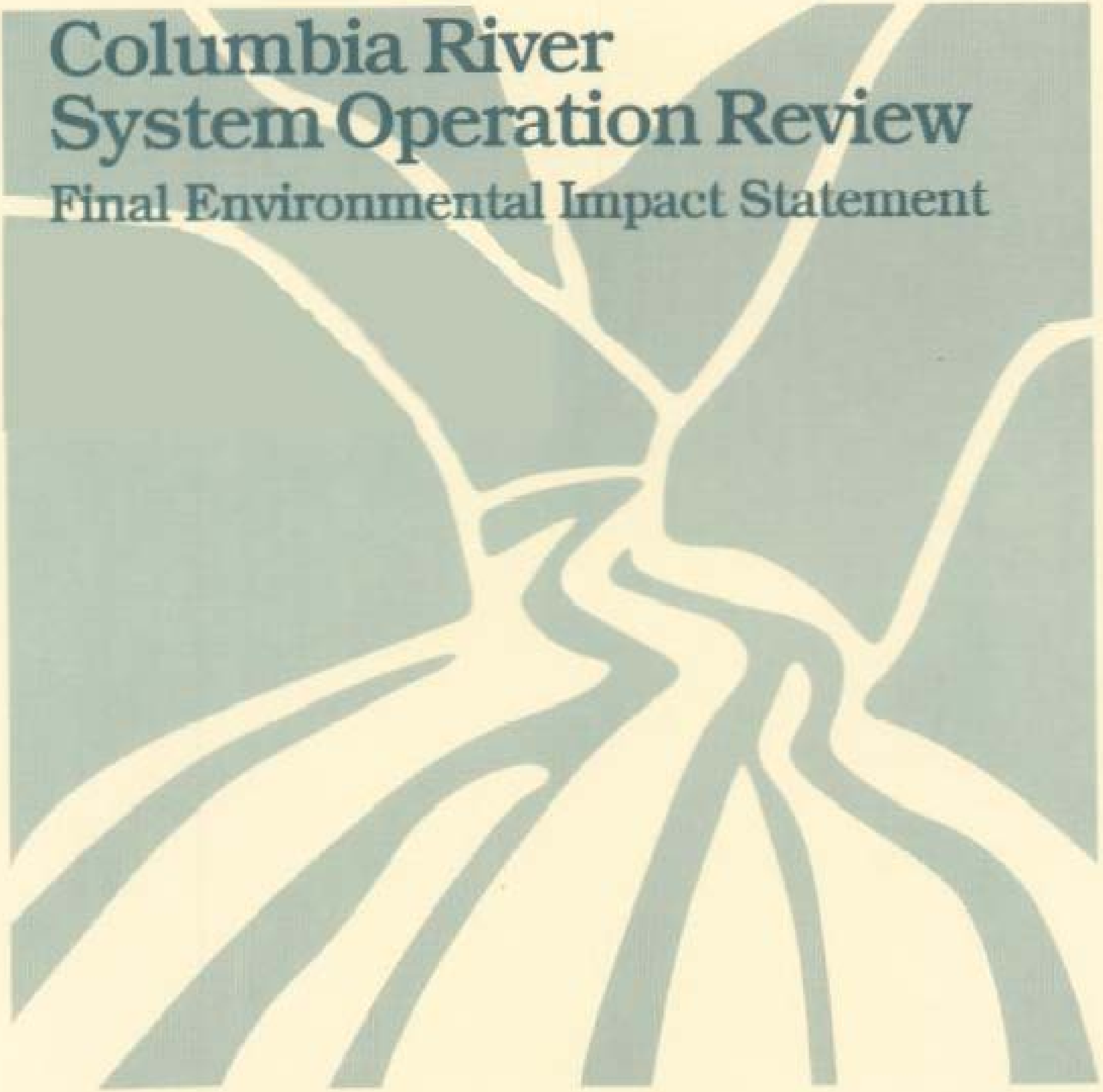
Columbia River System Operation Review

Final Environmental Impact Statement



Appendix C

Anadromous Fish and Juvenile Fish Transportation

BONNEVILLE

US Army Corps of Engineers
North Pacific Division

DOE/EIS-0170

November 1995

PUBLIC INVOLVEMENT IN THE SOR PROCESS

The Bureau of Reclamation, Corps of Engineers, and Bonneville Power Administration wish to thank those who reviewed the Columbia River System Operation Review (SOR) Draft EIS and appendices for their comments. Your comments have provided valuable public, agency, and tribal input to the SOR NEPA process. Throughout the SOR, we have made a continuing effort to keep the public informed and involved.

Fourteen public scoping meetings were held in 1990. A series of public roundtables was conducted in November 1991 to provide an update on the status of SOR studies. The lead agencies went back to most of the 14 communities in 1992 with 10 initial system operating strategies developed from the screening process. From those meetings and other consultations, seven SOS alternatives (with options) were developed and subjected to full–scale analysis. The analysis results were presented in the Draft EIS released in July 1994. The lead agencies also developed alternatives for the other proposed SOR actions, including a Columbia River Regional Forum for assisting in the determination of future SOSs, Pacific Northwest Coordination Agreement alternatives for power coordination, and Canadian Entitlement Allocation Agreements alternatives. A series of nine public meetings was held in September and October 1994 to present the Draft EIS and appendices and solicit public input on the SOR. The lead agencies received 282 formal written comments. Your comments have been used to revise and shape the alternatives presented in the Final EIS.

Regular newsletters on the progress of the SOR have been issued. Since 1990, 20 issues of *Streamline* have been sent to individuals, agencies, organizations, and tribes in the region on a mailing list of over 5,000. Several special publications explaining various aspects of the study have also been prepared and mailed to those on the mailing list. Those include:

The Columbia River: A System Under Stress
The Columbia River System: The Inside Story
Screening Analysis: A Summary
Screening Analysis: Volumes 1 and 2
Power System Coordination: A Guide to the Pacific Northwest Coordination Agreement
Modeling the System: How Computers are Used in Columbia River Planning
Daily/Hourly Hydrosystem Operation: How the Columbia River System Responds to Short–Term Needs

Copies of these documents, the Final EIS, and other appendices can be obtained from any of the lead agencies, or from libraries in your area.

Your questions and comments on these documents should be addressed to:

SOR Interagency Team
P .O. Box 2988
Portland, OR 97208–2988

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 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.

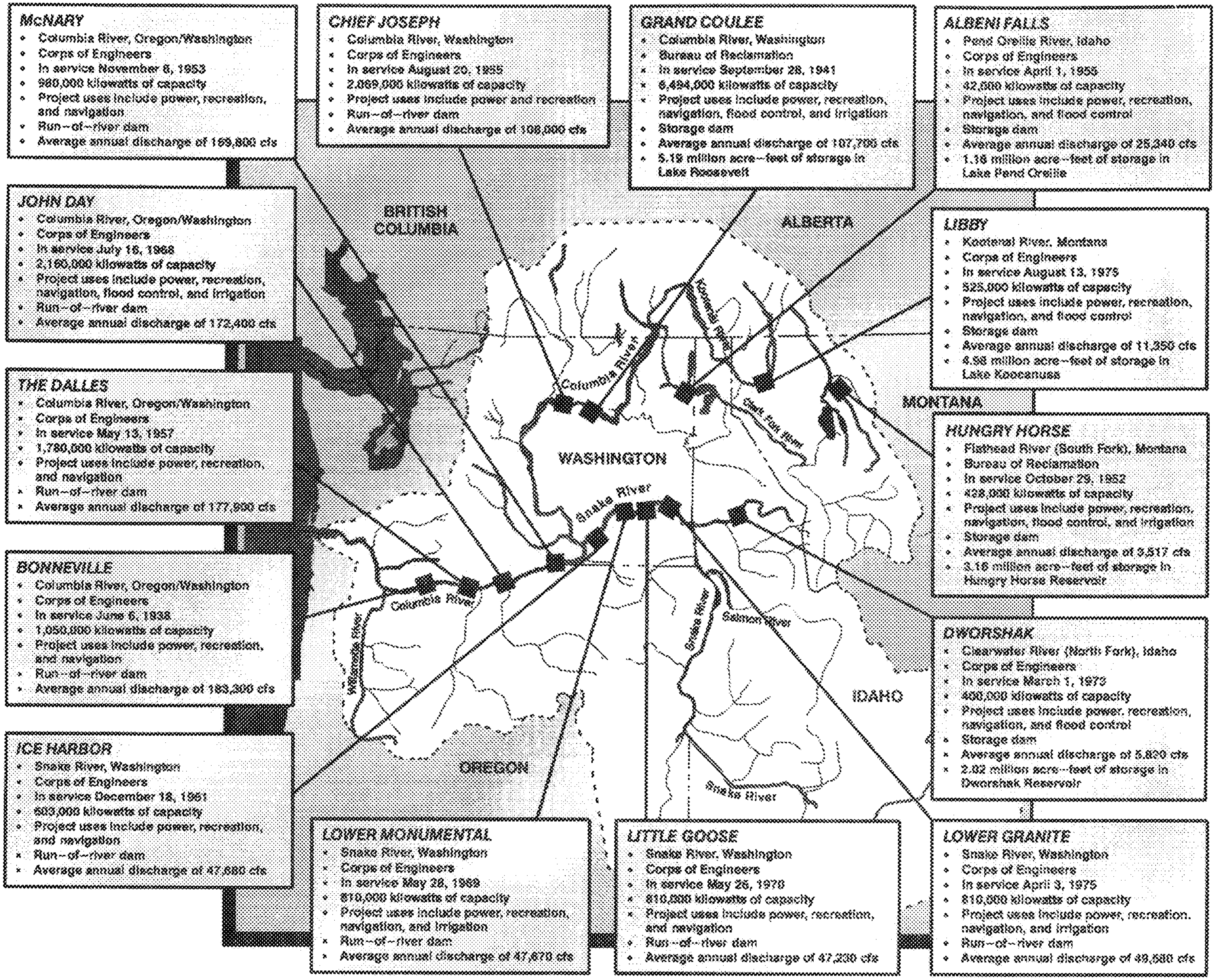
WHAT DO THE TECHNICAL APPENDICES COVER?

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.



McNARY
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service November 6, 1953
- 980,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 169,800 cfs

CHIEF JOSEPH
- Columbia River, Washington
- Corps of Engineers
- In service August 20, 1955
- 2,069,000 kilowatts of capacity
- Project uses include power and recreation
- Run–of–river dam
- Average annual discharge of 108,000 cfs

GRAND COULEE
- Columbia River, Washington
- Bureau of Reclamation
- In service September 28, 1941
- 6,494,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Storage dam
- Average annual discharge of 107,700 cfs
- 5.19 million acre–feet of storage in Lake Roosevelt

ALBENI FALLS
- Pend Oreille River, Idaho
- Corps of Engineers
- In service April 1, 1955
- 42,600 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 25,340 cfs
- 1.16 million acre–feet of storage in Lake Pend Oreille

JOHN DAY
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service July 16, 1968
- 2,160,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Run–of–river dam
- Average annual discharge of 172,400 cfs

LIBBY
- Kootenai River, Montana
- Corps of Engineers
- In service August 13, 1975
- 525,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 11,350 cfs
- 4.98 million acre–feet of storage in Lake Koocanusa

THE DALLES
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service May 13, 1957
- 1,780,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 177,930 cfs

HUNGRY HORSE
- Flathead River (South Fork), Montana
- Bureau of Reclamation
- In service October 29, 1952
- 428,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Storage dam
- Average annual discharge of 3,517 cfs
- 3.16 million acre–feet of storage in Hungry Horse Reservoir

BONNEVILLE
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service June 6, 1938
- 1,050,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 183,300 cfs

DWORSHAK
- Clearwater River (North Fork), Idaho
- Corps of Engineers
- In service March 1, 1973
- 400,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 5,820 cfs
- 2.02 million acre–feet of storage in Dworshak Reservoir

ICE HARBOR
- Snake River, Washington
- Corps of Engineers
- In service December 18, 1961
- 603,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 47,680 cfs

LOWER MONUMENTAL
- Snake River, Washington
- Corps of Engineers
- In service May 28, 1969
- 810,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and irrigation
- Run–of–river dam
- Average annual discharge of 47,670 cfs

LITTLE GOOSE
- Snake River, Washington
- Corps of Engineers
- In service May 26, 1970
- 810,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 47,230 cfs

LOWER GRANITE
- Snake River, Washington
- Corps of Engineers
- In service April 3, 1975
- 810,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and irrigation
- Run–of–river dam
- Average annual discharge of 48,580 cfs

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.

TABLE OF CONTENTS

TABLE OF CONTENTS – CONT

Chapter/Para Page

TABLE OF CONTENTS - CONT

TABLE OF CONTENTS - CONT

TABLE OF CONTENTS – CONT

TABLE OF CONTENTS – CONT

Chapter/Para Page

TABLE OF CONTENTS – CONT

Chapter/Para Page

TABLE OF CONTENTS – CONT

LIST OF TABLES

LIST OF TABLES – CONT

LIST OF TABLES – CONT

LIST OF FIGURES

LIST OF FIGURES – CONT

LIST OF FIGURES - CONT

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 harvesting 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.

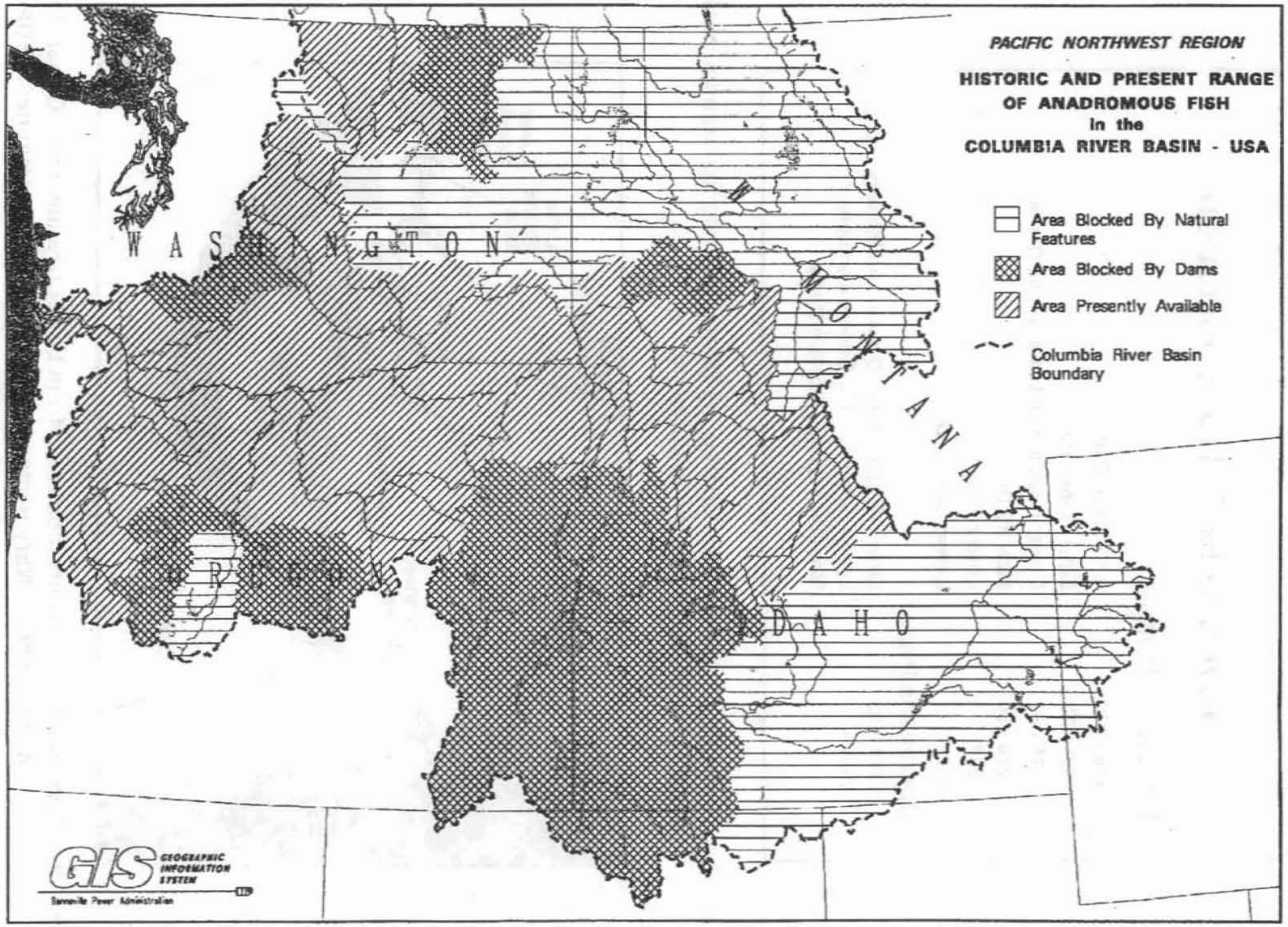


Figure 1–1. Historic and Present Range of Anadromous Fish in the Columbia River Basin – USA

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

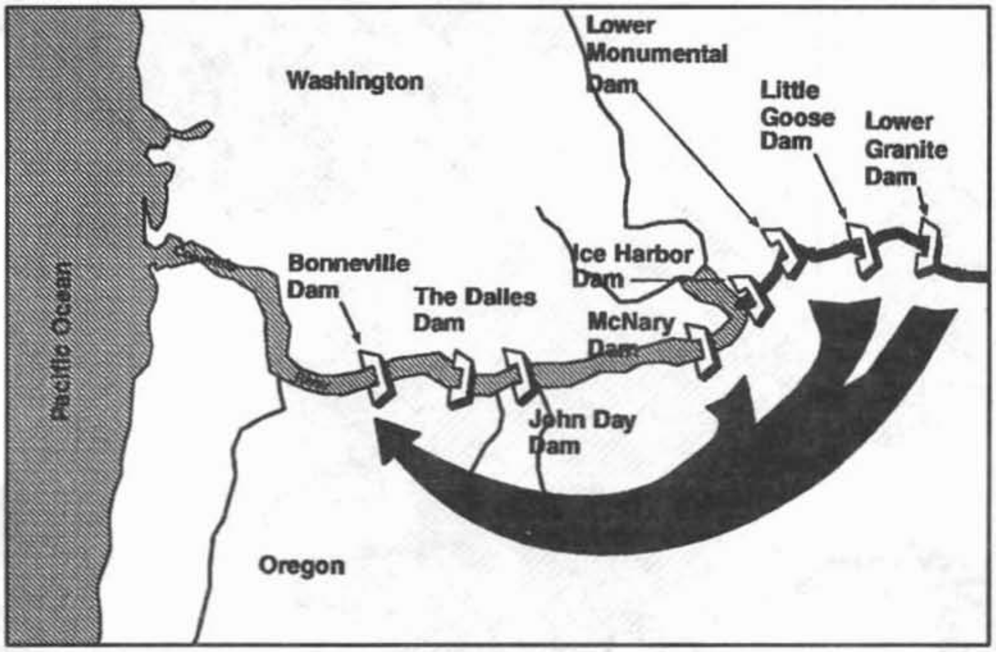


Figure 1–3. Juvenile fish transportation route from Lower Granite, Little Goose, Lower Monumental, and McNary dams to release areas below Bonneville Dam

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

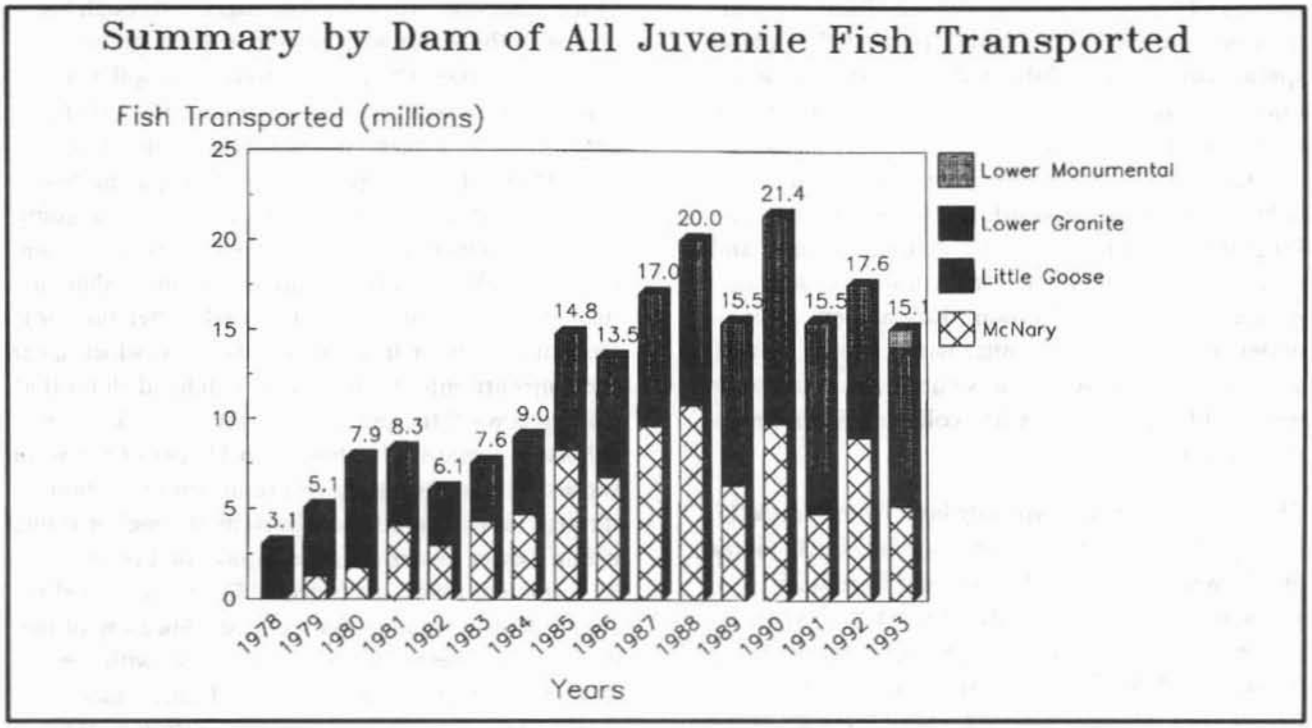


Figure 1–4. Summary by dam of all juvenile fish transported from 1978 through 1993

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.

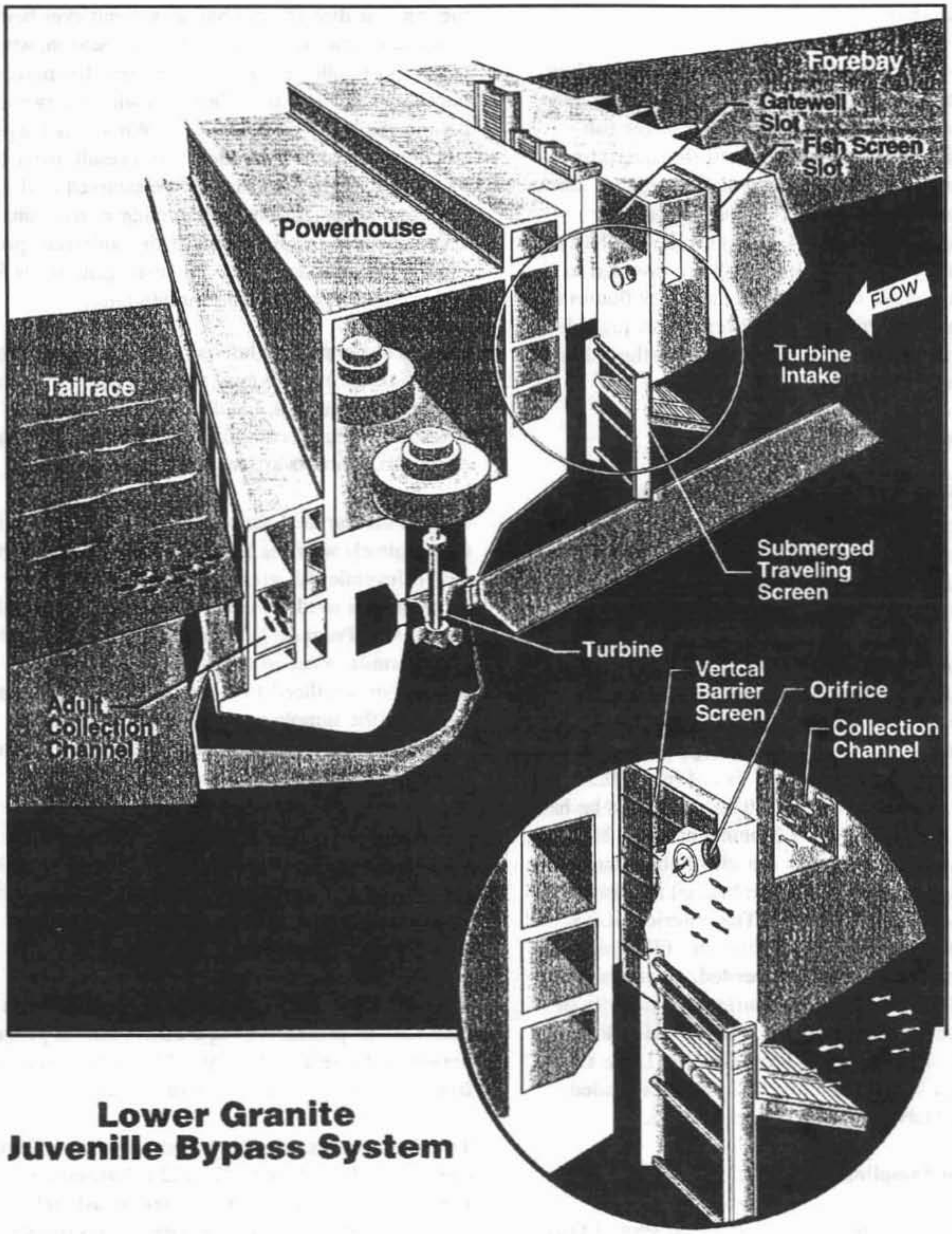


Figure 1–5. Lower Granite juvenile bypass system showing location of fish screen, orifice, and collection channel.

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.

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.

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

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

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.

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 hatchery 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 salmonid 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 inconsistent 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 necrosis 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 over-harvest, 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 concept 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.

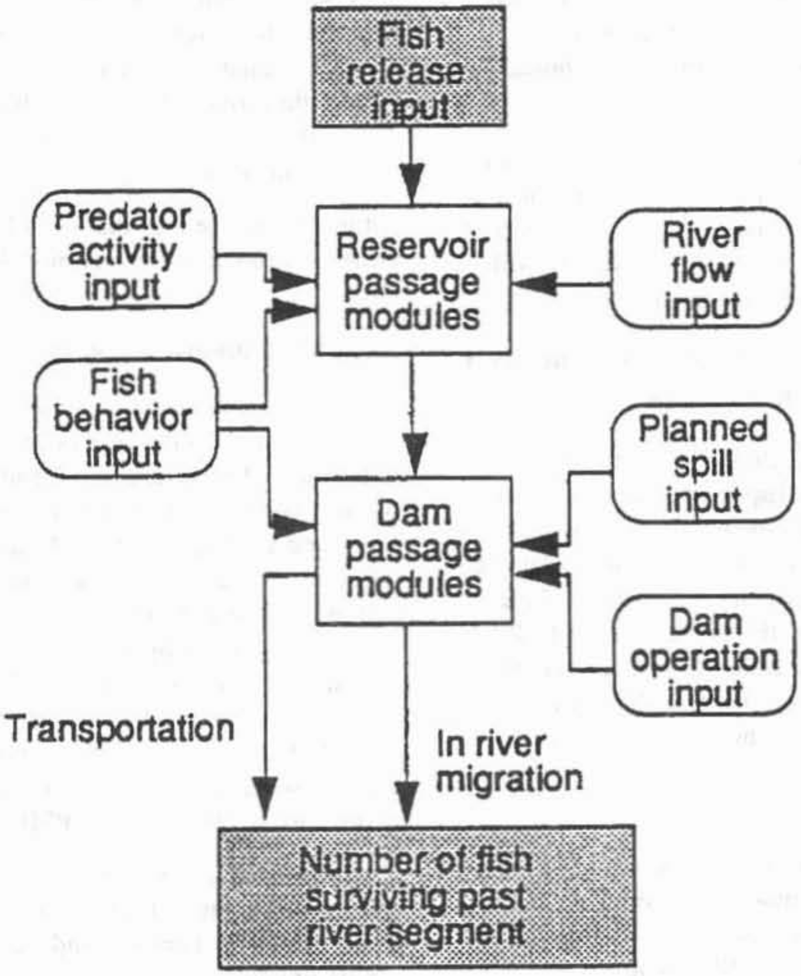


Figure 3–1. Overview of Columbia River Salmon Passage Model (CRiSP1.5)

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.

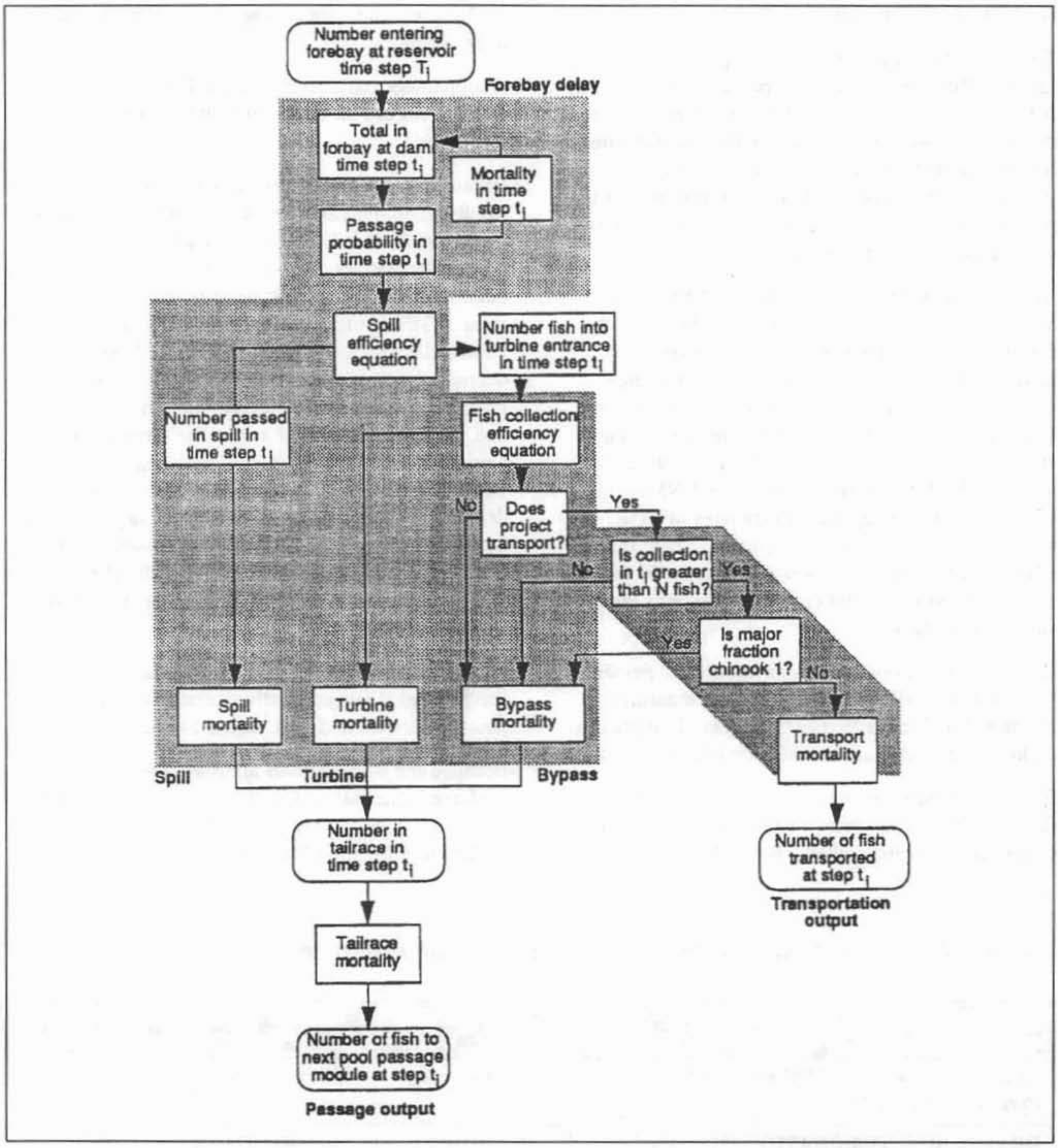


Figure 3–2. Dam Passage Module of CRiSP1.5

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	$(\%\ \text{spill x } 100)^{1.0437}/100$
Wanapum	(15.52 x ln(% spill x 100)/100)
Priest Rapids	$e^{(0.819 \text{ x } \ln(\%\ \text{spill x } 100))}/100$
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

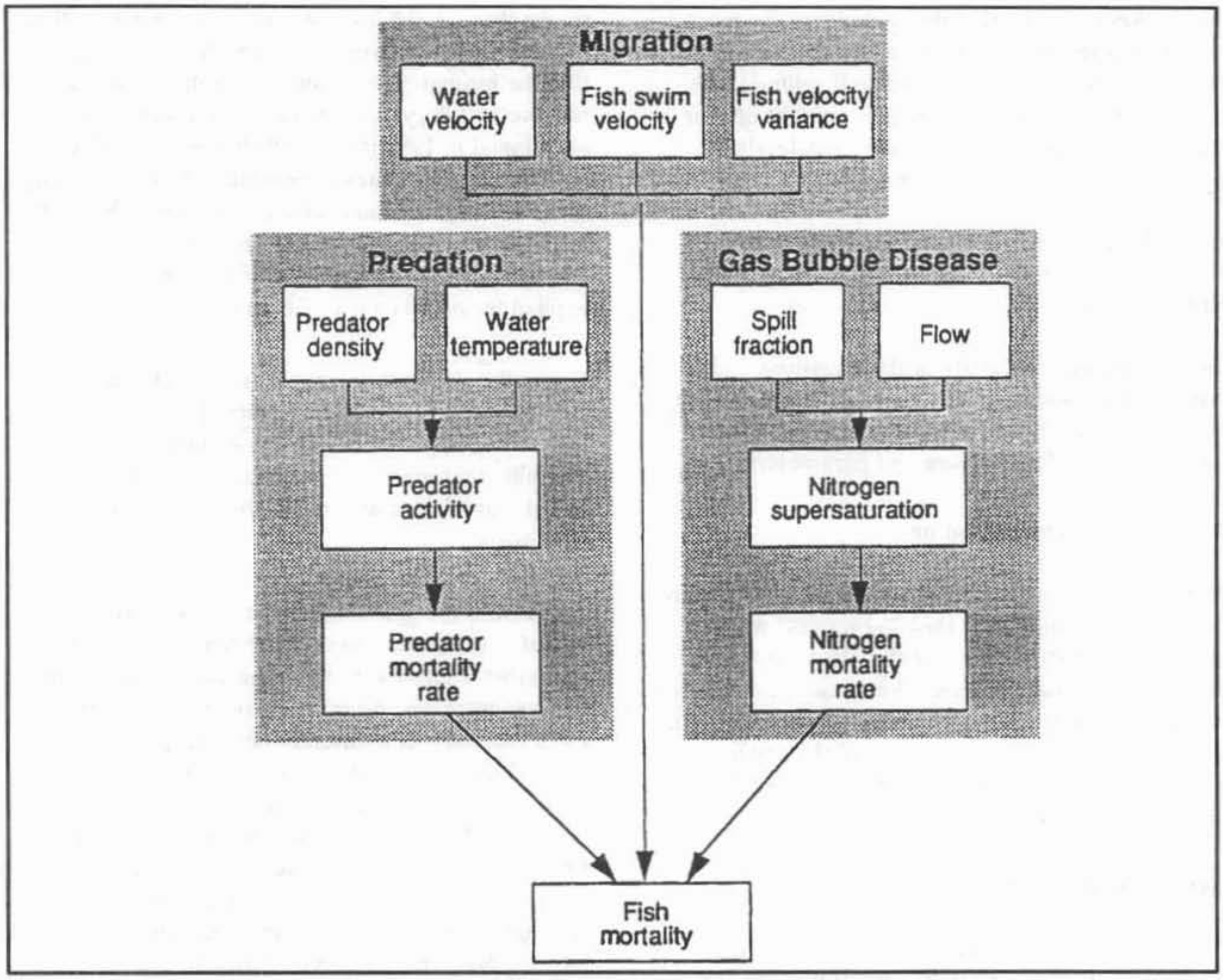


Figure 3–3. Reservoir Passage Module in CRiSP1.5

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:

$$\text{juvenile transportation survival} = \text{TIR} \times \text{juvenile "control" survival}$$

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.

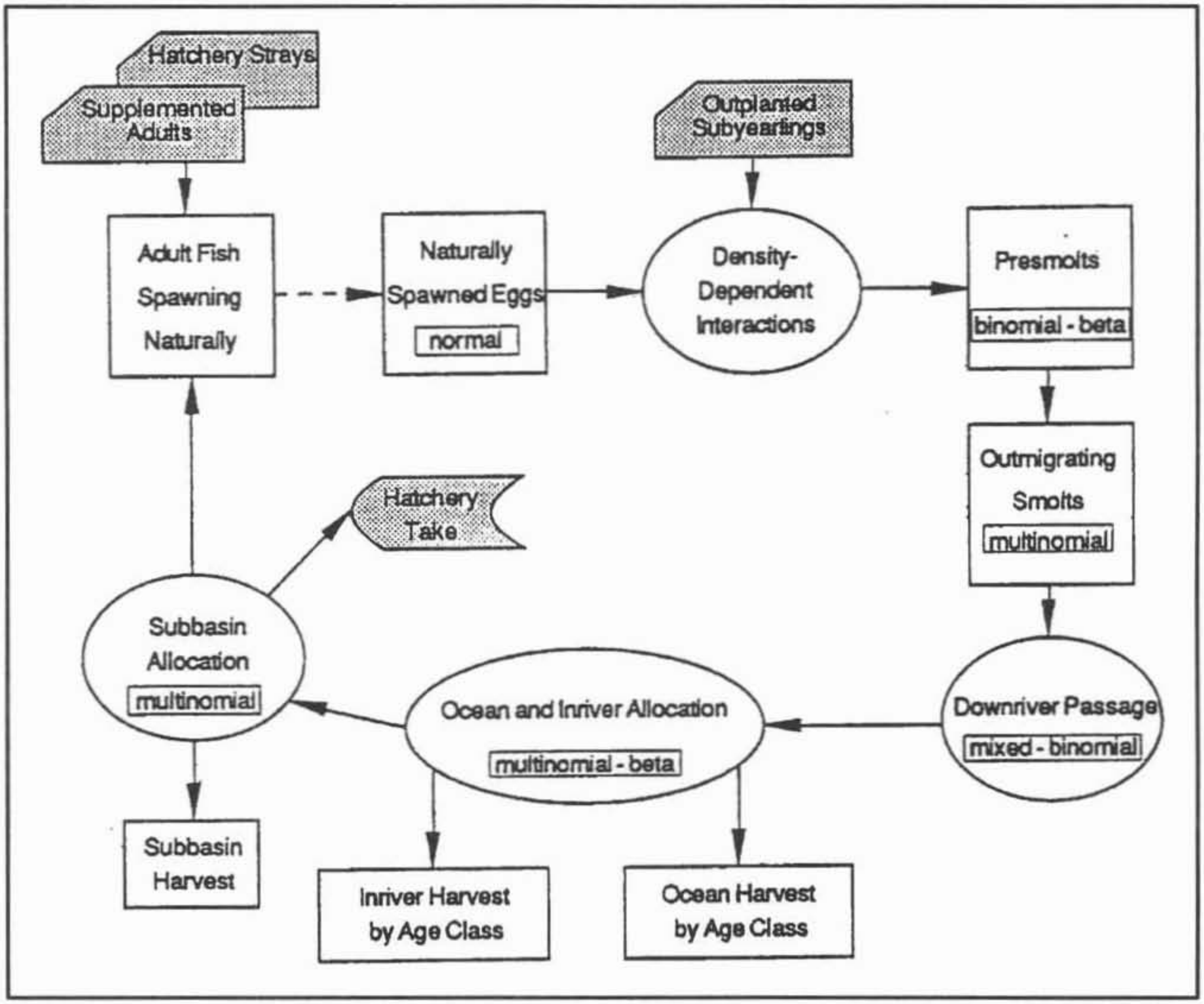


Figure 3–4. Flow Chart for SLCM. At each life cycle stage, the survival to the next stage is drawn from the stated probability distribution (*e.g.*, a normal distribution is used to simulate the transition from spawners to the egg stage).

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.