

Scoping: The process of defining the scope of a study, primarily with respect to the issues, geographic area, and alternatives to be considered. The term is typically used in association with environmental documents prepared under the National Environmental Policy Act.

SCS: System Configuration Study. A study by the Corps of alternatives for improving salmon passage and survival through the FCRPS, being conducted under the Columbia River Salmon Mitigation analysis.

Sedimentation/Siltation: The settling of material (such as dust or other particles) into water and eventual deposition on the bottoms of streams, rivers, and reservoirs.

Simulation: The representation of an actual system by analogous characteristics of some device easier to construct, modify, or understand, or by mathematical equations.

SLCM: Stochastic Life Cycle Model. A computer model developed by the Resources for the Future and the U.S. Forest Service to estimate the number of returning adult salmonids.

SMP: Smolt Monitoring Program. A program operated by the FPC at smolt monitoring sites in the rivers and at dams in the system to monitor smolt migrations each year.

Smolt: A juvenile salmon or steelhead migrating to the ocean and undergoing physiological changes to adapt its body from a freshwater to a saltwater environment.

Smoltification: Morphological and physiological processes involved in a juvenile salmon or steelhead for adaptation to a saltwater environment.

SOR: (Columbia River) System Operation Review

SOS: System Operating Strategy. An alternative operation considered under the SOR.

Spawning: The releasing and fertilizing of eggs by fish.

Spawning Channel: A man–made channel created in a natural system, as a spawning area for adult salmonids.

Spill: Water passed over a spillway without going through turbines to produce electricity. Spill can be forced, when there is no storage capability and flows exceed turbine capacity, or planned, such as when water is spilled to enhance juvenile fish passage.

Spillway: Overflow structure of a dam.

STFA: State, Tribal, and Federal Agencies. A grouping of the state, Tribal, and Federal fishery management agencies of the region.

Storage reservoirs: Reservoirs that have space for retaining water from springtime snowmelts. Retained water is released as necessary for multiple uses, including power production, fish passage, irrigation, and navigation.

Steelhead:

Group A: Enter the Columbia River from June – early August and are destined for tributaries throughout the Columbia River.

Group B: Enter the Columbia River in late August – October and are destined primarily for Snake River tributaries.

Streamflow: The rate at which water passes a given point in a stream, usually expressed in cubic feet per second (cfs).

Subyearlings: Juvenile fish less than one year old. Generally Snake River fall chinook, and mid–Columbia River summer and fall chinook.

TAG: Technical Advisory Group. A group of fishery agency, Tribal, Federal fishery managers, and other concerned interests, assembled periodically during the SCS process to review concepts and alternatives for biological and managerial efficacy.

Tailrace: The canal or channel that carries water away from a dam.

Tailwater: The water surface immediately downstream from a dam or hydroelectric powerplant.

TDA: The Dalles Dam.

T.E.C.H.: Ted, Earl, Charlie and Howard, a state agencies modeling group named after Ted Conney, Earl Weber, Charlie Petrosky, and Howard Schaller.

Thalweg: A line connecting the lowest points along a streambed.

Threatened: Legal status afforded to plant or animal species that are likely to become endangered within the foreseeable future throughout all or a significant portion of their range, as determined by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service.

TIR: Transport/Inriver Ratio. The ratio of percent return of transported fish compared to percent return of inriver migrants (set to one).

Trophic Levels: The levels of energy transfer within a community.

Tules: The name commonly applied to fall chinook salmon originating in the lower Columbia River.

Turbidity: A measure of the optical clarity of water, which depends on the light scattering and absorption characteristics of both suspended and dissolved material in the water.

Turbine: Machinery that converts kinetic energy of a moving fluid, such as falling water, to mechanical or electrical power.

UofI: University of Idaho.

Upriver brights: The name commonly applied to fall chinook salmon originating in the middle Columbia River, primarily in the area below Priest Rapids Dam.

Usable storage: Water occupying active storage capacity of a reservoir.

USFS: U.S. Forest Service

USFWS: U.S. Fish and Wildlife Service,.U.S. Department of the Interior.

Velocity: The time rate of linear motion in a given direction.

Water Budget: A part of the Northwest Power Planning Council's Fish and Wildlife Program calling for a volume of water to be reserved and released during the

spring, if needed, to assist in the downstream migration of juvenile salmon and steelhead.

Water conditions: The overall supply of water to operate the Pacific Northwest hydroelectric generating system at any given time, taking into account reservoir levels, snowpack, needs to provide water or retain water to meet various operating constraints (such as the Water Budget, flood control, flow constraints, etc.), weather conditions, and other factors.

Water particle travel time: The theoretical time that a water particle would take to travel through a given reservoir or river reach. It is calculated by dividing the flow (volume of water per unit time) by the cross–sectional area of the channel.

Water retention time: The length of time that a particle of water is resident in a lake or reservoir, based on rates of inflow, outflow and circulation within the water body.

Water rights: Priority claims to water. In western states, water rights are based on the principle "first in time, first in right," meaning older claims take precedence over newer ones.

WDF: Washington Department of Fisheries, combined with Washington Department of Wildlife (WDW) in 1994 to become Washington Department of Fish and Wildlife (WDFW).

WDFW: Washington Department of Fish and Wildlife

WDW: Washington Department of Wildlife

WSU: Washington State University

Yearlings: One–year old juvenile salmon and steelhead.

Zooplankton: Aquatic animals that cannot actively swim against the current and that cannot make their own food by photosynthesis.

CHAPTER 9

LIST OF PREPARERS

Table 9–1. List of Preparers

Name	Education/Years of Experience	Experience and Expertise	Role In Preparation
Anderson, Witt	M.S. Resource Management B.S. Botany 16 years	Water resource planning	Project manager
Barila, Teri	M.S. Fisheries Management 12 years	Columbia& Snake Rivers Mainstem/Bypass	Work group participation and review
Boehme, Christopher	B.A. Anthropology/Philosophy 10 yrs.	Science/Technical Writing	Technical Writer
Broderick, Susan	B.S. Natural Resources Mngt, M.S. Wildlife Biology/15 yrs.	Salmonid habitat restoration/fish ecology	Work group participation and review
Derby, Stephen L.	Ph.D Decision Analysis 20 yrs.	Decisions under uncertainty/ economic environmental systems	Work group participation and review
Ferguson, John	B.S. Fish Biology, M.S. Aquatic Ecology/16 yrs.	Columbia River Fish passage and hydrosystem operation	Work group participation and review
Giorgi, Al	Ph.D. Fisheries Science 15 years	Research scientist, technical analyst. Salmon Biology; fish passage	Technical analyst, work group participation, and review.
Hamilton, Laura	B.A. Zoology, M.M.A expected 1994/8 years	Aquatic Ecology and ecological modeling	SLCM model runs, work group participation and review
Hayes, Josh	B.A. Biology, M.S. Zoology, Ph.D Zoology/6 yrs.	Ecology modeling/aquatic biology	CRiSP model runs; work group participation and review
HymanJeff	B.S., M.S. Zoology, M.S. Statistics, Ph.D Ecology/3 yrs.	Ecological modeling/landscape ecology	Work group participation and review
Kenney, Dan	M.S. Fisheries Management 8 years	Lower Snake River Dworshak Reservoir	Drawdown Reviewer
MacKay, Robyn	B.S. Mechanical Engineering 14yrs	Longterm hydrosystem operations planning	Work group coordinator

Table 9–1. List of Preparers – CONT

Name	Education/Years of Experience	Experience and Expertise	Role In Preparation
McConnaha, Chip	M.S. Fisheries Science 13 years	Fisheries analysis PAM modeling	PAM model runs
McKern, John	M.S. Fisheries Science B.S. Wildlife Science 23 years	Fish and wildlife mitigation related to dams	Work group coordinator
McKown, Ronald R.	Ph.D Zoology 25 yrs.	Environmental planning/project operations	Work group participation and review
Olney, Fred	B.S., M.S Fisheries 24 years	Columbia River fisheries/Technical advisor to Courts on N.W.Treaty & Indian fishing right cases	Work group participation and review
Paulsen, Charlie	Masters, Environmental Management/12 years	Environmental modeling, environmental economics	Work group participation and review
Pinney, Chris	M.S. Aquatic Ecology B.S. Zoology 8 years	Ecosystem analysis	Work group participation and review
Thor, Philip	B.S. Mechanical Engineering 18 years	Project management and coordination. Operational analysis. NEPA compliance	Spreadsheet modeling; work group review
Shepard, Richard B.	B.A. Biology, M.S. Ecology, Ph.D Aquatic Ecology	Ecosystem structure, function & analysis	Work group participation and review
Smith, Mark	B.S. Fish&Wildlife Mngt. 4 yrs.	Columbia River Fish Passage	Work group participation and review
Rowan, John	B.S. Biology B.S. Soil Science 10 years	Environmental analysis; Project management; NEPA compliance	Anadromous Fish Work group Coordinator

TECHNICAL EXHIBIT A

SLCM INFORMATION, DATA PARAMETERS AND CALIBRATION

A.1 SLCM INTRODUCTION

A.1.1 Juvenile Production

The egg to pre–smolt transition function for natural spawners is the only density dependent function within the Stochastic Life Cycle Model (SLCM). The expected probability of survival from the egg stage to just before leaving the subbasin is calculated as a decreasing function of initial egg numbers. The number of female spawners determines the number of eggs produced. The number of eggs produced are drawn from a normal distribution. With the number of pre–smolts determined, the fish begin their migration seaward, and downstream survival values are determined using one of the downstream passage models.

A.1.2 Ocean and In–river Allocation

There are four fates possible for fish that survive downriver passage to below Bonneville Dam: they can (1) die from natural causes (in the estuary, ocean, or river); (2) be taken in the ocean or (3) in–river harvest; or (4) escape to their subbasin of origin (hatchery racks or other in–basin recovery sites). The proportion of fish of each age that die of natural causes in the estuary, ocean, and river is highly uncertain. Thus, the SLCM employs a single parameter that represents the total proportion of adult fish that survive from below Bonneville dam to potentially be recovered in either ocean harvest, in–river harvest, or subbasin escapement.

Note that all natural mortality of adults is collapsed into a single mortality rate. This parameter is used to calibrate the model output to observed escapements. The allocation of surviving fish into ocean harvest, in–river harvest, and subbasin escapement is calculated from empirical Coded–Wire Tag recovery data. Coded–Wire Tag data consists of the number of tagged fish that are recovered in each age group and recovery location.

A.1.3 Subbasin Allocation

SLCM then allocates those adults returning to the subbasin. Hatchery and natural adults are allocated among hatchery spawning, natural spawning, and terminal harvest. Hatchery needs and natural escapement targets have priority over harvest. All adults are subject to pre–spawning mortality, either within the hatchery or natural areas. Once the adults have returned to the subbasin, the production of juveniles begins either from natural spawning or through hatchery production.

A.2 SLCM PARAMETERS

The following is a list of data parameters for the eight indicator stocks used in the SLCM analysis, followed by a brief explanation for of the adult recovery and harvest parameters.

A.2.1 Data Sources for SLCM Parameters

A Subbasin Plans

B System Planning Model Parameter Files (NPPC)

C Mullan 1990

D Mullan 1987

E estimated from run data in Mullan 1987

F Howell et al. 1985

G Fisher, 1995

A.2.2 Parameter Name and Descriptors

```
ffem      ; /* fraction female */
```

```
prspsv    ; /* prespawning survival */
egfem     ; /* mean eggs per famale */
hatrem    ; /* adult take by hatchers */
hatsmolt  ; /* Hatchery fry released  */
hintsv    ; /* post–release survival */
bhincp    ; /* Beverton–Holt intercept */
bhcap     ; /* Beverton–Holt carrying capacity */
smtage1   ; /* yearling migrants (0–1) */
smtage2   ; /* 2nd year migrants */
smtage3   ; /* 3rd year migrants */
inbsmsv   ; /* inbasin overwinter survival */
adtrecv   ; /* fraction recovered as adults */
sadtrecv  ; /* C.V. or adult recovery */
ocn1har   ; /* 1st year ocean harvest */
ocn1rvh   ; /* 1st year river harvest */
ocn2har   ; /* 2nd year ocean harvest */
ocn2rvh   ; /* 2nd year river harvest */
ocn2suv   ; /* fraction recovered in years 3+ */
ocn3har   ; /* 3rd year ocean survival */
ocn3rvh   ; /* 3rd year river survival */
ocn3suv   ; /* fraction recovered in year 4 */
ocn4har   ; /* 4th year ocean survival */
ocn4rvh   ; /* 4th year river survival */
ocn1sbe   ; /* 1st year subbasin escapement */
ocn2sbe   ; /* 2nd year subbasin escapement */
ocn3sbe   ; /* 3rd year subbasin escapement */
ocn4sbe   ; /* 4th year subbasin escapement */
termhar   ; /* terminal harvest rate /natural fish */
suptermh  ; /* harv. rate /supplementation fish */
msurv     ; /* mean mainstem survival rate */
passcv    ; /* C.V. of mainstem survival */
jackspn   ; /* If 0, jacks do not contribute */
          ; /* to spawning population */
```

Table A–1. Snake River Spring Chinook

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.55	G
Fraction of spawners female	0.5394	
Average eggs per female	5319	
Do 1–ocean fish spawn?	No	
EGG TO SMOLT REARING STAGE		
Density–independent survival	–2.1972	G
Density–dependence parameter	–3.36E–09	
Variation in egg to presmolt survival	0.3	
Conditional chance of 1 overwinter	1	
Conditional chance of 2nd overwinter	0	
Conditional chance of 3rd overwinter	0	
Inbasin overwintering survival	0.95	
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.0001	G
1–ocean fish to river harvest	0.0001	
1–ocean fish to subbasin escapement	0.1192	
1–ocean fish surviving to 2–ocean	0.8805	
2–ocean fish to ocean harvest	0.0001	
2–ocean fish to river harvest	0.0717	
2–ocean fish to subbasin escapement	0.6642	
2–ocean fish surviving to 3–ocean	0.2639	
3–ocean fish to ocean harvest	0.0006	
3–ocean fish to river harvest	0.2471	
3–ocean fish to subbasin escapement	0.7495	
3–ocean fish surviving to 4–ocean	0.0028	
4–ocean fish to ocean harvest	0.2004	
4–ocean fish to river harvest	0.5992	
4–ocean fish to subbasin escapement	0.2004	

Location	Ocean Age	Tags Recovered
Ocean harv	1	1
River harv	1	1
Escapement	1	909
Ocean harv	2	1
River harv	2	1
Escapement	2	4460
Ocean harv	3	1
River harv	3	1
Escapement	3	1328
Ocean harv	4	1
River harv	4	1
Escapement	4	1

Table A–2. Snake River Summer Chinook

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.7	G
Fraction of spawners female	0.35	
Average eggs per female	4423	
Do 1–ocean fish spawn?	No	
EGG TO SMOLT REARING STAGE		
Density–independent survival	–1.73	G
Density–dependence parameter	–1.5E–08	
Variation in egg to presmolt survival	0.3	
Conditional chance of 1 overwinter	1	
Conditional chance of 2nd overwinter	0	
Conditional chance of 3rd overwinter	0	
Inbasin overwintering survival	0.95	
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.0002	G
1–ocean fish to river harvest	0.0002	
1–ocean fish to subbasin escapement	0.3283	
1–ocean fish surviving to 2–ocean	0.6713	
2–ocean fish to ocean harvest	0.0003	
2–ocean fish to river harvest	0.0180	
2–ocean fish to subbasin escapement	0.7570	
2–ocean fish surviving to 3–ocean	0.2247	
3–ocean fish to ocean harvest	0.0015	
3–ocean fish to river harvest	0.0847	
3–ocean fish to subbasin escapement	0.9095	
3–ocean fish surviving to 4–ocean	0.0044	
4–ocean fish to ocean harvest	0.3333	
4–ocean fish to river harvest	0.3333	
4–ocean fish to subbasin escapement	0.3333	
Location	**Ocean Age**	**Tags Recovered**
Ocean harv	1	1
River harv	1	1
Escapement	1	1495
Ocean harv	2	1
River harv	2	1
Escapement	2	2315
Ocean harv	3	1
River harv	3	1
Escapement	3	625
Ocean harv	4	1
River harv	4	1
Escapement	4	1

Table A–3. Snake River Fall Chinook

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.85	G
Fraction of spawners female	0.583	
Average eggs per female	4297	
Do 1–ocean fish spawn?	No	
EGG TO SMOLT REARING STAGE		
Density–independent survival	–1.76	G
Density–dependence parameter	–6.13E–08	
Variation in egg to presmolt survival	0.3	
Conditional chance of 1 overwinter	0.15	
Conditional chance of 2nd overwinter	0	
Conditional chance of 3rd overwinter	0	
Inbasin overwintering survival	0.25	
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.0213	G
1–ocean fish to river harvest	0.0287	
1–ocean fish to subbasin escapement	0.0089	
1–ocean fish surviving to 2–ocean	0.9412	
2–ocean fish to ocean harvest	0.3094	
2–ocean fish to river harvest	0.1085	
2–ocean fish to subbasin escapement	0.0857	
2–ocean fish surviving to 3–ocean	0.4963	
3–ocean fish to ocean harvest	0.5140	
3–ocean fish to river harvest	0.2841	
3–ocean fish to subbasin escapement	0.0973	
3–ocean fish surviving to 4–ocean	0.1046	
4–ocean fish to ocean harvest	0.4247	
4–ocean fish to river harvest	0.4347	
4–ocean fish to subbasin escapement	0.1407	
Location	**Ocean Age**	**Tags Recovered**
Ocean harv	1	213
River harv	1	287
Escapement	1	89
Ocean harv	2	213
River harv	2	1022
Escapement	2	807
Ocean harv	3	2401
River harv	3	1327
Escapement	3	455
Ocean harv	4	207
River harv	4	212
Escapement	4	69

Table A–4. Dworshak Hatchery Steelhead

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.592352	B
Fraction of spawners female	0.6	F
Average eggs per female	6000	F
Do 1–ocean fish spawn?	Yes	A
EGG TO SMOLT REARING STAGE		
Density–independent survival	N/A	
Density–dependence parameter	N/A	
Variation in egg to presmolt survival	N/A	
Conditional chance of 1 overwinter	N/A	
Conditional chance of 2nd overwinter	N/A	
Conditional chance of 3rd overwinter	N/A	
Inbasin overwintering survival	N/A	
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.000303	
1–ocean fish to river harvest	0.02975	
1–ocean fish to subbasin escapement	0.00121	
1–ocean fish surviving to 2–ocean	0.96873	
2–ocean fish to ocean harvest	0.00533	
2–ocean fish to river harvest	0.7781	
2–ocean fish to subbasin escapement	0.003603	
2–ocean fish surviving to 3–ocean	0.2129	
3–ocean fish to ocean harvest	0	
3–ocean fish to river harvest	0.8116	
3–ocean fish to subbasin escapement	0.1634	
3–ocean fish surviving to 4–ocean	0.02502	
4–ocean fish to ocean harvest	0	
4–ocean fish to river harvest	0.7647	
4–ocean fish to subbasin escapement	0.23529	
Location	**Ocean Age**	**Tags Recovered**
Ocean harv	1	2
River harv	1	196
Escapement	1	8
Ocean harv	2	34
River harv	2	4966
Escapement	2	23
Ocean harv	3	0
River harv	3	1103
Escapement	3	222
Ocean harv	4	0
River harv	4	26
Escapement	4	8

CODED WIRE TAG DATA PSC Tag Codes Used	Release Year	Release loc
050425	1979	Dworshak NFH
050455	1980	Dworshak NFH
051024, (025) , (026) , (027)	1982	Dworshak NFH
051349, (350), (351) , (352)	1983	Dworshak NFH
051335	1984	Dworshak NFH
051711, (712) , (713) , (714)	1988	Dworshak NFH
051729	1986	Dworshak NFH
051739	1988	Dworshak NFH
051753, (754)	1986	Dworshak NFH
051835, (836)	1987	Dworshak NFH
051846, (849) , (850) , (851) , (852), (853)	1988	Dworshak NFH
051945, (946)	1989	Dworshak NFH del
052041, (042)	1989	Dworshak NFH del
100231, (349)	1978	Dworshak NFH
100533, (534)	1979	Dworshak NFH
101307, (309) , (310) , (311), (312) , (313)	1977	Dworshak NFH
101315	1978	Dworshak NFH
102119, (161), (162)	1980	Dworshak NFH
102252, (253) , (341)	1981	Dworshak NFH
102516, (517)	1984	Dworshak NFH
102856	1986	Dworshak NFH
102928, (929)	1988	Dworshak NFH
102931, (932), (933) , (940), (941)	1987	Dworshak NFH
RDYW*1	1978	Dworshak NFH

Table A–5. Methow/Okanogan Summer Chinook

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.333	B
Fraction of spawners female	0.46	F
Average eggs per female	5240	C
Do 1–ocean fish spawn?	No	A
EGG TO SMOLT REARING STAGE		
Density–independent survival	0.3162	A
Density–dependence parameter	2,906,586	A
Variation in egg to presmolt survival	0.2	
Conditional chance of 1 overwinter	0.05	D
Conditional chance of 2nd overwinter	0	D
Conditional chance of 3rd overwinter	0	D
Inbasin overwintering survival	0.5	C
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.0590	
1–ocean fish to river harvest	0.0243	
1–ocean fish to subbasin escapement	0.04340	
1–ocean fish surviving to 2–ocean	0.87326	
2–ocean fish to ocean harvest	0.3519	
2–ocean fish to river harvest	0.1372	
2–ocean fish to subbasin escapement	0.05467	
2–ocean fish surviving to 3–ocean	0.45626	
3–ocean fish to ocean harvest	0.38778	
3–ocean fish to river harvest	0.3006	
3–ocean fish to subbasin escapement	0.2004	
3–ocean fish surviving to 4–ocean	0.1111	
4–ocean fish to ocean harvest	0.5490	
4–ocean fish to river harvest	0.451	
4–ocean fish to subbasin escapement	0	

Table A–5. Methow/Okanogan Summer Chinook – CONT

Location	Ocean Age	Tags Recovered
Ocean harv	1	68
River harv	1	28
Escapement	1	50
Ocean harv	2	354
River harv	2	138
Escapement	2	55
Ocean harv	3	178
River harv	3	138
Escapement	3	92
Ocean harv	4	28
River harv	4	23
Escapement	4	0

CODED WIRE TAG DATA PSC Tag Codes Used	Release Year	Release loc
632326	1985	Wells
632845	1984	Wells
633225	1986	Wells
633234	1985	Wells
633219	1985	Wells
633220	1985	Wells
633224	1986	Wells
B10309	1987	Wells
B10308	1987	Wells

Table A–6. URB Hanford Reach Fall Chinook

Parameter Name	Mean Value	Ref
SPAWNING STAGE		
Pre–spawning survival	0.8	Guess
Fraction of spawners female	0.53	Norman
Average eggs per female	4794	A
Do 1–ocean fish spawn?	No	
EGG TO SMOLT REARING STAGE		
Density–independent survival	0.1	Norman fig.15
Density–dependence parameter	3,500,000	A
Variation in egg to presmolt survival	0.36	Norman
Conditional chance of 1 overwinter	0.54	Norman
Conditional chance of 2nd overwinter	0	Norman
Conditional chance of 3rd overwinter	0	Norman
Inbasin overwintering survival	0.8	Guess
ADULT ALLOCATION STAGE		
1–ocean fish to ocean harvest	0.01096	
1–ocean fish to river harvest	0.00411	
1–ocean fish to subbasin escapement	0.0186	
1–ocean fish surviving to 2–ocean	0.966	
2–ocean fish to ocean harvest	0.09926	
2–ocean fish to river harvest	0.1134	
2–ocean fish to subbasin escapement	0.05048	
2–ocean fish surviving to 3–ocean	0.7368	
3–ocean fish to ocean harvest	0.3483	
3–ocean fish to river harvest	0.35758	
3–ocean fish to subbasin escapement	0.06466	
3–ocean fish surviving to 4–ocean	0.22940	
4–ocean fish to ocean harvest	0.37248	
4–ocean fish to river harvest	0.3859	
4–ocean fish to subbasin escapement	0.2416	
Location	**Ocean Age**	**Tags Recovered**
Ocean harv	1	40
River harv	1	15
Escapement	1	68
Ocean harv	2	350
River harv	2	400
Escapement	2	178
Ocean harv	3	905
River harv	3	929
Escapement	3	168
Ocean harv	4	222
River harv	4	230
Escapement	4	144

CODED WIRE TAG DATA PSC Tag Codes Used	Release Year	Release loc
051915	1987	Priest Rapids x
051916	1987	Priest Rapids x
051917	1987	Priest Rapids x
051918	1987	Priest Rapids x
051919	1987	Priest Rapids x
051920	1987	Priest Rapids x
051921	1987	Priest Rapids x
051922	1987	Priest Rapids x
631948	1980	Priest Rapids
632252	1982	Priest Rapids
634102	1986	Priest Rapids x
634128	1987	Priest Rapids x
635226	1988	Priest Rapids x
x = Listed in All Species Report		
Tags in Report but not used here:		
632330	1986	Priest, small release
635249	1989	
630732	1990	

A.2.3 Additional Information on Adult Recovery Parameters Including Harvest

The adult recovery parameter represents the fraction of smolts below Bonneville dam that survive either to be caught in harvest or return to the subbasins as adults. After applying this parameter we need to allocate the remaining fish into one of three compartments: ocean harvest, in–river harvest, or subbasin escapement. 15 SLCM parameters specify the proportions of fish of each age class allocated to these compartments. These parameters are calculated from coded–wire tag recovery data. Following is a brief description of how these parameters were calculated.

Raw coded wire tag data basically presents the number of tags (with attached fish) that are recovered at different monitoring locations throughout the river and ocean system over several years, for a given group of tag releases. We know the location, date, and initial number of fish for each tag–code group release. Since we know the age of the fish in the release group we also know the age of a recovered fish bearing the tag from that release group. For a particular release location, there are usually several releases over time, each with a unique tag–code. Working under the assumption that each set of tag recoveries from a particular subbasin reflects a characteristic pattern of harvest and subbasin return for that stock and subbasin, we add together the tag recovery data over all releases (i.e., tag–codes) for each stock/subbasin combination. Because the number of tags recovered can be very small for individual release groups, pooling across releases produces recovery data that may be more representative of the real behavior of the stock than data from an individual release group.

Each allocation parameter in the SLCM represents the conditional likelihood that a fish is recovered in compartment *j* (ocean harvest, in–river harvest or subbasin) at ocean–age *i*, or that it survives to enter the next ocean–age class. given that it has survived

to ocean–age *i*. The maximum ocean age we consider is $i = 4$. The formulae for calculating these conditional likelihoods are:

Estimate {Likelihood of recovery in compartment j, ocean–age i} =

$$\frac{\text{number of tags recovered in compartment j, ocean–age i}}{\text{\# tags recovered in all compartments for all ocean ages} >= \text{i}}$$

Estimate {Likelihood of surviving into next ocean–age i+1} =

1 – {Likelihood of recovery in any compartment at ocean–age i}

A small example is worked below using the tag data in Table A–7.

Est {Likelihood of recovery in ocean harvest, ocean–age 1 = 68/1152 = 0.059 = 5.9%

Est {Likelihood of recovery in river harvest, ocean–age 1 = 28/1152 = 2.4%

Est {Likelihood of recovery in subbasin, ocean–age 1 = 50/1152 = 4.3%

Est {Likelihood of surviving into ocean–age 2 = 1–0.126 = 87.4%

Est {Likelihood of recovery in ocean harvest, ocean–age 2 = 354/1006 = 35.2%

Est {Likelihood of recovery in river harvest, ocean–age 2 = 138/1006 = 13.7%

Est {Likelihood of recovery in subbasin, ocean–age 2 = 55/1006 = 5.5%

Est {Likelihood of surviving into ocean–age 3 = 1–0.544 = 45.6%

Est {Likelihood of recovery in ocean harvest, ocean–age 3 = 178/459 = 38.8%

Est {Likelihood of recovery in river harvest, ocean–age 3 = 138/459 = 30.1%

Est {Likelihood of recovery in subbasin, ocean–age 3 = 92/459 = 20.0%

Est {Likelihood of surviving into ocean–age 4 = 1–0.889 = 11.1%

Est {Likelihood of recovery in ocean harvest, ocean–age 4 = 28/51 = 54.9%

Est {Likelihood of recovery in river harvest, ocean–age 4 = 23/51 = 45.1%

Est {Likelihood of recovery in subbasin, ocean–age 4 = 0/51 = 0%

Table A–7. Methow Summer Chinook Tag Recovery Data for Example Calculation of Allocation Parameters

Tag Recovery Compartment	Ocean Age	Tags Recovered
Ocean Harvest	1	68
River Harvest	1	28
Subbasin Escapement	1	50
Ocean Harvest	2	354
River Harvest	2	138
Subbasin Escapement	2	55
Ocean Harvest	3	178
River Harvest	3	138
Subbasin Escapement	3	92
Ocean Harvest	4	28
River Harvest	4	23
Subbasin Escapement	4	0
TOTAL		**1152**

The allocation parameters described above incorporate ocean and in–river harvest for each stock. The remaining harvest mortality is terminal harvest –– the harvest of fish that have returned to the subbasin but have not yet spawned. In our calibration and we set terminal harvest to zero for all stocks. This does not significantly change the model output that we use (i.e., number of spawners) because during calibration the calibration parameter automatically adjusts to compensate for this removal of terminal harvest mortality. Specifically, the adult survival parameter is reduced as terminal harvest is taken out because the calibration routine still seeks to match the empirical time series of spawning abundance. This logic holds true also for any model parameter in the linear (density–independent) part of the SLCM. However, it also follows that the number of fish in ocean and in–river harvest and in subbasin escapement prior to harvest will not be the same across cases, and so it would not be valid to compare passage options with respect to these variables.

A.3 CALIBRATION OF SLCM

A.3.1 Introduction

There are generally two steps required to ready the SLCM for simulations. First, values for as many model parameters as possible are estimated from the literature, opinions of experts, other models, and Coded–Wire Tag data (see section A.2.3 for a description of CWT data). These parameters are shown in Tables A–1 through A–6. Second, SLCM is calibrated. Calibration is simply a process of adjusting a particular parameter until model output matches real–world observations as closely as possible. Typically, the parameter chosen for adjustment is the one whose value is most uncertain –– we choose a reasonable range of values for this parameter and adjust it within this range, and are willing to accept the value that produces a match between model predictions and the observations used as the calibration standard.

An ancillary model has been constructed in a spreadsheet for the purpose of calibrating SLCM. The input to the calibration model is a time series of observed escapements for each stock of interest. The body of this model basically consists of the estimated parameters of SLCM and determistic analogs of its relationships, and a routine for adjusting a calibration parameter until model output matches observed escapements. Our calibration parameter is the proportion of fish that survive from below Bonneville dam to potentially be recovered in either ocean harvest, in–river harvest, or subbasin escapement (see section A.2.3), and it is introduced as a series of yearly coefficients. The spreadsheet then adjusts all of these coefficients until the sum of squared errors between the predicted and observed subbasin escapement is minimized. The average of the fitted coefficients is then used as the smolt–to–adult survival (the adult recovery fraction) SLCM. Note that only this single parameter vector is allowed to vary to calibrate the model output to observations. In general, there are no reliable estimates of the recovery fraction, but a value between 1 percent and 10 percent seems reasonable.

The calibration model also calculates the mean and variance of the product of egg–to–presmolt, downriver migrant, and smolt–to–adult survival for each cohort. The variance of this product is partitioned among the three survival components algebraically. Since there is only one variance equation but three unknowns, the user must decide the relative proportions of the total variance to be allocated to each life stage, or alternatively must set two of the component variances to constants and solve for the third. In our calibrations we chose the latter alternative. We estimate the variance of egg–to–presmolt survival from published data, use the value produced by CRiSP 1.5 simulations for the variance of downriver migrant survival, and solve for the variance of smolt–to–adult survival.

To some extent, bias in the estimates of the fixed SLCM parameters is compensated for by adjusting the calibration parameter. The extent to which this statement holds true is limited by two factors, however. First, if some of the estimated parameter values are highly inaccurate, then the calibration parameter may need to take an unreasonable value to compensate for these inaccuracies. If the adult

recovery fraction determined by calibration is outside reasonable bounds, then the other SLCM parameters must be re–evaluated. All adult recovery fraction values determined during SOR calibrations fell within what we judged to be reasonable bounds. The second factor is related to the use of a routine that minimizes sums–of–squared errors to fit the model to observed escapement. Athough this is a standard method for minimizing error between predictions and observations, our sensitivity analyses show that the calibration model does not perfectly compensate for bias in non–calibration parameters through adjustment of the calibration parameter.

A.3.2 Explanation of Terms In Calibration Tables

Escapement: The exact definition varies among stocks. For Dworshak hatchery steelhead, escapement is actual hatchery returns, 1977–87. For Snake River spring, summer, and fall chinook, escapement is the estimated wild component of Lower Granite dam counts. See Fisher (1995) for details. For Hanford Reach fall chinook, it is McNary–Priest Rapids fall chinook dam counts. Finally, for the above–Wells stock, it is the Wells count of adult summer chinook.

Passage Survival: Taken from CRiSP1.5 estimates of downstream survival for each year and stock. Estimates were made by Josh Hayes, CQS. The transport hypothesis used is shown just below the stock name in the tables.

Adtrecv: Estimated survival of fish from smolts in the Bonneville tailrace to "recovery" as adults, either in harvest or back at the hatchery or dam (see "escapement," above). See Section A.3.1 for more information on how this is calculated.

Estimated Escapement: Calibration spreadsheet estimate of escapement, using the adtrecv's.

Squared Error: The squared difference between actual and estimated escapement (i.e., [actual–estimated]^2). The calibration procedure estimates the adtrecvs so as to minimize the sum of squared errors across all years for each stock and transport hypothesis.

Estimated Initial Population: Estimated subbasin escapement, etc. for the first year of the SLCM simulation. See Section A.2.2 for definitions of the terms used for each life–stage.

Graphs of Actual vs. Estimated Escapement: The graph under each table displays the "fit" of actual vs. estimated escapement for each stock and transport hypothesis. Note that when the fits are "perfect," as for Snake River chinook stocks, no legend is shown in the graph, since the two data series overlay each other.

A.3.3 Calibration Results Using Historical Escapement Data

Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results

Dworshak Hatchery Steelhead							
Fixed Barge Survival							
Year	Hatchery Escapement	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1977	3,100	0.535				subesp	8,259
1978	12,727	0.596				subharv	0
1979	4,939	0.608	0.500			o1sbe	213
1980	2,519	0.643	0.500			o2sbe	0
1981	1,968	0.607	0.300			o3sbe	7,820
1982	3,054	0.548	0.500			o4sbe	226
1983	7,672	0.492	0.500	7,489	33,645	o1suv	170,050
1984	3,284	0.640	0.500	3,641	127,257	o2suv	1
1985	14,018	0.616	0.000	4,921	82,750,038	o3suv	1,198
1986	4,462	0.650	0.360	2,993	2,157,075	recruits	160,569
1987	5,286	0.616	0.360	3,304	3,929,257	presmt0	
						presmt1	
						presmt2	
						smt_bon	446,024
						spawners	1,796
						Adtrecv	0.360001
						C.V.	0.641731

Note: See Text For Explanation of Terms

Dworshak Hatchery Steelhead Fixed Barge

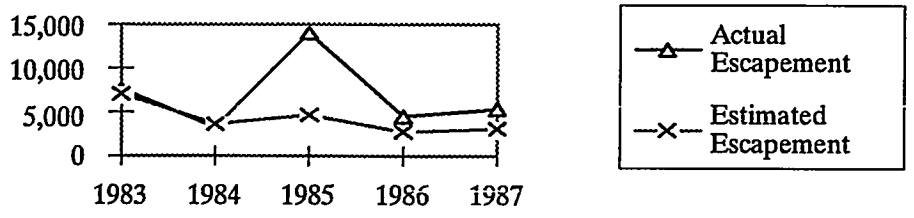


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Dworshak Hatchery Steelhead							
86 TIR							
Year	Hatchery Escapement	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1977	3,100	0.497				subesp	7,723
1978	12,727	0.557				subharv	0
1979	4,939	0.567	0.500			o1sbe	202
1980	2,519	0.598	0.500			o2sbe	0
1981	1,968	0.564	0.336			o3sbe	7,308
1982	3,054	0.513	0.500			o4sbe	212
1983	7,672	0.462	0.500	7,004	445,981	o1suv	161,461
1984	3,284	0.598	0.500	3,703	175,488	o2suv	1
1985	14,018	0.573	0.000	4,619	88,350,589	o3suv	1,119
1986	4,462	0.606	0.367	2,806	2,741,210	recruits	152,285
1987	5,286	0.573	0.367	3,089	4,826,258	presmt0	
						presmt1	
						presmt2	
						smt_bon	414,822
						spawners	1,684
						Adtrecv	0.3671
						C.V.	0.6427

Note: See Text For Explanation of Terms

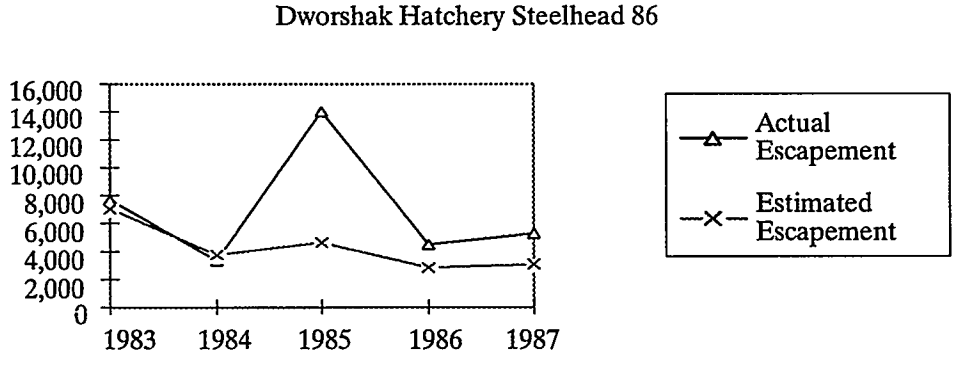


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Spring Chinook							
Fixed Barge Survival							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	16,100	0.328				subesp	7,057
1976	15,900	0.573				subharv	0
1977	23,175	0.539	0.015			o1sbe	857
1978	31,375	0.619	0.011			o2sbe	3,899
1979	4,828	0.626	0.002			o3sbe	2,300
1980	2,200	0.634	0.004			o4sbe	0
1981	5,371	0.631	0.016	5,371	0	o1suv	6,331
1982	6,448	0.508	0.019	6,448	0	o2suv	1,549
1983	6,175	0.425	0.027	6,175	0	o3suv	9
1984	3,250	0.639	0.017	3,250	0	recruits	4,642
1985	6,048	0.637	0.020	6,048	0	presmt0	1,243,672
1986	7,925	0.631	0.047	7,925	0	presmt1	0
1987	8,928	0.614	0.004	8,928	0	presmt2	0
1988	10,915	0.631	0.008	10,915	0	smt_bon	267,249
1989	3,900	0.638	0.003	3,900	0	spawners	4,508
1990	4,152	0.620	0.013	4,152	0	Adtrecv	0.0174
1991	2,706	0.668	0.017	2,706	0	C.V.	0.6996
1992	8,196	0.645	0.017	8,196	0		
1993	6,200	0.634	0.017	6,200	0		

Note: See Text For Explanation of Terms

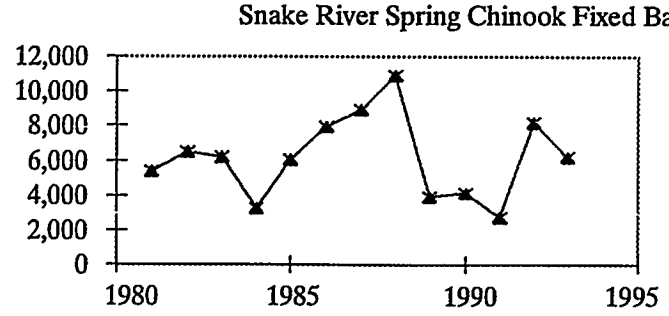


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Spring Chinook							
86 TIR							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
						hattake	0
1975	16,100	0.302				subesp	7,037
1976	15,900	0.468				subharv	0
1977	23,175	0.428	0.015			o1sbe	837
1978	31,375	0.500	0.014			o2sbe	3,899
1979	4,828	0.499	0.003			o3sbe	2,300
1980	2,200	0.503	0.005			o4sbe	0
1981	5,371	0.497	0.021	5,371	0	o1suv	6,179
1982	6,448	0.429	0.022	6,448	0	o2suv	1,549
1983	6,175	0.371	0.031	6,175	0	o3suv	9
1984	3,250	0.521	0.021	3,250	0	recruits	4,626
1985	6,048	0.502	0.025	6,048	0	presmt0	1,243,672
1986	7,925	0.507	0.059	7,925	0	presmt1	0
1987	8,928	0.483	0.005	8,928	0	presmt2	0
1988	10,915	0.496	0.011	10,915	0	smt_bon	215,907
1989	3,900	0.505	0.004	3,900	0	spawners	4,508
1990	4,152	0.489	0.017	4,152	0	Adtrecv	0.0214
1991	2,706	0.530	0.021	2,706	0	C.V.	0.6958
1992	8,196	0.510	0.021	8,196	0		
1993	6,200	0.512	0.021	6,200	0		

Note: See Text For Explanation of Terms

Snake River Spring Chinook 86

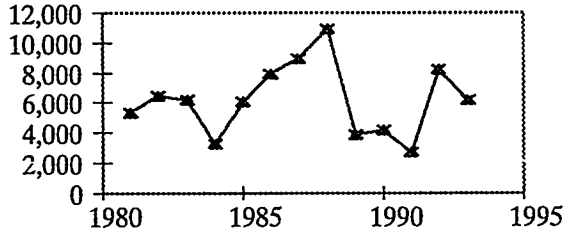


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Spring Chinook							
86 Adjusted TIR							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	16,100	0.254				subesp	6,971
1976	15,900	0.277				subharv	0
1977	23,175	0.226	0.015			o1sbe	771
1978	31,375	0.283	0.025			o2sbe	3,899
1979	4,828	0.269	0.005			o3sbe	2,300
1980	2,200	0.264	0.009			o4sbe	0
1981	5,371	0.252	0.041	5,371	0	o1suv	5,698
1982	6,448	0.285	0.033	6,448	0	o2suv	1,549
1983	6,175	0.271	0.042	6,175	0	o3suv	9
1984	3,250	0.306	0.036	3,250	0	recruits	4,657
1985	6,048	0.257	0.050	6,048	0	presmt0	1,243,672
1986	7,925	0.282	0.106	7,925	0	presmt1	0
1987	8,928	0.245	0.010	8,928	0	presmt2	0
1988	10,915	0.250	0.021	10,915	0	smt_bon	122,580
1989	3,900	0.263	0.008	3,900	0	spawners	4,508
1990	4,152	0.250	0.032	4,152	0	Adtrecv	0.0380
1991	2,706	0.278	0.040	2,706	0	C.V.	0.6896
1992	8,196	0.265	0.038	8,196	0		
1993	6,200	0.291	0.038	6,200	0		

Note: See Text For Explanation of Terms

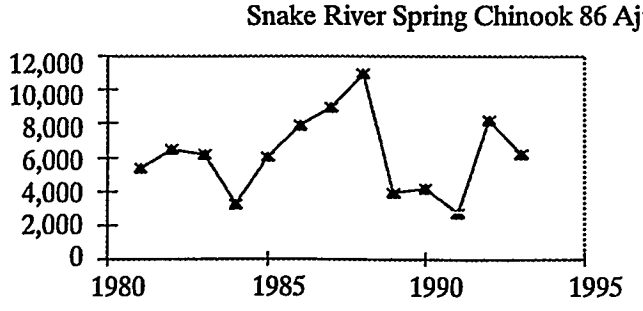


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Summer Chinook							
Fixed Barge Survival							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	7,600	0.676				subesp	5,785
1976	7,000	0.599				subharv	0
1977	7,700	0.502	0.018			o1sbe	1,785
1978	11,600	0.580	0.015			o2sbe	3,838
1979	2,714	0.586	0.009			o3sbe	161
1980	2,700	0.595	0.008			o4sbe	1
1981	3,300	0.573	0.026	3,300	0	o1suv	3,650
1982	3,529	0.428	0.051	3,529	0	o2suv	1,139
1983	3,233	0.422	0.027	3,233	0	o3suv	1
1984	4,200	0.475	0.033	4,200	0	recruits	4,925
1985	3,196	0.536	0.015	3,196	0	presmt0	138,287
1986	3,934	0.464	0.016	3,934	0	presmt1	0
1987	2,414	0.568	0.017	2,414	0	presmt2	0
1988	2,263	0.607	0.020	2,263	0	smt_bon	213,907
1989	2,350	0.584	0.024	2,350	0	spawners	804
1990	3,378	0.607	0.007	3,378	0	Adtrecv	0.0230
1991	2,814	0.612	0.044	2,814	0	C.V.	0.5846
1992	1,148	0.599	0.023	1,148	0		
1993	4,000	0.646	0.023	4,000	0		

Note: See Text For Explanation of Terms

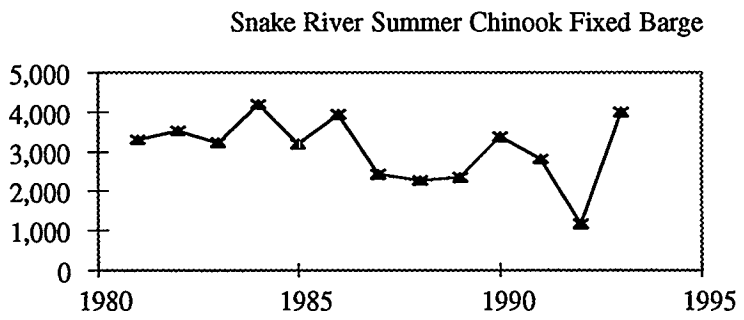


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Summer Chinook							
86 TIR							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	7,600	0.605				subesp	5,716
1976	7,000	0.496				subharv	0
1977	7,700	0.404	0.018			o1sbe	1,716
1978	11,600	0.468	0.017			o2sbe	3,838
1979	2,714	0.467	0.012			o3sbe	161
1980	2,700	0.473	0.010			o4sbe	1
1981	3,300	0.452	0.033	3,300	0	o1suv	3,509
1982	3,529	0.385	0.057	3,529	0	o2suv	1,139
1983	3,233	0.371	0.031	3,233	0	o3suv	1
1984	4,200	0.424	0.038	4,200	0	recruits	4,661
1985	3,196	0.436	0.018	3,196	0	presmt0	138,287
1986	3,934	0.400	0.019	3,934	0	presmt1	0
1987	2,414	0.452	0.022	2,414	0	presmt2	0
1988	2,263	0.478	0.026	2,263	0	smt_bon	168,529
1989	2,350	0.472	0.030	2,350	0	spawners	804
1990	3,378	0.485	0.009	3,378	0	Adtrecv	0.0277
1991	2,814	0.486	0.056	2,814	0	C.V.	0.5615
1992	1,148	0.479	0.028	1,148	0		
1993	4,000	0.509	0.028	4,000	0		

Note: See Text For Explanation of Terms

Snake River Summer Chinook 86

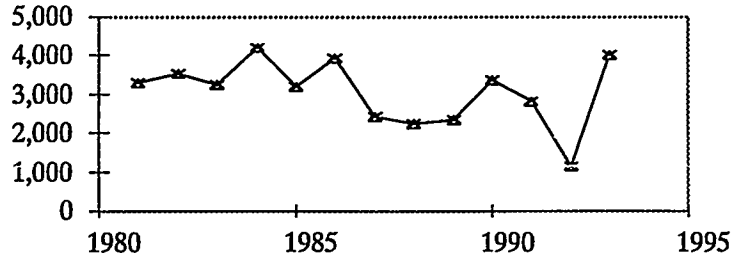


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Summer Chinook							
Adjusted 86 TIR							
Year	Escapement at LGR	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	7,600	0.476				subesp	5,544
1976	7,000	0.309				subharv	0
1977	7,700	0.225	0.018			o1sbe	1,544
1978	11,600	0.266	0.024			o2sbe	3,838
1979	2,714	0.251	0.024			o3sbe	161
1980	2,700	0.250	0.018			o4sbe	1
1981	3,300	0.231	0.066	3,300	0	o1suv	3,157
1982	3,529	0.308	0.071	3,529	0	o2suv	1,139
1983	3,233	0.278	0.041	3,233	0	o3suv	1
1984	4,200	0.330	0.048	4,200	0	recruits	3,920
1985	3,196	0.253	0.031	3,196	0	presmt0	138,287
1986	3,934	0.283	0.027	3,934	0	presmt1	0
1987	2,414	0.243	0.040	2,414	0	presmt2	0
1988	2,263	0.242	0.051	2,263	0	smt_bon	86,020
1989	2,350	0.269	0.052	2,350	0	spawners	804
1990	3,378	0.264	0.017	3,378	0	Adtrecv	0.0456
1991	2,814	0.257	0.106	2,814	0	C.V.	0.5517
1992	1,148	0.262	0.046	1,148	0		
1993	4,000	0.260	0.046	4,000	0		

Note: See Text For Explanation of Terms

Snake River Summer Chinook Adjusted 86

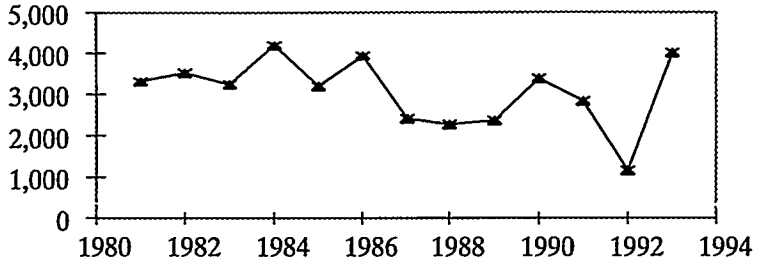


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Snake River Fall Chinook							
Fixed Barge Survival							
Year	Natural Escapement	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1975	1,000	0.041				subesp	930
1976	470	0.163				subharv	0
1977	600	0.073	0.065			o1sbe	57
1978	640	0.148	0.104			o2sbe	593
1979	500	0.072	0.240			o3sbe	249
1980	450	0.120	0.452			o4sbe	31
1981	340	0.140	0.063	340	0	o1suv	6,037
1982	720	0.227	0.135	720	0	o2suv	3,435
1983	428	0.202	0.104	428	0	o3suv	267
1984	324	0.198	0.114	324	0	recruits	10,680
1985	438	0.053	0.113	438	0	presmt0	225,512
1986	449	0.081	0.264	449	0	presmt1	0
1987	252	0.086	0.082	251	0	presmt2	0
1988	368	0.076	0.000	370	0	smt_bon	61,164
1989	295	0.125	0.187	289	0	spawners	549
1990	78	0.070	0.376	89	0	Adtrecv	0.1746
1991	318	0.140	0.481	318	0	C.V.	0.8730
1992	549	0.209	0.175	549	0		
1993	742	0.307	0.175	742	0		

Note: See Text For Explanation of Terms

Snake River Fall Chinook

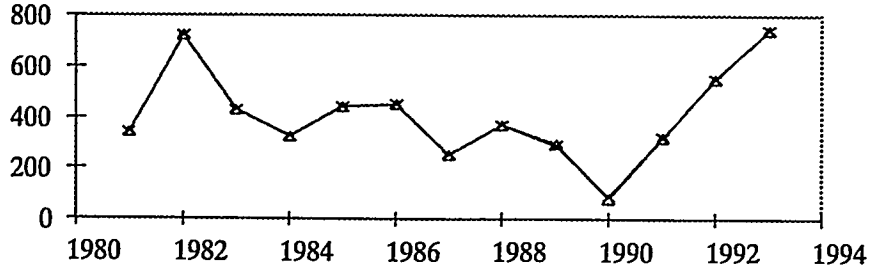


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Hanford Reach Fall Chinook							
Fixed Barge Survival							
Year	MCN–PRD Escapement	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
						Estimated Initial Population	
1977	31,600	0.179				subesp	73,267
1978	20,600	0.195	0.300			subharv	0
1979	23,600	0.188	0.300			o1sbe	9,357
1980	21,900	0.271	0.087			o2sbe	24,866
1981	15,300	0.451	0.301			o3sbe	12,706
1982	20,400	0.360	0.363	20,400	0	o4sbe	26,338
1983	37,000	0.366	0.437	37,000	0	o1suv	485,088
1984	45,300	0.361	0.463	45,300	0	o2suv	362,943
1985	60,600	0.247	0.448	60,600	0	o3suv	45,081
1986	73,499	0.337	0.112	73,499	0	recruits	427,394
1987	85,354	0.299	0.195	85,354	0	presmt0	5,655,890
1988	73,533	0.315	0.162	73,533	0	presmt1	0
1989	63,910	0.269	0.162	63,910	0	presmt2	0
						smt_bon	2,644,003
						spawners	58,826
						Adtrecv	0.3008
						C.V.	0.4130

Note: See Text For Explanation of Terms

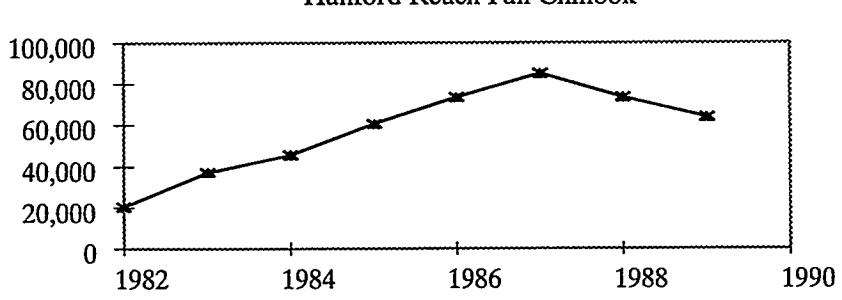
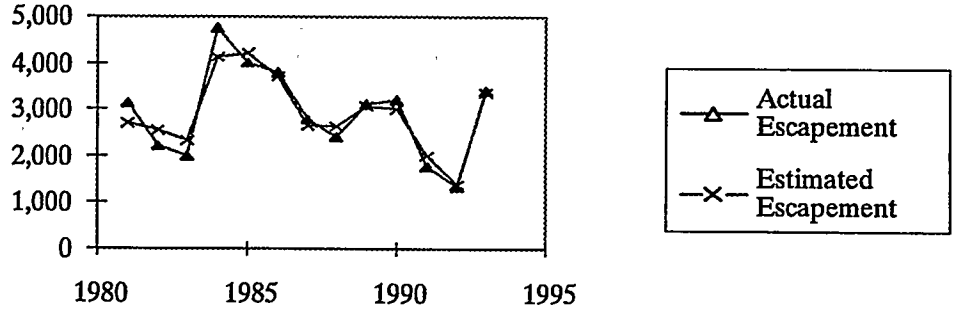


Table A–8. Calibration Results for SLCM Using Historical Escapement Data and CRiSP1.5 Passage Results – CONT

Above–Wells Summer Chinook							
Fixed Barge Survival							
Year	Escapement at Wells (Adults)	Passage Survival	Adtrecv	Estimated Escapement	Squared Error		
1976	5365	0.072				Estimated Initial Population	
1977	5055	0.033	1.000			subesp	4,106
1978	5127	0.043	1.000			subharv	0
1979	7106	0.035	0.000			o1sbe	746
1980	3910	0.061	0.290			o2sbe	2,895
1981	3141	0.132	0.348	2,695	198,624	o3sbe	464
1982	2223	0.069	1.000	2,554	109,381	o4sbe	0
1983	2002	0.089	0.581	2,326	104,660	o1suv	15,154
1984	4768	0.080	0.578	4,129	408,573	o2suv	24,003
1985	4018	0.052	0.419	4,219	40,509	o3suv	537
1986	3786	0.068	0.456	3,696	8,090	recruits	13,733
1987	2790	0.058	0.729	2,649	19,855	presmt0	15,131
1988	2411	0.060	0.540	2,631	48,226	presmt1	0
1989	3115	0.053	0.000	3,078	1,355	presmt2	0
1990	3207	0.064	0.317	3,000	42,757	smt_bon	28,528
1991	1776	0.098	1.000	1,995	47,892	spawners	455
1992	1343	0.094	0.481	1,378	1,255	Adtrecv	0.4814
1993	3404	0.096	0.481	3,359	1,981	C.V.	0.6449

Note: See Text For Explanation of Terms

Methow/Okanagan/Similkameen Summer Chinook



A.3.4 Calibration of the SLCM Under Different Transport Hypotheses

In their comments on the SOR Draft EIS Anadromous Fish Appendix, the US Fish and Wildlife Service (USFWS, 1994) requested that the work group report on the results of SLCM model calibrations under all transport hypotheses. They made the request because "[i]nformation needs to be presented on how well the models used in the SOR process fit empirical data on adult returns for past years." (USFWS, 1994, p. 11). Apparently, the commentors thought that SLCM calibration might be used to help find the "best" transport hypothesis.

Table A–8 displays the results of the calibration procedure for each stock and transport hypothesis used in the final SOR analysis. Table A–9 summarizes this information for Snake River spring chinook, and includes the mean values for downriver passage and the adtrecv's. (See Section A.3 for definitions of model parameters.) As might be expected, mean passage survival decreases as hypothesized barge survival is lowered. However, contrary to the expectations noted above, the "goodness of fit" measure (sum of squared errors) used in the calibration procedure is zero for all three transport hypotheses. Therefore, all three transport hypotheses fit the historical series of spawning escapements equally well.

Of course, it is possible that the calibration procedure is able to fit the three hypotheses only by using unreasonable values for the adtrecv's (survival from smolts below Bonneville to harvested adults or fish returning to Lower Granite). From Table A–9, one can see that the mean adtrecv's vary from 0.017 for the Fixed Barge TIR to 0.038 for the Adjusted 86 TIR. Conversely, mean passage survival varies from 0.59 to 0.27. In both cases, the ranges are quite large. However, survival from smolt leaving the Snake Basin to adult returning to Lower Granite (the last column of Table A–9) is nearly constant across the different hypotheses, at about 1 percent. This value is well within the range of estimated smolt–to–adult survivals for Columbia Basin chinook stocks.

To understand why estimated smolt–to–adult survival is constant across transport hypotheses, recall from Section A.3.1 that the model is calibrated to observed escapements, and that all parameters except the adtrecv's are held constant during the calibration. Thus, for each year in the calibration, regardless of transport hypothesis, the model will "produce" the same number of eggs and presmolts leaving the Snake River. In addition, regardless of transport hypothesis, the calibration procedure fits the same time series of adults returning to Lower Granite. Therefore, as downstream passage survival changes across transport hypotheses, ocean survival (the adtrecv's) changes to fit the observed escapements. Because the calibration can fit observed escapements under each transport hypothesis equally well, it cannot be used to distinguish which hypothesis is the most realistic depiction of actual transport survival. If reliable information on ocean survival were available, one could use those data to select the most reasonable transport hypothesis. Unfortunately, available data (based on coded–wire–tag recoveries) have a very high variance, and cannot be used to unambiguously choose among hypotheses.

Reference:

USFWS, 1994. Columbia River SOR Draft EIS, Appendix S, "US Fish and Wildlife Service Planning Aid Report." July, 1994

A.4 SLCM DETAILED MODEL RESULTS

As noted in Section 4.1, SLCM was run for the same alternatives and transport hypotheses as CRiSP1.5. This section contains detailed results on all of the SLCM runs performed for the SOR Final EIS. These are shown in Table A–10.

Table A–10 shows the 10th, 50th, and 90th percentiles for spawning escapement and total harvest for each stock, transport hypothesis, and SOR alternative. The percentiles refer to where the "moments" of the distribution are. Figure A–1 is a histogram of a hypothetical distribution of SLCM results. The 10th percentile means that 10 percent of the results were lower (400, in the figure) The 90th percentile means that 90 percent of the results were lower (1600, in the example). The 50th percentile is the

mid–point (medium) of the distribution –– half the results were higher and half lower.

In general the various moments of each distribution are highly correlated. Table A–11 shows the correlations among the moments for Snake River Spring chinook for the 1986 TIR. The correlations among the 10th, 50th, and 90th percentiles are very close to 1. Therefore, although SLCM results in Section 4.1 are shown in terms of the 50th percentile, any of the other percentiles could have been used without affecting the ranking of alternatives.

A.4.1 86 Adjusted TIR Vs. Fixed Barge and 86 (unadjusted) TIR

For three of six stocks analyzed for the SOR Final EIS, CRiSP1.5 and SLCM were run under two or more transport hypotheses: Snake River spring chinook, Snake River summer chinook, and Dworshak steelhead. For steelhead, the results for the two transport hypotheses (fixed barge and 86 TIR) rank the SOS's in roughly the same order (see Figure A–2). For spring and summer chinook, however, the results across transport hypotheses are quite different. Figure A–3 shows the results for Snake River spring chinook; summer chinook have a similar relationship among transport hypotheses. Although the fixed barge and 86 TIR results are similar in their ranking of SOS's, the adjusted 86 TIR is obviously very different. Two items in the figure are especially striking. First, spawner abundance under alternative 9A+ is much higher for the Adjusted 86 TIR than for either of the other hypotheses. This is counter–intuitive since 9A has no transport, and downriver survival is the same under all three TIR's. Second, spawner abundance is much higher under the 86 Adjusted TIR for alternatives 5B, 5C, 6B+, and 9C+, despite the fact that passage survival is lower under the 86 Adjusted TIR.

The explanation for the differences lies in how the various transport hypotheses rank the alternatives *relative to the calibration period.* What "drives" SLCM results is not the absolute value of passage survival, but the values of passage survival changes in comparison to the calibration period (1975–93 for Snake River chinook). Table A–12 illustrates this. The left half of the table shows downriver survivals for Snake River spring chinook, taken from Table 5–1, page 5–3. The right half of Table A–12 shows the ratio of those survivals to survival during the calibration period.

A close examination of the Table A–12 helps explain the anomalies noted above. Although downriver survival is the same across hypotheses for 9A+, the ratio of 9A+ survival to the calibration period is very different. For the Adjusted 86 TIR, survival is 1.39 times the calibration period, while for the Fixed Barge and 86 TIR, it is 0.63 and 0.78 times the calibration period, respectively. This helps explain why projected spawner abundance is so much higher for the Adjusted 86 TIR: Survival improves by 39% relative to the calibration period, and decreases substantially for the other two hypotheses. Similar logic applies for alternatives 5B, 5C, 6B+, and 9C+, where survival improves *relative to the calibration period* for the Adjusted 86 TIR, and decreases for the other two hypotheses.

Table A–9. Calibration Passage and Ocean Survival for Snake River Spring Chinook

Transport Hypothesis	Barge Survival	Mean Passage Survival	Sum of Squared Errors	Mean Adtrecv	(Mean Passage Survival) * (Mean Adtrecv)
Fixed Barge	98%	0.592	0	0.0174	0.010276
86 TIR	76%	0.476	0	0.0214	0.010205
86 Adjusted TIR	36%	0.267	0	0.0380	0.010134

Table A–10. SLCM Detailed Results

Dworshak Hatchery Steelhead							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	86 TIR	5,197	15,244	28,170	148,506	386,449	687,058
1B	86 TIR	5,132	15,189	28,157	148,383	385,770	688,767
2C	86 TIR	5,235	15,350	28,344	149,479	389,499	694,004
2D	86 TIR	5,080	15,316	28,207	149,428	387,598	691,397
4C	86 TIR	5,205	15,332	28,354	148,763	387,920	692,068
5B	86 TIR	3,524	10,410	19,220	100,303	262,774	469,659
5C	86 TIR	3,533	10,491	19,383	101,011	264,389	473,213
6B+	86 TIR	2,595	7,683	14,547	72,300	189,596	346,067
6B–	86 TIR	1,519	4,468	8,514	41,483	109,652	202,734
6D+	86 TIR	4,216	12,509	23,054	121,026	315,581	566,623
6D–	86 TIR	3,688	10,810	20,097	103,878	272,604	489,711
9A+	86 TIR	2,091	6,195	11,684	57,250	151,418	279,223
9A–	86 TIR	1,251	3,661	7,078	34,250	89,597	167,416
9B	86 TIR	4,679	13,968	26,091	134,384	348,227	624,842
9C+	86 TIR	2,561	7,793	14,709	73,057	190,735	351,156
9C–	86 TIR	1,639	4,797	9,034	44,060	116,810	214,541
PA	86 TIR	5,186	15,058	27,741	146,812	382,475	679,923
1A	Fixed Barge	5,681	16,326	30,147	160,008	414,387	737,260
1B	Fixed Barge	5,548	16,228	29,952	159,791	413,100	734,595
2C	Fixed Barge	5,623	16,412	30,343	161,323	417,637	742,939
2D	Fixed Barge	5,561	16,366	30,171	160,178	415,838	739,243
4C	Fixed Barge	5,624	16,314	30,165	160,392	416,704	741,444
5B	Fixed Barge	3,622	10,770	19,938	104,253	273,151	488,242
5C	Fixed Barge	3,708	10,896	20,221	105,273	275,749	491,304
6B+	Fixed Barge	2,732	8,001	15,124	75,809	198,764	361,129
6B–	Fixed Barge	1,572	4,709	8,889	43,366	114,056	211,294
6D+	Fixed Barge	4,631	13,396	24,731	129,949	338,607	605,620
6D–	Fixed Barge	3,921	11,581	21,467	112,168	292,817	524,267
9A+	Fixed Barge	2,110	6,151	11,659	57,285	150,632	277,684
9A–	Fixed Barge	1,236	3,640	7,014	34,138	89,126	166,460
9B	Fixed Barge	5,053	14,976	27,919	144,604	372,452	668,992
9C+	Fixed Barge	2,697	8,079	15,368	76,583	199,786	364,304
9C–	Fixed Barge	1,705	5,001	9,483	46,164	122,189	223,083
PA	Fixed Barge	5,545	16,145	29,807	158,023	410,741	730,480

Table A–10. SLCM Detailed Results – CONT

Hanford Fall Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Fixed Barge	25,303	31,962	36,224	311,312	507,414	787,331
1B	Fixed Barge	25,322	31,868	36,211	315,557	510,657	794,390
2C	Fixed Barge	24,871	31,821	36,270	317,342	511,171	793,708
2D	Fixed Barge	25,034	31,642	36,212	322,391	523,319	808,017
4C	Fixed Barge	25,134	31,628	36,159	326,519	519,954	807,169
5B	Fixed Barge	25,196	31,825	36,142	319,505	513,395	795,868
5C	Fixed Barge	25,222	31,966	36,179	314,440	509,195	781,197
6B	Fixed Barge	25,281	31,875	36,112	316,815	515,704	807,788
6D	Fixed Barge	25,292	31,857	36,240	322,233	508,750	782,745
6D	Fixed Barge	25,254	31,820	36,145	315,912	512,033	779,368
9A	Fixed Barge	25,907	33,277	36,954	202,732	331,410	517,104
9B	Fixed Barge	25,725	32,190	36,486	302,566	488,570	754,706
9C	Fixed Barge	25,484	32,141	36,451	306,630	491,791	763,796
PA	Fixed Barge	24,824	31,510	36,049	325,017	532,431	818,086

Wells Summer Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Fixed Barge	152	556	1,453	2,650	9,305	23,778
1B	Fixed Barge	131	522	1,432	2,316	8,772	22,487
2C	Fixed Barge	153	573	1,470	2,607	9,513	23,226
2D	Fixed Barge	198	686	1,728	3,300	11,534	27,132
4C	Fixed Barge	172	629	1,646	3,055	10,496	26,293
5B	Fixed Barge	152	565	1,501	2,718	9,464	23,986
5C	Fixed Barge	140	491	1,355	2,330	8,165	21,188
6B	Fixed Barge	152	615	1,560	2,535	10,276	24,719
6D	Fixed Barge	135	551	1,504	2,417	9,191	23,384
6D	Fixed Barge	145	566	1,506	2,443	9,280	23,187
9A	Fixed Barge	2	21	92	32	299	1,320
9B	Fixed Barge	92	393	1,108	1,561	6,327	18,123
9C	Fixed Barge	69	329	934	1,105	5,277	14,967
PA	Fixed Barge	211	732	1,784	3,470	12,168	28,549

Table A–10. SLCM Detailed Results – CONT

Snake Fall Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Fixed Barge	1,700	5,091	12,056	15,409	39,981	87,014
1B	Fixed Barge	1,738	5,108	11,936	15,109	39,620	85,597
2C	Fixed Barge	1,740	5,075	11,885	15,391	39,803	85,968
2D	Fixed Barge	1,684	5,190	12,146	15,544	40,528	86,641
4C	Fixed Barge	1,683	5,119	11,865	15,072	39,793	85,051
5B	Fixed Barge	524	2,068	5,614	4,948	16,319	41,178
5C	Fixed Barge	490	1,956	5,604	4,325	15,670	40,383
6B+	Fixed Barge	9	80	441	78	586	3,173
6B–	Fixed Barge	0	0	1	0	0	6
6D+	Fixed Barge	621	2,349	6,175	5,688	19,364	45,385
6D–	Fixed Barge	368	1,659	4,824	3,593	13,191	34,717
9A+	Fixed Barge	0	0	9	0	0	45
9A–	Fixed Barge	0	0	0	0	0	0
9B	Fixed Barge	611	2,288	6,094	5,509	18,673	44,794
9C	Fixed Barge	390	1,780	4,730	3,894	14,000	36,557
PA	Fixed Barge	1,754	5,270	12,492	15,783	40,775	87,373

Table A–10. SLCM Detailed Results – CONT

Snake Spring Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Adjusted 86	593	3,035	12,168	192	977	3,455
1B	Adjusted 86	554	2,828	11,586	184	873	3,460
2C	Adjusted 86	614	3,210	12,968	192	978	3,507
2D	Adjusted 86	599	3,209	12,688	198	947	3,630
4C	Adjusted 86	575	3,154	13,500	190	962	3,673
5B	Adjusted 86	8,941	31,172	81,144	3,266	9,706	22,451
5C	Adjusted 86	8,631	29,332	77,682	2,773	9,167	21,765
6B+	Adjusted 86	2,058	10,072	32,174	642	3,147	8,849
6B–	Adjusted 86	13	106	497	3	31	124
6D+	Adjusted 86	336	1,922	7,825	105	581	2,158
6D–	Adjusted 86	104	573	2,719	30	172	753
9A+	Adjusted 86	6,149	23,385	67,390	2,141	7,501	18,938
9A–	Adjusted 86	166	1,038	4,470	55	307	1,350
9B	Adjusted 86	550	2,925	12,035	172	867	3,448
9C+	Adjusted 86	2,782	12,133	40,496	899	3,909	10,988
9C–	Adjusted 86	40	254	1,289	11	76	341
PA	Adjusted 86	616	3,177	12,823	200	963	3,662
1A	86 TIR	1,161	5,707	23,185	383	1,750	6,179
1B	86 TIR	1,069	5,690	23,625	350	1,800	5,949
2C	86 TIR	1,238	5,886	23,284	404	1,829	6,466
2D	86 TIR	1,324	6,264	24,429	421	1,930	6,597
4C	86 TIR	1,250	6,080	22,835	405	1,932	5,988
5B	86 TIR	717	4,200	17,579	257	1,237	4,654
5C	86 TIR	725	3,759	15,105	229	1,150	4,031
6B+	86 TIR	122	720	3,296	40	210	879
6B–	86 TIR	0	4	28	0	1	8
6D+	86 TIR	227	1,353	5,927	70	399	1,633
6D–	86 TIR	70	426	2,082	24	121	585
9A+	86 TIR	110	690	3,053	32	209	801
9A–	86 TIR	1	13	66	0	3	20
9B	86 TIR	755	4,008	17,014	237	1,257	4,630
9C+	86 TIR	178	992	4,062	56	291	1,118
9C–	86 TIR	1	12	76	0	3	19
PA	86 TIR	1,143	5,839	23,600	369	1,862	6,196

Table A–10. SLCM Detailed Results – CONT

Snake Spring Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Fixed Barge	1,402	6,938	26,512	463	2,169	7,127
1B	Fixed Barge	1,340	6,772	27,391	446	2,184	7,133
2C	Fixed Barge	1,366	6,863	27,394	471	2,222	7,181
2D	Fixed Barge	1,468	7,112	29,636	483	2,258	7,788
4C	Fixed Barge	1,444	7,341	27,834	499	2,320	7,133
5B	Fixed Barge	283	1,776	7,589	108	527	2,239
5C	Fixed Barge	268	1,667	6,973	86	486	2,082
6B+	Fixed Barge	48	304	1,465	14	82	401
6B–	Fixed Barge	0	2	16	0	0	4
6D+	Fixed Barge	219	1,257	5,818	70	370	1,553
6D–	Fixed Barge	57	395	1,875	17	110	509
9A+	Fixed Barge	20	143	655	5	39	183
9A–	Fixed Barge	0	2	16	0	0	4
9B	Fixed Barge	809	4,302	17,757	265	1,327	4,981
9C+	Fixed Barge	63	389	1,823	17	112	479
9C–	Fixed Barge	0	6	33	0	1	9
PA	Fixed Barge	1,357	6,779	26,614	457	2,153	6,906

Table A–10. SLCM Detailed Results – CONT

Snake Summer Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Adjusted 86	113	456	1,519	6	26	83
1B	Adjusted 86	123	456	1,448	7	26	79
2C	Adjusted 86	122	487	1,577	8	29	87
2D	Adjusted 86	122	465	1,499	8	28	83
4C	Adjusted 86	113	471	1,565	7	27	87
5B	Adjusted 86	2,347	7,330	18,505	163	470	1,006
5C	Adjusted 86	2,107	6,832	17,476	144	423	912
6B+	Adjusted 86	747	2,584	7,457	51	163	414
6B–	Adjusted 86	3	27	101	0	1	6
6D+	Adjusted 86	83	368	1,284	4	21	71
6D–	Adjusted 86	31	153	593	2	9	34
9A+	Adjusted 86	2,111	6,547	17,175	142	399	906
9A–	Adjusted 86	51	211	726	3	12	40
9B	Adjusted 86	152	598	1,904	9	37	105
9C+	Adjusted 86	1,033	3,630	10,304	67	228	558
9C–	Adjusted 86	16	77	290	1	4	16
PA	Adjusted 86	129	519	1,776	8	33	96
1A	86 TIR	214	884	2,890	14	55	154
1B	86 TIR	213	863	2,905	14	54	160
2C	86 TIR	188	854	2,930	12	52	170
2D	86 TIR	231	927	3,150	15	57	175
4C	86 TIR	214	878	2,880	15	54	159
5B	86 TIR	275	1,039	3,136	17	64	190
5C	86 TIR	247	1,007	2,979	17	59	168
6B+	86 TIR	41	189	672	2	10	37
6B–	86 TIR	0	0	8	0	0	0
6D+	86 TIR	57	247	867	3	15	51
6D–	86 TIR	21	103	377	1	5	20
9A+	86 TIR	52	228	821	3	14	46
9A–	86 TIR	0	3	21	0	0	2
9B	86 TIR	151	599	2,056	10	37	114
9C+	86 TIR	56	277	1,026	3	16	56
9C–	86 TIR	0	3	20	0	0	2
PA	86 TIR	216	880	3,068	14	56	167

Table A–10. SLCM Detailed Results – CONT

Snake Summer Chinook							
SOR Alt	Transport Sensitivity	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
1A	Fixed Barge	253	1,121	3,976	17	70	217
1B	Fixed Barge	242	1,133	3,734	16	70	214
2C	Fixed Barge	209	947	3,556	14	60	191
2D	Fixed Barge	253	1,186	3,898	16	75	211
4C	Fixed Barge	242	1,095	3,865	16	69	204
5B	Fixed Barge	109	496	1,839	7	30	100
5C	Fixed Barge	111	447	1,569	6	27	91
6B+	Fixed Barge	11	67	289	0	4	15
6B–	Fixed Barge	0	0	3	0	0	0
6D+	Fixed Barge	46	229	955	2	13	53
6D–	Fixed Barge	18	91	380	1	6	20
9A+	Fixed Barge	10	51	212	0	3	13
9A–	Fixed Barge	0	0	6	0	0	0
9B	Fixed Barge	133	668	2,355	9	40	130
9C+	Fixed Barge	18	103	419	1	6	23
9C–	Fixed Barge	0	1	8	0	0	1
PA	Fixed Barge	230	1,055	3,585	15	67	193

Table A–11. Correlation Among Distribution Moments: Snake River Spring Chinook, 86 TIR

	Spawners – 10th percentile	Spawners – 50th percentile	Spawners – 90th Percentile	Harvest – 10th percentile	Harvest – 50th percentile	Harvest – 90th Percentile
Spawners – 10th percentile	1.0000					
Spawners – 50th percentile	0.9960	1.0000				
Spawners – 90th Percentile	0.9903	0.9983	1.0000			
Harvest – 10th percentile	0.9990	0.9973	0.9923	1.0000		
Harvest – 50th percentile	0.9964	0.9995	0.9974	0.9969	1.0000	
Harvest – 90th Percentile	0.9919	0.9978	0.9989	0.9935	0.9963	1.0000

Table A–12. Snake River Spring Chinook Downstream Survival and Ratio to Calibration Period Survival

	Downriver Survival (%)			Downriver Survival/ Calibration Period Survival		
SOR Alt	Adjusted 86 TIR	Fixed Barge TIR	86 TIR	Adjusted 86 TIR	Fixed Barge TIR	86 TIR
1A	26	64	51	0.96	1.09	1.06
1B	26	64	51	0.96	1.09	1.06
2C	26	65	51	0.97	1.09	1.07
2D	26	65	51	0.97	1.10	1.08
4C	26	65	51	0.97	1.09	1.07
5B	40	52	48	1.49	0.89	1.01
5C	39	52	47	1.47	0.87	0.99
6B+	31	41	37	1.15	0.69	0.79
6B–	16	22	20	0.60	0.37	0.42
6D+	24	50	41	0.89	0.84	0.85
6D–	20	43	35	0.76	0.72	0.73
9A+	37	37	37	1.39	0.63	0.78
9A–	22	22	22	0.82	0.37	0.46
9B	25	60	48	0.95	1.02	1.00
9C+	32	42	39	1.21	0.72	0.81
9C–	18	24	22	0.68	0.41	0.47
PA	26	64	51	0.97	1.09	1.06
Calibration Period	27	59	48	1	1	1

Figure A–1. Example Histogram Showing 10th, 50th, and 90th Percentiles

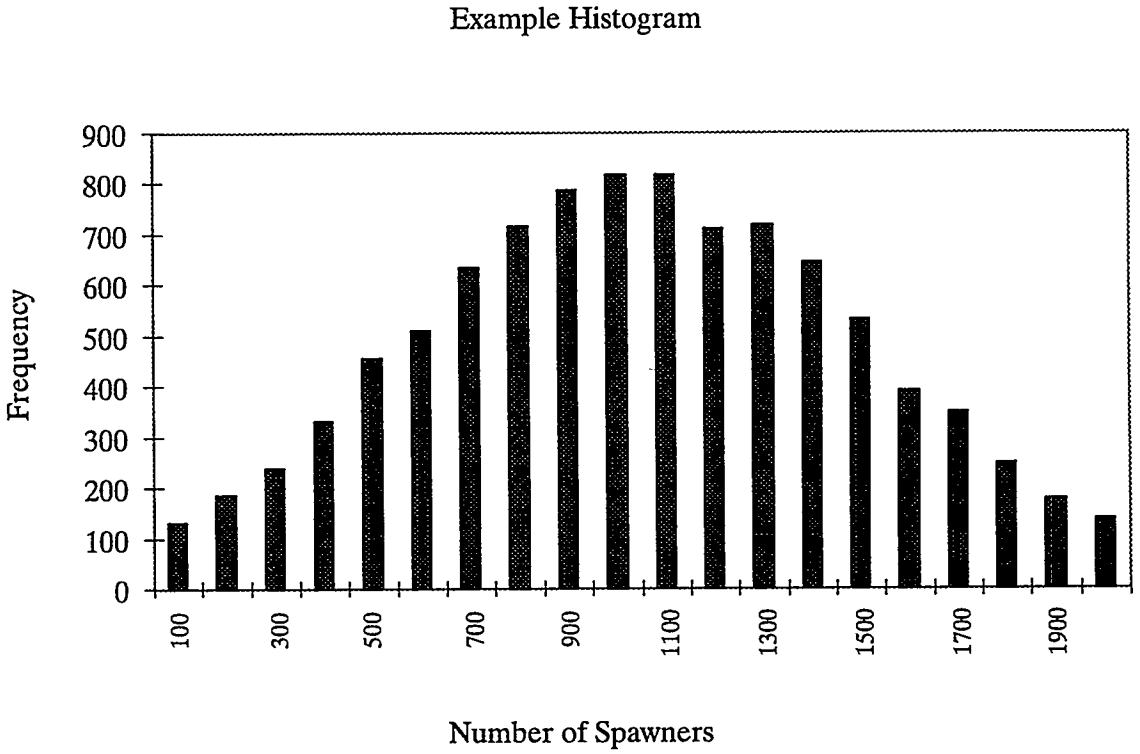


Figure A–2. Median Spawning Escapement for Dworshak Hatchery Steelhead

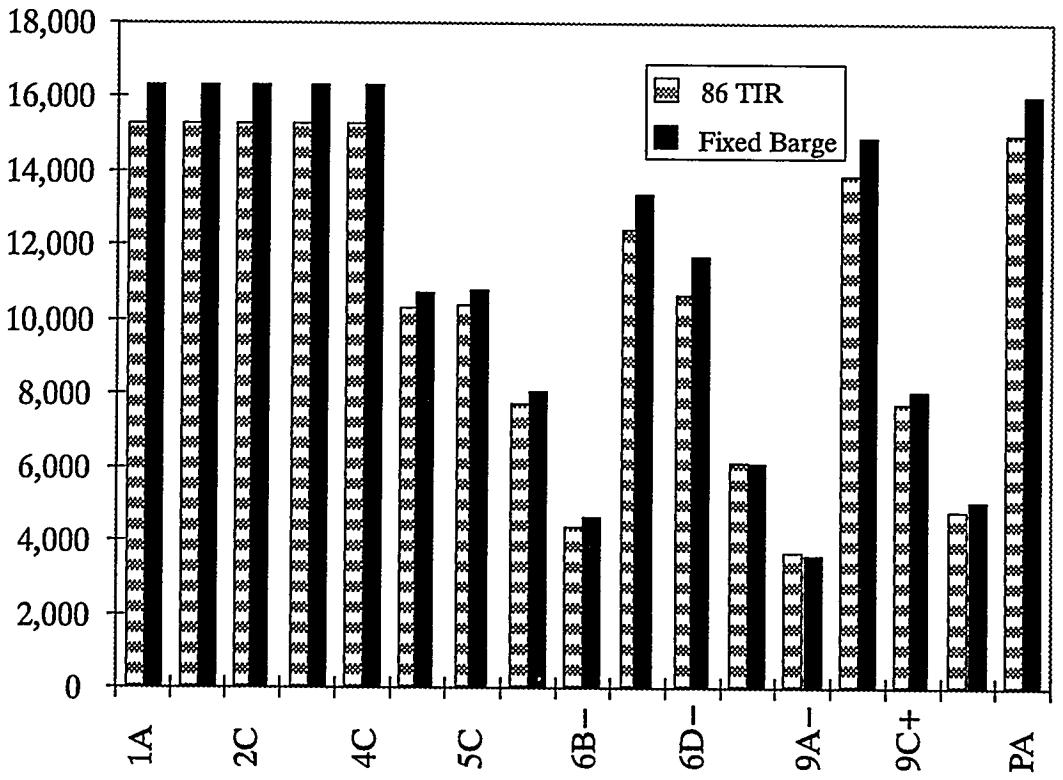
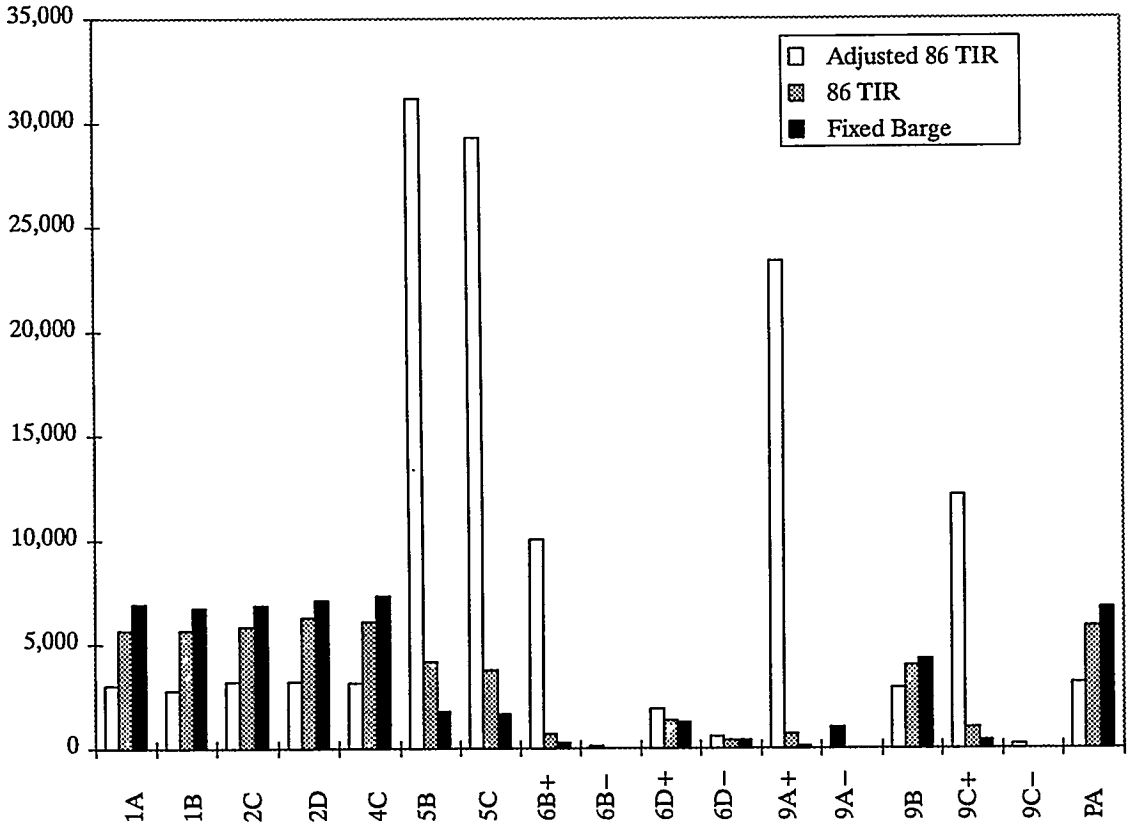


Figure A–3. Median Spawning Escapement for Snake River Spring Chinook

Snake River Spring Chinook – 50th percentile Spawning Escapement



TECHNICAL EXHIBIT B

ORIGIN AND HISTORY OF JUVENILE FISH TRANSPORTATION

B.1 PROBLEMS CREATED BY THE HYDROSYSTEM FOR JUVENILE MIGRANTS

B.1.1 Turbine and Spillways

In 1937, prior to the enactment of the Bonneville Project Act, the U.S. Senate directed the Commissioner of Fisheries to issue a report on the impacts of the proposed project on anadromous fish. The report listed as a chief objective: "ensuring safe passage over power dams..." In 1938, the Corps' Division Engineer specifically recommended that, "adequate provision should be made at all dams for the passage of fish" (Reed, 1991).

A report produced in 1938 noted that, "Extensive laboratory and field tests indicate that there is little danger of injury to small fish passing through the Bonneville Turbines." (USACE, 1938)

By 1952, however, Harlan Holmes (1952, unpublished report), a biologist with the Bureau of Commercial Fisheries (BCF), summarized experiments from 1938 to 1948 estimating the mortality of juveniles at Bonneville Dam to be between 11 and 15 percent. Most of this mortality resulted from juveniles passing through turbines, where rapid pressure changes from turbine operations was the main factor in juvenile mortality, and direct encounter with turbine blades a lesser factor. Passage over the spillway, meanwhile, created its own dangers, injury and death resulting from high velocity collisions with the tainter gates, or from stress or gas bubble trauma.

In 1961, biologists at the Washington Department of Fisheries, estimated direct mortality of juvenile chinook passing over the spillway at McNary Dam to be 2 percent, and those passing through the turbines to be 11 percent (Shoeneman, *et al.*, 1961). By the 1970s, other researchers reported the estimation of a 15 percent juvenile mortality rate to be conservative (Collins, unpublished).

Additional studies in the 1970s demonstrated mortality to be as high as 30 percent for juvenile coho passing through turbines at Ice harbor and Lower Monumental dams, when indirect mortality from predation in the tailrace was included. (Long, *et at.,* 1968).

The cumulative effect of juveniles passing through turbines of eight dams is substantial, even if the lowest turbine mortality estimate is used and predation is assumed to be zero. For example, an 11 percent loss for each dam results in only 35 percent survival of juvenile migrants if they must pass through the turbines of all eight Corps dams on the lower Columbia and Snake Rivers. During the low flow years of 1973 and 1977 – when only limited spill occurred – almost all the juvenile migrants passed through turbines. At that time, biologists estimated losses of 95 to 99 percent (Raymond, 1979).

B.1.2 Gas Bubble Trauma

In the late 1960s, studies revealed that a substantial number of young migrating salmon were dying of gas bubble trauma as a result of gas supersaturated water conditions in the system.

As water plunges deep in the pool below the spillway at a dam, the hydrostatic pressure causes air, mostly nitrogen gas, to be dissolved in the river. Gas supersaturation occurs naturally, such as at a waterfall, but it usually quickly dissolves into the atmosphere as the water cascades over rapids and ripples in the river. Dams, however, create slack–water, and low–velocity pools that do not allow the dissolved gas to escape back into the atmosphere.

Fish absorb the gas which causes emboli and erupts in bubbles in their flesh and bloodstream. Bubbles in

the bloodstream may block essential vessels and cause death outright, either before or after external symptoms begin to appear. External symptoms include bubbles in the lateral line, bubbles in fins, bubbles in the skin of the gill cover, bubbles in the roof of the mouth, or bubbles behind the eye. Salmon and steelhead with gas bubble trauma develop blisters as well as swollen and ruptured eyes.

Supersaturation (dissolved gas levels above 100 percent) emerged as a major problem when dams were constructed so close together that the reservoir of one dam backed water up to the base of the next dam upstream. Without rapids to disperse the gas back to the atmosphere, high supersaturation caused by one dam was maintained and, in some cases, increased by the next dam downstream. As a result, gas supersaturation caused by Lower Granite Dam could persist to well below Bonneville Dam.

B.1.3 Predation

Evidence that predators might be a significant problem in the reservoirs emerged in the late 1960s and early 1970s. At that time, dam counts revealed increasing numbers of squawfish, which are particularly aggressive in their pursuit of young salmon. The NMFS initiated studies to define the problem in 1973, and continued research through 1978 (Sims, *et al.*, 1979).

In 1977, researchers estimated 106,000 and 164,000 squawfish respectively were present in the tailrace areas of Little Goose and Lower Granite dams.

Owing to a lack of funding, the Corps stopped supporting predation research in 1978. Studies were resumed by the USFWS and the Oregon Department of Fish and Wildlife in the 1980s under the Northwest Power Planning Council's Fish and Wildlife program. These agencies further refined population estimates and developed a predation index, expanding the studies to include walleye and smallmouth bass. They recommended a systemwide predation control and evaluation program, which is currently underway.

B.1.4 Delays in Migration

Another problem young fish encounter is a delay in downstream migration. The upstream storage dams control the runoff from freshets and spring and summer snow melt that once rapidly carried migrating juveniles to the sea. The construction of hydroelectric projects eliminated favorable seasonal flow conditions under which juvenile salmonids evolved. In the mainstem reservoirs, the water – and the fish – move more slowly than they did in the free flowing river. Research on the effects of the impoundments behind run–of–river dams on the Columbia River has demonstrated that the average impoundment delays young migrants about three days (Raymond, 1968). The problem is especially significant from Lower Granite Dam to Bonneville Dam, where young fish are delayed almost a month in reaching the estuary. (Figure B–1)

Delays in migration through the river extend the exposure of young fish to hazards such as disease and predation. Delays of this magnitude can also result in failure of some migrants to reach the ocean while they are in a smolted condition. Smoltification is a physiological and behavioral process whereby the juvenile salmon and steelhead prepare for life in saltwater. Internally, one of the most significant changes is the conversion of their kidneys from a condition whereby they concentrate salts and excrete excess water to a condition whereby they concentrate water and excrete salt. Externally, the fish change from blending with their background through dark, mottled coloring, to greenish–blue above and silvery or white below. With this coloration, they are less visible to predators from above as they blend with the seawater color, and less visible to predators from below as they blend with the reflection from the surface of the sea. Behaviorally, they change from bottom dwellers to schooling, free swimming dwellers of the near–surface area of the sea.

The greater surface area of the impoundments behind the dams also results in a shift in temperature regimes. Overall, the reservoirs are cooler than the shallower river had been. However, they also retain heat after the summer due to the larger water volume. As a result, the cooling trend that normally occurs in late summer and early fall is delayed approximately one month into the fall. This temperature shift improves the habitat for the predators and competitors of juvenile salmon (Berrgren and Filardo, 1992).

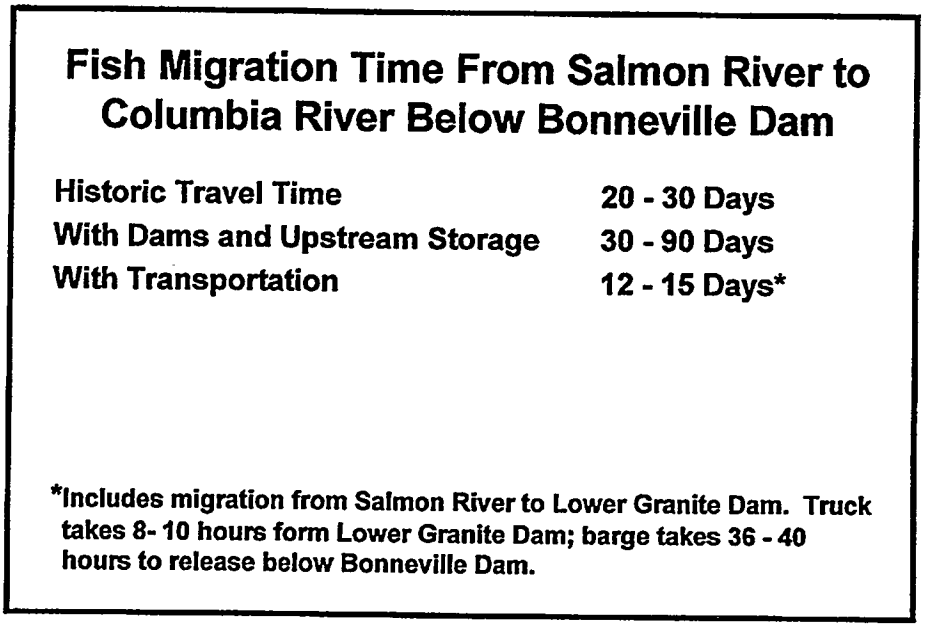


Figure B–1. Fish migration time from the Salmon River to below Bonneville Dam without dams, with dams and upstream storage, and with transportation

B.2 RESPONSE TO PROBLEMS

B.2.1 Turbine Bypass

When the Corps built Bonneville Dam in the late 1930s, scientists knew very little about the migratory behavior of Pacific salmon. Although biologists prior to this period had collected information on artificial propagation, fish screening, and fishway construction, their knowledge resulted from trial and error rather than scientific research. Funding for such efforts was scarce, in part because state and federal agencies failed to appreciate the value of fish research. During the 1930s, this perception was changing as Americans began to recognize that "the fishery was in serious jeopardy as a result of water use development and the dearth of factual information on fish protection and propagation." (Mighetto and Ebel, 1994).

The Fish and Wildlife Coordination Act, first passed in 1934 and amended in 1946, first required that the water resource development agencies cooperate and consult with the newly–created USFWS and the states in considering damages to natural resources.

In the 1940s, the Corps began developing a large–scale research program in cooperation with the Bureau of Commercial Fisheries (BCF – now the NMFS) and the USFWS, and the state fishery agencies. By 1958, Congress again amended the act to require that the water resource development agencies give conservation and enhancement of fish and wildlife 'equal consideration' with water development in the agency's project planning.

In 1951, the Corps established the Fisheries Engineering Research Program (FERP), later called the Fish Passage Development and Evaluation Program (FPDEP).

From its beginning, the FERP attempted to discover a way to divert young migrants away from turbine intakes (Anon., 1954; Mains, 1957). The fishery agencies, universities, and Corps scientists contributed to this effort. Laboratory and field studies included the use of electricity, lights, louvers, water jets, air jets, traveling screens, and sounds (Fields, 1966). Researchers in the 1960s measured the distribution of young fish in the turbine intakes to

determine if and where they were concentrating. They detailed the nature and extent of injuries to juvenile migrants passing through turbines and related the injuries to various modes of turbine operation (Bell, *et al.*, 1967). Although engineers attempted several techniques to reduce losses, none sufficiently reduced turbine mortalities.

Researchers learned that most turbine losses resulted not from smolts being injured by turbine blades, but from the severe pressure changes caused by water over a hundred feet deep passing over the turbine blades. At the edge of the turbine blade, areas of negative pressure (cavitation) occurred that were strong enough to pull molecules of metal from the turbine blades. Such extreme pressure changes were also deadly to the delicate little fish that happened to pass close to the edges of the blades. In particular, high demands for power often resulted in the operation of turbines at maximum overload, which produced more cavitation and higher loss of juveniles. In 1967, Milo Bell, a hydraulics engineer at the University of Washington, suggested that the best way to reduce mortality of smolts passing through the turbines was to operate the turbines at maximum efficiency, which smoothed out the levels of cavitation.

Meanwhile, in the early 1960s, biologists with the BCF at Ice Harbor Dam discovered that juvenile migrants collected in large numbers in turbine intake gatewells (Marquette, *et al.*, 1970). On the theory that these smolts might be bypassed around the dams rather than through them, engineers drilled a hole from the gatewell into the ice and trash sluiceway running along the upstream face of the dam. Smolts passed through the hole from the gatewell into the sluiceway, and were funneled down to the end of the dam. This route around the dam proved successful for the 2 to 4 percent of juveniles that were swimming up the gatewell from the turbine intake. Following the Ice Harbor Dam modification, Corps workers went back to Bonneville, The Dalles, and McNary dams and drilled the holes between the gatewells and the ice and trash sluiceways.

Research later in the decade demonstrated that juvenile salmon entering the turbine intakes concentrated in the upper one–third of the water column. This led to the concept that, with the proper device, the majority of juveniles traveling in the upper third of the water column might be actively guided into the gatewells for bypass around the dams. By the spring of 1969, the biologists had convinced the engineers to test a prototype turbine intake traveling screen at Ice Harbor Dam (Marquette, *et al.*, 1970). Traveling screens are screens placed at an angle in front of the turbines, inside the turbine intake (Figure B–2). The screens intercept fish approaching the turbines, and route them upwards into the gatewell slot. The mesh on the screens travels in a loop around the frame, carrying debris upward and away from the screen (hence, 'traveling' screen). Depending on several factors such as the angle at which the screen is set, its extension into the water column and the resulting hydraulics, fish, while guided upward, may experience descaling and/or injury. Eventually, turbine screen modifications moved in the direction of designing and positioning the screens to maximize their ability to intercept fish, while minimizing the risk of injury to the fish.

Results of this first test proved encouraging to the NMFS researchers, and by the time the Corps placed Little Goose Dam in operation in 1970, the engineers had a major effort underway to develop a juvenile bypass system utilizing screens.

As a result of studies at Ice Harbor and McNary dams, the ice–trash sluiceways were used to bypass fish out of turbine intakes, and by 1971, sluiceways at Bonneville and The Dalles dams were also tested and in use for this purpose (Michimoto, 1971).

The Corps did not construct ice and trash sluiceways when building John Day (1968), Lower Monumental (1969), and Little Goose (1970) dams because there was not enough need to bypass ice and trash at those sites. However, the engineers emulated the sluiceways' bypass capabilities by embedding a pipeline lengthwise through the powerhouse to carry fish from the gatewells down to the river below these dams. A six inch orifice led from each gatewell into the pipe. The fish came up the gatewell slots, and entered the embedded pipe through the orifice. The pipe expanded from one to three feet in diameter to accommodate the flow from increasing numbers of orifices,

providing a pathway down through the dam, and out between the spillway and the powerhouse into the tailrace. When facilities were set up for the NMFS to begin collecting and transporting fish at Little Goose Dam, the pipe was extended along the face of the dam to collection facilities onshore.

The six inch orifice into the embedded pipe ultimately proved inadequate to handle the volume of fish diverted by the traveling screens. Prior to the addition of screens, only 2 to 4 percent of the fish were passing up the gatewell (Sims, 1979). When fish screens were first installed at Little Goose Dam (1971), however, the six inch pipe proved too narrow for the higher volume of guided fish, and debris tended to collect in them, injuring fish that made it into the pipe (Ebel, *et al.,* 1973).

NMFS researchers spent years of study on orifice size, and orifice passage efficiency. They tested 8, 10, 12 and 18 inch orifices. They tested north–oriented vs. south– orifices, and the efficiency of two vs. one orifices; and they tested the maximal distance that an orifice should be from the endwalls of the gatewell (Krcma, *et al.*, 1978, 1979, etc.). Ultimately, a 12 inch orifice became the standard.

The orifice was not the only bypass component under study: In 1975, when the Corps constructed Lower Granite Dam, they scrapped the concept of the embedded pipe, substituting instead a tunnel running lengthwise in the powerhouse. Eight inch orifices were cast in place from the gatewell slots into the tunnel, but these were enlarged to 10–inch orifices in 1988, and are due to be enlarged to 12–inch when the Lower Granite facility is updated in 1997.

By 1975 the Corps' bypass system had reached state–of–the–art at Lower Granite Dam, although refinements continue. The Corps re–engineered the bypass systems at Little Goose Dam in 1978/79, at John Day Dam in 1983/84, and at Lower Monumental Dam in 1991, removing the imbedded pipes and retrofitting tunnels into the powerhouses.

B.2.2 Gas Supersaturation in the 1970s.

The evolving bypass system mitigated one of the problems created by the dams: mortality from passing through the turbines. However, research in the late 1960s and early 1970s was beginning to demonstrate that factors other than turbines were killing migrating juvenile salmon and steelhead (Ebel, 1974; Raymond, 1979).

The first indication that gas supersaturation was a problem for adult fish occurred in 1964. At this time, researchers noted a high rate of prespawning mortality caused by gas bubble disease in adult chinook at the McNary Dam spawning channel (Westgard, 1964). The McNary spawning channel drew its water from the reservoir that was supersaturated with atmospheric gas during periods of high spill at Ice Harbor Dam.

More catastrophic losses from gas bubble trauma occurred in 1968 with the closing of John Day Dam. With no turbines operating, all river flow was passed over the spillway. Based on the recovery of dead salmon, the Fish Commission of Oregon estimated that more than 20,000 adult summer chinook were missing in the area of concern. The magnitude of this loss related to the delay of adult migrants in the tailrace of John Day Dam, where gas concentrations soared to 143 percent saturation (Beiningen and Ebel, 1970).

With limited numbers of turbines installed at most dams in the late 1960s and early 1970s, significant quantities of water were usually spilled. Since smolt mortality from passage over the spillway had been estimated at 2 percent, this spill was theoretically safely bypassing juvenile fish. The John Day fish kill focused regional attention on the effects of gas supersaturation in the Snake and Columbia River on salmon and steelhead, including gas supersaturation caused by spill. A regionwide inter–agency Nitrogen Task Force (NTF) was formed with representatives from the state fishery agencies, Federal fishery and environmental agencies, and the Corps. In 1971, the Governors of Idaho, Oregon, and Washington signed a regional agreement imploring the Corps and other agencies to solve the problem and save the salmon and steelhead.



Figure B–2. 1969 Submerged Traveling Screen

The NTF was instrumental in supporting research to define the problem, in providing information for the establishment of state and Federal standards for gas supersaturation, and for instigating the corrective measures. Corrective measures included: (1) completion of upstream storage projects to lessen the spring peak flows in the river system; (2) expedited installation of turbines at The Dalles, the four lower Snake River dams, and construction of the second powerhouse at Bonneville Dam, all of which reduced the amount of involuntary spill; and (3) installation of spillway deflectors at Lower Granite, Little Goose, Lower Monumental, McNary, and Bonneville dams to lessen gas supersaturation when spill occurred. Spillway deflectors, also known as 'fliplips,' deflect spill out over the tailrace, thus reducing the deep plunging that leads to supersaturated water.

B.2.3 Juvenile Fish Transportation

Among the solutions available to the NTF was the JFTP then being developed by the NMFS. In 1968, the Corps funded a NMFS experiment at Ice Harbor Dam to increase the survival of juvenile salmon and steelhead by using trucks to transport them downstream. A major concern at the time was whether juveniles transported several hundred miles – bypassing normal migration routes – could find their way back to their point of origin as adults. The results appeared promising. Survival increased and the homing ability of adults was not seriously affected (Ebel, 1980).

Biologists from the NMFS proposed an expanded prototype collection and transportation system in a request for funding by the Corps through the Columbia Basin Fisheries Technical Committee (CBFTC) in 1970. This committee, which reviewed all matters pertaining to fish passage activities on the Columbia River, included representatives from the Oregon Game Commission, the Oregon Fish Commission, Washington Department of Game, Washington Department of Fisheries, Idaho Department of Fish and Game, USFWS, and NMFS. The committee approved the proposal on an experimental basis and the NMFS subsequently submitted it to the Corps. By 1971, the system proposed by the NMFS was in place and operating at Little Goose Dam.

The research continued focusing primarily on whether adult returns could be increased both to the fishery and to the parent stream or hatchery by collecting and transporting juveniles around several dams and reservoirs, thereby avoiding losses to young migrants. Initial results looked best for steelhead and successful enough for chinook salmon to convince the Corps to begin a major collection and transport operation from Little Goose, Lower Granite, and McNary dams by the late 1970s (Park and Athearn, 1985).

The decision to collect and transport fish required collection and handling facilities be constructed so that juveniles could be routed from the dam into raceways for loading. Almost immediately researchers recognized the need to separate the smolts from debris (before transportation), and from adult fish returning upstream. The earliest form of separation was hand separation. For this purpose a trap to collect smolts was set up in the ice and trash sluiceway at Ice Harbor Dam. When research moved to Little Goose Dam, the collection facility contained the first actual separator designed by NMFS: a box four feet wide and eight feet long, its design based on a Morton Fish Grader used at fish hatcheries for sorting fish into ponds. The fish proceeded down the embedded pipe running lengthwise through the dam and extended underground to the shore and upward into the collection facility. Once in the collection facility, the juveniles emerged from the pipe onto a set of bars lubricated from overhead by a set of spray nozzles. The bars nearest the pipe opening were closer together, so that smaller chinook smolts flowing down the face of the separator dropped into the hopper below. The space between the bars widened down the face of the separator so that the larger steelhead fell into a second hopper. From their separate hoppers, the fish were routed into the raceways.

In this "dry" separator, the fish tended to drop through tail first and hang up by their pectoral fins or their gill covers. At the urging of the fishery

agencies and Corps, in 1978, NMFS designed a wet separator to alleviate the problem. The water level in the wet separator was raised above the bars, allowing fish to swim head–first down into the hoppers. To attract the fish downward, water supply pipes in the box created attraction currents flowing upward between the bars. Two sets of bars were installed in the wet separator, one set 5/8– inch apart for chinook, and 1 1/4–inch apart for steelhead.

The transport trucks used by the NMFS in the late 1960s and early 1970s were converted 5,000 gal Air Force surplus gasoline tankers. The NMFS modified these trucks by coating them with insulation, installing fish release valves at the stern, installing liquid oxygen supply systems and tanks, and providing a compressed–air backup system. Two trucks were used by NMFS at Little Goose Dam in the early years.

While these developments in the transportation program were being made, with a very low water year in 1973, it became apparent that additional measures would be needed to safeguard the fish runs. This meant that additional flow would be required to pass juvenile fish downriver. A committee on fishery operations (COFO) was established.

B.2.4 Committee on Fishery Operations

The COFO, composed of Idaho, Oregon, and Washington fishery agencies, NMFS, USFWS, and tribal representatives, and Corps, BOR, BPA, and Federal Energy Regulatory Commission (FERC) representatives, was initiated in 1975 under the aegis of the Columbia River Water Management Group. In addition to assisting in the curtailment of the gas supersaturation problem, completion of upstream storage projects reduced seasonal peak flows affecting the migration rates and timing of the Columbia River salmon and steelhead. The COFO was established to arrange special flows and spill, and to coordinate such activities with the transportation program being developed by the NMFS and Corps. Typically, the COFO was co–chaired by NMFS and Corps or other agency representatives. In addition to meeting monthly in the winter and spring to coordinate annual river operations for fish, the COFO prepared an annual report (anon., 1975 through 1983). During the final year of COFO, the energy/water management agencies developed their plan for operation (which evolved into the Corps' Fish Passage Plan [FPP]), and the fishery agencies and Tribes began preparing their DFOP. The COFO continued its coordination process into the mid–1980s, until it was superseded by the Water Budget management process.

In 1976, using a design and criteria provided by the NMFS, the Corps acquired the first of five 3,500 gal fish trailers. These trailers were divided internally into four compartments, were designed to haul groups of juvenile salmonids separately, and were designed to haul adult fish if so desired. These trailers were equipped with liquid oxygen, compressed air, recirculation, refrigeration, filtration, and aeration systems.

B.2.5 First Fish Barging

As the severe drought of 1977 began to take shape in the late winter, the COFO expressed deep concern that the Snake River juvenile salmon and steelhead outmigration would be devastated by the drastically reduced flows that were expected. At the urging of the NMFS and other fishery agencies, the Walla Walla District located two barges which could be converted for fish transportation. These privately owned barges, which had been used for hauling paper mill effluent out into the ocean for dumping, were equipped with pumps, fish compartments, and fish release mechanisms. An emergency barge dock was installed at Lower Granite Dam, and barge loading lines were jury–rigged. Eventually, some 234,000 salmon and steelhead were barged from Lower Granite Dam, and another 3 million were barged from Spring Creek National Fish Hatchery around Bonneville Dam.

B.2.6 Northwest Power Planning Council

With the passage of the Northwest Electric Power Planning Council Act in 1980, the BPA was required to fund the establishment of the Northwest Power Planning Council (NPPC). The NPPC was to develop a Fish and Wildlife Program for the region to

mitigate for the impacts of the federal hydro–electric dams on the Columbia River system.

Based on input received from the fishery agencies, Tribes, and energy/water management agencies, the NPPC drafted their first Fish and Wildlife Program in 1982. In addition to many other measures, the NPPC established the Water Budget, a block of storage water to be used by the fishery agencies to offset irrigation/flood storage impacts to the natural flow regime needed for juvenile fish migration. Water Budget Managers were appointed, one for the fishery agencies and one for the Tribes, and what has become the Fish Passage Center (FPC) was established. The first Water Budget was provided in 1983, although storage and spill had been manipulated for fish for several years under the COFO process.

Meanwhile, when the NMFS turned the operation of the JFTP over to the Corps after 1980, the Corps and fishery agencies and Tribes agreed that the program should be run under the guidance of an inter–agency team. The Fish Transportation Oversight Team (FTOT) was formed, comprised of Corps, NMFS, IDFG biologists, and during some years, CRITFC, and the ODFW biologists as well. The FTOT prepared an annual work plan, provided oversight for the operation, and prepared annual reports on activities and fish transported from 1981 through 1992.

In 1983, operations at Little Goose were plagued with fish bypass problems severe enough that the facility was shut down on July 8th. Problems included severe gas bubble trauma and widespread descaling. In attempting to isolate the source of the problem, researchers held fish in various parts of the collection system, monitored fish taken from the gatewells before the fish entered the bypass pipe, held the fish at different depths in the tailrace, and simulated a truck trip to the Bonneville release site by holding fish in a trailer for seven hours with oxygen flow turned to high.

While none of these tests conclusively discovered the source of the problems, researchers began to believe that the problem was in the pressurized pipe system that delivered the smolts from the tunnel to the collection facility.

The angles in the pipe themselves were thought to be a source of descaling and, in emergency modifications completed before the 1984 season, the angles were re–engineered out of the pipes.

The other problem, thought to contribute to both descaling and gas bubble trauma, was the pressurization in the pipe that ranged up to four atmospheres (one atmosphere being air pressure at sea level, and approximately one atmosphere of pressure added for each 33 feet of hydraulic head).

Oregon Department of Fish and Wildlife biologists working in the transportation program at Little Goose Dam first suggested the concept of an open flume to carry fish from the dam to the collection facility in 1983. Given the results of testing, the corrugated metal flume was incorporated in the new collection/bypass system at Little Goose Dam in 1990, the Lower Monumental system in 1992, and the McNary system in 1994. It is proposed for incorporation in the Lower Granite system in 1997.

With the encouraging results from both the traveling screen research and the transportation experiments, it appeared that biologists had within their grasp a solution to the juvenile migration problems. By combining a bypass and collection system with a transportation system, fish could be collected and transported from key dams to downstream locations. Thus, losses from migration delays, turbine operation, gas supersaturation, and predation could be eliminated from a large portion of the juveniles' migration route.

However, as participants in the management of the Columbia River fisheries changed over the years, new biologists with the fishery agencies and Tribes began to question the use of transportation to protect fish. They asked that the Corps install full bypass systems at each dam. To encourage this development, they requested more use of spill and established fish bypass criteria that required not only screening of every powerhouse, but improvement of guiding efficiency to meet their criteria. The Corps responded by installing full sets of screens at Bonneville First and Second powerhouses, and John Day Dam in addition to those

at Lower Granite, Little Goose, and McNary dams. Use of the ice/trash sluiceways was expanded at Ice Harbor and The Dalles dams (Johnson, *et al.*, 1983; Nichols, *et al,* 1976).

Because judicious use of spill promised higher fish survival (Schoeneman, *et al.*, 1961), the Corps employed side–scanning sonar to detect fish approaching the dams, then spilled enough water to pass most of the fish from 1979 through 1982 (Magne). The agencies, meanwhile, asked for set quantities of spill over set numbers of hours at projects without full bypass systems. This resulted in a criterion of 90 percent survival at each dam in the 1986 NPPC Fish and Wildlife Program Amendments.

In March 1985, the **"Spread the Risk"** policy was formalized in an agreement signed by the fishery agencies and the Corps. Underlying the policy of "Spread the Risk" is the concept that yearling chinook salmon survive in–river at certain flow levels as well as or better than they do in the collection and transportation program. Therefore, when flows exceed certain trigger levels, yearling chinook should be returned to the river to migrate by that route. Accompanying the implementation of "spread the risk" the NPPC directed the Fish Passage Center to monitor the effects of in–river passage. No final results have been provided to this date verifying whether "spread the risk" slowed the decline of the Columbia River salmon.

Closer coordination between the Corps and the NPPC was encouraged by the development of the Mainstem Executive Committee in 1986, and the Corps, fishery agencies, Tribes, BPA, BOR, and NPPC discussed many of the issues. The NPPC also recognized the juvenile fish transportation program for the first time, and specified that transportation was to be carried out "in accordance with provisions developed by the fish and wildlife agencies and Tribes...."

In the late 1980s, the fishery agencies and Tribes again imposed more stringent criteria for juvenile fish passage at the dams. As research showed that different stocks of fish were guided at different rates, the fishery agencies and Tribes advocated the use of fish passage efficiency (FPE) rather than project survival rates used in the 1987 Fish and Wildlife Program. This meant that a certain percentage of fish had to be bypassed without going through the turbines. For example, the FPEs of the late 1980s were 50 percent for fall chinook, and 70 percent for spring/summer chinook and steelhead. If screens were not installed, or were installed but could not meet the FPE criteria, the fishery agencies and Tribes requested spill to provide the FPE required. At the collector dams, collection was to be maximized, i.e. no spill was to occur. At the other dams, spill was to be provided to give the required FPE.

This spurred the installation of screens and bypass/collection systems at all dams, and spurred the development of screens with higher guiding efficiency. In 1991, Lower Monumental Dam received a full compliment of screens. By 1992, the collection and holding facilities were completed, and transportation was expanded to include this fourth collector dam. In 1992, Ice Harbor Dam was equipped with a full compliment of screens, although no collection and transportation facilities are scheduled for installation. The McNary juvenile fish collection facility was replaced during 1993 and 1994 with all new collection facilities.

The Corps and NMFS have continued in the development of extended–length screens for Lower Granite, Little Goose, McNary, and The Dalles dams. Research since 1990 should culminate in installation of new screens at Lower Granite and Little Goose dams by 1996, McNary Dam by 1997, and The Dalles Dam by 1998. (Figure B–3)

By the early 1990s, most of this research was conducted under the aegis of the Fish Passage Development and Evaluation Program (FPDEP) – formerly the FERP – which, since FERPs formation in 1951, had come to include representatives from the NMFS, the USFWS, the Columbia River Inter–tribal Fish Commission (CRITFC), the Oregon Department of Fish and Wildlife (ODFW), the Idaho Department



Figure B–3. Extended–length turbine intake screen being tested at McNary Dam

of Fish and Game (IDFG), the Washington Department of Fisheries (WDF), and the Washington Department of Wildlife (WDW) which have recently merged into the Washington Department of Fish and Wildlife (WDFW). Four subcommittees of FPDEP – the Research Needs and Priorities Subcommittee, the Fish Research Scientific Review Subcommittee, the Fish Facilities Design Review Subcommittee, and the Operation and Maintenance Subcommittee – coordinate all aspects of research and dam operations with the fishery agencies and Tribes.

The Fish Transportation Oversight Team, on the other hand, disbanded in 1993 due to the withdrawal of NMFS and IDFG representatives because of possible conflicts of interest stemming from the ESA listing of Snake River salmon (NMFS) and pending litigation (IDFG).

In the last four years, many new ideas have arisen as a result of the SCS, drawdown studies and intense regional involvement in Columbia River salmon issues. The remaining scheduled improvements to the transportation program include replacing the Lower Granite juvenile fish collection facility with a new one similar to those recently installed at Little Goose, Lower Monumental, and McNary dams.

The position of the CRITFC on transportation, as stated in 1981, was: 'Smolt transportation is viewed by the Columbia River Inter–Tribal Fish Commission (CRITFC) as inconsistent with treaty obligations. The member tribes of CRITFC have a treaty right to the protection of anadromous fishery habitat; barge transportation is not protection of habitat. Modification of dam operations, improved flows and bypass facilities at Columbia River system dams are viewed as the preferred alternatives to barge and truck transportation. This is consistent with the obligations of the federal water managers to operate the FCRPS projects so as not to impair or destroy Tribal fishing entitlements (Ad Hoc Committee Recommendations, 1981). That is the position of the CRITFC at this time.

B.3 TIMELINE FOR RESEARCH AND DEVELOPMENT OF JUVENILE FISH TRANSPORTATION PROGRAM FACILITIES AND OPERATIONS.

1930s

- Experts conclude that juvenile fish will pass through Bonneville Dam (BON) turbines with minimal mortality (Mighetto and Ebel, 1994).

1938

- BON constructed with rudimentary juvenile fish bypass and ice/trash sluiceway.

1948

- BON turbine mortality studies (1938 to 1948) summarized; 11% mortality reported by Bureau of Commercial Fisheries (BCF) (Holmes, unpublished report).

1950

- Washington Department of Fisheries (WDF) begins studies on juvenile salmon bypass at Baker Dam (Hamilton and Andrew, 1954).

1951

- Corps Fisheries Engineering Research Program (now Fish Passage Development and Evaluation Program [FPDEP]) authorized.
- Fisheries Engineering Technical Advisory Committee comprised of Corps, Idaho Department of Fish and Game (IDFG), Oregon Fish Commission (OFC), Oregon Game Commission (OGC), WDF, Washington Department of Game (WDG), US. BCF, and US. Bureau of Sport Fisheries and Wildlife (USFWS).

1952

- WDF starts studies of juvenile fish bypass systems at dams on Elwha River, under Corps contract (Schoeneman and Junge, 1954; Mains, 1958).
- OGC conducts study of juvenile fish screens at Marmot Dam on the Sandy River under Corps contract (OGC, 1956).

1953

- McNary Dam (MCN) constructed with rudimentary juvenile fish bypass and ice/trash sluiceway (see "Description of Oregon Intake Structure" in Fields, *et al.*, 1966).
- WDF studies juvenile fish bypass at Alder Dam under Corps contract (Schoeneman, 1958).

1954

- Bureau of Reclamation (BOR) publishes Engineering Monograph on fish mortality in turbines (Krueger, 1954).

1955

- WDF studies turbine and spillway mortality at McNary Dam under Corps contract, 13% turbine mortality reported (Schoeneman and Junge, 1956).

1956

- WDF studies turbine and spillway mortality at McNary Dam under contract to Corps; 0 to 2% spillway, 8% turbine mortality reported (Schoeneman and Junge, 1956).

1957

- WDF studies turbine and spillway mortality at Big Cliff Dam; 2 % spillway,11% turbine mortality reported, fish survival related to turbine operating efficiency (Schoeneman and Junge, 1957; Schoeneman, *et al.* 1961).
- University of British Columbia summarizes adult and juvenile fish passage at dams (Muir, 1957).

1958

- The Dalles Dam (TDA) constructed with ice/trash sluiceway.

1960

- Juvenile fish mortality in turbines related to pressure changes (Von Gunten, 1960).
- Corps reports studies on juvenile fish passage through model turbines (Cramer, 1960).
- Corps reports studies on juvenile fish passage through Cushman No.2 Hydroelectric Plant (Cramer and Oligher, 1960)

1961

- Ice Harbor Dam (IHR) constructed with ice/trash sluiceway.
- Corps models fish mortality through francis turbines (Cramer and Oligher, 1961).
- Corps reports further studies at Cushman No. 2 (Cramer and Oligher, 1961)

1962

- Mortality in ice/trash sluiceway at MCN estimated at 16.8% for sockeye, 18.6% for subyearling chinook, 6.6% for yearling chinook, and 0.9% for steelhead (Fields, *et al.*, 1966).
- Corps studies mortality through turbines at Shasta Dam (Corps, 1963).
- Diel movement of juvenile fish entering turbines studied at TDA and MCN, 75% of vertical distribution into 1/3 of turbine intake (Long, 1968).

1964

- BCF (now National Marine Fisheries Service [NMFS]) begins studies at IHR on methods of diverting juvenile salmonids out of gatewells under Corps contract (Liscom, 1965).

1965

- BCF drills and tests experimental orifice and siphon removal system from bulkhead slot to ice/trash sluiceway at IHR (Liscom, 1965).
- BCF research on gatwell dipping fish for research at IHR (Marquette, 1965).

1966

- Corps reports 92% turbine survival at Big Cliff Dam (Bell, *et al.*, 1967; Oligher and Donaldson, 1966).
- MCN spillway mortality reported at 42 to 46% for full gate tests, 1.5 to 9.1% for split–gate tests (Fields, *et al.*, 1966).
- Validity of Schoeneman, *et al*, 1961, 2% spillway mortality questioned because 1)tests conducted in March, 2) spill only through test gates, insufficient discharge to simulate backroll and plunging flows, 3)full gate opening tested, and 4) tailwater effect not representative of high flow conditions (Fields, *et al.*, 1966).
- Studies show light can be used to repel or attract juvenile fish, depending on conditions (Fields, *et al.*, 1966).

1967

- Corps drills 6–inch orifices from gatewells to ice/trash sluiceway to create juvenile fish bypass at IHR.
- OFC recommends standardized spill patterns for IHR (Junge, 1968).

1968

- John Day Dam (JDA) constructed with first imbedded pipeline juvenile fish bypass (replaces ice/trash sluiceway bypass).
- OFC estimated loss of 20,000 adult spring chinook at JDA due, in large part, to gas supersaturation (Haas, et al., 1969).
- BCF research on guiding fish from turbines at IHR, Corps contract to BCF (Marquette, *et al.*, 1970); submerged orifices provide positive results at MCN (Long and Krcma, 1969).
- Transport research initiated with spring/summer chinook collected from gatewells at IHR transported below JDA and BON dams, Corps contract to BCF (Ebel, 1970).
- BCF reports 10% direct, 33% predation, 30% combined mortality to juvenile fish passing through turbines at IHR, Corps contract to BCF (Long, 1968).

1969

- Lower Monumental Dam (LMO) constructed with imbedded pipeline juvenile fish bypass.
- First submerged traveling fish screen (STS) tested at IHR, Corps contract to BCF (Marquette, *et al.*, 1970).
- Second year of transport research, IHR to JDA and BON by BCF; fish marking expanded to include steelhead, Corps contract to BCF (Ebel, 1970).
- Orifices installed in all 44 gatewells at MCN to create ice/trash sluiceway juvenile fish bypass (Marquette, *et al.*, 1970).
- Orifice efficiency tested at MCN, orifice lighting recommended, descaling 2 to 6% (Marquette, *et al.*, 1970)
- OFC recommends ice/trash sluiceways be used as bypasses at all dams so equipped (Michimoto, 1971).

1970

- Little Goose Dam (LGO) constructed with imbedded pipeline juvenile fish bypass.
- Third year of transport research with yearling chinook and steelhead, IHR to JDA and BON by NMFS; one STS used in Unit 1 (Ebel, 1970).
- Orifices drilled from remaining bulkhead slots to ice/trash sluiceway at IHR; orifices drilled at BON dam; sluiceways used as juvenile fish bypasses with orifice flow.
- Spring/summer chinook transport/control ratio (TCR) 1.5:1 before spill, 4.0:1 with spill (Ebel, 1975).

1971

- Ice/trash sluiceways at BON and TDA began operating as surface spill juvenile fish by-passes (Michimoto, 1971)
- IHR STS modified and moved to LGO; two new STS constructed by NMFS for research; fish guiding efficiency (FGE) tests conducted in Unit 2 with crowder screens, lighted gate-wells, and lighted orifices; FGE 81 % for yearling chinook, 97 % for steelhead (Long, *et al*, 1972).
- Transport research started at LGO; delayed mortality 0 to 3.3% (average 0.97%) for steelhead, 3.4 to 51.2% (average 22.8%) for yearling chinook.
- Slotted bullkhead tested at LGO for gas supersaturation control.
- 109,000 of 4 million chinook (3%) and 154,000 of 5.5 million steelhead (3%) arriving at LGO transported (Smith, *et al.*, 1980)

1972

- Columbia Basin Fishery Technical Committee (CBFTC) requested all additional fish collected be transported from LGO; 600,000 of 900,000 fish collected were transported.
- Slotted bulkheads used at LGO, LMO, and IHR dams; significantly lowered gas supersaturation levels; removed when massive fish kill started.
- Prototype spillway deflectors tested in Bay 18 at BON and Bays at 2 and 5 LMO.
- Three STSs modified and used at LGO.
- Transport research with yearling chinook and steelhead controls at Central Ferry or at LGO and transport below BON and to Dalton Point; Spring chinook return shows 1.17:1 benefit (0.875:1 for spring chinook, 2.67:1 for summer chinook at BON; 1.11:1 for spring chinook, 1.67:1 for summer chinook at Dalton Point) (Park, *et al.*, 1976).
- Stress evaluations in collection and transport started.
- Delayed mortality for marked steelhead 0 to 4.0% (average 1.4%), marked yearling chinook 0 to 26.0% (average 10%), unmarked steelhead 0.85%, unmarked chinook 12.2%; stress and descaling relatively high (Park, *et al.*, 1976).
- Mortality through slotted bulkheads estimated at 50% (Long, et al., 1972; Long and Ossiander, 1974).
- Vertical barrier screens modified with solid panels.
- 360,000 of 5 million chinook (7%) and 227,000 of 2.5 million steelhead (9%) transported from LGO (Smith, *et al.*, 1980).

1973

- Nine STSs installed at LGO; 6 removed because of excessive descaling; descaling related to metal–mesh screens and turbine operations.
- Spillway deflectors modified in Bays 2 and 4 at LMO.
- Air bubble curtain tested to screen fish from turbine intakes – not succesful.
- Transport mortality 0.70% for chinook, 0.51 % for steelhead; delayed mortality 2.9 to 43.0% for marked chinook (17.2% average), 15.3% for unmarked chinook; 0 to 16.6% (4.5% average) for marked steelhead, 4.4% for unmarked steelhead; BON release site TCR 13.83:1, Dalton Point TCR 18.5:1 for spring/summer chinook (Park, *et al.*, 1976).
- Gas supersaturation low due to drought conditions.
- Mortality from slotted bulkheads estimated at 44% (Long and Ossiander, 1974).
- 247,000 of 5 million chinook (5%), and 176,000 of 5.5 million steelhead (3%) transported from LGO (Smith, *et al.*, 1980).

1974

- Spillway deflectors installed in bays 13 through 15 at BON.
- Modify spillway deflector in Bay 2, install deflectors in Bays 3,5,6,7 at LMO.
- NMFS results show 2.2% mortality for steelhead passing through spillway bay with flow deflector, 27.5% through spillway without flow deflector (Long, *et al.*, 1975).
- 3.5 million chinook, 5 million steelhead estimated to LGO, no transport (Smith, *et al.*, 1980).

1975

- Lower Granite Dam (LWG) installed with spillway deflectors in all bays.
- Move three STSs and 3 VBSs from LGO to LWG.
- Spillway deflectors installed in bays 4 through 12 at BON.
- Fish collection and transportation from LWG started; new juvenile fish facility operational, 8–inch orifices standard in all bulkhead slots; fish screen slot evaluated.
- Emergency mass transportation of chinook and steelhead from LGO requested by fishery agencies.
- Corps acquires first of five 3,500 gal fish transport trucks.
- NMFS's 1973–1975 evaluation of JDA juvenile fish bypass 2 to 4% effective, vertical barrier screens increase collection 6 times (Sims and Johnson, 1976).
- 307,083 salmonids collected at LWG; 112,452 chinook and 110,076 steelhead marked for transport evalutation; delayed mortality 11.5% for chinook, 0.38% for steelhead; TCR for chinook 1.6:1, 1.1:1, and 15.6:1 for 1971, 1972, 1973; TCR for steelhead 2.7:1, 3.25:1, 15.0:1 for same years; STS tested in fish screen slot at LWG; 20% descaling, poor guidance; chinook survival from Salmon River to TDA 25%, steelhead 42%; chinook 60% Rapid River Hatchery fish; 8–inch orifices twice as effective as 6–inch at LWG, spillway deflectors reduce gas levels in moderately high flow year (Park, *et al.*, 1976).
- 414,000 chinook out of 4 million (10%) and 549,000 steelhead out of 3.2 million (17%) transported from LWG/LGO (Smith, *et al.*, 1980).

1976

- Spillway deflectors in bays 3 through 20 at MCN.
- Spillway deflectors in bays 2 through 7 at LGO.
- Move 3 STSs and VBS from LGO to LWG Unit 2.
- Construct 3 STSs for Unit 2 at LGO.
- Construct new (2nd generation) plastic mesh STSs for Unit 3 at LWG.
- Install seven STSs and 6 VBS in Units 2 and 3, LWG.
- Construct 3 VBS for Unit 3 at LGO.
- OFC recommends no spillway deflectors at IHR (Junge and Carnegie, 1976).
- Airplane tested for fish transport at LWG; Mass transport of 1.2 million from LWG, LGO; Disease monitoring started at LWG; BKD discovered in chinook; descaling 7% at LWG, 11.5% at LGO; 1973 TCR 12.8:1 for chinook, 13.3:1 for steelhead; lighted 8–inch orifice recommended for LWG; spillway deflectors reduce gas supersaturation in moderate flow year(Park, *et al.*, 1977).
- 8–, 10–, 12–, 18–inch orifices tested at BON, 12–inch found optimum (Long and Krcma, 1977).

- No effective way found to make juvenile bypass at JDA work; gatewell salvage operation recommended; MCN south sluiceway exit recommended (Sims and Johnson, 1977).
- 751,000 out of 5 million chinook (15%) and 435,000 out of 3.2 million steelhead (14%) transported from LWG/LGO (Smith, *et al.*, 1980).

1977

- Two barges and towboats rented for first barge transport; temporary barge dock installed at LWG.
- Orifice lighting installed in Units 1 through 6 at LGO.
- Orifice lighting installed in Units 1 through 6 at LWG.
- Two new (3rd generation) plastic mesh STSs installed in Unit 3B and 3C at LWG.
- Tests at BON confirm 12–inch orifice, relate FGE to flow up gatewell; test fixed bar screen (Krcma, *et al.*, 1978).
- JDA juvenile fish bypass outfall unacceptable due to discharge in slack water, high predation area; MCN north sluiceway exit found acceptable (Sims and Johnsen, 1978).
- 1,365,000 out of 2 million chinook (68%) and 895,000 out of 1.4 million steelhead (64%) transported from LWG/LGO (Smith, *et al.*, 1980).

1978

- Vertical barrier screens installed in Units 4, 5, and 6 at LWG.
- Eighteen new (4th generation) STSs installed in Units 1 through 6 at LWG.
- Nine VBSs installed in Units 4,6, and 8 at MCN; 3 STSs available for research; temporary flume and collection facility constructed.
- Two used barges 86,000 gallon (23,000 lb capacity) acquired, modified, and used in transport; contract two towboats, barge transport from LWG only.
- Mining of bypass tunnel started at LGO; gatewells dipped and fish transported by truck or barge.
- Wet separator tested at LGO.
- Fixed bar screen rejected for BON, testing intitiated for MCN; 12–inch orifice found more effective at MCN (Krcma, *et al.*, 1979).
- 1,623,000 out 3.18 million chinook (51%), 1,355,000 out of 2.12 million (64%) steelhead transported from LWG/LGO (Smith, *et al.*, 1980).
- 1,980,600 fish transported from LWG, 996,285 from LGO, 82,211 from MCN, total transport 3,059,906 (Basham, *et al.*, 1982).

1979

- Thirty three VBSs (remaining units) installed at MCN.
- Mining of bypass tunnel completed at LGO; gatewells dipped and 1,454,000 fish transported by truck or barge.
- 2,109,000 out of 4.27 million chinook (49%) and 1,712,000 out of 2.55 million steelhead (67%) transported from LWG/LGO (Smith, *et al.*, 1980).
- 1.6 million fish collected at MCN, 1,247,000 transported; 3 million fish barged from LWG, LGO, MCN (Smith, *et al.*, 1980)
- 2,367,446 fish transported from LWG, 1,453,615 from LGO, 1,247,120 from MCN for total of 5,068,181 (Basham, *et al.*, 1982).

1980

- New tunnel, pipeline, and separator operational at LGO.
- Ice/trash sluiceway operated at 1200 cfs as juvenile fish bypass at IHR.

- NMFS/Corps share operation of transportation – transition from research to operations; Corps personnel trained on transport operations by NMFS.
- 3,254,000 out of 5.6 million chinook (58%), 2,860,000 out of 3.6 million steelhead (79%) arriving at LWG transported from LWG/LGO; (Smith, *et al.*, 1981).
- 3,830,747 fish transported from LWG, 2,282,987 from LGO, 1,740,545 from MCN for total of 7,854,279; transport mortality 0.56% for barged chinook, 0.047% for barged steelhead; facility mortality 0.3% at LWG, 1.3% at MCN (Basham, *et al.*, 1982).

1981

- First new 100,000 gallon (50,000 lb capacity) barge added.
- Trash rake and crane istalled at LWG.
- IHR ice/trash sluiceway use as bypass expanded with 1,200 cfs spill from forebay.
- Corps assumes operation of transportation program; Fish Transportation Oversight Team (Corps, NMFS, IDFG) created to coordinate Juvenile Fish Transportation Program.
- First wet separator installed at LGO.
- 13 new STSs installed at LGO; 39 new STSs installed at MCN.
- FGE research at BON First Powerhouse shows 70% + for all species (71.5% for fall chinook); descaling 7%; ice/trash sluiceway 24% effective as surface skimmer bypass; vertical and horizontal distributions measured; orifice cycling tested; balanced flow vertical barrier screen (BFVBS) concept developed (Krcma, *et al.*, 1982).
- FGE determined lower than desired at LWG, OPE and orifice cycling studied; larger orifices, raised operating gates recommended (Swan, *et al.*, 1983).
- 8,308,850 fish transported, 1,730,856 from LWG, 1,464,991 from LGO, and 4,112,993 from MCN, for total of 8,308,850 (Basham, *et al.*, 1982).
- Facility mortality 0.6% at LWG, 1.4% at MCN (Basham, *et al.*, 1982).

1982

- Second 100,000 gal barge added to fleet.
- Wet separator installed at LWG, electronic sampling system installed; direct loading line to barge installed, 6–inch lines in facility upgraded to 10–inch; underwater TV inspection of STSs initiated (Basham, *et al.*, 1983.
- Wet separator modified, 6–inch distribution and loading lines upgraded to 10–inch at LGO; gas supersaturation problem developed in collection system (Park and Athearn, 1985).
- Wet separator installed at MCN; distribution system upgraded to LWG criteria; open flume installed for truck loading (Park and Athearn, 1985).
- BON Second Powerhouse constructed with LWG type juvenile fish bypass with 12–inch orifices, collection tunnel in dam, and downstream migrant sampling system.
- Trucked fish released at Bradford Island, Dalton Point, or BON Second Powerhouse.
- Hydroacoustic study at IHR to evaluate use of ice/trash sluiceway as juvenile fish bypass; 24% bypass with 1,200 cfs.(1.5% of powerhouse flow) observed (Johnson, *et al.*, 1982).
- Transport densities of 0.25, 0.5, 1.0, and 1.5 lb/gal tested by NMFS.
- Transport tests show stress in chinook from transport with steelhead – NMFS.
- Stress identified in Lower Granite collection system – pressurized pipe – NMFS.

- 1,851,616 transported from LWG, 1,234,110 from LGO, and 1,003,853 from MCN for total of 6,089,579 (Basham, *et al.*, 1983).
- Transport mortality for trucked fish 0.1 percent from LWG, 1.2% from LGO, 0.1% from MCN; barge mortality 1.27%; facility mortality at LWG 0.49%; 0.42% at LGO, 1.13% at MCN (Basham, *et al.*, 1983).
- 581,000 out of 2.1 million chinook (28%) and 2,271,000 out of 4.3 million (53%) steelhead arriving at LWG transported from LWG/LGO; 0.79 out of 3.8 million yearling chinook (21%), 0.354 out of 1.5 million steelhead (24%) transported from MCN (Park and Athearn, 1985).

1983

- Fish agencies and tribes request bypass of all yearling chinook, voluntary spill at LWG and size separation at LGO; MCN used to bypass yearling chinook (DeLarm, *et al.*, 1984; Park and Athearn, 1985).
- Raceways 6 through 10 added at LWG juvenile fish facility; temporary debris boom installed at LWG; STS cycling initiated to decrease wear, all fish transport and loading pipes upgraded to 10–inch, mechanical boom installed for barge loading (DeLarm, *et al.*, 1984).
- LGO collection facility operations were restricted due to excessive mortality from gas bubble disease, forced to shut down July 8 (Park and Athearn, 1985).
- BON Second Powerhouse juvenile fish system evaluated; 10% sampler very effective (McConnel and Muir, 1982).
- Hydroacoustic evaluation at IHR shows spillway passes 40.0% of fish with 40.6% of flow, sluiceway passes 30.6% of fish with 2.2%, powerhouse passes 29.2% with 57.2% of flow; 51% of powerhouse passage through sluiceway (Johnson, *et.al.*, 1984).
- Transport mortality by truck 0.29% from LWG, 0.62% from LGO, 0.05% from MCN; barge mortality 0.27% for yearling chinook, 0.16% for steelhead, and 1.4% for fall chinook; lower barging mortality observed for direct loading; facility mortality 0.45% at LWG, 2.7% at LGO, 0.37% (raceway) and 0.99% (sample tank) at MCN (DeLarm, *et al.*, 1984).
- 2,029,000 out of 4.6 million (26%) chinook and 1,939,000 out of 2.9 million (69%) steelhead arriving at LWG transported from LWG/LGO; 11,000 out of 3.7 million yearling chinook (0.3%), 55,000 out of 1.7 million steelhead (3%), and 4,200,000 out of 12.3 million subyearling chinook (30%) transported from MCN; 31% direct barge loading at LWG (Park and Athearn, 1985).

1984

- Six gates automated on ice/trash sluiceway juvenile bypass at IHR.
- Permanent debris boom installed at LWG.
- LGO bypass pipeline modified to reduce mortality and gas bubble trauma; collection gallery surfaces smoothed; 18 orifices converted to 12–inch, 6 orifices to 8–inch.
- Size separator installed at MCN; wet separator at LGO modified to increase size separation; 6–inch distribution and loading lines at MCN converted to 10–inch; summer barging instituted at request of fishery agencies and tribes (Park and Athearn, 1985).
- 11,033,317 fish collected, 2,052,119 at LWG, 2,717,422 at LGO, 6,243,776 at MCN, 1,504,941 bypassed at MCN, 445,922 bypassed at LGO; 9,028,959 transported, 2,046,020 from LWG, 2,274,307 from LGO, 4,708, 632 from MCN; facility mortality 0.3% at LWG, 0.7 at LGO, 0.7% in raceways, 1.04% in sample tank at MCN; barge mortality 0.8% for direct loaded fish, 0.7% for fish loaded from raceways (Koski, *et al.*, 1985).

- 1,313,000 out of 4.6 million (28%) chinook and 2,731,000 out of 6.2 million steelhead arriving at LWG transported from LWG/LGO; 293,000 out of 5.2 million yearling chinook (6%), 367,000 out of 1.9 million steelhead (19%), and 3.9 out of 12.9 million subyearling chinook (30%) transported from MCN; 63% direct barge loading at LWG (Park and Athearn, 1985).

1985

- Permanent truck release site constructed at Bradford Island below BON First Powerhouse.
- Corps, fishery agencies and tribes sign agreement to implement "spread the risk" policy, retest transportation effectiveness.
- Bypass flumes tested at LWG for new LGO facility (Congleton, *et al.*, 1986).
- 18,210,309 fish collected, 4,482,333at LWG, 2,270,618 at LGO, 11,457,358 at MCN; 13,245 bypassed at LWG, 247,780 at LGO, and 3,107,164 at MCN; 14,787,592 fish transported, 4,459,438 at LWG, 2,008,980 at LGO, and 8,319,174 at MCN; collection mortality 0.22% at LWG, 0.60% at LGO, and 1.75% at MCN (Koski, *et al.*, 1986).

1986

- Sample tank with pre–anesthetic system installed at LWG.
- FGE test at LGO shows 70% FGE for yearling chinook with raised operating gate (Swan, *et al.*, 1987).
- IHR ice/trash sluiceway passage evaluted at 50.4% at 2,700 cfs (2.2% of river flow) (Sullivan, *et al.*, 1986).
- Trash rack deflector tested at MCN to simulate extended turbine intake screen.
- Prototype STS tested at IHR.
- FGE at LMO measured at 73% (sp/su chinook), 83% steelhead, and 35% fall chinook with raised operating gates, MBFVBS, and standard STS.
- 17,082,770 fish collected, 4,773,941 at LWG, 2,093,232 at LGO, and 10,215,597 at MCN; 80,963 fish bypassed at LWG, 32,495 at LGO, and 3,306,666 at MCN; 13,495,834 fish transported, 4,683,260 from LWG, 2,052,153 from LGO, and 6,760,421 from MCN; facility mortality 0.19% at LWG, 0.36% at LGO, and 1.45% at MCN; 55.4% of fish direct loaded onto barges at LWG (Koski, *et al.*, 1987).

1987

- Pre–anesthetic systems installed at MCN.
- PIT tag detectors installed at LGO.
- Hydroacoustic tests at IHR show 34% of fish pass in 5% of total discharge (21% in 6% of flow at night; 48% in 4% of flow in daytime) (Ransom and Ouelette, 1988).
- FGE tests at IHR show 77.7% FGE for yearling chinook, 92.5% for steelhead (Brege, *et al.*, 1988).
- Juvenile fish bypass flumes tested at LWG for new LGO collection/bypass facility; corrugated metal flume selected based on low stress, no descaling, effective debris passage (Congleton *et al.*, 1988).
- FGE tests at LWG show simulated extended screen increases FGE from 63 to 74% for yearling chinook, 74 to 89% for steelhead, FGE increases as smoltification progresses at LGO (Ledgerwood, *et al.*, 1988; Muir, *et al.*, 1988).
- 19,821,789 fish collected, 5,512,434 at LWG, 1,982,312 at LGO, and 12,326,034 at MCN; 50,740 bypassed at LGO, and 2,345,147 at MCN; 17,036,566 fish transported, 5,470,665 from LWG, 1,910,026 from LGO, and 9,655,789 from MCN; facility mortality 0.72% at LWG, 1.14% at LGO, and 2.64% at MCN; 31.9% of fish direct loaded onto barges at LWG (Koski, *et al.*, 1988).

1988

- PIT tag detector installed at LWG.
- FGE tests at BON second powerhouse show significant improvement from turbine intake extensions; variable FGE during migration season (Gessel, *et al.,* 1989).
- 20,404,524 juvenile fish collected, 7,534,218 at LWG, 1,726,771 at LGO, and 11,143,535 at MCN; 20,033,865 juvenile fish transported, 7,504,860 at LWG, 1,708,413 at LGO, and 10,820,592 at MCN; facility mortality 0.35% at LWG, 1.06% at LGO, and 1.66% at MCN; 59.3% of barged fish direct loaded at LWG (Koski, *et al.,* 1989).

1989

- PIT tag detectors installed at MCN.
- Turbine/spillway/bypass study at BON shows 80, 83, 83, 86, 91, and 96 percent survival through bypass, lower turbine, upper turbine, frontroll, downstream, and spillway releases.
- Simulated 40 foot ESTS tested at LWG increased FGE from 57.3 to 66% for yearling chinook, 77.3 to 82.7 % for steelhead.
- Prototype STS tested at LMO.
- 20,042,966 juvenile fish collected, 7,846,419 at LWG, 2,975,098 at LGO, 9,221,449 at MCN; 15,458,495 juvenile fish transported, 6,781,524 from LWG, 2,310,508 from LGO, and 6,366,463 from MCN; facility mortality 0.41% at LWG, 0.92% at LGO, and 0.96% at MCN; 41.2% of barged fish direct loaded at LWG (Koski, *et al.,* 1990).

1990

- New juvenile fish facility with gravity flume completed at LGO; new barge and truck loading.
- Two 150,000 gallon (75,000 lb capacity) barges added.
- Orifices enlarged to 10 inch at LWG.
- PIT tag detector systems installed at LWG and LGO.
- NMFS research reports 1.6:1 T/C ratio for spring/summer chinook marked at LWG in 1986; NMFS recommends transport of spring/summer chinook in all flow years (Matthews, *et al.,* 1990).
- NMFS evaluation of new LGO juvenile fish facility shows minimal descaling, injury, or mortality; stress responses appear normal for yearling chinook and steelhead (Monk, *et al.,* 1992).
- 22,261,661 juvenile salmonids collected, 9,356,391 at LWG, 2,340,516 at LGO, and 10,564,754 at MCN; 21,446,589 juvenile salmonids transported, 9,336,878 at LWG, 2,318,978 at LGO, and 9,789,773 at MCN; collection mortality 0.2% at LWG, 0.8% at LGO, and 1.3% at MCN; 75.3% of barged fish direct loaded at LWG (Ceballos, *et al.,* 1991)

1991

- New bypass tunnel mined at LMO.
- FGE tests at BON show raised operating gate increases yearling chinook FGE from 28.9% to 49.5%.
- Extended length STSs (ESTS)and bar screens (ESBS) tested at MCN; FGE about 80% for yearling chinook, over 50% for subyearling chinook.
- Grant Co. PUD transport tests show 2.6:1 benefit for truck/barge, and 4.4:1 benefit for truck transported sockeye marked in 1987 and 1988 (Carlson and Matthews, 1991.
- 17,730,445 juvenile salmonids collected, 8,617,488 at LWG, 2,263,179 at LGO, and 6,849,778 at MCN; 15,474,702 juvenile salmonids transported, 8,420,639 at LWG, 2,245,587 at LGO, and 4,808,476 at MCN; collection mortality 0.2% at LWG, 0.7% at LGO, and 1.0% at MCN; 54.0% of barged fish direct loaded at LWG (Ceballos, *et. al.,* 1992),

1992

- Eighteen standard STS and 18 MBFVBSs installed at LMO, operating gates raised, bypass system installed; OPE for sp/su chinook 88%, 66% for steelhead.
- Gatewell dipping at LMO until new juvenile fish facility operational; new fish facility operational April 15.
- PIT tag deflector system installed at LGO.
- New laboratory facility operational at LWG.
- Roof installed over raceways 1 – 5 and over separator at LWG.
- Eighteen modified STSs and 18 MBFVBSs installed at IHR; 18 14–inch orifices drilled; interim bypass using STSs, orifices, and ice/trash sluiceway (six overflow gates).
- FGE tests at BON2 show 70% for yearling chinook, 55% for coho, 41% for fall chinook.
- FGE tests at BON1 show FGE not improved by lowering STS, raising operating gate improved FGE for subyearling chinook, coho, and steelhead, but not yearling chinook; FGE and TFGE declined as migration progressed (Monk, *et al.*, 1993).
- FGE tests at MCN show 80 and 53% FGE for yearling and subyearling chinook with ESBS compared with 61 and 30% with STS; 30% perforated plate with ESBS lowered descaling, raised FGE from 71 to 80% for yearling chinook; remove operating gate gave 6.6% descaling for ESBS compared with 5.1% with STS (McComas, *et al.*, 1993).
- Grant Co. PUD transport tests show 1.2:1 benefit for truck/barge, and 1.4:1 benefit for truck transported sockeye marked in 1988 (Carlson and Matthews, 1992).
- FGE test at LMO show 69% for yearling chinook, >85% for steelhead with standard STSs; descaling for yearling chinook 7%, 6.4% for steelhead; OPE 88% for yearling chinook, 66% for steelhead (Gessel, *et al.*, 1993).
- 18,258,627 juvenile salmonids collected, 6,911,174 at LWG, 1,795,837 at LGO, 9,551,616 at MCN; 17,558,982 juvenile salmonids were transported, 6,765,403 from LWG, 1,777,984 from LGO, and 9,015,595 from MCN; collection mortality 0.4% at LWG, 0.6% at LGO, and 3.9% at MCN (highest recorded at MCN due to low flow, warm water); 47.0% of fish barged from LWG direct loaded (Ceballos, *et. al.*, 1993),

1993

- Eighteen new design STSs installed at IHR; 14 inch orifices drilled; ice/trash sluiceway operated as bypass with 2000 cfs flow from orifices (250 cfs) and sluiceway gates (1750 cfs).
- Roof installed over raceways and separator at LGO.
- PIT tag deflector system installed at LMO.
- Extended length screens tested at LGO; yearling chinook FGE 85%, steelhead 90%; ESTS descaling 12%, ESBS 9%, STS 7% (Gessel, et al., 1994 (in publication)).
- At BON2, turbine intake extensions (TIES) in alternating units increased passage in non–TIE slots, spring season FGE for yearling chinook 44% with four or six turbines operating, 50% with eight turbines operating, FGE ranged from 35 to 60% for other salmonids with four, six, or eight turbines operating; with four turbines operating, 75% more fish entered non–TIE slots; with six turbines operating, 25% more yearling chinook entered non–TIE slots; with eight turbines operating, equal numbers of fish entered TIE and non–TIE slots; with four or six turbines operating, FGE higher for non–TIE slots; with eight turbines operating, no difference; spring descaling 5.2% for yearling chinook; summer FGEs 25 to 34% for subyearling

chinook; summer descaling 1.5% for subyearling chinook (Monk, *et al.*, 1994).

- FGE studies at MCN show 88% for yearling chinook with ESTS, 81% with ESBS; no difference from partially raised or removed operating gate; no difference in descaling for ESTS, ESBS, or STS; FGE for subyearling chinook (ESTS 67%) significantly higher (ESBS 52%) with raised operating gate; descaling higher (12.2%) for subyearling chinook with ESTS (McComas, *et. al.*, 1994).
- 18,035,182 juvenile salmonids were collected, 8,025,621 at LWG, 2,012,599 at LGO, 1,337,339 at LMO, and 6,659,623 at MCN; 15,550,165 juvenile salmonids were transported, 7,577,848 from LWG, 1,334,358 from LGO, 985,986 from LMO, and 5,208,347 from MCN; facility mortality was 0.12% at LWG, 0.7% at LGO, 0.1% at LMO, and 1.3% at MCN; 35.8% of fish barged from LWG were direct loaded into barges (Hurson, *et al.*, 1994 (in publication)).

1994

- New collection channel, transport flume, size separator, holding raceways, laboratory, truck loading, and barge loading facilities installed at MCN.
- Four new 3,500 gallon fish tankers acquired to replace old ones.
- Hi–Z tag studies show 94.6% immediate and 93.4% 120 hour survival for yearling chinook through LWG turbines (RMC Environmental Services, Inc., *et al.*, 1994).
- 18,796,196 juvenile salmonids were collected, 6,907,125 at LWG, 1,510,787 at LGO, 1,634,928 at LMO, and 8,743,356 at MCN; 17,368,977 juvenile salmonids were transported, 6,837,657 from LWG, 1,453,089 from LGO, 1,634,928 from LMO, and 7,662,433 from MCN; (Hurson, *et al.*, 1994 (in publication)).