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Managing Water in the West

Assessment of the Effects of the Yakima Basin Storage Study on Columbia River Fish Proximate to Proposed Intake Locations

A component of
Yakima River Basin Water Storage Feasibility Study, Washington

Technical Series No. TS-YSS-13

Columbia River, potential pump site

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

January 2008

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PREFACE

The Congress directed the Secretary of the Interior, acting through the Bureau of Reclamation, to conduct a feasibility study of options for additional water storage in the Yakima River basin. Section 214 of the Act of February 20, 2003 (Public Law 108-7), contains this authorization and includes the provision "… with emphasis on the feasibility of storage of Columbia River water in the potential Black Rock Reservoir and the benefit of additional storage to endangered and threatened fish, irrigated agriculture, and municipal water supply."

Reclamation initiated the Yakima River Basin Water Storage Feasibility Study (Storage Study) in May 2003. As guided by the authorization, the purpose of the Storage Study is to identify and examine the viability and acceptability of alternate projects by: (1) diversion of Columbia River water to a potential Black Rock reservoir for further water transfer to irrigation entities in the lower Yakima River basin as an exchange supply, thereby reducing irrigation demand on Yakima River water and improving Yakima Project stored water supplies; and (2) creation of additional water storage within the Yakima River basin. In considering the benefits to be achieved, study objectives are to modify Yakima Project flow management operations to improve the flow regime of the Yakima River system for fisheries, provide a more reliable supply for existing proratable water users, and provide water supply for future municipal demands.

State support for the Storage Study was provided in the 2003 Legislative session. The 2003 budget included appropriations for the Washington State Department of Ecology (Ecology) with the provision that the funds ". . . are provided solely for expenditure under a contract between the department of ecology and the United States bureau of reclamation for the development of plans, engineering, and financing reports and other preconstruction activities associated with the development of water storage projects in the Yakima river basin, consistent with the Yakima river basin water enhancement project, P.L. 103-434. The initial water storage feasibility study shall be for the Black Rock reservoir project." Since that initial legislation, the State of Washington has appropriated additional matching funds.

Storage Study alternatives were identified from previous studies by other entities and Reclamation, appraisal assessments by Reclamation in 2003 through 2006, and public input. Reclamation filed a Notice of Intent and Ecology filed a Determination of Significance to prepare a combined *Draft Planning Report and Environmental Impact Statement* (*Draft PR/EIS*) on December 29, 2006. A scoping process, including public scoping meetings, in January 2007 identified several concepts to be considered in the *Draft PR/EIS*. Those concepts have been developed into “Joint” and “State” Alternatives.

The Joint Alternatives fall under the congressional authorization and the analyses are being cost-shared by Reclamation and Ecology. The State Alternatives are outside the congressional authorization, but within the authority of the State legislation, and will be analyzed by Ecology only. Analysis of all alternatives will be included in the *Draft PR/EIS*.

This technical document and others explain the analyses performed to determine how well the alternatives meet the goals of the Storage Study and the impacts of the alternatives on the environment. These documents will address such issues as hydrologic modeling, sediment modeling, temperature modeling, fish habitat modeling and designs and costs. All technical documents will be referenced in the *Draft PR/EIS* and available for review

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SUMMARY

The following five questions from the *Defining the Fish and Wildlife Resource Issues for the Yakima River Basin Water Storage Feasibility Study* report (Biology Technical Work Group, 2004) were posed to the Bureau of Reclamation's Technical Service Center to determine the potential effects of the Black Rock Alternative of the Yakima River Basin Water Storage Feasibility Study (Storage Study) on Columbia River fish species proximate to the proposed intake location at Priest Rapids Lake. The summarized findings that follow are based on and supported by the details addressed in the main body or appendices to this document.

It should be noted that three options were considered when defining the Black Rock Alternative—a 3,500-cfs pump-only option (to lift water to Black Rock Valley), a 6,000-cfs pump-only option, and a 3,500-cfs pump/generation option. (Reclamation, 2004). When the modeling for this report was initiated, the 6,000-cfs withdrawal scenario was generally the one used in analyses of the flow field zone of influence, as it was assumed to create the larger (worst case) area of fish influence and temperature effect. However, after further analyses, Reclamation decided to carry forward the 3,500-cfs pump-only option into the feasibility study. Therefore, the 3,500-cfs scenario is used in the analysis and estimates of effects instead of the 6,000-cfs scenario used in the computer-modeled flows. This report assumes that the 3,500-cfs pumping plant would have fewer adverse effects than the 6,000-cfs option modeled.

(1) How would withdrawal of water from Priest Rapids Lake affect anadromous fish spawning and rearing habitat, fry and juvenile stranding, and passage and migration?

It is unlikely that salmon spawning is present within the Priest Rapids Lake intake location. In addition, the amount of water withdrawn is so small when compared to the total Columbia River capacity that withdrawal would not impact spawning to any greater degree than current reservoir operations. Juvenile stranding information has primarily been investigated in the Hanford reach below Priest Rapids Dam. Although the level of fluctuations are dampened by the channel configuration (Nugent, 2002), an operations plan with constraints specifically designed to reduce loss of juveniles by stranding and entrapment was developed. The *Hanford Reach Fall Chinook Protection Program Agreement* (*Hanford Reach Agreement*), dated April 5, 2004 (Appendix A) outlined dam operations to reduce the impacts on the salmon in the Hanford Reach by stabilizing flows and limiting the magnitude of changes in water releases. With releases maintained in accordance with the *Hanford Reach Agreement* and the relatively small fluctuations that would occur due to withdrawal, there is a low likelihood of impacts in downstream stranding of juvenile salmonids.

If a project were implemented, monitoring should be a component. The nearest juvenile salmon monitoring site is 56 miles (90.1 km) upriver at Rock Island Dam—where estimates of outmigration through the pool are determined. The Listed Salmonid Operations Plan (LSOP) and the *Hanford Reach Agreement* provide operating restrictions on Priest Rapids Dam operations from June to July when the majority of fall Chinook outmigrants are in the pool. The earlier sockeye, Chinook, and steelhead outmigrants could be attracted to the intake and the appearance of a "downstream" flow, but the magnitude of that flow compared to the through-reservoir flows would be small. Reclamation used the National Marine Fisheries Services (NMFS) criteria (NMFS, 1997) for salmonids to design the fish screens and bypass pipes. These criteria include channel velocities, screen approach velocities, screen sweeping velocities, exposure time along screen, maximum bypass pipe flow velocity, and minimum radius of bypass pipe bends.

If young salmonids are drawn to the pumped flows, they most likely would be able to escape the screen's approach velocity. However, if they were entrained into the intake, they would be screened and bypassed back into the river below the dam.

(2) How would withdrawal of water from Priest Rapids Lake affect resident fish spawning and rearing habitat?

The spawning and rearing habitats are generally in the shallow littoral zones of the reservoir. Impacts to these zones are most likely to occur due to elevation fluctuations and wave action. Current operation scenarios described for the Black Rock Alternative generally do not indicate reservoir elevation changes anywhere near the magnitude of present operations, and the area affected by the intake pumps is minor in comparison to the total amount of littoral habitat available in Priest Rapids Lake. Fish that have been able to spawn and rear in the present conditions should be able to continue with little change in habitats or opportunities to spawn. Resident fish inhabiting Priest Rapids Lake are primarily composed of nonnative species whose reduction through fish entrainment could be considered beneficial if direct competition with native species (including salmonids) is determined.

Fish residing near the intake would be most affected by the withdrawal of water due to their proximity to the intake for longer periods than passing anadromous fish. In addition, all spring, summer, and protracted season spawning fish with demersal fry would be highly susceptible to entrainment, as well as drifting white sturgeon fry. These young life stages would not have the swimming ability to hold or pull out of the entraining flows into the pumping facility.

(3) What is a likely estimate of fish mortality at the intake site on Priest Rapids Lake?

This is a very difficult number to estimate, though various analyses have been performed. Screening is planned at the intake and pumping facility located in Priest Rapids Lake and rigorous criteria to protect salmonids from impingement and entrainment has been designed. The submerged screen area and screen mesh size required to meet NMFS screen criteria will be met at this facility. The computer flow model determined the zone of influence at the 6,000-cfs pumping scenario to be a 580-foot radius in front of the intake, with water velocities of 0.2 fps or greater. This velocity (0.2 fps) was determined to be half the approach velocity criteria for salmon as established by NMFS fish screen protection guidelines.

A hydroacoustic survey was performed in June 2006 and a density of 9 to 14 fish per 1,000 cubic meters of water in the 580-foot radius was found. This snapshot of data suggests there were few fish within this zone of influence at that time and they could potentially be drawn in and either impinged on the screens or screened and bypassed back to the river through the protected intake facility. With the predicted smaller zone of influence in the 3,500-cfs scenario, the number of fish entrained should be even lower.

A correlated passage index is used to estimate passage of salmon through the Columbia River reservoirs. This technique shows how a proportion of salmon passing a dam is correlated to the proportion of flow. For instance, the 3,500-cfs flow proposed for this project is a small proportion of the total Columbia River flow. Therefore, a small proportion of fish could be entrained and a proportion of these entrained fish could die.

Very little information can be found as to mortality of fish encountering screens. Tests performed on rotary screens (Neitzel et al., 1996), commonly used in the Yakima River basin, indicate low fish injury rates exposed to various angled approach screens. No mortalities were indicated, nor was determination of mortality the objective of the test. Further testing regarding instant and long-term mortality at a screen site is needed to quantify the mortality of various species and the relationship between mortality and duration of screen exposure.

Predators are a common cause of mortality to disoriented fish exiting the bypass systems back into the river (Shively et al., 1995), and salmonid mortality will undoubtedly occur at the bypass outfall below Priest Rapids Dam. Selecting a proper discharge site location and using the most current hydraulic designs to reduce fish predation will be needed.

Few studies have evaluated survival through bypass systems or the entire bypass system. The use of voluntary spill to improve passage survival is based on data indicating that survival of juvenile salmonids passing dams is greatest at spillways, followed by juvenile bypass systems and then turbines (Muir et al. 2001). This benefit, however, could be offset by reduced survival due to the effects of gas bubble disease caused by increased total dissolved gas supersaturation when air entrained in spilled water dissolves under hydrostatic pressure in dam tailraces (Beeman and Maule, 2006). There is potential for higher survival of fish that would be transported through the proposed diversion bypass than survival of fish that pass through the turbines. Further investigation and testing is needed.

Studies performed by Muir et al. (2001) evaluated the Little Goose Dam (Snake River) bypass system in 1997 and were the first to estimate mortality for fish that passed along the submersible traveling screen, into the gatewell, through the orifice into the collection channel, and into the bypass outfall area, where predation can be especially high. Estimated survival through bypass systems ranged from 95.4 to 99.4 percent for yearling Chinook salmon and from 92.9 to 98.3 percent for steelhead released into the collection channel. Estimated survival was 95.3 percent for steelhead that passed through the entire bypass system. Estimated turbine survival ranged from 86.5 to 92.7 percent for yearling Chinook salmon and was 93.4 percent for steelhead at Little Goose Dam in 1997.

Table S-1 presents a summary of potential Priest Rapids Lake resident fish species affected by the project operations. These potential impacts are principally from intake flows bringing weak-swimming young larval fish into the screen and bypass system. There is potential loss of several nonnative and native fish larvae/fry known to spawn in the Priest Rapids Lake area due to impingement of the weak-swimming young. Further information as to their abundance, timing, and true proximity to the zone of pumping influence during their spawning/nursery season needs further study. Fish impinged on screens and unable to pull themselves off would have the highest mortality rate.

Table S-1. Potentially Impacted Fish Species

Common Name	Scientific Name	Status**
*lake whitefish	*Coregonus clupeaformis*	native game fish, rare
white sturgeon	*Acipenser transmontanus*	native game fish, common
*northern pikeminnow	*Ptychocheilus oregonensis*	native non-game fish, abundant
*redside shiner	*Richardsonius balteatus*	native non-game fish, abundant
*longnose dace	*Rhinichthys cataractae*	native non-game fish, common
*carp	*Cyprinus carpio*	introduced non-game fish, common

*bridgelip sucker	*Catostomus columbianus*	native non-game fish, abundant
*largescale sucker	*Catostomus macrocheilus*	native non-game fish, abundant
*channel catfish	*Ictalurus punctatus*	introduced game fish, common
brown bullhead	*Amiurus nebulosus*	introduced game fish, common
*black bullhead	*Amiurus melas*	introduced game fish, uncommon
yellow bullhead	*Amiurus natalis*	introduced game fish, uncommon
*three-spined stickleback	*Gasterosteus aculeatus*	native non-game fish, abundant
sandroller	*Percopsis transmontana*	native non-game fish, rare
*largemouth bass	*Micropterus salmoides*	introduced game fish, common
*smallmouth bass	*Micropterus dolomieu*	introduced game fish, common
*black crappie	*Pomoxis nigromaculatus*	introduced game fish, common
*white crappie	*Pomoxis annularis*	introduced game fish, common
*bluegill	*Lepomis macrochirus*	introduced game fish, uncommon
*pumpkinseed	*Lepomis gibbosus*	introduced game fish, uncommon
American shad	*Alosa sapidissma*	introduced non-game fish, uncommon
*walleye	*Stizostedion vitreum*	introduced game fish, common
*yellow perch	*Perca flavescens*	introduced game fish, common

*Indicates that individuals of this species were sampled during 1999 descriptive survey.
**Based on estimate of relative abundance in one of four categories: abundant, common, uncommon, rare.

(4) How would withdrawal of water from Priest Rapids Lake affect water temperature and water chemistry parameters, and how far would such effects extend within the pool and downstream?

This question was primarily dealt with an examination of water temperature model scenarios. Predictions using SSTEMP and CE-QUAL-W2 could not be performed without violating model assumptions. The primary violations were in volume of water used in estimation. In an attempt to use a “scaled” SSTEMP analysis, the sensitivity of prediction [within about 1.8°F (1°C)] is not sensitive enough to predict what looks like a minute change in withdrawing 6,000 cfs. This temperature change should be even less in the Plan 2 (3,500-cfs) withdrawal scenario. Water temperature predictions were nearly identical in using with and without withdrawal scenarios. In examination of other water quality parameters there was no obvious scenario whereby the withdrawal of water would affect the chemical constituents downstream. The estimated percentage of withdrawal was between 2.68 to 8.67 (mean 5.99) percent of instantaneous outflow of Priest Rapids. If further detailed temperatures predictions are needed, it is recommended that a specific model be developed with full-scale water passage magnitude capabilities. Due to the peaking nature of Priest Rapids, an already agreed-upon reservoir fluctuation scenario, and the uncertainty of project operations, elevation models have not yet been created to examine effective changes on pool water surface elevations. Potentially, the small percentage of change in water withdrawal relative to the pool capacity and flows would result in a relatively small change in water surface elevation.

The Water Quality section (section 4.6) of the Yakima River Basin Water Storage Feasibility Study Draft Planning Report/Environmental Impact Statement (Draft PR/EIS) reported other water quality parameters. Results were similar, with a very low detectable change between project and nonproject operations.

(5) How would additional storage and resulting changes in water delivery operations affect false attraction of salmonids in situations where Yakima River fish are attracted into or delayed at inappropriate locations, and/or situations where Columbia River fish are attracted into or delayed at Yakima River locations?

There is sparse information on determination of chemical cues (odors) upon which salmon imprint. One proposed theory includes the proportion of discharge water that would allow orientation. At a qualitative level, the likelihood of disorientation by the salmon is most likely related to the proportional contribution of the unfamiliar water (i.e., the proportion of the discharge that they would detect that was "pure" Yakima River system water and what proportion was from the Columbia River upstream from the Yakima River). The smaller the proportion of unfamiliar water, the less likely the salmon would be to experience delay or disorientation. With the Black Rock Alternative, as little Columbia River water as possible would enter the Yakima River as irrigation return flow. Between .05 percent and 1.5 percent of the Yakima River flow would be from irrigation return flows during proposed project operations. Water from the Columbia River that had seeped through the ground in the Yakima basin would presumably be changed during that period to become more similar to "pure" Yakima River system water than the Columbia River water was before it was diverted. It seems likely that the longer the Columbia River water is within the Yakima River system and the higher the proportion of water that seeps through the ground before returning to the Yakima River (and from there into the Columbia), the less likely the fish are to be confused. However, at present there does not seem to be an objective way of evaluating the relative importance of these factors—the proportion of imported water and extent to which that imported water would become "naturalized" to the Yakima River system.

The first generations of salmon returning to the spawning areas in the Columbia River system above the confluence with the Yakima River after the diversion occurs would encounter Columbia River water (including, presumably, some water from their natal system) in both the mainstem and also the Yakima River itself. In general, it seems likely that the Columbia River will be sufficiently modified by the reservoir system that it will probably not cause the fish to detour into the Yakima River, though they might delay briefly there. In subsequent generations, salmon that migrated downstream and passed the confluence with the Yakima River on their way downstream would probably imprint on that area as part of their overall sequence of learning, and would be less likely to be confused than the first generations. Therefore, the likelihood of disorientation seems to be greater for the first generations (i.e., those salmon that went to sea before the diversion was completed) than subsequent generations (fish that migrated as smolts under the new set of conditions).

However, there are clearly two major uncertainties—the first is the relationship between the small proportion of Columbia River water in the Yakima River and the proportion of salmon disoriented. There may be some threshold, below which no salmon are disoriented, followed by a linear or an accelerating proportion of salmon disoriented as the proportion of Columbia River water increases.

Second, little is known about the process by which Columbia River water would become indistinguishable from Yakima River water, i.e., is it because of residence time in the system, is residence time in the reservoir equivalent to time seeping through the soil, does the season of the year matter, etc.? The complex relationship between the residence time of foreign water within a watershed and potential impacts on olfactory-mediated migrations are also not known. Fundamentally, biologists know very little about the ways in which odors important to salmon homing vary from season to season and year to year, and do not know how to characterize the odors that fish use to distinguish one river from another. This lack of understanding about basic olfaction and water chemistry hampers the ability to foresee how the fish will react to some future set of conditions.

It should also be noted that the previous discussion assumes that the proportion of diverted Columbia River water relative to Yakima River water would remain constant seasonally (i.e., the amount of diverted water released into the Yakima River would be proportionally equivalent during both the juvenile outmigration and the subsequent adult homing migration). In reality, most water diversion projects, especially those used for irrigation, are operated seasonally so that water is collected during periods of high natural runoff (spring) and released for irrigation during low flow periods (summer/fall). Depending on the species of salmonid and their particular migratory patterns, this could mean that the water homing adults experience may be very different than the water learned as outmigrating juveniles. This suggests that it is important that all operational planning for the water divergence project anticipate potential problems associated with seasonal variation of operations and the migratory life histories of Yakima and upper Columbia River salmonids.

The magnitude of the proposed diversion is very great and there are clearly uncertainties as to whether there will be any deleterious (harmful) effects on salmon homing, along with the other issues that will pertain to this proposed project. Water diversion projects have been implemented in many places for many purposes around the world and fisheries biologists have raised concerns about the general impact of water transfer projects on fisheries resources (Meador, 1996). In some cases, “false attraction” has been raised as a concern, either because the temperature, flow, odors, or some other property of one water source might attract fish from another water source. Such projects are not generic, like laboratory experiments, but rather are unique to the situation in which they are planned or occur. Anecdotal or correlative reports of straying or migration delay have been reported at water diversions (Unwin and Quinn, 1993), but despite the large numbers of water diversion projects throughout the regions occupied by anadromous salmonids, there appear to be relatively few well-documented cases of straying related to false attraction or masking of homestream odors by diversion projects. This might be interpreted to mean that such projects have little impact on homing, but is probably more indicative of a lack of careful monitoring and studies directly examining these questions.

In tests performed in British Columbia, salmon could detect the home water and were attracted in higher proportions to water sources that contained home water. In tests performed at the Seton Dam with Seton Lake sockeye salmon, the fish did not significantly change preference in natal water that was diluted with 10 percent or less nonnatal water. This 10 percent should be a guiding threshold to begin with in operation scenarios and proportions of Columbia River water in the Yakima River at any time. At this time, the percentage of mixed water is predicted to be less than 2 percent of the Yakima River. In general, it seems likely that the Columbia River water will probably not cause significant detour. Although a delay and orientation could occur, how significant this would be requires further analyses. Relative volumes of water will determine magnitude of delay or false attraction.

Experiments investigating sockeye attraction under dilutions of local river water have started. These tests are being performed in the University of Washington to further understand the potential effects of this project or anadromous fish and false attraction.

The Wanapum Pool was another withdrawal site proposed. This option would withdraw water from the Columbia River at the Wanapum Pool and transport it to the Lmuma Creek confluence with the Yakima River. Appendix D of this report includes some field data regarding the Wanapum Pool. However, the location for the intake was poor and screening would be complicated. Therefore, this concept has been eliminated from further consideration in the Draft PR/EIS.

Chapter 1 INTRODUCTION

1.1 Background

In 2004, as part of the Yakima River Basin Water Storage Feasibility Study (Storage Study), Reclamation requested that the Washington Department of Fish and Wildlife (WDFW) identify fish and wildlife issues that the Storage Study should address. WDFW prepared a 45-item list of issues.

Reclamation then asked area fish and wildlife experts to form a Biology Technical Work Group (Biology TWG), consisting of technical representatives from National Oceanic and Atmospheric Administration (NOAA) Fisheries, U.S. Fish and Wildlife Service, WDFW, Ecology, the Yakama Nation, Yakima Basin Joint Board, Yakima Subbasin Fish and Wildlife Planning Board, and Reclamation's Upper Columbia Area Office (UCAO) and Technical Service Center (TSC). The Biology TWG refined the 45-item list down to 16 significant issues to serve as the foundation for fish and wildlife analyses and an environmental impact statement. A fish or wildlife issue was considered significant if the resource response was anticipated to be: (1) measurable (*i.e.*, either a positive or negative change from existing conditions); and (2) can be linked to more or less water in the Columbia or Yakima River systems resulting from implementation of an alternative of the Storage Study. The *Defining Fish and Wildlife Resource Issues for the Yakima River Basin Water Storage Feasibility Study* report (Biology Technical Work Group, 2004), describes the above Storage Study activities in more detail.)

1.2 Purpose of this Report

Reclamation's TSC was asked to answer five of those sixteen questions relating to the effects of the Storage Study on fish in close proximity to the proposed intake location at Priest Rapids Lake for the Black Rock Alternative. This alternative proposes to store Columbia River water in a potential offstream reservoir for exchange with Yakima River water. A key component of this alternative is the intake structure from the Columbia River. The focus of this report is to answer those five questions, as stated below:

(1) How would withdrawal of water from the Priest Rapids Lake affect anadromous fish spawning and rearing habitat, fry and juvenile stranding, and passage and migration?

(2) How would withdrawal of water from Priest Rapids Lake affect resident fish spawning and rearing habitat?

(3) What is the likely estimate of fish mortality at the intake site on Priest Rapids Lake?

(4) How would withdrawal of water from Priest Rapids Lake affect water temperature and water chemistry parameters, and how far would such effects extend within the pool and downstream?

(5) How would additional storage and resulting changes in water delivery operations affect false attraction of salmonids in situations where Yakima River fish are attracted into or delayed at inappropriate locations, and/or situations where Columbia River fish are attracted into or delayed at Yakima River locations?

It should be noted, that while questions number 1-4 relate specifically to the Priest Rapids Lake, there was another site proposed during the early stages of the Storage Study. This option would withdraw water from the Columbia River at the Wanupum Pool and transport it to the Lmuma Creek confluence with the Yakima River. The intake site was surveyed with hydroacoustics for fish density and bathymetry. The initial location for the intake was in the back of a slough (possibly an existing irrigation pump) and was not determined to be a good location as there are extensive wetland and shallow areas that currently provide good nursery habitat. Screening would be more complicated with production of aquatic macrophytes, and it is likely increased fish impingement of local fish (nursery area) would occur. Appendix D of this report includes some field data regarding the Wanapum Pool; however, this concept has been eliminated from further consideration in the Draft PR/DEIS.

Chapter 2 EXISTING FACILITIES AND OPERATIONS

This chapter describes the current operations of both the Priest Rapids Dam and Reservoir and the Wanapum Dam and Reservoir. Also described are the intake structures for both alternatives.

It should be noted that three options were considered when defining the Black Rock Alternative—a 3,500-cfs pump-only option (to lift water to Black Rock Valley), a 6,000-cfs pump-only option, and a 3,500-cfs pump/generation option. (Reclamation, 2004). When the modeling for this report was initiated, the 6,000-cfs withdrawal scenario was generally the one used in analyses of the flow field zone of influence, as it was assumed to create the larger (worst case) area of fish influence and temperature effect. However, after further analyses, Reclamation decided to carry forward the 3,500-cfs pump-only option into the feasibility study. Therefore, the 3,500-cfs scenario is used in the analysis and estimates of effects instead of the 6,000-cfs scenario used in the computer-modeled flows. This report assumes that the 3,500-cfs pumping plant would have fewer adverse effects than the 6,000-cfs option modeled.

2.1 Current Operations

Wanapum and Priest Rapids Lakes are operated to meet a variety of power and nonpower objectives. Typical power operations are geared toward meeting daily load requirements through assignment of coordinated generation under the *Hanford Reach Agreement*. Power and nonpower operations are also coordinated on a regional scale under the Pacific Northwest Coordination Agreement. Priest Rapids Lake is also operated to meet nonpower demands including flood control surcharges, minimum flow requirements, reshaping flows for fall Chinook spawning and rearing protection, and maintaining reservoir elevations for recreation purposes. Key physical characteristics of each reservoir are summarized in Table 2-1, below.

Table 2-1. Estimated Physical Characteristics of Wanapum and Priest Rapids Lakes (source: Grant County PUD, 2003)

Characteristic	Wanapum Reservoir	Priest Rapids Lake
Surcharge elevation (feet)	575.0	491.5
Normal maximum operating elevation (feet)	571.5	488.0
Minimum operating elevation (feet)	560.0	481.5
Storage at normal maximum elevation (acre-feet)*	693,600.0	237,100.0
Surface area (acres)	14,680.0	7,725.0
Maximum depth (feet)	185.0	135.0
Mean depth (feet)	50.11	32.21
Mean width (feet)	3,200.0	3,440.0
Length (miles)	38.0	18.0
Shoreline at normal maximum elevation (miles)	124.1	73.9
Average flushing rate at 120,000 cfs (hours)	69.9	23.9
Storage at normal maximum elevation (acre-feet) includes both the volume of the original channel storage plus the volume of the storage caused by impoundment.		

The minimum operating elevation for Priest Rapids Lake is 481.5 feet with a maximum surcharge elevation of 491.5 feet. The normal maximum operating elevation for Priest Rapids Lake is 488.0 feet. Thus, Priest Rapids Lake may fluctuate up to 6.5 feet during normal operations, although in practice fluctuations are typically much lower. Operations of the Priest Rapids and Wanapum projects to meet power demand (load-following) currently result in large hourly and daily fluctuations in discharge during the spawning, incubation, emergence, and rearing periods for fall Chinook salmon. Typical project operations result in fluctuations as great as ~7 feet/hour (2.1 meters/hour) and 12.7 feet (4 meters) in a 24-hour period in the Priest Rapids dam tailrace during the fall Chinook salmon emergence and rearing period (Nugent et al., 2002). During the spawning season, reverse load-following operations result in fluctuations as great as 1.6 feet (0.5 meters) per hour and 10.7 feet (3.4 meters) in a 24-hour period.

On April 5, 2004, the *Hanford Reach Fall Chinook Protection Program Agreement* (*Hanford Reach Agreement*) (Appendix A) was executed for protection of fall Chinook in the Hanford Reach of the Columbia River. The *Hanford Reach Agreement* was the result of 7 years of study and negotiation between Grant County Public Utilities District (PUD), other Mid-Columbia Hydro Operators, and representatives from state and Federal fisheries agencies and tribes. The *Hanford Reach Agreement* formalized operations during the post-emergence and early rearing period for fall Chinook to address issues related to flow fluctuations causing stranding and entrapment of fall Chinook fry. The specific flow constraints outlined under the *Hanford Reach Agreement* for the rearing period as detailed in Section C.5(b) are:

“During the rearing period, Grant County Public Utilities District (PUD) will operate Priest Rapids Project No. 2114 to the extent feasible through use of the Mid-Columbia Hourly Coordination to produce a Priest Rapids outflow that limits flow fluctuations according to the following criteria:

(1) When the previous day’s average weekday Wanapum inflow is between 36k and 80k cfs, limit Priest Rapids Weekday Outflow Delta to no more than 20k cfs. When the average of Bonneville Power Administration’s (BPA) Friday Chief Joseph outflow estimates plus side flow estimates for Saturday and Sunday is between 36k and 80k cfs, limit the Priest Rapids weekend outflow delta to no more than 20k cfs.

(2) When the previous day’s average weekday Wanapum inflow is between 80k and 110k cfs, limit Priest Rapids weekday outflow delta to no more than 30k cfs. When the average of BPA’s Friday Chief Joseph outflow estimates plus side flow estimates for Saturday and Sunday is between 80k and 110k cfs, limit the Priest Rapids weekend outflow delta to no more than 30k cfs.

(3) When the previous day’s average weekday Wanapum inflow is between 110k and 140k cfs, limit Priest Rapids weekday outflow delta to no more than 40k cfs. When the average of BPA’s Friday Chief Joseph outflow estimates plus side flow estimates for Saturday and Sunday is between 110k and 140k cfs, limit the Priest Rapids weekend outflow delta to no more than 40k cfs.

(4) When the previous day’s average weekday Wanapum inflow is between 140k and 170k cfs, limit Priest Rapids weekday outflow delta to no more than 60k cfs. When the average of BPA’s Friday Chief Joseph outflow estimates plus side flow estimates for Saturday and Sunday is between 140k and 170k cfs, limit the Priest Rapids weekend outflow delta to no more than 60k cfs.

(5) When the previous day’s average weekday Wanapum inflow is greater than 170k cfs, Priest Rapids outflow for the following weekday will be at least 150k cfs. When the average of BPA’s Friday Chief Joseph outflow estimates plus side flow estimates for Saturday and Sunday is greater than 170k cfs, Priest Rapids outflow for Saturday and Sunday will be at least 150k cfs.

(6) On four consecutive Saturdays and Sundays that occur after 800 temperature units (TU) have accumulated after the end of the spawning period, Priest Rapids outflow will be maintained to at least a

> minimum flow calculated as the average of the daily hourly minimum flow from Monday through Thursday of the current week."

When evaluating this report, readers should also recognize that sections C.5(c) and C.5(d) of the *Hanford Reach Agreement* state that absolute compliance with the constraints of C.5(b) above was not anticipated or required.

The following Table 2-2 provides an estimate of pumping that is used as an outline for potential operations of the project. This table shows what could have been pumped in the previous 25 years if the proposed Black Rock Alternative were in operation. The table also includes the constraints of low-to-no pumping in June, July, and August to protect juvenile fish.

2.2 Intake Area—Priest Rapids Lake

Priest Rapids Dam was constructed on the Columbia River between 1956 and 1961 and consists of left and right earth embankment sections, right bank gravity dam, two fish ladders, a gated spillway, and a powerhouse. Priest Rapids Dam is operated by the Grant County PUD, and the active storage of the reservoir at maximum operating water elevation (488.0 feet) is 237,000 acre-feet. The proposed intake for the Black Rock Alternative is located upstream along the right bank approximately 3,600 feet (1,097 meters) from Priest Rapids Dam (**Error! Reference source not found.**). This location provides adequate room for the physical layout of the intake, intake channel, pumping plant, switchyard, and tunnel portal, and also provides minimal impact to the existing embankment portion of Priest Rapids Dam (Figure 2-2). In addition to the stable water surface, locating the intake upstream of Priest Rapids Dam provides adequate hydraulic head for fish bypasses and adequate area for the fish screens, pumping plant, and switchyard. The upstream location of the intake will also minimize encroachment of the pumping plant facilities on the Wanapum Indian Village located downstream of the dam on the right side of the river (Reclamation, 2004).

Description of Proposed Intake Facility on the Priest Rapids Lake

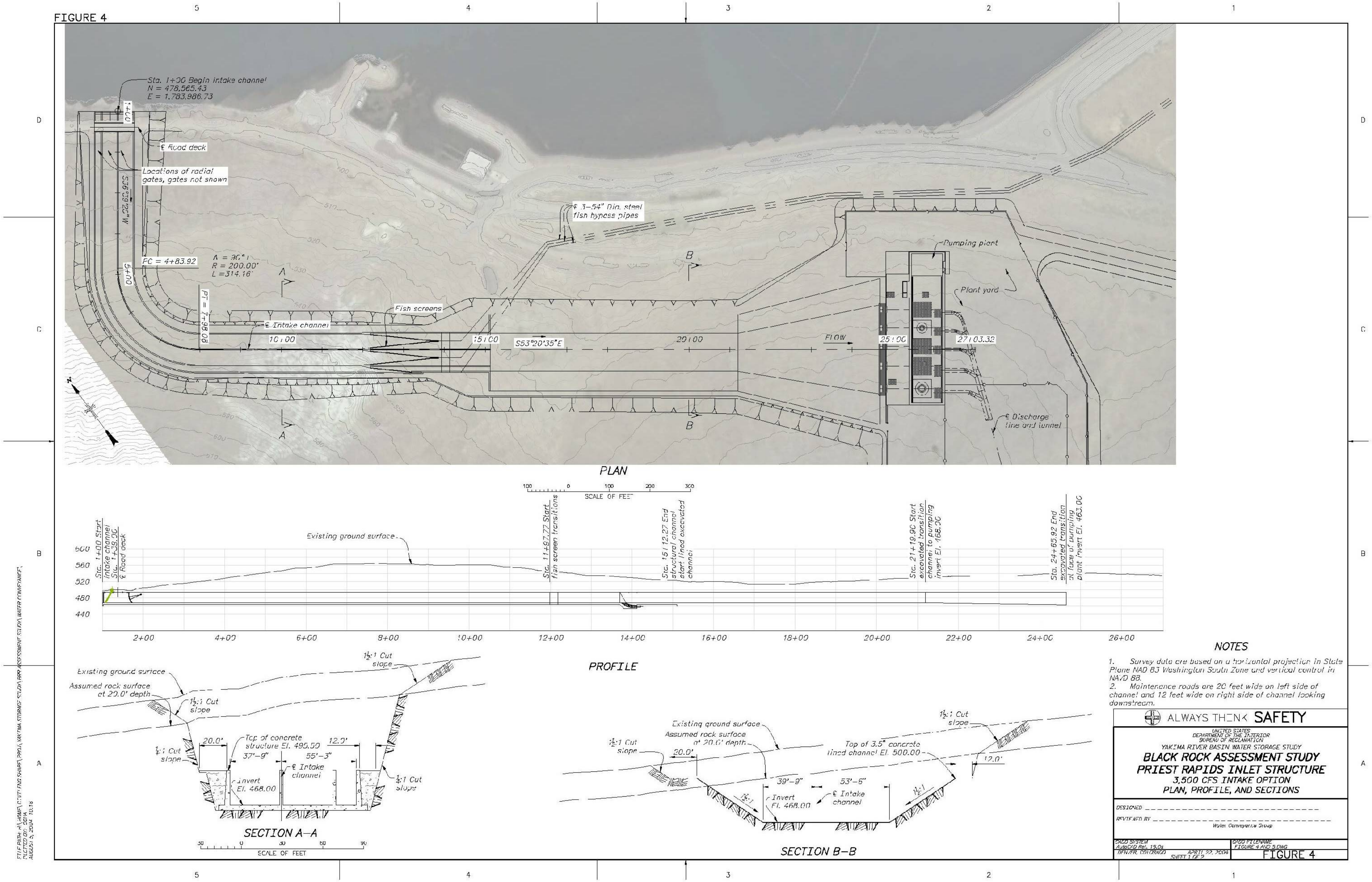
An identified site for the intake structure would be on the right bank of Priest Rapids Lake about 3,600 feet upstream from Priest Rapids Dam. The intake channels and fish screen design would meet the maximum and minimum Priest Rapids Lake operating water surface elevations and provide sufficient freeboard to prevent overtopping during flood events. The fish screens and bypass pipes would meet the NOAA Fisheries salmonid criteria which include channel velocities, screen approach velocities, screen sweeping velocities, exposure time along screen, maximum bypass pipe flow velocity, and minimum radius of bypass pipe bends.

The 3,500-cfs pump option would have a 2,366-foot-long intake channel running from the intake at Priest Rapids Lake to the face of the pumping plant. Guardrails and fencing would provide for safety protection. The initial 1,412 feet of the intake channel would have three channel bays with vertical structural concrete walls. Two of the channel bays would be each sized for 1,500-cfs flows, with a third channel sized for 500 cfs, totaling the 3,500-cfs flow capacity. Each channel would have bulkheads and guides to isolate that channel while maintaining the water diverting operation. Downstream from the fish screen, the three intake channels would open to a 608-foot-long single channel section. It would then widen into a 346-foot-long transition to the pumping plant.

Figure 2-1. Aerial view of Priest Rapids Dam and location of proposed Black Rock reservoir pumping plant.

Table 2-2 Black Rock pumping volumes (acre-feet)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1981	0	132,420	6,240	6,020	7,660	0	0	208,260	0	0	208,260	215,210	784,070
1982	0	21,310	6,240	6,020	7,660	30,520	88,760	68,390	0	0	208,260	148,130	585,290
1983	0	12,730	6,240	6,020	7,660	21,420	86,800	82,050	0	0	208,260	161,170	592,350
1984	6,480	6,250	6,240	6,250	7,720	56,320	0	178,250	0	0	208,260	149,160	624,930
1985	6,460	6,240	6,240	6,020	7,660	46,020	120,880	0	0	0	208,260	215,210	622,990
1986	81,950	0	12,490	6,020	7,660	69,100	0	207,460	0	0	208,260	182,150	775,090
1987	0	0	18,970	6,020	7,660	0	0	0	0	0	208,260	215,210	456,120
1988	0	0	0	0	0	0	0	0	0	0	208,260	215,210	423,470
1989	0	0	215,210	0	207,000	134,010	97,820	0	0	0	208,260	215,210	1077,510
1990	0	88,180	6,240	6,020	7,660	39,840	0	207,460	0	0	208,260	177,300	740,960
1991	6,480	6,250	6,240	6,020	7,660	0	166,810	109,930	0	0	208,260	182,150	699,800
1992	0	0	0	25,220	,7720	0	0	0	0	0	208,260	215,210	456,410
1993	0	0	0	0	0	0	0	0	0	0	208,260	215,210	423,470
1994	0	0	215,210	0	0	0	0	0	0	0	208,260	215,210	638,680
1995	0	0	215,210	194,380	62,160	30,520	136,360	0	0	0	208,260	215,210	,1062,100
1996	81,960	6,250	6,240	6,250	7,720	33,320	93,500	108,280	0	0	208,260	179,120	730,900
1997	0	12,700	6,240	6,020	7,660	33,290	45,530	59,090	0	0	208,260	99,260	478,050
1998	6,480	6,250	6,240	6,020	7,660	0	110,950	87,380	0	0	208,260	179,370	618,610
1999	6,480	6,250	6,240	6,020	7,660	29,100	86,100	58,470	0	0	208,260	94,070	508,650
2000	4,000	8,730	6,240	6,250	7,720	15,120	0	0	0	0	208,260	215,210	471,530
2001	169,100	6,240	6,240	6,020	7,660	0	0	0	0	0	208,260	215,210	618,730
2002	189,620	6,250	6,240	6,020	7,g60	21,500	0	184,050	0	0	208,260	149,860	779,460
2003	0	0	0	24,990	7,660	30,520	0	0	0	0	208,260	215,210	486,640
2004	110,000	0	118,520	6,250	7,720	0	0	0	0	0	208,260	215,210	665,960
2005	50,000	202,160	6,240	6,020	7,660	0	0	0	0	0	208,260	215,210	695,550
Avg	28,760	21,128	35,568	14,155	16,906	23,624	41,340	62,363	0	0	208,260	188,587	640,693
Min	0	0	0	0	0	0	0	0	0	0	208,260	94,070	423,470
Max	189,620	202,160	215,210	194,380	207,000	134,010	166,810	208,260	0	0	208,260	215,210	1,077,510



NOTES

1. Survey data are based on a horizontal projection in State Plane NAD 83 Washington South Zone and vertical control in NAVD 88.
2. Maintenance roads are 20 feet wide on left side of channel and 12 feet wide on right side of channel looking downstream.

Figure 2-2. Proposed intake facility on Priest Rapids Lake

Trashracks with an automated rake and a conveyor system would collect trash at the inlet. Three top-sealed radial gates at the reservoir intake would isolate the channels for emergency or short-term maintenance of the fish screens and could also regulate downstream water surfaces. An access bridge deck over the inlet would allow access across the intake channel.

The 3,500-cfs pumping plant would house three 500-cfs pump units and two 1,000-cfs pump units that would require 62 feet of submergence below the minimum intake water surface elevation (see Table 2-3). The 1,400-foot steady state lift from Priest Rapids Lake to a Black Rock reservoir is very high. Therefore, the spiral-case-type, two-stage pumping units would accommodate water in the months when downstream Columbia River flow targets would restrict the volume of water that could be pumped from the river. The smaller units would provide flexibility of operations, reduce the unit submergence requirements, and permit unit maintenance without sacrificing a large percentage of the plant capacity.

Table 2-3. Preliminary Priest Rapids 3,500-cfs pumping plant data

Unit Data	500-cfs Units	1,000-cfs Units
number of pump units	three	two
type of units	two-stage spiral case	two-stage spiral case
design discharge	500 cfs	1,000 cfs
design head	1,400 feet	1,400 feet
motor	98,000 hp	200,000 hp
minimum impeller submergence	62 feet	62 feet
maximum spiral case dimension	18.2 feet	26.0 feet
top elevation of suction tube invert	468.0 feet	468.0 feet
guard valve	60-inch spherical	78-inch spherical
guard valve weight	110,000 lbs. each	175,000 lbs.

Description of Screening Facilities

Fish screens were designed to meet the NMFS screen criteria for salmonid fry criteria (NMFS, 1997). These criteria state that for salmonid fry, the approach velocity shall not exceed 0.40 fps. Approach velocity is defined as the water velocity component perpendicular and approximately 3 inches (7.62 cm) in front of the screen face. The total required submerged screen area (excluding area affected by structural components) was calculated by dividing the maximum diverted flow by the allowable approach velocity.

The proposed fish screens for the Priest Rapids intake are vertical flat panels installed within metal guide/support structures. The screen panels were assumed to be stainless steel wedge wire panels bolted to steel backing panels or supports. The NMFS screen criteria states that the screen slot openings (narrowest dimension) shall not exceed 0.0689 inches (1.75 mm). Adjustable baffles are provided in guides directly downstream of the screens to provide for uniform flow distribution over the screen surface. The fish screens will be cleaned by horizontal brush-type fish screen cleaners. Since the screens are designed for the maximum flow at the minimum operating water depth, metal barrier panels are provided above the screens to extend above the maximum design operating water surface.

The initial 1,412 feet of the intake channel is designed with three channel bays with vertical structural concrete walls (Figure 2-2). Two of the channel bays are sized for flows of 1,500 cfs each, and a third channel is sized for 500 cfs, for a total flow capacity of 3,500 cfs. The channels were designed with the top of concrete at elevation 495.50 feet and the invert elevation at 468.00 feet. The channel depths are 27 feet, 6 inches. The width of the two 1,500-cfs channels is 36 feet, 6 inches, and the 500-cfs channel is 15 feet wide.

To meet exposure time criteria, V-configurations of the fish screens were utilized for the 1,500-cfs channel and fish screens in a single diagonal configuration were utilized for the 500-cfs channel. The following tables (Table 2-4, Table 2-5, Table 2-6, Table 2-7) list the design criteria for the fish screens and the design values associated with the selected concept. Three 54-inch-diameter bypass pipes are located at the end of the fish screens to deliver screened fish to the river channel below Priest Rapids Dam (Figure 2-2).[1]

Table 2-4. Screen design parameters for 1,500 cfs at water surface el. 481.5 feet

Fish Screen Parameters	Screen Criteria Values	1,500 cfs Design Values
Approach velocity	0.4 fps*	0.4 fps
Sweeping velocity	Greater than approach velocity	3.98 fps
Screen angle (from parallel with channel)	Less than 45 degrees	5.74 degrees
Exposure time along screen	60 to 90 seconds**	39 seconds
Screen length plus 10% for metal works	n/a	153 feet

* Criteria for Salmonid fry. **Not part of 1995 NMFS Criteria

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[1] Further fish screen, trashrack, and channel design details for 3,500-cfs and other withdrawal flow options are detailed in the *Appraisal Assessment of the Black Rock Alternatives Facilities and Field Cost Estimates* (Reclamation, 2004).

Table 2-5. Screen design parameters for 1,500 cfs at water surface el. 488.0 feet

Fish Screen Parameters	Screen Criteria Values	1,500 cfs Design Values
Approach velocity	0.4 fps*	0.23 fps
Sweeping velocity	Greater than approach velocity	2.30 fps
Screen angle (from parallel with channel)	Less than 45 degrees	5.74 degrees
Exposure time along screen	60 to 90 seconds**	65 seconds
Screen length plus 10% for nonpower metal works	n/a	153 feet

* Criteria for Salmonid fry.
**Not part of 1995 NMFS Criteria

Table 2-6. Screen design parameters for 500 cfs at water surface el. 481.5 feet

Fish Screen Parameters	Screen Criteria Values	1,500 cfs Design Values
Approach velocity	0.4 fps*	0.4 fps
Sweeping velocity	Greater than approach velocity	3.98 fps
Screen angle (from parallel with channel)	Less than 45 degrees	6.21 degrees
Exposure time along screen	60 to 90 seconds**	26 seconds
Screen length plus 10% for metal works	n/a	102 feet

* Criteria for Salmonid fry.
**Not part of 1995 NMFS Criteria

Table 2-7. Screen design parameters for 500 cfs at water surface el. 488.0 feet

Fish Screen Parameters	Screen Criteria Values	1,500 cfs Design Values
Approach velocity	0.4 fps*	0.4 fps
Sweeping velocity	Greater than approach velocity	2.71 fps
Screen angle (from parallel with channel)	Less than 45 degrees	6.21 degrees
Exposure time along screen	60 to 90 seconds**	42 seconds
Screen length plus 10% for metal works	n/a	102 feet

* Criteria for Salmonid fry.
**Not part of 1995 NMFS Criteria

2.3 Intake Area in Wanapum Pool

Another option includes an exchange of Yakima River and Columbia River water at Lmuma Creek. For this report, the proposed intake area was surveyed with hydroacoustics for fish density and bathymetry. Figure 2-3 illustrates the proposed intake for this option.

Figure 2-3. Proposed Columbia River Intake Site Location for Wanapum Withdrawal

Chapter 3 METHODOLOGY

3.1 Computational Fluid Dynamics (CFD)

A critical need identified in all questions related to the withdrawal of water from the Columbia River Priest Rapids Lake was, “what is a defined zone of influence that will exist at the intake area?” In an attempt to define that zone of influence, Reclamation employed computational fluid dynamics (CFD) mathematical modeling to provide a reasonable accurate zone definition. This model provides an estimate of the 0.2-fps flow field in front of the proposed intake pumping 6,000cfs, and also illustrated some estimated flow field within the pool. Hydroacoustic information from the proposed site location provided bathymetry. In addition, Grant County PUD provided the flow data used in this modeling.

There are many steps required to develop an appropriate CFD model. These include development, refinement, and testing of the grid, boundary conditions, model extents, and obstacles (structures) for the CFD program.

3.1.1 CFD Program Description

The CFD program FLOW-3D (Flow Science Inc., 2005) was used to model the proposed withdrawal of 6,000 cfs from the Priest Rapids Lake at varying elevations. FLOW-3D is a finite difference/volume, free surface, transient flow modeling system that was developed to solve the Navier-Stokes equations (Navier, 1822; Stokes, 1845) in three spatial dimensions.

The finite difference equations are based on an Eulerian mesh of nonuniform hexahedral control (brick shaped) volumes (mesh-blocks) using the Fractional Area/Volume (FAVOR) method (Sicilian, 1990). Free surfaces and material interfaces are defined by a fractional volume-of-fluid (VOF) function (Barkhudarov, 2003). FLOW-3D uses an orthogonal coordinate system as opposed to a body-fitted system.

Flow-3D can have a single mesh block, nested (one completely contained by another) mesh blocks, linked (adjacent) mesh blocks, or a combination of nested and linked mesh blocks.

3.1.2 Model Description

Geometries

The existing bathymetry was estimated using hydroacoustic survey data and satellite imagery (Figure 3-1). To generate the stereolithography of the lake, the satellite imagery was used to estimate the length of shoreline, while survey data was used to determine the bathymetry along its path. In Figure 3-1, the survey path (light blue segment) was acquired using a boat and an Acoustic Doppler CP. The satellite imagery was obtained from Google Earth. The red lines represent the "long leg" segment of the survey that has been translated, rotated, and scaled to match the satellite imagery. To smooth out interpolation of the bathymetry by AutoCAD, several more segments were imposed between the red lines shown in the figure.

Figure 3-1. Development of the bathymetry at Priest Rapids Dam and Lake

Mesh Blocks

The CFD process used various cell configurations and spatial extents to optimize computation time. While smaller cell sizes develop more precise definition of obstacles and flows, they also increase the size of the computational domain, and decrease the time step (when the explicit option is used) of the simulation. Both of these increase computational time required for obtaining a quasi-steady state.

Balancing the accuracy of the solution with the time and computational resources available is always a challenge.

Flow-3D can use multiple hexahedral shaped mesh blocks, containing the nonuniform hexahedral control volumes. In Flow-3D V9.0, multiple mesh blocks can be nested or linked (Flow Science, Inc., 2005).

As is typical of this type of modeling, several mesh-block techniques were used to optimize performance for the reasons discussed above. The three final models used a variety of mesh-block configurations, and depended on the stability of the computations.

Boundary and Outflow Conditions

Boundaries conditions applied to a CFD model simulate how the fluid acts/reacts at the sides of the mesh blocks, which are the extents of the model.

The upstream part of the reservoir intersects with the model on one side (the minimum X value), which was modeled using a pressure boundary condition with a water surface elevation of 487.76 feet. This type of boundary condition adjusts the velocities into the model to maintain that elevation at the boundary. All other boundaries were modeled as wall, including the maximum X dam wall.

Outflow through the dam was modeled as an object sink, an object which withdraws water from the flow field at a constant rate. The object was a simple block that spanned the range of the penstock intakes and withdrew 231,000 cfs in two of the three simulations.

The proposed diversion outflow was modeled by cutting a channel as indicated by Figure B-2 in Appendix B, and using another object sink to withdraw 6,000 cfs in two of the three simulations. Since the proposed intake design does not reach out to the water, a channel was extended using a channel approximately 10 feet wider on each side into the reservoir.

Other Modeling Options

The final models used the Renormalized Group (RNG) (Yakhot and Smith, 1992) option for viscosity, which is an advanced turbulence simulation technique. The RNG model uses equations similar to the more common K-epsilon turbulence model. However, equation constants are found empirically in the k-e model, but are derived explicitly in the RNG model. Generally, the RNG model has wider applicability than the k-e turbulence model. In particular, the RNG model is known to describe more accurately low intensity turbulence flows and flows having strong shear regions.

For the momentum equation approximations, the first-order advection approximation was used. For pressure iterations, the successive over-relaxation option was chosen.

A rigid lid was used on all three final simulations. A rigid lid fixes the elevation of the free water surface and provides faster computations. Minor errors may be introduced due to the inaccurate depth; however, the errors seemed to be acceptable for this level of study.

Three operating configurations (simulations) were tested. All used an inlet water surface elevation of 487.76 feet with "slices" through the Lake at different elevations.

- Diversion flow only
    - Outflow through the proposed diversion of 6,000cfs.
    - Extents of the model were limited to a small portion of the lake due to very minimal impact on the rest of the lake.
    - The dimensions of the model were:
        - 4,500 feet long (flow direction to dam) using 703 real cell rolls
        - 2,800 feet wide (partial width of the lake) using 437 real cell rows
        - 22.76 feet high (maximum depth of flow) using 7 real cell rows
        - A total of 2,795,760 cells were used in the model.
- Riverflow only
    - Outflow through the penstock intakes of 231,000 cfs
    - Extents of the model were limited to a major portion of the lake to capture the flow characteristics.
    - The dimensions of the model were:
        - 10,500 feet long (flow direction to dam) using 525 real cell rows.

        - 10,000 feet wide (includes lake width plus shore land) using 500 real cell rows.
        - 45 feet high (maximum depth of flow) using 9 real cell rows.
        - A total of 2,915,616 cells were used in the model.
- River and Diversion flow
    - Outflow through the penstock intakes of 231,000 cfs and the proposed diversion of 6,000 cfs.
    - Extents of the model were limited to a major portion of the lake to capture the flow characteristics.
    - The dimensions of the model were:
        - 10,500 feet long (flow direction to dam) using 568 real cell rolls.
        - 10,000 feet wide (includes lake width plus shore land) using 541 real cell rows.
        - 22.76 feet high (maximum depth of flow) using 5 real cell rows.
        - A total of 2,170,371 cells were used in the model.

3.1.3 Results

All simulations that modeled a majority of the reservoir had long prototype times before a steady state appeared, even with the rigid lid. This implies that outlet flow changes at the dam could result in unsteady flow conditions the majority of the time in the area of interest. Results presented here are steady state.

Diversion Flow Only

For the outflow through the proposed diversion-only simulation, only a small extent of the reservoir was simulated because the rest of the reservoir would have very low velocities, less than 0.1fps. The region of influence on fish has been interpreted to be velocities greater than 0.2fps. The results of this simulation could be used to estimate the region of influence on fish for other flow conditions. From this model and for future use in definition of zone of influence, the zone is the radius area with 580 feet (177 meters) of center of the intake channel entrance.

Figure 3-2 presents a simulated shoreline (gray on bottom of figure) and radiating velocity gradients indicated by differing colors. Red is the highest velocity and the target 0.2 fps is the outer edge of the yellow. Each grid box represents 18.1 square feet. This plot represents 1,850 feet of shoreline and 580 feet out into the Priest Rapids Lake.

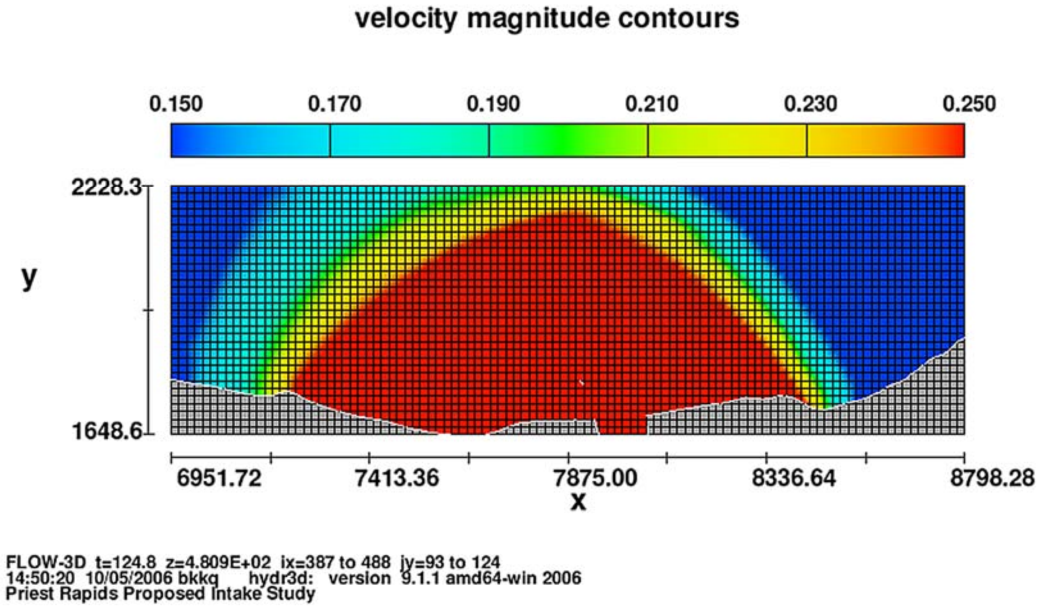


Figure 3-2. Velocity Magnitude Contours

Appendix B contains details and plots of existing Priest Rapids flows as well as flow fields in various elevations at the proposed diversion.

3.2 Hydroacoustic Survey

In order to get the local bathymetry and to obtain a relative density and distribution of fish, a hydroacoustic survey was performed in June 2006.

3.2.1 Methods

Sampling at Priest Rapids Intake Site (PRIS) involved daylight and a dark component. Initially, the proposed intake location was determined and that position recorded on a GPS. From that point, four transects were run at 30-degree intervals centered off of the PRIS. Lengths of all transects were similar, about ¼-mile (400 m). A single transect across the pool was also performed for bathymetry, and for the first 0.25 mile (402 m) fish density and distribution were collected for comparisons with the four radiating transects (Figure 3-1).

Acoustic data were collected using a Biosonics TM Split beam system. The system utilized two 200-kHz transducers mounted on a retractable boom that positioned one transducer in a downward aspect, and one in a side-looking (starboard side) aspect (Figure 3-3). This type of transducer orientation allows for effective sampling of fish in both deep and shallow areas of the water column.

Data collection was at a rate of 3 to 4 pings per second, and acquisition thresholds were typically -55 to -65 dB (all dark transects were collected at -65 dB). This low threshold detects targets as small as 0.39 in (1 cm) long.

Transect data were collected and stored on disk using a laptop computer. Analysis of transects was accomplished using Sonar Data's™ Echoview software. Transects were brought into an analysis template where they were edited, and echo counts were performed to enumerate number of fish per transect.

3.2.2 Results

The surveyed area was relatively shallow [average 39.3 feet (12 m)] with low densities of fish, particularly during daytime transects. Table 3-1 summarizes the results for nighttime surveys for the five transects sampled. Daytime results for the same transects indicated very low fish densities, with no fish detected in four of the five radiating transect lines. With the downlooking transducer, few fish were observed near the surface during either day or night surveys. The data from each transect were calculated on the entire transect which included the 580 feet (177 m) estimated zone of influence. Within the zone of influence the depths were all under 32.8 feet (10 m).

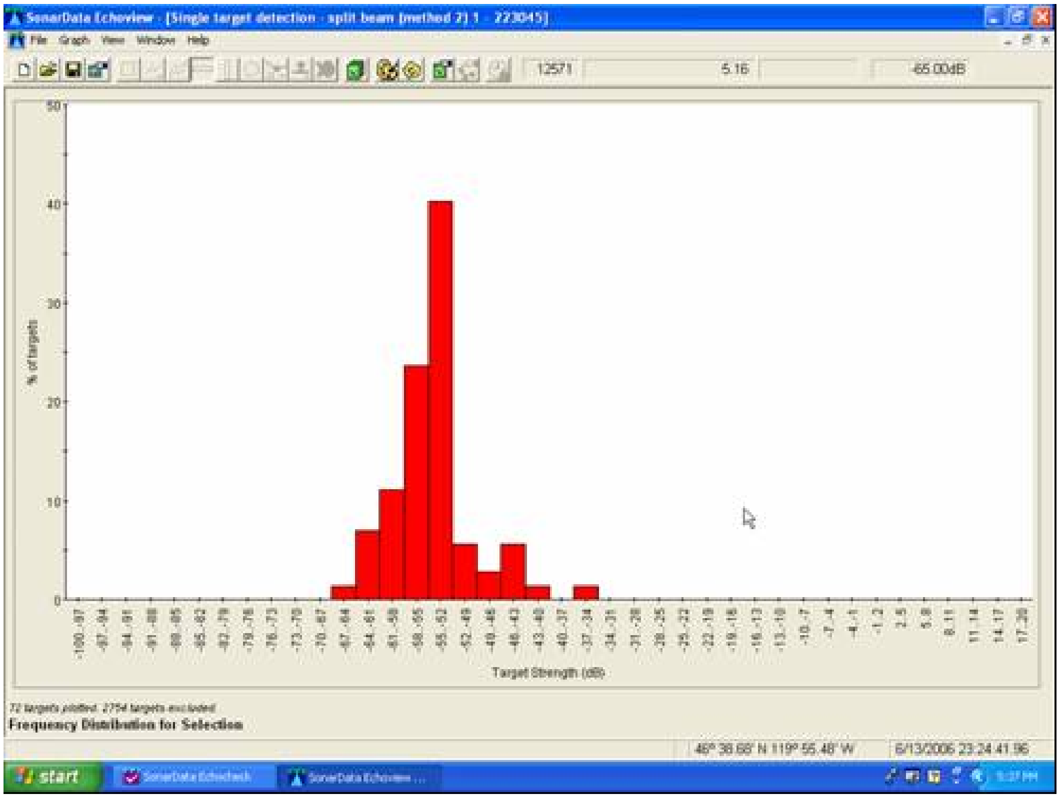
Figure 3-3. Transducer Mounts for Columbia River Surveys

Table 3-1. Summary Table of the Hydroacoustic Survey Performed June 12-15, 2006, in the Proposed Intake Location with the Priest Rapids Lake

Transect	Average target fish length (cm)	Minimum target fish length (cm)	Transect average fish per 1,000 cubic meters water
Perpendicular to shore	2.7	1.2	9.5
75 Degree	4.5	0.9	11.6
105 Degrees	3.6	3.2	14.3
15 Degrees	4.7	1.4	16.8
245 Degrees	4.1	1.2	14.0
Grand Means	3.9	1.6	13.2

Results from the surveys show low densities of fish in the local area of influence of the proposed intake facility. The average fish size is about 1.5 inch (3.9 cm). Small fish were visually observed within a foot of the shore but no capture or identification was performed. The zone of influence is approximately a radius of 580 feet (177 m) out from the bank as determined from the computer flow models at the 6,000 cfs alternative. This zone should be smaller in the 3,500-cfs alternative outlined in the Draft PR/EIS.

This survey estimates the average fish density of 13.2 fish per 1,000 cubic meters of water. The fish are of sufficient size to avoid (escape) the flows at the outside of the flow field. Over the operations and daily cycles of withdrawing 3,500 cfs, the small, weaker swimming fish would certainly be pulled into the intake and could potentially be entrained into the intake and bypassed through the screened facility. Quantification of entrainment was not performed, as more detailed seasonal density determination would be needed for reliable estimates. The following Figure 3-4 combines all five downlooking transducer transects.

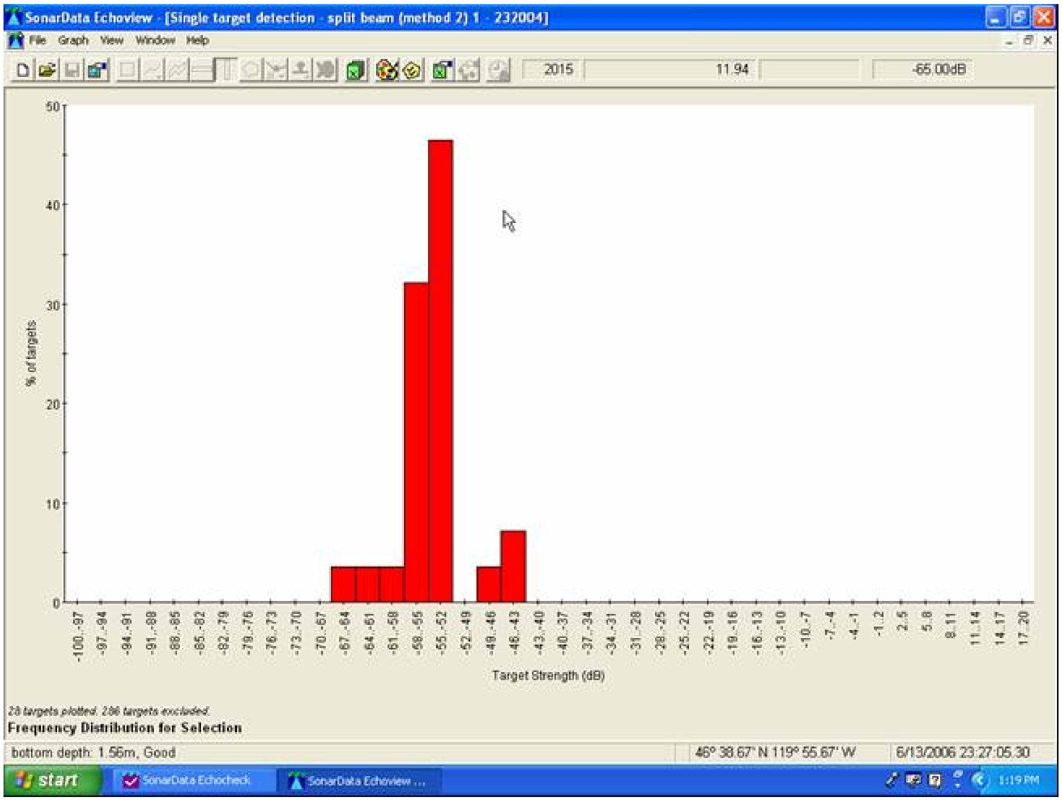


72 targets plotted. 2754 targets excluded

Frequency Distribution for Selection

Figure 3-4. Single Target Percentage Frequency Graph Showing Most Targets (Fish) Were Small.

Figure 3-5 shows the low densities and few large fish that were seen in the surveys. These graphs are combined of all transect data in night time transects.



28 targets plotted. 286 targets excluded.

Frequency Distribution for Selection

bottom depth: 1.56m, Good

46° 38.67' N 119° 55.67' W

6/13/2006 23:27:05.30

Figure 3-5. Densities and Fish Size Seen in Surveys.

Chapter 4 POTENTIAL PROJECT EFFECTS ON ANADROMOUS FISH SPAWNING, JUVENILE REARING HABITAT, FRY STRANDING, PASSAGE AND MIGRATION

4.1 Introduction

The Priest Rapids Dam is located at River Mile 397 from the mouth of the Columbia River. The dam has two fish ladders located on each side of the dam (east bank and west bank) where adult upstream migration counts are made. There are currently no juvenile outmigration counts performed at Priest Rapids Dam. The nearest anadromous juvenile salmonid outmigration monitoring station is located 56.4 miles (90.76 km) upriver at Rock Island Dam (RM 453.4) or 105 miles (168.98 km) downstream at McNary Dam (RM 292) (Columbia River DART, http://www.cbr.washington.edu/mcpud/). Outmigration assessments at McNary Dam include juvenile salmonids from both the Snake and Yakima rivers, whereas, there are no major tributaries between Priest Rapids Dam and Rock Island Dam. Therefore, we must rely on the Rock Island Dam smolt monitoring station to obtain estimates of juvenile salmon outmigration timing and smolt abundance at Priest Rapids Dam.

4.2 Description of Salmonid Species

4.2.1 Sockeye salmon (*Oncorhynchus nerka*)

Sockeye salmon that occur in the project area are from populations that spawn upstream of the project area in either the Okanogan River or Lake Wenatchee (Wenatchee River) and use the mainstem Columbia as a migration corridor (NPPC 2004). Neither population is listed under the ESA.

Adult sockeye migrate up the Columbia River between June and August with the peak generally occurring at Rock Island Dam (upstream of Wanapum Dam) in mid-July. Juveniles migrate downstream in April and May (NPPC, 2004).

Only one sockeye salmon was collected (from Priest Rapids Lake/Tailrace) during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum Reservoirs conducted in May 1999 (Pfeiffer et al, 2001).

4.2.2 Rainbow trout/Steelhead (*Oncorhynchus mykiss*)

Steelhead that may occur in Priest Rapids or Wanapum reservoirs are included in the Upper Columbia River Steelhead ESU and are listed as Threatened under the ESA. Critical Habitat for the UCR Steelhead ESU was designated in 2005.

Adults return to the Columbia River in the late summer and early fall, moving relatively slowly upstream to tributary spawning streams. A portion of the returning adults overwinter in the mainstem reservoirs, passing over the mid- and upper-Columbia mainstream dams in April and May of the following year. Spawning occurs in late spring of the calendar year following entry into the river. Currently, and for the past 20+ years, most steelhead spawning in the wild are hatchery fish (UCSRB, 2005).

Juvenile steelhead generally spend 1 to 3 years rearing in freshwater before migrating to the ocean, but can spend as many as 7 years in freshwater before migrating. Most adult steelhead return to the Upper Columbia after 1 or 2 years at sea (UCSRB, 2005).

Rainbow trout/steelhead were frequently the most numerous species collected during tributary surveys conducted as part of intensive fish surveys of Priest Rapids and Wanapum reservoirs conducted in 1999; however, far fewer rainbow trout/steelhead were collected from the reservoirs during the survey's multiple electofishing and beach seining efforts (Pfeiffer, et al, 2001).

4.2.3 Chinook salmon (*Oncorhynchus tshawytscha*)

Upper Columbia River spring Chinook are listed as Endangered under the ESA. Critical habitat for the UCR spring Chinook was designated September 2, 2005. Upper Columbia River fall/summer-run Chinook is not currently listed.

Adult spring Chinook from the Columbia River return to freshwater primarily between March and May, entering Upper Columbia tributaries from April through July, and holding in the tributaries until spawning in early fall (UCSRB, 2005). Summer Chinook return to freshwater in June and July and spawn from late September through November. Fall Chinook return to freshwater in August and September and generally spawn in the fall (Wydoski and Whitney, 2003).

Generally, spring Chinook select the upper reaches of tributaries, summer Chinook use mouths of tributaries, and fall Chinook use the mainstem of larger streams (Wydoski and Whitney, 2003). Optimal water temperature for juvenile spring Chinook is 54 to 55 °F (12 to 13 °C), while optimal temperatures for fall Chinook is about 59 to 64 °F (15 to 18 °C). Water temperatures exceeding 73 °F

(23 °C) are lethal to most Chinook juveniles and smolts (Wydoski and Whitney, 2003). Chinook generally spawn at depths of less than 10 feet (3 m), but fall Chinook in the Hanford Reach were observed spawning at depths to 35 feet (11 feet) (Wydoski and Whitney, 2003). Chinook salmon have been observed spawning in the tailraces of most Columbia and Snake River dams (Wydoski and Whitney, 2003).

Juvenile spring Chinook spend a year maturing in freshwater before migrating to the ocean in the spring of their second year of life. Most Upper Columbia spring Chinook return to spawn as adults (4- and 5-year-old fish) after 2 or 3 years in the ocean, although jacks return after one winter at sea (UCSRB, 2005).

Chinook salmon were collected in small numbers from most tributaries during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum Reservoirs conducted in 1999. Numerous Chinook salmon were collected from both reservoirs during multiple electofishing and beach seining efforts, with the largest numbers collected during May surveys (Pfeiffer et al 2001).

These fish spawn in predominantly deeper water than that seen within the zone of influence. Salmon young stay in the gravel until swim up and at that time they have ability to possibly avoid become impinged on the screens during operation.

4.2.4 Coho salmon (*Oncorhynchus kisutch*)

Natural stocks of Coho salmon have been extirpated from the Mid- and Upper-Columbia regions since the 1930s (NPPC 2004). Current populations that may occur in the project area are of hatchery origin, produced from closed or currently operating hatcheries upstream and downstream of the project area (NPPC 2004). None of the mid- or upper-Columbia populations are listed under the ESA.

Coho salmon that occur in the project area spawn upstream of the project area in either the Methow or Wenatchee basins and use the mainstem Columbia as a migration corridor (NPPC, 2004). Young spend 1 to 2 years in freshwater before migrating to the ocean in March and late June, with peak outmigration in late April to mid May (Wydoski and Whitney, 2003). Outmigrating juveniles use mainstem reservoirs' natural rearing habitats and tend to be found near the surface (Wydoski and Whitney, 2003). Adults remain in the ocean for about 18 months before returning to their natal streams to spawn between September and late January (Wydoski and Whitney, 2003).

Thirteen coho salmon were collected (from Wanapum Reservoir/Tailrace) during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum reservoirs conducted in May 1999 (Pfeiffer et al 2001).

Adult Coho salmon commonly range from 21 to 30 inches (53 to 76 cm) (Wydoski and Whitney, 2003).

Coho spawn at a considerable distance from the Priest Rapids Lake. The direct effects on eggs and fry would be rare. The downstream migrants pass the intake zone but certainly have good swimming ability to avoid any impingement lows.

4.3 Juvenile Salmon Monitoring Programs

The upper Columbia River evolutionary significant unit (ESU) of Chinook salmon adults are divided into three runs; spring, summer, and fall which are determined by the time of year that they pass Priest Rapids Dam. Chinook salmon adults that pass Priest Rapids Dam between April 17 and June 13 are considered “spring Chinook,” June 14 to August 13 are classified as “summer Chinook,” and “fall Chinook” pass between August 14 to November 15. However, the outmigrating juvenile Chinook salmon are not delineated as part of a specific run according to the time of year that they pass Priest Rapids Dam but rather are classified as “yearling” or “subyearling” according to their size. Yearling Chinook juveniles are also referred to as “stream-type” that rear for 1 year in freshwater and are considered as being juveniles of the spring Chinook salmon runs. The stream-type yearling juveniles are typically 5 to 5.3 inches (120 to 135 mm) in fork length. The subyearling juveniles, also know as “ocean type,” are considerably smaller in fork length and are the progeny of summer- and fall-run Chinook salmon (Entrix INC., 2003). Thus, we have two size classes of juvenile Chinook salmon that represent the three runs of adult Chinook salmon.

The Rock Island Dam smolt monitoring station has been in operation since 1985 under the direction of the Fish Passage Center (FPC) that is funded by the Northwest Power Planning Council (NPPC). Smolts are captured in the Rock Island Bypass Trap at the second powerhouse turbine intake gatewells and fishway attraction water intake. Fish entering the gatewells and attraction water intakes pass into a bypass channel through a series of submerged orifices. Incline dewatering screens separate the fish from the bypass flow and then are held in a 4.4-m^3 tank for up to 24 hours. Each morning fish are crowded from the holding tank into a hopper and hoisted to the upper deck of the trap where they are transferred from the hopper into a 4-m^3 aluminum holding tank prior to being sampled. Here, fish are netted using sanctuary nets into a smaller tank where they are mildly anesthetized with a solution of tricaine methanesulfonate (MS-222) and are examined and enumerated. All salmonids are enumerated by species and size class; scanned for passive integrated transponder (PIT) tags; visually inspected for anchor tags, visual implant elastomer (VIE) tags, freeze brands, coded wire tags, clipped fins, and eroded fins; and assessed for descaling (Breidert and Brothers 2006).

In 2000, the FPC modified the identification criteria for juvenile salmonids that are now classified as either clipped or unclipped based on the presence or absence of the adipose fin (Table 4-1). In addition, the Chelan County Public Utilities District also modified fish identification criteria for juvenile salmonids in 2006.

Table 4-1. Chelan Public Utilities District juvenile salmonid fish identification criteria (Breidert and Brothers 2006)

Species	Fork Length (mm)	Classification
Chinook yearling*	80-180	Clipped/unclipped
Chinook subyearling*	60-160	Clipped/unclipped
Chinook fry	<61	Unclipped
Coho	61-180	Clipped/unclipped
Coho fry	<61	Unclipped
Sockeye	<211	Clipped/unclipped
	>211	Kokanee
Steelhead	<301	Clipped/unclipped
	>301	Rainbow trout
Steelhead fry	<61	Unclipped

*determined by emigration timing

The additional criteria for identification of steelhead, spring Chinook, and yearling Chinook further helps to designate hatchery fish from wild fish. Unclipped steelhead are examined for "eroded fins" in addition to the check for VIE and coded wire tags or combination of these characteristics. Thus, steelhead that were unclipped, but possessed frayed or eroded fins were identified as an "eroded fin" steelhead or an "unclipped" hatchery fish with no distinguishing tags or marks. Only unclipped steelhead that possess none of these distinguishing marks or tags were classified as wild steelhead. Yearling Chinook have similar classification criteria to identify wild fish from unclipped hatchery fish. Hatchery sockeye are either ventral or adipose fin clipped (Breidert and Brothers, 2006).

The juvenile salmonid outmigration monitoring program has been in operation since 1985 at Rock Island Dam and is performed 24 hours a day from April1 to August 31. This annual time period encompasses the vast majority of outmigrating juvenile salmonids at Rock Island Dam. There are currently two websites where juvenile salmonid outmigration data can be located for Rock Island Dam. The FPC website, http://www.fpc.org/fpc_homepage.html is the home website of the FPC which has been enumerating salmonid passage since 1985 in the Pacific Northwest and is where daily salmonid outmigration index counts can be downloaded. The Columbia River data access in real time (DART) website, http://www.cbr.washington.edu/dart/dart.html lists annual trends, run forecasting and timing, and passage index counts on major tributaries and for the mainstem Columbia River. The Columbia River DART website has passage index data dating back to 1992.

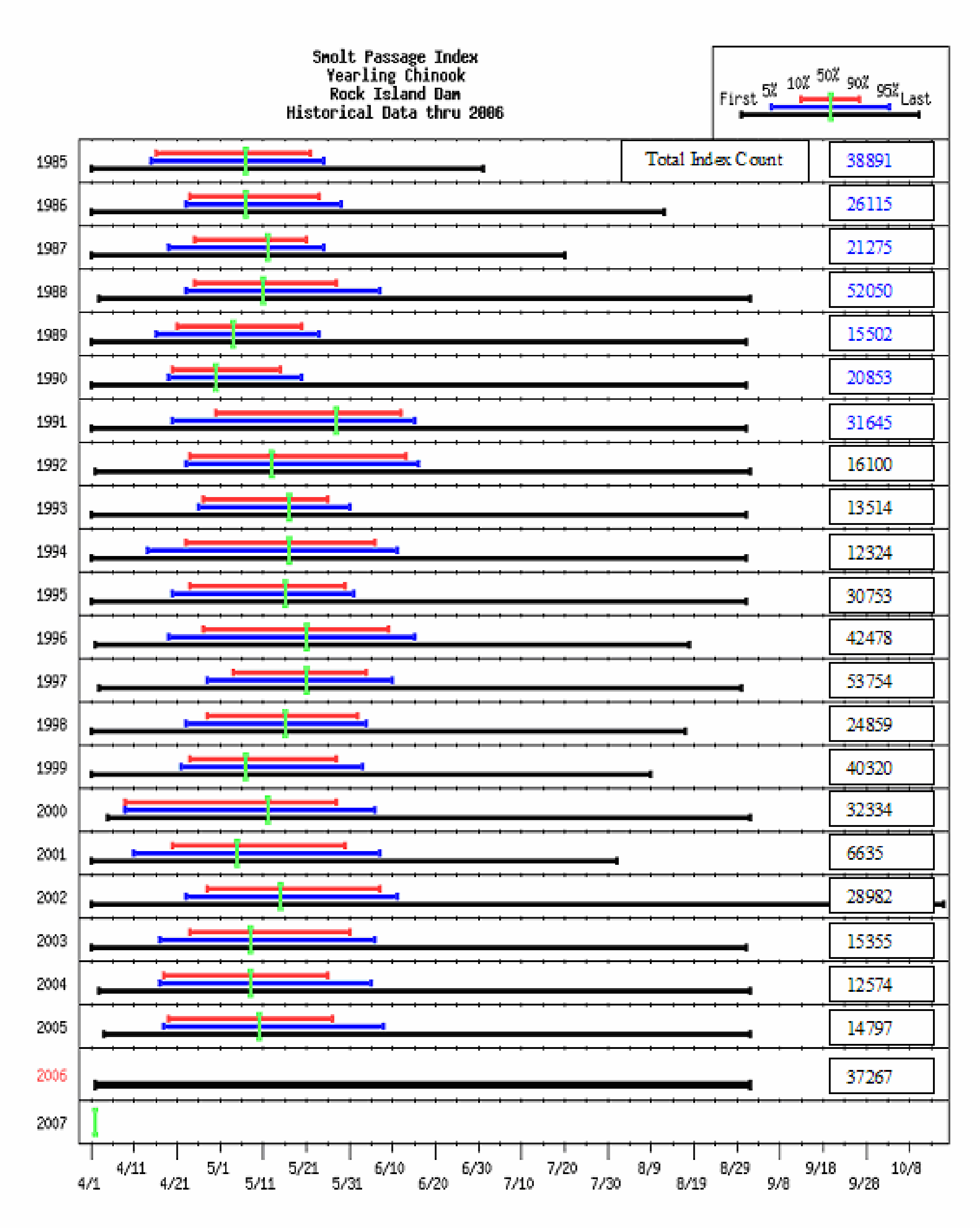
The source of the data for both websites is the FPC; however, both websites are not completely in agreement when enumerating the passage index counts of total juvenile salmonids captured in the Rock Island Dam juvenile bypass trap. The discrepancies between the passage index counts for the two data sources could be attributed to the differences in the calculated proportion of water that is not sampled. To get the passage index counts, the collection counts in the bypass trap are divided by the proportion of water passing through the sampling system and then expanded to the total flow through the reservoir. However, the Rock Island Dam juvenile bypass trap is less than 5 percent efficient meaning that less than 5 percent of the outmigrating salmonids are actually collected in the bypass trap (Peven and Hays, 1989). Thus, the passage index counts found in the Columbia River DART (CR DART) and Fish Passage Center (FPC) websites represent less than 5 percent of the outmigrating population (Pers. Comm. Hemstrom, S. and B. Keesee, Chelan PUD)

While the annual passage index counts at Rock Island Dam are just fractions of the annual juvenile salmonid outmigration populations, the passage index counts do serve as indices for outmigration timing of juvenile salmonids through Rock Island Dam and subsequently through Priest Rapids Dam (Table 4-2). With this downstream juvenile passage index data, reservoir operators can better predict when large numbers of juvenile salmonids are present in the reservoir thus, necessitating bypass flows or “spill” over the dam to improve dam passage survival and downstream migration timing. The Columbia River DART website compiles annual outmigration index counts and has provided passage bar graphs by year displaying the annual outmigration of juvenile salmonids. The passage bar graphs display when the first and last juvenile salmonid has passed as well as when run passage is achieved at 5, 10, 50, 90, and 95 percent passage. Figure 4-1 through Figure 4-5 display outmigration run passage timing for Chinook salmon yearlings, Chinook subyearlings, juvenile coho, juvenile sockeye, and juvenile steelhead.

Table 4-2. Annual passage index counts of juvenile salmonids at Rock Island Dam

Year	**Chinook 1+**		**Chinook 0+**		**Coho**		**Sockeye**		**Steelhead**	
	CR DART	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*
2006	37267	37269	27107	32152	61284	61284	34604	34609	26931	26931
2005	14797	14582	18710	22352	37195	35644	1991	1965	15974	15662
2004	12574	12574	23563	25924	28668	28668	7114	7107	10735	10735
2003	15355	15355	25916	28113	41690	41690	10312	10306	15507	15507
2002	28982	28982	24911	25466	86227	86227	20629	20632	28714	28714
2001	6635	6575	22043	22638	45437	45428	3032	3022	17914	17846
2000	32334	25298	11610	13693	49552	49552	2430	2428	26297	23596
1999	40320	40284	26079	28340	46173	46173	23371	23121	48192	39625
1998	24859	24996	14659	17207	41837	41809	16635	16708	21390	21490
1997	53754	53754	18975	19240	4301	4301	13426	13429	33979	33979
1996	42478	42517	14752	15308	26521	26527	9995	10189	39650	39802
1995	30753	30753	13207	14193			27056	27066	18084	18084
1994	12324	12334		14323				13157	15323	15322
1993	13514	15447		16085		38312		16069	4032	10250
1992	16100	18573	9162	10245		35438		2547	4906	16775
1991		31645		34448		45770		15091		27819
1990		20853		54682		15617		4297		18087
1989		15502		44198		37833		26469		38457
1988		52050		38292		42561		24272		44198
1987		21275		18360		35175		27678		40390
1986		26115		72980		59307		42811		38894
1985		38891		24374		13655		36804		34255

Figure 4-1. Total passage index count and outmigration timing for yearling



Chinook salmon at Rock Island Dam (Columbia River DART, historical index count in blue font from FPC data)

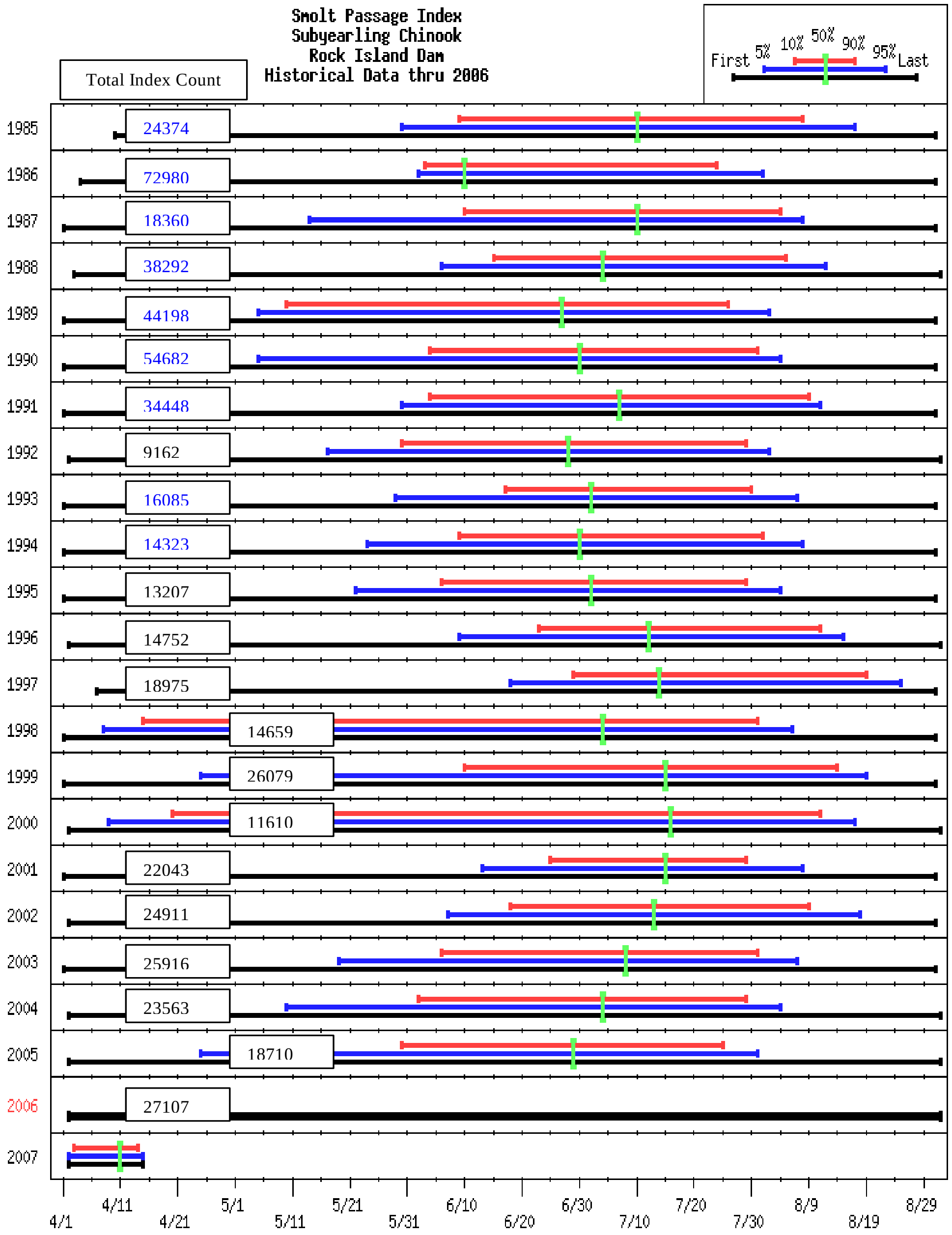


Figure 4-2. Total passage index count and outmigration timing for subyearling Chinook salmon at Rock Island Dam (Columbia River DART, historical index count in blue font from FPC data)

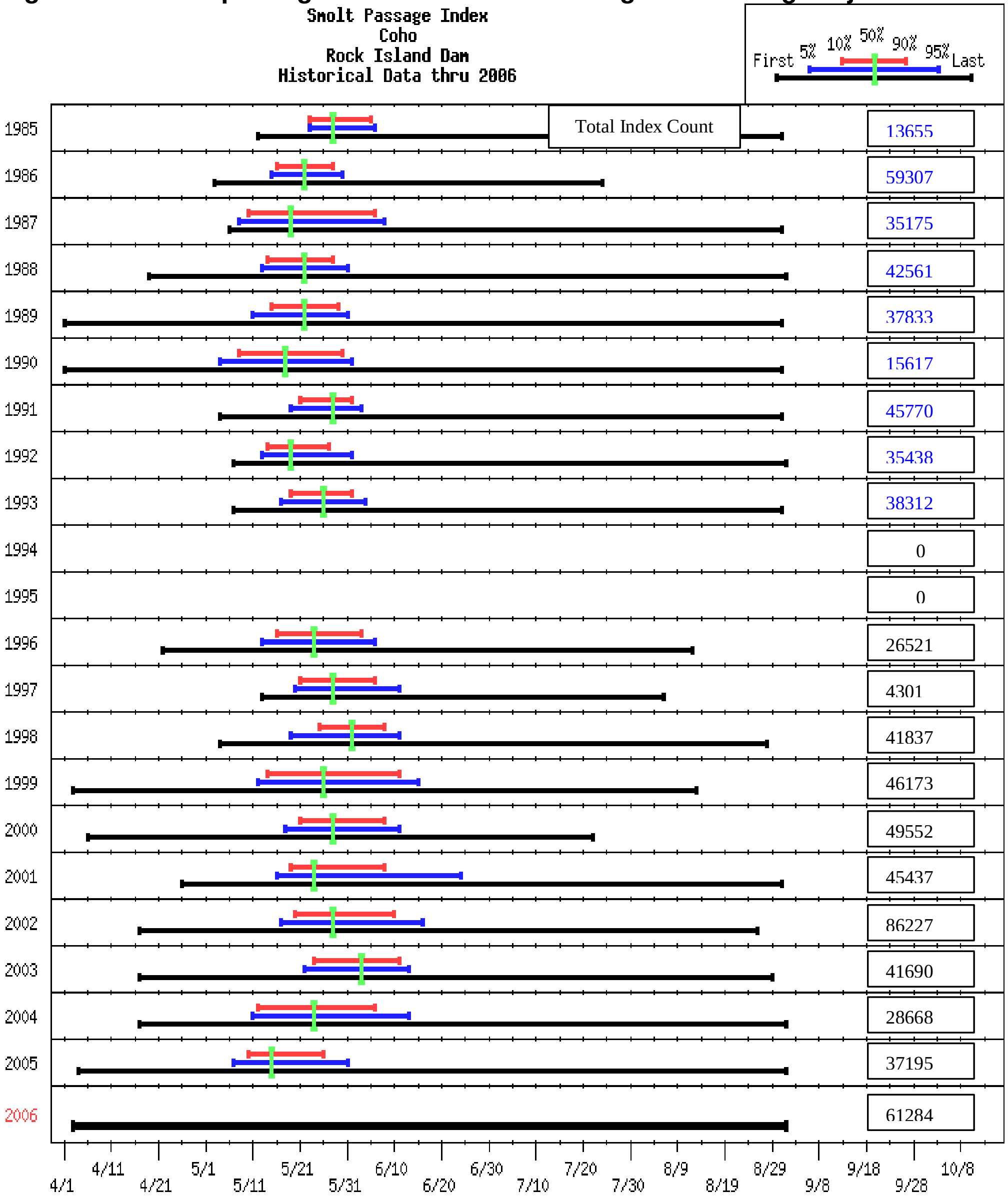


Figure 4-3. Total passage index count and outmigration timing for juvenile coho salmon at Rock Island Dam (Columbia River DART, historical index count in blue font from FPC data)

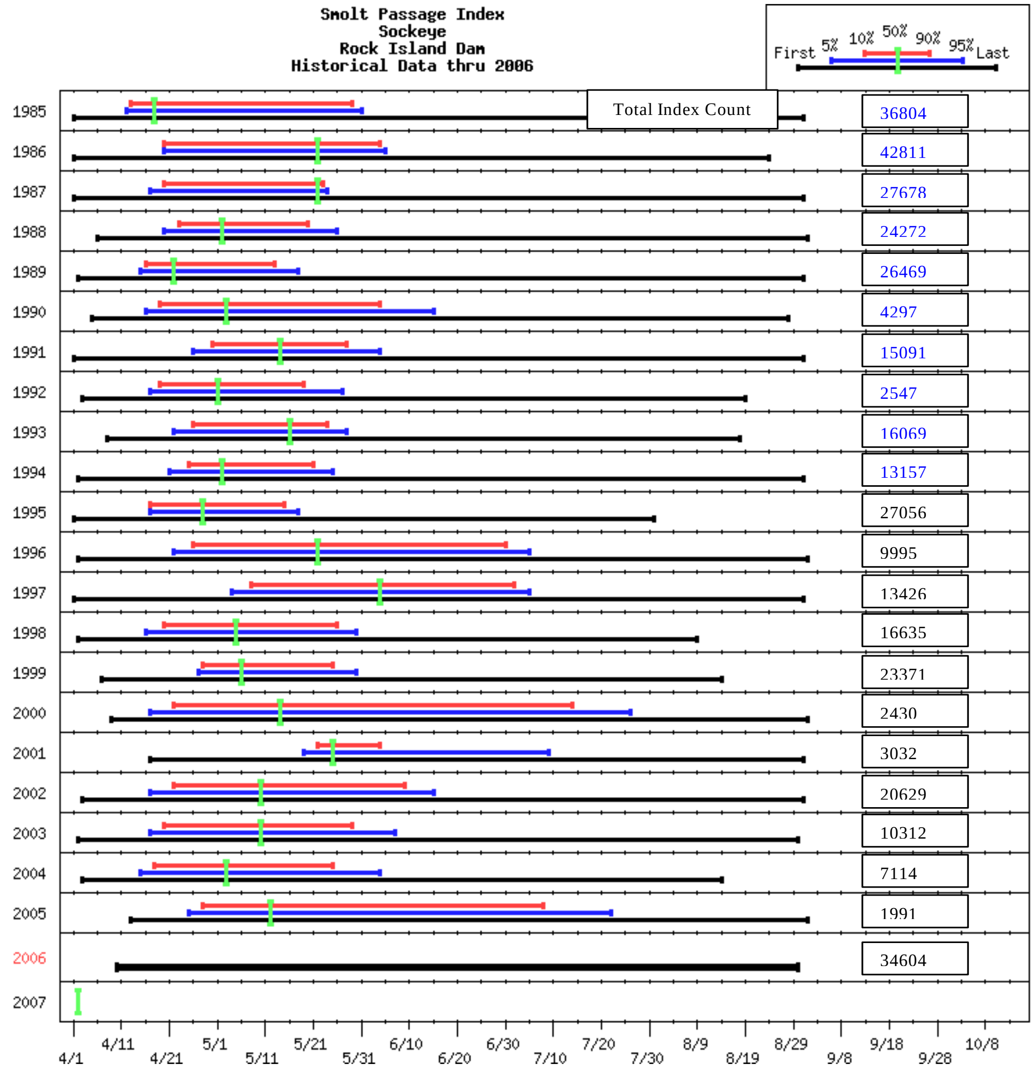


Figure 4-4. Total passage index count and outmigration timing for juvenile sockeye salmon at Rock Island Dam (Columbia River DART, historical index count in blue font from FPC data)

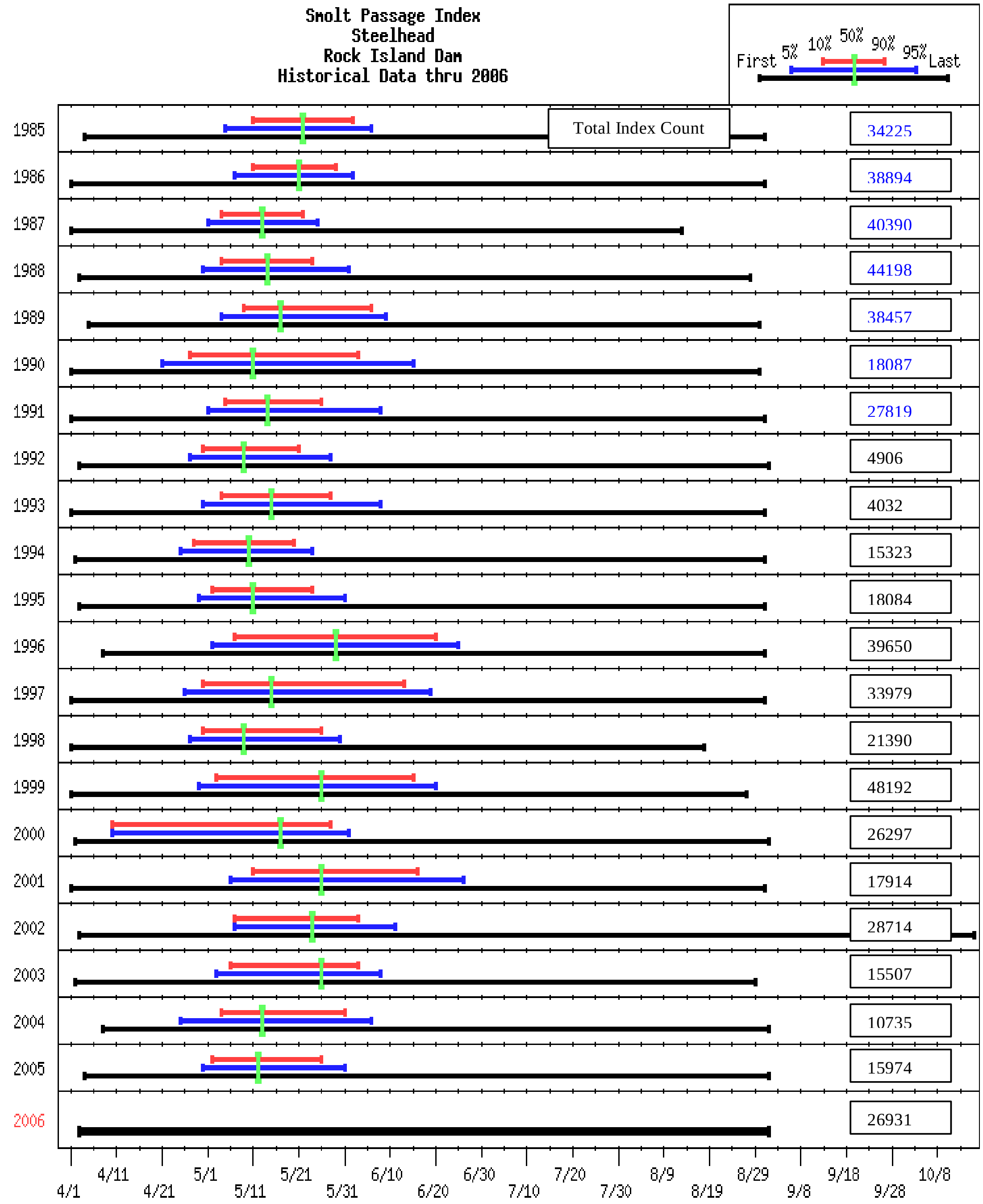


Figure 4-5. Total passage index count and outmigration timing for juvenile steelhead at Rock Island Dam (Columbia River DART, historical index count in blue font from FPC data)

Outmigration for yearling and subyearling Chinook salmon typically starts during the first week of April whereas, the last record of juvenile Chinook salmon passing downstream is during late-August. However, the peak outmigration of the yearling Chinook salmon occurs during the month of May but the peak of the outmigration for subyearling Chinook salmon occur in late-June or early-July. Outmigration for juvenile coho also typically starts and ends during the same time frame. Peak juvenile coho outmigration is considerably more condensed into the mid-May to mid-June time frame. Peak juvenile sockeye salmon outmigration, on the other hand, can occur during mid-April to early-June and is more spread out over the spring months. Juvenile steelhead show consistent outmigration patterns peaking in mid- to late-May and the first and last migrant are also found at the beginning and end of the sampling season (see Table 4-3, Table 4-4, and Table 4-5).

Table 4-3. Conservative estimation of annual smolt abundance using Rock Island Dam index counts and trap efficiency of 5 percent

	Chinook yearling		**Chinook subyearling**		**Coho**		**Sockeye**		**Steelhead**	
Year	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*
2006	745,340	745,380	542,140	643,040	1,225,680	1,225,680	692,080	692,180	538,620	538,620
2005	295,940	291,640	374,200	447,040	743,900	712,880	39,820	39,300	319,480	313,240
2004	251,480	251,480	471,260	518,480	573,360	573,360	142,280	142,140	214,700	214,700
2003	307,100	307,100	518,320	562,260	833,800	833,800	206,240	206,120	310,140	310,140
2002	579,640	579,640	498,220	509,320	1,724,540	1,724,540	412,580	412,640	574,280	574,280
2001	132,700	131,500	440,860	452,760	908,740	908,560	60,640	60,440	358,280	356,920
2000	646,680	505,960	232,200	273,860	991,040	991,040	48,600	48,560	525,940	471,920
1999	806,400	805,680	521,580	566,800	923,460	923,460	467,420	462,420	963,840	792,500
1998	497,180	499,920	293,180	344,140	836,740	836,180	332,700	334,160	427,800	429,800
1997	1,075,080	1,075,080	379,500	384,800	86,020	86,020	268,520	268,580	679,580	679,580
1996	849,560	850,340	295,040	306,160	530,420	530,540	199,900	203,780	793,000	796,040
1995	615,060	615,060	264,140	283,860			541,120	541,320	361,680	361,680
1994	246,480	246,680		286,460				263,140	306,460	306,440
1993	270,280	308,940		321,700		766,240		321,380	80,640	205,000
1992	322,000	371,460	183,240	204,900		708,760		50,940	98,120	335,500
1991		632,900		688,960		915,400		301,820		556,380
1990		417,060		1,093,640		312,340		85,940		361,740
1989		310,040		883,960		756,660		529,380		769,140
1988		1,041,000		765,840		851,220		485,440		883,960
1987		425,500		367,200		703,500		553,560		807,800
1986		522,300		1,459,600		1,186,140		856,220		777,880
1985		777,820		487,480		273,100		736,080		685,100

Table 4-4. Conservative estimation of annual smolt abundance over Priest Rapids Dam using Rock Island Dam index counts (trap efficiency of 5 percent) and per project survival of 93.7 percent (Peven and Hays 1989) for smolt abundance in Priest Rapids Lake.

	Chinook yearling		Chinook subyearling		Coho		Sockeye		Steelhead	
Year	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*	*CR DART*	*FPC*
2006	698,384	698,421	507,985	602,528	1,148,462	1,148,462	648,479	648,573	504,687	504,687
2005	277,296	273,267	350,625	418,876	697,034	667,969	37,311	36,824	299,353	293,506
2004	235,637	235,637	441,571	485,816	537,238	537,238	133,316	133,185	201,174	201,174
2003	287,753	287,753	485,666	526,838	781,271	781,271	193,247	193,134	290,601	290,601
2002	543,123	543,123	466,832	477,233	1,615,894	1,615,894	386,587	386,644	538,100	538,100
2001	124,340	123,216	413,086	424,236	851,489	851,321	56,820	56,632	335,708	334,434
2000	605,939	474,085	217,571	256,607	928,604	928,604	45,538	45,501	492,806	442,189
1999	755,597	754,922	488,720	531,092	865,282	865,282	437,973	433,288	903,118	742,573
1998	465,858	468,425	274,710	322,459	784,025	783,501	311,740	313,108	400,849	402,723
1997	1,007,350	1,007,350	355,592	360,558	80,601	80,601	251,603	251,659	636,766	636,766
1996	796,038	796,769	276,452	286,872	497,004	497,116	187,306	190,942	743,041	745,889
1995	576,311	576,311	247,499	265,977			507,029	507,217	338,894	338,894
1994	230,952	231,139		268,413				246,562	287,153	287,134
1993	253,252	289,477		301,433		717,967		301,133	75,560	192,085
1992	301,714	348,058	171,696	191,991		664,108		47,731	91,938	314,364
1991		593,027		645,556		857,730		282,805		521,328
1990		390,785		1,024,741		292,663		80,526		338,950
1989		290,507		828,271		708,990		496,029		720,684
1988		975,417		717,592		797,593		454,857		828,271
1987		398,694		344,066		659,180		518,686		756,909
1986		489,395		1,367,645		1,111,413		802,278		728,874
1985		728,817		456,769		255,895		689,707		641,939

Table 4-5. Conservative estimation of smolt abundance using FPC Rock Island Dam index counts (trap efficiency of 5 percent) and 5-year mean smolt survival data (1998-2002, FPC 2002 Annual Report) from Rock Island Dam to McNary Dam for average, lower, and upper multiproject.

	Chinook yearling				Chinook subyearling				Sockeye				Steelhead			
			Lower	Upper			Lower	Upper			Lower	Upper			Lower	Upper
		Avg. Surv.	Limit	Limit		Avg. Surv.	Limit	Limit		Avg. Surv.	Limit	Limit		Avg. Surv.	Limit	Limit
Year	FPC	0.6972	0.5824	0.8118	FPC	0.5307	0.4629	0.5986	FPC	0.607	0.3992	0.8147	FPC	0.5542	0.442	0.6668
2006	**745,380**	519,679	434,109	605,099	**643,040**	341,261	297,663	384,924	**692,180**	420,153	276,318	563,919	**538,620**	298,503	238,070	359,152
2005	**291,640**	203,331	169,851	236,753	**447,040**	237,244	206,935	267,598	**39,300**	23,855	15,689	32,018	**313,240**	173,598	138,452	208,868
2004	**251,480**	175,332	146,462	204,151	**518,480**	275,157	240,004	310,362	**142,140**	86,279	56,742	115,801	**214,700**	118,987	94,897	143,162
2003	**307,100**	214,110	178,855	249,304	**562,260**	298,391	260,270	336,569	**206,120**	125,115	82,283	167,926	**310,140**	171,880	137,082	206,801
2002	**579,640**	404,125	337,582	470,552	**509,320**	270,296	235,764	304,879	**412,640**	250,472	164,726	336,178	**574,280**	318,266	253,832	382,930
2001	**131,500**	91,682	76,586	106,752	**452,760**	240,280	209,583	271,022	**60,440**	36,687	24,128	49,240	**356,920**	197,805	157,759	237,994
2000	**505,960**	352,755	294,671	410,738	**273,860**	145,338	126,770	163,933	**48,560**	29,476	19,385	39,562	**471,920**	261,538	208,589	314,676
1999	**805,680**	561,720	469,228	654,051	**566,800**	300,801	262,372	339,286	**462,420**	280,689	184,598	376,734	**792,500**	439,204	350,285	528,439
1998	**499,920**	348,544	291,153	405,835	**344,140**	182,635	159,302	206,002	**334,160**	202,835	133,397	272,240	**429,800**	238,195	189,972	286,591
1997	**1,075,080**	749,546	626,127	872,750	**384,800**	204,213	178,124	230,341	**268,580**	163,028	107,217	218,812	**679,580**	376,623	300,374	453,144
1996	**850,340**	592,857	495,238	690,306	**306,160**	162,479	141,721	183,267	**203,780**	123,694	81,349	166,020	**796,040**	441,165	351,850	530,799
1995	**615,060**	428,820	358,211	499,306	**283,860**	150,645	131,399	169,919	**541,320**	328,581	216,095	441,013	**361,680**	200,443	159,863	241,168
1994	**246,680**	171,985	143,666	200,255	**286,460**	152,024	132,602	171,475	**263,140**	159,726	105,045	214,380	**306,440**	169,829	135,446	204,334
1993	**308,940**	215,393	179,927	250,797	**321,700**	170,726	148,915	192,570	**321,380**	195,078	128,295	261,828	**205,000**	113,611	90,610	136,694
1992	**371,460**	258,982	216,338	301,551	**204,900**	108,740	94,848	122,653	**50,940**	30,921	20,335	41,501	**335,500**	185,934	148,291	223,711
1991	**632,900**	441,258	368,601	513,788	**688,960**	365,631	318,920	412,411	**301,820**	183,205	120,487	245,893	**556,380**	308,346	245,920	370,994
1990	**417,060**	290,774	242,896	338,569	**1,093,640**	580,395	506,246	654,653	**85,940**	52,166	34,307	70,015	**361,740**	200,476	159,889	241,208
1989	**310,040**	216,160	180,567	251,690	**883,960**	469,118	409,185	529,138	**529,380**	321,334	211,328	431,286	**769,140**	426,257	339,960	512,863
1988	**1,041,000**	725,785	606,278	845,084	**765,840**	406,431	354,507	458,432	**485,440**	294,662	193,788	395,488	**883,960**	489,891	390,710	589,425
1987	**425,500**	296,659	247,811	345,421	**367,200**	194,873	169,977	219,806	**553,560**	336,011	220,981	450,985	**807,800**	447,683	357,048	538,641
1986	**522,300**	364,148	304,188	424,003	**1,459,600**	774,610	675,649	873,717	**856,220**	519,726	341,803	697,562	**777,880**	431,101	343,823	518,690
1985	**777,820**	542,296	453,002	631,434	**487,480**	258,706	225,654	291,806	**736,080**	446,801	293,843	599,684	**685,100**	379,682	302,814	456,825

Chapter 5 RESIDENT FISH SPECIES AND POTENTIAL PROJECT EFFECTS

5.1 Description of Individual Species

A list of fish species present in the Priest Rapids Lake of the Columbia River was compiled and determination of risks to each species by the operation of the Pumping intake. A list of these species as compiled by Fisher et al. 2003 is presented in Table with a summary column indicating if the species could be potentially impacted. The potential impact is based on the presence of young, poor-swimming fish in the intake zone of influence from literature and field observations. The young larval stages were considered most vulnerable to impingement. The intake is to be screened with 1.75mm opening mesh with a fish by-pass and should protect fish from the pumps and penstock impacts.

Table 5-1. Summarized resident and transient fish species known or likely in the Priest Rapids hydroelectric facility area

Common Name	Scientific Name	Status**	Potentially Impacted
*white sturgeon	*Acipenser transmontanus*	native game fish, common	X
brook trout	*Salvelinus fontinalis*	introduced game fish, rare	
*bull trout	*Salvelinus confluentus*	native game fish, Federal threatened, rare	
*rainbow trout	*Oncorhynchus mykiss*	native game fish, common	X
*cutthroat trout	*Oncorhynchus clarki*	native game fish, uncommon	
*brown trout	*Salmo trutta*	introduced game fish, uncommon	
*mountain whitefish	*Prosopium williamsoni*	native game fish, common	
*lake whitefish	*Coregonus clupeaformis*	native game fish, rare	X
*northern pikeminnow	*Ptychocheilus oregonensis*	native non-game fish, abundant	X
*peamouth	*Mylocheilus caurinus*	native non-game fish, abundant	
*chiselmouth	*Acrocheilus alutaceus*	native non-game fish, abundant	
*redside shiner	*Richardsonius balteatus*	native non-game fish, abundant	X
*longnose dace	*Rhinichthys cataractae*	native non-game fish, common	X
*speckled dace	*Rhinichthys osculus*	native non-game fish, common	
*leopard dace	*Rhinichthys falcatus*	native non-game fish, rare	
Tui chub	*Gila bicolor*	native non-game fish, rare	
*carp	*Cyprinus carpio*	introduced non-game fish, common	X
*tench	*Tinca tinca*	introduced non-game fish, uncommon	
*bridgelip sucker	*Catostomus columbianus*	native non-game fish, abundant	X
*largescale sucker	*Catostomus macrocheilus*	native non-game fish, abundant	X
mountain sucker	*Catostomus platyrhynchus*	native non-game fish, rare	
*longnose sucker	*Catostomus catostomus*	native non-game fish, common	
*channel catfish	*Ictalurus punctatus*	introduced game fish, common	X
brown bullhead	*Amiurus nebulosus*	introduced game fish, common	X
*black bullhead	*Amiurus melas*	introduced game fish, uncommon	X

Common Name	Scientific Name	Status**	Potentially Impacted
yellow bullhead	*Amiurus natalis*	introduced game fish, uncommon	X
*burbot	*Lota lota*	native game fish, rare	
*three-spined stickleback	*Gasterosteus aculeatus*	native non-game fish, abundant	X
*sandroller	*Percopsis transmontana*	native non-game fish, rare	X
*largemouth bass	*Micropterus salmoides*	introduced game fish, common	X
*smallmouth bass	*Micropterus dolomieu*	introduced game fish, common	X
*black crappie	*Pomoxis nigromaculatus*	introduced game fish, common	X
*white crappie	*Pomoxis annularis*	introduced game fish, common	X
*bluegill	*Lepomis macrochirus*	introduced game fish, uncommon	X
*pumpkinseed	*Lepomis gibbosus*	introduced game fish, uncommon	X
shorthead sculpin	*Cottus confusus*	native non-game fish, uncommon	
Piute sculpin	*Cottus beldingi*	native non-game fish, uncommon	
*torrent sculpin	*Cottus rhotheus*	native non-game fish, common	
American shad	*Alosa sapidissma*	introduced non-game fish, uncommon	X
mottled sculpin	*Cottus bairdi*	native non-game fish, uncommon	
*prickly sculpin	*Cottus asper*	native non-game fish, common	
slimy sculpin	*Cottus cognatus*	native non-game fish, uncommon	
*walleye	*Stizostedion vitreum*	introduced game fish, common	X
*yellow perch	*Perca flavescens*	introduced game fish, common	X

*Indicates that individuals of this species were sampled during 1999 descriptive survey.
**Based on estimate of relative abundance in one of four categories: abundant, common, uncommon, rare.

All of the fish listed in the above table as being potentially impacted generally have a high likelihood of being present near the intake during pumping, and they have a susceptible life history stage such as eggs or young fish that could be entrained or impinged on the screens, resulting in mortality.

5.1.1 Acipenseridae

White sturgeon (*Acipenser transmontanus*)

White sturgeon are found in nearshore marine environments, estuaries, and large cool rivers and streams (NatureServe, 2006). Although considered anadromous, some Columbia River populations are considered landlocked (e.g., above Chief Joseph Dam) (Wydoski and Whitney, 2003). In the unimpounded Lower Columbia below Bonneville Dam and where fish passage at mainstem dams is provided, sturgeon migrate upstream to spawn in the fall and back downstream in late winter and spring when spawning is completed. Sturgeon upstream of Bonneville Dam generally tend to remain within a single reservoir for their entire lives (Wydoski and Whitney, 2003). One large specimen became lodged in a fish ladder at Priest Rapids Dam, indicating that the dam’s fishways were not designed to allow passage of large sturgeon (Wydoski and Whitney, 2003).

Anadromous populations make extensive saltwater migrations; however, many move more locally from estuaries to freshwater, or farther inland within freshwater, to spawn (NatureServe, 2006). Sexual maturity is reached at about 9 years of age, with spawning occurring at intervals ranging from 4 to 11 years (NatureServe, 2006). In the Columbia River, spawning occurs from May through July, either over deep gravel riffles or in deep holes with swift currents and rock bottoms (Wydoski and Whitney, 2003). Spawning probably occurs below Rock Island Dam and larval drift probably occurs through Priest Rapids Lake during periods of proposed pumping. Larvae drift, following hatching, until they come to rest in slow backwater nursery habitats (Fisher et. al, 2003).

White sturgeon commonly reach lengths of up to 133 inches (340 cm) (NatureServe, 2006), but may reach up to 20 feet (6.1 m) and live for over 100 years (Page and Burr, 1991).

White sturgeon were noted as a species with some potential of larval impingement by Fisher et all (2003). July was speculated as the approximate time that any white sturgeaon larvae from the pool or up river could be in danger of being impinged (trapped on screens).

5.1.2 Clupeidae

American shad (***Alosa sapidissima***)

American shad are anadromous, inhabiting nearshore marine waters except when ascending coastal rivers during the breeding season (NatureServe, 2006; Page and Burr, 1991). Extremely large runs occur in the Columbia River Basin, with migrating adults passing through the fishways at Priest Rapids Dam in numbers ranging between 14,000 to 41,000 between 1990 and 1997; however no shad are counted at dams farther upstream (Wydoski and Whitney, 2003). Some biologists believe that shad have become so abundant in the Columbia River system that they may interfere with passage of other fish species (Wydoski and Whitney, 2003).

Spawning in the Columbia River occurs between late June and early July in various riverine habitats (NatureServe, 2006). Semi-bouyant eggs are laid in open water, fertilized, and carried downstream by river currents where they eventually sink and settle in crevices or vegetation (Wydoski and Whitney, 2003). Eggs hatch in 3 to 10 days (Wydoski and Whitney, 2003). Larvae summer in the rivers, enter sea by fall when they are 3 to 5 inches (8 to 13 cm) in length, and return to freshwater when mature (3 to 5 years of age) (NatureServe, 2006). Many adults also return to the Pacific Ocean after spawning (Wydoski and Whitney, 2003).

Adults in the Columbia River commonly reach 17 to 19 inches (43 to 48 cm) long, but rarely over 24 inches (61 cm) (Wydoski and Whitney, 2003).

Newly emerged shad larvae are small and could be small enough to pass screens if they are present with a day or two of hatching. The summer spawning makes this species larval form potentially at risk to the operations of the pumping facility.

5.1.3 Cyprinidae

Chiselmouth (***Acrocheilus alutaceus***)

Chiselmouth inhabit both stream and lake habitats, preferring lake margins (NatureServe, 2006) and large, warmer streams with slow current (Wydoski and Whitney, 2003). They are common to abundant where found, but in the Yakima River are most numerous below Roza Dam (Wydoski and Whitney, 2003). Juveniles are commonly found in shallow pools with cobble and boulder substrates, rarely over gravel or silt (Wydoski and Whitney, 2003).

In the mid-Columbia region, spawning takes place in streams from late May through July over open substrates composed of gravel, small rubble, and boulders (Wydoski and Whitney, 2003).

Adults average 9 to 10 in (23 to 24 cm), with a maximum length up to 12.6 in (32 cm) (Wydoski and Whitney, 2003).

Common carp (***Cyprinus carpio***)

Common carp are common in small to large turbid rivers and in reservoirs and ponds with large amounts of organic matter (Page and Burr, 1991). Optimal lake habitat has warm water (> 68 °F; >20 °C) mid-June through August, at least 25 percent littoral area, abundant shallows or flooded areas (generally < 1.5 feet; 0.5 m deep) with aquatic or inundated vegetation for spawning, deeper waters for overwintering, and fertile conditions. Although tolerant of a wide range of oxygen, salinity, turbidity, and bottom conditions, they generally are not found in cold, first order streams or in deep lakes with little or no littoral zone (NatureServe, 2006).

Carp have well-defined home ranges in both summer and winter, but do not use the same ranges from season to season or from year to year. Extensive movements sometimes occur, although in a Missouri mark-recapture study, 51.3 percent of marked carp were recaptured within 1 mile (1.6 km) and 90 percent stayed within 25 miles (40 km) (NatureServe, 2006).

Eggs are scattered and stick to submerged objects. After hatching, fry attach to vegetation for a few days before dropping to the bottom, inhabiting shallow (<79 in; < 2 m), warm sluggish water during their first summer (NatureServe, 2006; Wydoski and Whitney, 2003).

Adults average length is up to 48 inches (122 cm) (NatureServe, 2006; Page and Burr, 1991).

Carp are a nonnative found near shore at times spawning. Their eggs and larvae are larger and probably not at risk by the pump operation.

Peamouth (***Mylocheilus alutaceus***)

Peamouth are common, and frequently locally abundant, in lakes and slow parts of small to medium rivers (NatureServe, 2006). They generally are associated with vegetation and weedy shallows (NatureServe, 2006). During spring, summer and fall they generally inhabit shallow water, moving to deep parts of lakes in winter. In deep water, peamouth are found at all depths up to 200 feet (61 m) and always near the bottom in water less than 60 feet (18 m) deep (Wydoski and Whitney, 2003). Peamouth also appear to move shoreward into shallows at night and, except during spawning season, return to deep water by day (NatureServe, 2006).

In the mid-Columbia region, spawning typically begins in mid-May, peaking in June (Wydoski and Whitney, 2003). Peamouth spawn in streams or along lake shores, over gravel or rubble, in shallow water within 3 feet (0.9 m) of shore (NatureServe, 2006). Eggs are broadcast on the bottom and adhere to the substrate, hatching in 7 to 8 days (Wydoski and Whitney, 2003).

Peamouth generally grow up to 11 inches (28 cm) (Wydoski and Whitney, 2003).

The area within the >2fps velocity zone had very few aquatic plants as observed during the day prior to the hydroacoustic transects and seen as a very hard bottom reflection in the hydroacoustic transects. If the vegetation were to remain absent from this location, it would be undesirable for peamouth spawning.

Northern pikeminnow (***Ptychocheilus oregonensis***)

Northern pikeminnow are found in lakes and small-to-large rivers, preferring areas of still or slow-moving waters. They are common in Columbia Basin mainstem reservoirs and in tailwaters of dams. In lakes, adults usually are found offshore; however, in summer they move to shallows or nearer the surface of the water column, and return to deeper offshore waters during fall (NatureServe, 2006; Wydoski and Whitney, 2003).

Spawning in the mid-Columbia region typically occurs from late June through early August. Gravel, cobble, and rubble substrates are used in both streams and lakes. No nest is constructed and fish do not guard the spawning site. Eggs hatch in 7 days, larvae drift for 1 to 3 days after hatching, and become free-swimming in 14 days. Rearing occurs in warmer, low-velocity shoreline and backwater habitats (Wydoski and Whitney, 2003).

Large northern pikeminnow are considered to be the most effective predator on salmonid outmigrants in the Columbia River system (Wydoski and Whitney, 2003).

Northern pikeminnow grow up to 25 inches (63 cm) (Page and Burr, 1991), but generally are less than 20 inches (51 cm) in the Columbia Basin (Wydoski and Whitney, 2003).

This native fish could potentially use the gravel substrate area at the proposed intake location as a spawning location. The later spawning season could also make the hatched larvae most susceptible to impingement on the projects screen array.

Redside shiner (***Richardsonius balteatus***)

Red shiner are common, often abundant, in a variety of habitats including lakes, ponds, sloughs, irrigation ditches, headwaters, creeks, and small-to-medium rivers where current is slow or lacking; usually over mud or sand and often near vegetation in shallow areas (NatureServe, 2006; Page and Burr, 1991). In lakes, they may move into deep water at night and in winter (NatureServe, 2006).

Spawning takes place from late June through July (in the Hanford Reach) over gravel substrate or in submerged vegetation in streams or along lake shorelines. No nest is built. The broadcast eggs sink and adhere to rocks, vegetation, and detritus (NatureServe, 2006; Wydoski and Whitney, 2003).

Redside shiner compete for forage species with juvenile spring Chinook in the Columbia Basin. Diet overlap was up to 67 percent in five study reaches in the Yakima River (Wydoski and Whitney, 2003).

Redside shiner can grow up to 7 inches (18 cm), but most are less than 5 inches (13 cm) (Wydoski and Whitney, 2003).

These fish spawn along shorelines and have been observed in more backwater cusps in the Priest Rapids Lake. If they were to spawn within the 250 feet (76 m) radius of the zone of influence, then the larvae would be susceptible to impingement.

Speckled dace (***Rhinichthys osculus***)

Speckled dace are found in riffles, runs, and pools of cool, flowing headwater creeks and small to medium rivers with mostly rocky substrates (NatureServe, 2006; Page and Burr, 1991). They usually prefer shallow water (< 3 feet; < 0.9 m deep) (Wydoski and Whitney, 2003). Young tend to occupy the edges of streams in slower, shallow water; larger adults generally are in relatively quiet water where cover (e.g., LWD, boulders, overhanging branches) is available (NatureServe, 2006). Speckled dace rarely are found in lakes (NatureServe, 2006; Page and Burr, 1991).

Spawning occurs from June through August, peaking in late June (Wydoski and Whitney, 2003). Stream populations spawn in swift water over rocky substrates. Lake populations spawn in shallow waters with gravel substrate or on graveled edges of riffles in inlet streams. Eggs typically are unexposed, attached to the undersides of rocks or in interstices between rocks (NatureServe, 2006)

Speckled dace can grow up to 4.25 inches (11 cm) (Page and Burr, 1991).

This species prefers more flow velocities than what was seen at the proposed intake site. They would be a low risk as far as effects unless the intake water increased velocity were to make this location more desirable habitat. Even with increases flow, the relatively smooth gravels could possibly not be satisfactory habitat; a rocky cobble is preferred substrate.

Longnose dace (***Rhinichthys cataractae***)

Longnose dace have the widest range of any North American minnow (NatureServe, 2006). They are characteristic of rocky shores of lakes (Page and Burr, 1991) and clean, cool (55 to 70 °F; 13 to 21 °C) in summer, swiftly flowing, rock- and boulder-bottomed creeks and small-to-medium rivers (NatureServe, 2006; Wydoski and Whitney, 2003). They rarely are found on mud bottoms (Wydoski and Whitney, 2003). In warm lakes, they may move offshore to deeper water (NatureServe, 2006).

Spawning occurs from May through early July, generally on small rock or rubble (2 to 6 in; 5 to 15 cm) diameter in velocities ranging from 1.5 to 3.3fps (Wydoski and Whitney, 2003). They also spawn in shallow, pebble-bottomed, wave-swept shorelines of lakes (NatureServe, 2006). Eggs hatch in 7 to 10 days (Wydoski and Whitney, 2003). After hatching, fry are pelagic, living near the surface in shallow open water along the protected margins of streams, then moving to bottom habitats at about 4 months (Wydoski and Whitney, 2003).

Size range up to 6.25 inches (16 cm) (Page and Burr, 1991), but generally < 4 inches (11 cm) (Wydoski and Whitney, 2003).

As with the speckled dace, this species prefers more flow velocities than what was seen at the proposed intake site, although their occurrence along wave-swept shores in lakes does make them susceptible if this shore is used. The hatched larvae would be at risk if found within the zone of influence.

Leopard dace (***Rhinichthys falcatus***)

Leopard dace are listed as a Candidate Species by Washington Department of Fish and Wildlife (WDFW).

Leopard dace are generally uncommon in Washington, with a spotty and disjunct distribution. They utilize habitat on or near the bottom of streams and small-to-mid-sized rivers with slow-moving current (< 1.5fps). They sometimes are found in lakes (Wydoski and Whitney, 2003), specifically along rocky margins (Page and Burr, 1991). They prefer substrates comprised of stones covered by fine sediments, with summer temperatures ranging from 59 to 64 °F (15 to18 °C). They are rarely found at depths > 3.3 ft (1.0 m) and usually are found in slower, deeper water than longnose dace. (Wydoski and Whitney, 2003).

Spawning is thought to occur between May and July (Wydoski and Whitney, 2003), although very little is known about spawning habitat or behavior (WDNR, 2005). Spawning is believed to be similar to longnose and speckled dace. These dace primarily spawn in riffles over unprepared gravel or small stones (WDNR, 2005).

Leopard dace grow up to 4.7 inches (12 cm) (Page and Burr, 1991; Wydoski and Whitney, 2003).

This species would be rare in the Priest Rapids Lake. More flow than what was seen along the shore at the proposed intake site is preferred by these fish.

Tench (***Tinca tinca***)

Tench are found in warm, quiet, mud-bottomed waters such as ponds, oxbow lakes, sloughs, shallow areas of lakes and reservoirs, backwaters and other slow-moving areas of small to large rivers, generally with dense aquatic vegetation (Page and Burr, 1991; Wydoski and Whitney, 2003). They are capable of living in poorly oxygenated water. In summer, they may move to deep holes and shady locations. (NatureServe, 2006).

Depending on location, tench spawn from May to August in weedy shallows where adhesive eggs are broadcast over aquatic vegetation (NatureServe, 2006; Wydoski and Whitney, 2003).

Tench grow up to 33 inches (84 cm) (Page and Burr, 1991), although more commonly 18 inches (46 cm) (Wydoski and Whitney, 2003).

Tench do not prefer this open shore habitat and would not be directly affected by this intake operation.

5.1.4 Catostomidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Longnose sucker (*Catostomus catostomus*)

The longnose sucker is the most widespread sucker in North America (Page and Burr, 1991). They usually occupy clear, deep water of coldwater lakes and tributary streams (Page and Burr, 1991). Older fish are generally found in deeper water, moving offshore during the day, although subadults may remain in shallow (<11 feet; 3.4 m) weedy areas of lakes (Wydoski and Whitney, 2003).

Spawning may begin in early June while temperatures are still in the low- to mid-40 °F (4 °C) range and typically occurs over gravel substrates in the swift riffles of streams (Wydoski and Whitney, 2003), otherwise in lakes where eggs sink to the bottom (NatureServe, 2006). Eggs hatch in about 2 weeks (NatureServe, 2006), and fry will remain in the spawning area for 1 to 2 weeks (Wydoski and Whitney, 2003).

Longnose sucker grow up to 25 inches (64 cm) (NatureServe, 2006; Page and Burr, 1991; Wydoski and Whitney, 2003).

If longnose suckers spawned in the area and time as water intake operation, the young larval fish could potentially be impinged on the screens. The flows at the proposed site are currently probably too slow for use by longnose suckers.

Bridgelip sucker (*Catostomus columbianus*)

Bridgelip sucker frequently occur as a predominant species in a variety of Columbia Basin habitats including lake margins, backwaters or edges of rivers with sand and silt bottoms, and riffles of small-to-medium rivers and creeks with swift (up to 4fps) cold water and sand, gravel, or rocky bottoms (Wydoski and Whitney, 2003; NatureServe, 2006). They are common in the backwaters and pools of the Yakima River, moving to deeper pools during daylight and to slower, shallower water near shore at night (Wydoski and Whitney, 2003).

In the mid-Columbia region, spawning occurs from mid-April until mid-June in shallow (0.5 feet; 0.15 m) tributary streams over substrates consisting primarily of pebbles, cobbles, and gravel (Wydoski and Whitney, 2003). Eggs settle into or adhere to the substrates. Fry emerge approximately 25 days after spawning and utilize areas inshore of the main channel currents (Wydoski and Whitney, 2003).

Bridgelip sucker commonly grow up 2 to 17 inches (30 to 43 cm) (Page and Burr, 1991; Wydoski and Whitney, 2003).

These fish spawn relatively early and if they are present they could be susceptible based on proposed earlier season pumping operation.

Largescale sucker (***Catostomus macrocheilus***)

Largescale sucker are the predominant sucker species in the Columbia River and its major tributaries. Large numbers of upstream migrants typically are counted in June at the Priest Rapids Dam fish ladder (Wydoski and Whitney, 2003).

They occur in lakes and in pools and runs of medium-to-large rivers (NatureServe, 2006; Page and Burr, 1991). Largescale sucker are often abundant at the mouths of streams entering lakes (Wydoski and Whitney, 2003) or along weedy shores or in backwaters (NatureServe, 2006). Subadults are common in backwater areas less than 3.3 feet (1.0 m) deep; however, adults favor deeper mid-river channels and pools during the day and move inshore at night (Wydoski and Whitney, 2003). They also may move to deeper, cooler water in summer, sometimes as deep as 80 feet (24 m) (NatureServe, 2006).

In the mid-Columbia region, spawning occurs from early April into July in shallow water (3 to 9 feet; 0.9 to 2.7 m deep), usually over a gravel substrate embedded with sand or silt (Wydoski and Whitney, 2003). Spawning has been observed in sandy areas of streams or along lake shorelines in areas with sand or gravel substrates. Eggs hatch in about 2 weeks. (NatureServe, 2006). Fry move to shallows to feed by day and to deeper water at night (NatureServe, 2006; Wydoski and Whitney, 2003).

Largescale sucker grow up to 24 inches (61 cm) (NatureServe, 2006l; Page and Burr, 1991; Wydoski and Whitney, 2003).

This relatively common sucker could be spawning proximate to the inake zone earlier in the year when the project is expected to be operation. Young larval fish would be impinged should they hatch within the zone of influence.

5.1.5 Ictaluridae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Black bullhead (***Ameiurus melas***)

Black bullhead are rare in the mid-Columbia region (Wydoski and Whitney, 2003). They are found in ponds, small lakes, river backwaters, swamps, impoundments, and small stream pools, preferring warm and turbid water, muddy bottoms, slow or stagnant currents, and few other fish species (NatureServe, 2006). Adults are generally inactive in schools in aquatic vegetation during day and feed at night (Wydoski and Whitney, 2003).

Spawning occurs in warm (65 to 70 ºF; 18 to 21 °C), shallow water (2 to 4 feet; 0.6 to 1.2 m deep) from April through July (Wydoski and Whitney, 2003). Eggs are laid in a shallow nest in mud or sand, in secluded areas such as under logs or mats of aquatic vegetation (NatureServe, 2006; Wydoski and Whitney, 2003). After hatching, juveniles remain in compact schools until large enough to disperse (Wydoski and Whitney, 2003).

Black bullhead average 18 inches (46 cm), but most are less than 12 inches (30 cm) (Wydoski and Whitney, 2003).

These fish are more cover oriented and would be very infrequently found along this shoreline.

Yellow bullhead (***Ameiurus natalis***)

Yellow bullhead are common to a few locations in Washington, but distribution is spotty elsewhere in the state, and where found is never numerous (Wydoski and Whitney, 2003). They prefer shallow weedy areas in clear warm lakes, ponds, or slow-moving streams or canals (NatureServe, 2006). They generally do not occur where largemouth bass have been introduced (Wydoski and Whitney, 2003).

Spawning occurs in May or June in water up to 1.5 to 4 feet deep (0.5 to 1.2 m). Shallow nests are formed in soft substrates similar to other species of bullhead.

Eggs hatch in 5 to 10 days. Young grow rapidly, but are guarded by the male until they reach about 2 inches (5 cm) (Wydoski and Whitney, 2003).

Yellow bullhead usually mature to 15 inches (38 cm) (NatureServe, 2006).

As with black bullheads, these fish are more cover oriented and would not be frequently found along this shoreline.

Brown bullhead (***Ameiurus nebulosus***)

Brown bullhead are the most common bullhead species in Washington (Wydoski and Whitney, 2003). They are found in warm water ponds, lakes, and reservoirs (preferring shallow bays and sloughs), sluggish streams, and backwaters (Wydoski and Whitney, 2003). They generally occur in vegetated shallows over sand, rock, mud, or silt, in clear to turbid water (NatureServe, 2006). Adults are usually in deeper water along the shoreline of lakes during daylight, but move into shallow, weedy areas to feed and spawn at night (Wydoski and Whitney, 2003). Brown bullhead are tolerant of high temperatures (up to 97 ºF; 36 ºC) (Wydoski and Whitney, 2003).

Nests are usually located near shore or in coves or creek mouths. Eggs are laid in an open excavation in sand, gravel, or (rarely) mud, often in the shelter of logs, rocks, vegetation, or debris. (NatureServe, 2006).

Brown bullhead grow up to 21 inches (50 cm) (Page and Burr, 1991), but generally under 12 inches (30 cm) in Washington (Wydoski and Whitney, 2003).

These fish could be found along the intake shore but they would use other habitat to spawn. The adults would not be at risk as they could escape any flows in front of the screens.

Channel catfish (***Ictalurus punctatus***)

Channel catfish generally are found in clear lakes, reservoirs, and the main channels of large and small rivers and streams; however, they also occur in turbid or muddy water. In streams, they are usually found in moderate-to-swift current over sand, gravel and rubble bottoms (Wydoski and Whitney, 2003). Upland streams are generally avoided (NatureServe, 2006). In flowing water, they are sometimes found over mud bottoms. Unlike bullhead, they are seldom found in dense aquatic vegetation. Adults are most active at night, moving into shallow water of streams to feed and returning to deep holes or under log jams, cutbanks, debris, or other shelters during daylight (NatureServe, 2006; Wydoski and Whitney, 2003). Adults over 12 in (30 cm) in length are primarily piscivorous and are a significant predator of juvenile salmon and steelhead (Wydoski and Whitney, 2003).

Spawning occurs in spring with eggs laid in sheltered cave-like nest sites such as old muskrat burrows, undercut banks, hollow submerged logs, and log jams (Wydoski and Whitney, 2003). Young-of-year live in riffles. (NatureServe, 2006).

Channel catfish grow up to 50 inches (127 cm) (NatureServe, 2006); however, typically less than 36 inches (92 cm) (Wydoski and Whitney, 2003).

Channel catfish are cover oriented and spawn on debris and depressions. These fish would not be susceptible to effects of the intake operation.

5.1.6 Salmonidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Lake whitefish (*Coregonus clupeaformis*)

In the Columbia River system, lake whitefish are found upstream of McNary Reservoir (Wydoski and Whitney, 2003). They are a coolwater species found in large deep lakes and large rivers and are most abundant at depths of 50 to 90 feet (15 to 27 m) (Wydoski and Whitney, 2003).

Lake whitefish spawn in the fall between October and January depending on local conditions (Wydoski and Whitney, 2003). They generally spawn in shallow water over a hard or stony bottom and exhibit a strong fidelity to spawning sites (NatureServe, 2006). Their semibuoyant eggs hatch in early spring (NatureServe, 2006).

Lake whitefish can grow up to 31 inches (80 cm) (Page and Burr, 1991), but typically are under 24 inches (61 cm) (Wydoski and Whitney, 2003).

White fish early season spawning could make their semi-buoyant drifting eggs and larval stages both susceptible to impingement.

Cutthroat trout (west slope) (***Oncorhynchus clarkii***)

In the mid-Columbia region, west slope cutthroat trout occur in lakes and major tributaries ranging from upstream of the project area (in the Wenatchee, Entiat, and Methow Rivers, and the Lake Chelan and Pend Orielle River drainages) to downstream of the project area (in the Upper Yakima and lower Snake River drainages (Wydoski and Whitney, 2003).

Westslope cutthroat trout are non-anadromous and include adfluvial, fluvial, and resident stocks. Adfluvial stocks spawn between March and July depending on water temperature and spend only a short time in spawning tributaries before returning to lake habitats when spawning is completed. Juveniles of the adfluvial form spend from 1 to 4 years in tributary streams before moving into the lakes (Wydoski and Whitney, 2003). Fluvial populations spawn in small upstream tributaries and move downstream to larger river segments as they grow, seldom moving significant distances. In Washington, habitat of resident stocks is generally limited to pristine headwater streams and alpine lakes (Wydoski and Whitney, 2003).

Westslope cutthroat trout typically reach 12 to 15 inches (30 to 38 cm), but occasionally grow up to 24 inches (61 cm) in productive, lightly fished lakes (Wydoski and Whitney, 2003).

Only three cutthroat trout were collected during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum reservoirs conducted in 1999 (Pfeiffer et al 2001).

These fish would no be susceptible to direct effects of the operation of this facility. Their young are of sufficient size and swimming ability when they are in the pool to avoid impingement

Mountain whitefish (***Prosopium williamsoni***)

Mountain whitefish are locally abundant, occurring throughout the state in coldwater mountain lakes (to depths of at least 33 feet; 10 m) and fast, clear or silty rivers and streams with large pools (NatureServe, 2006; Wydoski and Whitney, 2003). They frequently are found in the tailraces below Priest Rapids and Wanapum dams (Wydoski and Whitney, 2003). They prefer riffle areas in streams in summer and large pools and slow-moving runs in winter (Wydoski and Whitney, 2003).

Mountain whitefish spawn in late October to early November, depending on elevation. Stream populations spawn in riffles over gravel and small rubble; lake populations move into tributaries or gravel shoals and shallows (NatureServe, 2006). Eggs hatch in about 5 months at temperatures above 35 °F (2 °C) (NatureServe, 2006). Emerging fry drift downstream to suitable shallow (<10 inches; <25 cm deep) backwater holding areas (Wydoski and Whitney, 2003).

In Washington, 12-inch (30 cm) mountain whitefish are considered good-sized, although individuals up to 22 inches (57 cm) have been caught (Wydoski and Whitney, 2003).

The mountain whitefish drifting fry could be at some risk of impingement but their spawning locations is in higher order streams and are probable not spawning in the Priest Rapids Lake.

Brown trout (***Salmo trutta***)

Brown trout mostly occur in cold, medium-to-high gradient streams, but lake populations also exist (NatureServe, 2006). The distribution of brown trout in Washington is generally limited to various lakes throughout the state; to several rivers in the northeastern part of the state; the Yakima River and Crab Creek (Mid-Columbia Basin tributaries); and several Snake River tributaries (Wydoski and Whitney, 2003). They tend to occupy deeper, lower velocity, and warmer waters than other species of trout (NatureServe, 2006) and may survive in waters up to 81°F (27 °C) for short periods (Wydoski and Whitney, 2003). They also tolerate more turbid water and lower oxygen levels than most other trout (Wydoski and Whitney, 2003). Some migratory populations spend their first 2 years in river habitat, 1 to 2 years in lake habitat, then return to their natal river to spawn at 3 to 4 years of age (NatureServe, 2006).

Spawning occurs in fall or early winter in waters ranging from large streams to small spring-fed tributaries; shallow gravelly headwaters; rocky lake margins; or sometimes over sand or hard clay if no gravel is available (NatureServe, 2006). Eggs hatch in about 50 days when water temperature is 50 °F (10 °C) (Wydoski and Whitney, 2003).

No brown trout were collected during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum reservoirs conducted in 1999, although one was recorded from Tarpiscan Creek (Pfeiffer et al 2001).

Bull trout (***Salvelinus confluentus***)

The Upper Columbia distinct population segment (DPS) of bull trout is currently listed as threatened under the ESA (NPCC, 2004). In addition, critical habitat for the DPS has been designated that includes Columbia River segments and major tributaries in the mid- and upper Columbia regions (Fed. Reg. 2005).

Bull trout that occur in the mid- and upper Columbia region may exhibit fluvial, adfluvial, or stream-resident life forms; however, stream-resident forms are generally restricted to small headwater streams where they spend their entire lives (NatureServe, 2006) and thus do not utilize the Columbia mainstem or lower tributaries in the vicinity of Priest Rapids or Wanapum reservoirs. Fluvial and adfluvial forms may use the mainstem and lower tributaries for foraging, overwintering, and migration (NPCC, 2004).

Adult fluvial and adfluvial bull trout spawn between August and November and return to the Columbia in October or November (NPCC, 2004). Juveniles typically emigrate out of their natal streams between 2 and 4 years of age (WDNR, 2005). Most migratory bull trout pass counting windows at Columbia River dams during May and June (NPCC, 2004). Telemetry studies indicate that the Columbia River from upstream of Wells Dam to an area near Wanapum Dam is used by bull trout during fall, winter, and spring to (1) move to and from the mainstem and tributaries, (2) move upstream and downstream within the mainstem, and (3) to overwinter (NPCC, 2004).

Bull trout have occasionally been collected from the tailrace at Priest Rapids and Wanapum Dams (Wydoski and Whitney, 2003); however, only two bull trout were collected during intensive tributary and reservoir fish surveys of Priest Rapids and Wanapum reservoirs conducted in November 1999 (Pfeiffer et al, 2001).

These are rare in the pool area and do not appear to be directly effected at any life stage.

Brook trout (***Salvelinus fontinalis***)

Brook trout occupy cool, clear, well-oxygenated streams, small-to-medium rivers, and lakes, preferring water temperatures of 57 to 61 °F (14 to 16 °C) (NatureServe, 2006). They generally do poorly above 68 °F (20 °C) for extended periods (NatureServe, 2006). In Washington, they are most common in mountain lakes (Wydoski and Whitney, 2003).

Spawning occurs in late summer to early fall (NatureServe, 2006). They typically spawn over gravel in shallow headwater streams, but also have been observed in gravelly lake shallows in areas of groundwater upwelling or spring-fed coolwater inflow (NatureServe, 2006; Wydoski and Whitney, 2003).

Brook trout grow up to 16 inches (40 cm) (NatureServe, 2006).

5.2 Percopsidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Sand roller (***Percopsis transmontana***)

Sand rollers are found only in the Columbia River system, and are reported to be rather common in the tailraces below Priest Rapids and Wanapum dams (Wydoski and Whitney, 2003).

They occur in quiet backwaters, pool margins, and slow moving portions of small-to-large rivers with vegetated rubble, mud-sand, or rock and sand substrates, usually near vegetation (NatureServe, 2006; Page and Burr, 1991). In Columbia River tributaries, they commonly utilize shallow water habitats with dense cover consisting of brush, tree roots, or undercut banks during the day but move to stream riffles or the tail-end of pools at night (Wydoski and Whitney, 2003). In deep river habitats, they have been found at depths of over 50 feet (15 m) during daytime, however, at night they return to shallower water (Wydoski and Whitney, 2003).

In the Columbia River region, spawning occurs in May through mid-July (Wydoski and Whitney, 2003). Little is known of sand roller spawning behavior. Spawning has been reported in mainstem rivers and in reservoirs (Wydoski and Whitney, 2003), but they may also move to shallow streams or to shallow shores of rivers to spawn (NatureServe, 2006).

Size range is up to 3.75 inches (9.6 cm) (Page and Burr, 1991).

These fish could be susceptible to impingement in larval form as they are documented as common in the vicinity. Their spawning period could place early spawned sand rollers larvae in the vicinity during operations.

5.3 Gadidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Burbot (***Lota lota***)

Burbot are listed as a Species of Concern by the WDFW.

They inhabit cold, deep waters of large reservoirs and lakes at depths of up to 300 feet (90 m) and large rivers. Adult burbot may move to shallower water at night (when most active) and also tend to move to shallower water in the spring and fall (Wydoski and Whitney, 2003). Young fish are found under rocks or other structures in streams and in the shallow littoral zone of lakes and reservoirs (Wydoski and Whitney, 2003).

Burbot usually spawn in shallow bays of lakes, but may also move into rivers to spawn (NatureServe, 2006). Spawning sites up to 10 feet (3 m) in depth, with sand or gravel bottoms, are preferred (NatureServe, 2006). Spawning typically occurs at night in late winter and early spring when water temperatures reach about 35 ºF (36 ºC) (Wydoski and Whitney, 2003). River spawning populations prefer low-velocity areas in main channels or in side channels behind deposition bars (NatureServe, 2006).

These fish range in size up to 33 inches (84 cm) (Page and Burr, 1991).

The burbot preferred habitat and spawning location make them a low risk for direct effect from the pumping project.

5.4 Gasterosteidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Three-spine stickleback (***Gasterosteus aculeatus***)

Resident inland populations of three-spine stickleback are abundant in the Columbia Basin, and typically are found in still or slow-moving weedy pools and backwaters, or among emergent plants at stream edges, over bottoms of sand and mud (Wydoski and Whitney, 2003). Anadromous populations occur in estuary and near-shore habitats (Wydoski and Whitney, 2003). In some lakes, two ecologically distinct forms may occur, one utilizing littoral habitat and the other mainly limnetic (NatureServe, 2006). Three-spine stickleback are small, weak swimmers that are easily displaced by high streamflows, if off-channel refugia is not available (Wydoski and Whitney, 2003).

Spawning occurs from May to July when adults are 1 or 2 years old (Wydoski and Whitney, 2003). Eggs are deposited in a nest of algae and debris constructed by the male in shallow water either on the bottom or in vegetation (NatureServe, 2006; Wydoski and Whitney, 2003). Eggs hatch in about 7 days. In Washington, three-spine stickleback typically do not live beyond 4 years, with up to 90 percent presumably dying at the end of their first breeding season (NatureServe, 2006; Wydoski and Whitney, 2003).

Three-spine stickleback are a significant forage species for piscivorous fish and birds, and have disappeared quickly from warm water lakes where brown bullhead were introduced. (Wydoski and Whitney, 2003).

Size ranges up to 4 inches (10 cm) (NatureServe, 2006).

The stickleback preference of aquatic vegetation makes them rare in the weed-free zone of influence, although their weak swimming ability could place them against the screens should they be in the zone of influence.

5.5 Cottidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Prickly sculpin (***Cottus asper***)

Prickly sculpin are often locally abundant, and are an important forage fish (Wydoski and Whitney, 2003). They usually occur over sand in pools and quiet runs of small-to-medium rivers, and along sandy and rocky shores of lakes. They also occur in tidewater areas where they can tolerate brackish water (tidepools, estuaries) (NatureServe, 2006; Page and Burr, 1991). Downstream migration of adults and upstream migration of young of the year (YOY) is typical of many populations (NatureServe, 2006). Adults typically hide under submerged objects during the day, emerging at night to feed (NatureServe, 2006). In winter, adults move to deeper water (NatureServe, 2006).

Spawning in Washington typically peaks from April to mid-June (Wydoski and Whitney, 2003) over flat rocks and moderate current (NatureServe, 2006). Males prepare nests under rocks, logs, or debris (NatureServe, 2006). Eggs hatch in 11 to 24 days, depending on water temperature (Wydoski and Whitney, 2003).

Prickly sculpin typically grow to 3.5 inches (9 cm) (NatureServe, 2006) and seldom are over 6 inches (15 cm) (Wydoski and Whitney, 2003).

Sculpins are probably present along the shore and if young larvae were to be in the area they could be impinged on screens.

Paiute sculpin (***Cottus beldingii***)

Paiute sculpin are typically found in riffle areas of clear, cold creeks, and small-to-medium rivers that have a slight-to-moderate gradient and rubble or large gravel bottoms. They also are found along rocky shorelines of lakes and near mouths of streams in areas with rubble or gravel substrate, or in aquatic beds in deep water (NatureServe, 2006).

Spawning usually occurs in late spring over gravel substrate in riffles near rocks, or along wave-swept beaches of lakes. Eggs are deposited underneath rocks (Wydoski and Whitney, 2003).

Size ranges up to 5 inches (13 cm) (Wydoski and Whitney, 2003).

These fish riffle preference makes them a low risk for direct effects of operations.

Slimy sculpin (***Cottus cognatus***)

Slimy sculpin are not thought to occur in the vicinity of the proposed project. They generally are found in rocky riffles of cold, clear streams and rocky areas of lakes, commonly near inlet streams. In lake environments, they can be found at depths of 300 to 350 feet (90 to106 m) or more (Page and Burr, 1991; (Wydoski and Whitney, 2003). At night they may move from deeper water into lake shallows (NatureServe, 2006).

Eggs are laid in early spring under a rock, ledge, submerged tree, or similar situation in streams. Lake spawning behavior is poorly known (NatureServe, 2006).

Slimy sculpin grow up to 4.5 inches (12 cm) (Page and Burr, 1991; Wydoski and Whitney, 2003).

Shorthead sculpin (***Cottus confusus***)

Shorthead sculpin are found in fast riffles of cold headwater creeks and in rivers with rubble, cobble, or gravel bottoms. They also have been observed in backwater and shoreline areas in large rivers with slow-moving water, but seem to prefer the cooler upstream habitats (NatureServe, 2006; Troffe 1999; Wydoski and Whitney, 2003). In general, they are found at higher elevations than most sculpin (Wydoski and Whitney, 2003).

Spawning occurs in early spring in the rocks and cobble of larger streams. Eggs are deposited in clusters underneath rocks (Troffe 1999; Wydoski and Whitney, 2003).

Shorthead sculpin grow typically up to 4 inches (10 cm) (NatureServe, 2006).

As with the Paiute sculpin, preference for riffle habitat makes these fish a low risk for direct effects of operations

Margined sculpin (***Cottus marginatus***)

Margined sculpin are listed as a Sensitive Species by the State of Washington; however, they do not occur in the vicinity of the proposed project.

Margined sculpin have the smallest range of any fish species in Washington. Their occurrence is confined to the northern Blue Mountains in southeastern Washington and northeastern Oregon where they are found only in the Tucannon, Walla Walla, and Umatilla River drainages (Mongillo and Hallock 1998; Wydoski and Whitney, 2003).

Torrent sculpin (***Cottus rhotheus***)

Torrent sculpin occupy rocky lakeshores and swift current reaches (generally with velocities of 1.4 to 4.0fps) of small to large rivers with stable bottoms of gravel, rubble, and large rocks (Wydoski and Whitney, 2003).

Spawning occurs in late spring. Eggs are laid in swift water, under stones (NatureServe, 2006; Wydoski and Whitney, 2003).

Size ranges up to 6 inches (15 cm) (Page and Burr, 1991; Wydoski and Whitney, 2003).

As with some of the other sculpins, preference for riffle habitat makes these fish a low risk for direct effects of operations

5.6 Centrarchidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Pumpkinseed (***Lepomis gibbosus***)

Pumpkinseed are native to the Eastern United States, but were widely introduced in the West. They now occur in Columbia Basin's reservoirs, weedy lakes and ponds, backwaters and sloughs of slow-moving rivers and sluggish streams (NatureServe, 2006; Wydoski and Whitney, 2003). They prefer quiet, clear water with dense aquatic vegetation and generally avoid deeper open waters (NatureServe, 2006; Wydoski and Whitney, 2003).

Spawning occurs from late spring to August depending on location and water temperature (Wydoski and Whitney, 2003). Nests are constructed in sand, gravel, or mud in shallow water (7 to 27 inches; 18 to 69 cm deep) (Wydoski and Whitney, 2003).

Pumpkinsee typically are less than 7 inches (18 cm) in length in Washington (Wydoski and Whitney, 2003).

The pumpkinseed's shallow water spawning preference could make them susceptible to impingement in the hatched larval stage.

Bluegill (***Lepomis macrochirus***)

Bluegill are native to the Central and Eastern United States, but were widely introduced in the West, including the lower Columbia Basin (Wydoski and Whitney, 2003). They inhabit warm shallow lakes, reservoirs, ponds, swamps, sloughs and backwaters, and slow-moving rivers and streams with rooted aquatic vegetation (NatureServe, 2006; Wydoski and Whitney, 2003). Bluegill typically feed during the day, traveling in small, loose schools while feeding (Wydoski and Whitney, 2003).

Spawning begins in the spring when water temperature is above 67 °F (19 °C) and may continue into late summer (Wydoski and Whitney, 2003). Nests are constructed in shallow water on bottoms of gravel, sand, or mud, often in colonies. Eggs hatch in 2 to 3 days (NatureServe, 2006).

In Washington, bluegill weighing 1 lb (0.45 kg) are considered to be large (Wydoski and Whitney, 2003).

The bluegills protracted spawning season and shallow water spawning preference could make them susceptible to impingement in the hatched larval stage.

Smallmouth bass (***Micropterus dolomieu***)

Smallmouth bass are native to the Central and Eastern United States, but were widely introduced in the West, including the Columbia Basin, where significant populations are now widespread. They prefer summer water temperatures of 68-80 °F (20-27 °C) and generally utilize shallow rocky areas and gravel bars in large clear lakes, and rivers and larger streams having many large pools and broken rock or gravel-bottomed runs (Wydoski and Whitney, 2003; NatureServe, 2006). Adults are almost entirely piscivorous (NatureServe, 2006) and are significant predators of juvenile salmonids (Wydoski and Whitney, 2003).

Spawning usually occurs from late spring to early summer in lake shallows or quiet areas of streams. Smallmouth bass have a strong fidelity to specific nest sites and will return annually to those sites (Wydoski and Whitney, 2003). Lake populations may move a short distance up a stream to spawn. Nests are constructed near cover at depths of about 3 feet (1 m) in gravel or sand substrates. Eggs hatch in 3 to10 days. (NatureServe, 2006).

Size ranges up to 27 inches (69 cm) (Page and Burr, 1991).

The shallow gravel areas in the intake zone of influence could be good conditions for smallmouth bass to spawn. The young larvae would then be very susceptible to impingement.

Largemouth bass (***Micropterus salmoides***)

Largemouth bass are common and widespread in the Columbia Basin, occurring in warm quiet waters with low turbidity, soft bottom, and beds of rooted vegetation (NatureServe, 2006). The largest numbers occur in mesotrophic and eutrophic lakes and reservoirs where they are usually found close to shore (NatureServe, 2006). They generally move to deeper water in winter, but seldom deeper than the limit of rooted plants (Wydoski and Whitney, 2003).

Spawning occurs from mid-May through June in shallow bays, sloughs, and backwaters (Wydoski and Whitney, 2003). Eggs are laid in shallow nests formed in sand, gravel, or debris-littered bottoms, most frequently at depths of 1-6 feet (0.3 to 1.8 m) and next to submerged objects (Wydoski and Whitney, 2003). Nests are usually more than 30 feet (9 m) apart (NatureServe, 2006).

Size ranges up to 27 inches (70 cm) (NatureServe, 2006).

These fish spawn near shore and although there is not much cover, there could be spawning along shallow gravel areas in the intake zone of influence. The young larvae would be very susceptible to impingement.

White crappie (***Pomoxis annularis***)

White crappie are most common in sand- and mud-bottomed pools and backwaters of warm turbid creeks, small-to-large rivers, lakes, and reservoirs (NatureServe, 2006; Page and Burr, 1991). Abundant populations occur in the reservoirs and backwater sloughs of the Columbia River (Wydoski and Whitney, 2003). Unlike black crappie, they do not appear to require rooted vegetation (Wydoski and Whitney, 2003). White crappie are relatively inactive during the day, tending to congregate around submerged logs or boulders in quiet water 6.6 to 13 feet (2 to 4 m) deep or in the dimly lit profundal zone of reservoirs (NatureServe, 2006).

Spawning occurs in spring to early summer (NatureServe, 2006) near objects such as stumps, brush piles, and rock outcrops (Wydoski and Whitney, 2003). Ill-defined nests are near or in beds of vegetation or plant debris (including flooded terrestrial vegetation) in water less than 5 feet (1.5 m) deep (NatureServe, 2006). Eggs hatch in about 2 to 5 days. (NatureServe, 2006).

White crappie can grow to 21 inches (53 cm) (Page and Burr, 1991), but typically are less than 12 inches (30 cm) (Wydoski and Whitney, 2003).

As with the large mouth, these fish like some sort of cover or vegetation. They are probably not going to spawn in the zone of influence.

Black crappie (***Pomoxis nigromaculatus***)

Black crappie are more widespread in Washington than white crappie, occurring in all of the Columbia and Snake river mainstem reservoirs (Wydoski and Whitney, 2003). They are most abundant in large clear lakes and reservoirs, and clear backwaters of rivers and streams, preferring cooler waters than the white crappie (Wydoski and Whitney, 2003). They prefer large dense beds of aquatic vegetation over sandy to mucky bottoms (NatureServe, 2006; Wydoski and Whitney, 2003).

Spawning occurs during May or early June in most of their range (Wydoski and Whitney, 2003). Nests are constructed in substrates ranging from soft mud to gravel, usually in water less than 8 feet (2.4 m) deep in or near beds of aquatic plants (NatureServe, 2006; Wydoski and Whitney, 2003). Eggs hatch in 2 to 5 days (NatureServe, 2006).

In Washington, 10-inch (25-cm) black crappie are considered a good size, although individuals up to 17 inches (43 cm) have been recorded (Wydoski and Whitney, 2003).

As with the large mouth bass and white crappie, these fish prefer cover or vegetation. They are probably not going to spawn in the zone of influence.

5.7 Percidae

Usually occurs in rivers, lakes, ponds, reservoirs, swamps, or low-salinity estuaries; usually in shallow water with abundant vegetation and little or no current; generally does not inhabit first-order, cold streams or deep lakes with little or no littoral zone. Tolerant of wide range in oxygen, salinity, turbidity, and bottom conditions.

Yellow perch (***Perca flavescens***)

Yellow perch occur in all reservoirs in the mid- and lower Columbia and lower Snake rivers (Wydoski and Whitney, 2003). They usually inhabit shallow clear waters of lakes and large ponds, and clear weedy backwaters and pools of small-to-large rivers and streams (NatureServe, 2006). They generally are associated with moderate-to-heavy growths of aquatic plants in reservoirs and lakes. (NatureServe, 2006; Wydoski and Whitney, 2003).

Yellow perch migrate to lake shallows or into tributary streams to spawn (NatureServe, 2006). Spawning usually begins in April or May when water temperature reaches 45 to 52 °F (7 to 11 °C) and occurs in quiet waters on beds of aquatic vegetation or submerged brush over sand, gravel, or rubble (Wydoski and Whitney, 2003). Eggs are deposited at depths of up to 13 feet (4 m) and hatch in about 10 to 20 days (NatureServe, 2006).

Yellow perch grow to approximately 13 inches (33 cm) maximum in Washington (Wydoski and Whitney, 2003).

The early spawning of these could make larval stages susceptible to impingement during the early year operations.

Walleye (*Sander vitreus*)

Walleye were first reported from the Columbia River system in the 1960's and by the 1980's had become a popular sportfish in all of the mainstem reservoirs (Wydoski and Whitney, 2003). They mainly occur in large lakes and reservoirs, and in pools, backwaters, and runs of medium-to-large rivers, generally in quiet, moderately deep waters (NatureServe, 2006). The highest catch rates of walleye in the Columbia River were in tailraces below dams (Wydoski and Whitney, 2003). They tend to avoid summer temperatures above 75 °F (24 °C), and during the day move to deeper water or seek cover in beds of aquatic vegetation, in holes among tree roots, or in or near similar cover (NatureServe, 2006).

Walleye spawn in early spring when water temperatures are 38 to 44 °F (3 to 7 ^{o}C). They may migrate long distances (100+ miles) between spawning and nonspawning habitats (Wydoski and Whitney, 2003). Lake populations often move up rivers to spawn (NatureServe, 2006). They typically spawn at night in 2 to 3 feet (0.6 to 0.9 m) of water in turbulent rocky areas of rivers, along riprapped dam faces, in rocky or coarsely graveled shoals of lakes, and in flooded marshes (NatureServe, 2006; Wydoski and Whitney, 2003). Eggs hatch in 21 days at 50 to 55 °F (10 to 13 °C) (Wydoski and Whitney, 2003).

Size ranges up to 31 inches (78 cm) (NatureServe, 2006).

The early spawning of these could make larval stages susceptible to impingement during the early year operations.

Chapter 6 FACTORS AND ESTIMATE OF FISH MORTALITY AT THE INTAKE OF PRIEST RAPIDS LAKE.

6.1 Smolt Passage Survival in the Columbia River

Hydroelectric development has long been identified as a critical factor that has contributed to decreased populations of salmonids in the Columbia River basin. Outmigrating smolts die as they pass through hydroelectric turbines, bypasses, and spillways at dams (Giorgi et al., 1997). Various researchers have attributed the prolonged seaward migration of smolts to the lower water velocities now found throughout the mainstem Columbia River system. Travel time for out-migrating juvenile salmonids is estimated to move at a 33- 50-percent slower rate than they did through free-flowing river stretches of the same length. Slower migration subsequently exposes smolts to predatory fish for longer periods of time thus, potentially increasing smolt mortality (Giorgi et al., 1997).

In a 1989–1995 study investigating migration rates for Columbia River salmonids, researchers examined smolt migration travel time in relation to increased water velocity through flow augmentation. The intention of the study was to increase smolt outmigration rates in effort to decrease overall smolt mortality. Giorgi et al. (1997) found that across all study years, on average, the steelhead migrated downstream the fastest, with a median travel rate of 18.9 miles/day (30.4 kilometers/day [km/d]). Sockeye salmon traveled 16.3 miles/day (26.3 km/d) and yearling Chinook salmon traveled 13.4 miles/day (21.5 km/d). Subyearling Chinook salmon were the slowest moving smolt, migrating at a median rate of 9.7 miles/day (15.6 km/d). Since subyearling Chinook salmon rear and actively forage throughout the Columbia River reservoirs during the summer months, their slower outmigration is expected, in contrast to the spring-migrating yearling salmonids. For the spring-migrating sockeye salmon and steelhead, increased flow was the primary predictor variable. Yearling Chinook salmon travel time was not correlated with any variable, and subyearling Chinook salmon showed no response to flow over a broad range of discharge (~53,000 to ~177,000 cfs [1,500-5,000 m3/s]).

Previous studies indicate that among the different passage routes through dams, direct passage survival for juvenile salmonids was generally highest for spillways, followed by bypass systems and then turbines. Spillway survival estimates have ranged from 73 percent to 100 percent, and turbine survival estimates are from 81 to 98 percent. Bypass survival was evaluated in only a few studies and usually not through the entire bypass system. Survival is often assumed to be 97-98 percent through bypass systems (Whitney et al., 1997). Bypass systems include extended-length submersible bar screens or standard-length submersible traveling screens, which guide smolts away from turbine intakes and all turbine units (Muir et al., 2001).

Muir et al. (2001) evaluated the Little Goose Dam (Snake River) bypass system in 1997 and were the first to estimate mortality for fish that passed along the submersible traveling screen into the gatewell, through the orifice into the collection channel, and into the bypass outfall area, where predation can be especially high. Estimated survival through bypass systems ranged from 95.4 to 99.4 percent for yearling Chinook salmon and from 92.9 to 98.3 percent for steelhead released into the collection channel. Estimated survival was 95.3 percent for steelhead that passed through the entire bypass system. Estimated turbine survival ranged from 86.5 to 92.7 percent for yearling Chinook salmon and was 93.4 percent for steelhead at Little Goose Dam in 1997 (Muir et al., 2001).

Prolonged time within juvenile collection systems can affect fish health and survival via several mechanisms. Extended residence times within collection systems can increase stress of juvenile salmonids or prolonged exposure to environmental pollutants such as total dissolved gas supersaturation. Maule et al. (1988) demonstrated that each section of the collection system at McNary Dam added to the total stress experienced by juvenile Chinook salmon going through the system. They concluded that reductions in the time fish spent within any part of the system could cause a decrease in the stress experienced within the system as a whole. McNary Dam was evaluated again by Beeman and Maule (2001) and found the median gate well residence time for juvenile spring Chinook salmon was 9.2 hours. Median gatewell residence time was 10.3 hours for fish released in midday and 1.1 hours for those released in the evening. The 9.2-hour difference was similar to the 8.7-hour difference in median release times of the two groups. Most fish released during midday (71 percent) and evening (69 percent) left the gatewell within 24 hours, and almost all passage occurred before midnight on the day of release (70 percent midday and 69 percent evening). The telemetry system in the gatewell detected 88 percent of the juvenile spring Chinook salmon released (Beeman and Maule 2001).

Median gatewell residence time of juvenile steelhead was 3.2 hours. Of the steelhead released at midday, 64 percent left the gatewell within 24 hours, whereas 88 percent of those released in the evening left within that time. As with juvenile Chinook salmon, the median gatewell residence time of juvenile steelhead released at midday (12.9 hours) was longer than for fish released during the evening (0.3 hours), reflecting the difference in median release times (7.8 hours). Most juvenile steelhead left the gatewell between dusk and dawn, but 24 percent left between 1200 and 1600 hours. All juvenile steelhead released were detected in the gatewell. Juvenile spring Chinook salmon spent little time in the collection channel. Residence time from the orifices of gatewell 5A to the south end of the collection channel ranged from 1.5 minutes to 4.8 hours. Median collection channel residence time of juvenile steelhead was 28.3 minutes (range, 1.3 minutes to 88.1 hours). All but one juvenile steelhead left the collection channel within 27.3 hours (Beeman and Maule, 2001).

The depths of tagged fish within the gatewell were mostly within the upper ~35 feet (10.7 meters). Tagged juvenile spring Chinook salmon spent an average of 83 percent of time within the gatewell within the detection range of the upper antenna (upper ~30 feet [9.1 meters] for 1.5-V test tag). Less than 8 percent of their time was spent at depths greater than 9.9 meters, as indicated by detection of the lower antenna. Depths of juvenile steelhead were also largely within the range of the upper antenna (96 percent; maximum detection depth ~30 feet (10.7 meters] for 3.0-V test tag); they spent little time within range of the lowest antenna (10 percent; minimum detection depth ~40 feet [12.2 meters]) (Beeman and Maule, 2001).

Results of the Beeman and Maule (2001) study indicated that most Chinook salmon and steelhead juveniles spent little time in the gatewell and collection channel at McNary dam, though some species-specific differences existed. Most fish passed from the gatewell to the collection channel during the evening, regardless of the time they were released into the gatewell. Juvenile salmonids enter and pass through juvenile collection systems at several Columbia and Snake River dams primarily at night; this passage behavior is not consistent with natural migration behaviors of these two species within the reservoirs.

Untagged juvenile steelhead were often visually observed swimming against the current immediately downstream of structures that altered the velocity in the channel (e.g., pipes used to house dewatering-screen equipment); this was not observed for juvenile Chinook salmon. Most juvenile spring Chinook salmon and steelhead released into the gatewell passed to the collection channel during the evening on the day of the release. However, some individuals of both species remained in the gatewell for over 5 days. Therefore, juvenile salmonids entering the gatewell during the day will have prolonged residence times in the juvenile bypass system, which will increase their stress while in the system (Beeman and Maule, 2001). Another study of diel passage of juvenile salmonids into the gatewells of McNary and John Day dams found that numbers of fish entering the gatewells from the reservoir began to increase at dusk, peaked at midnight, and generally declined to nearly zero by dawn. Few fish entered the gatewells during the day. This passage pattern appears common, but it is important to note that this is not the natural diel migration pattern of these species and represents a delay in dam passage.

Ledgerwood et al. (1991), in a study based on purse seine and beach seine catches, reported that juvenile salmonids migrated through the Columbia River estuary primarily during the day. Interrupting the natural migration patterns of juvenile salmonids approaching dams prolongs forebay residence times, which could increase juvenile salmonid mortality. Peterson (1994), in an analysis of the spatial pattern of predation in the reservoir below McNary Dam, reported that approximately 10-15 percent of the predation of juvenile salmonids by northern pikeminnow in the entire reservoir occurred in the comparatively small area of the forebay of John Day Dam, indicating forebay environments, can be areas of significant mortality. Peterson also reported that the greatest proportion of predation in the forebay occurred during May and July. Forebay delays of other juvenile salmonids have also been reported. Venditti et al. (2000) found that the migration of radio-tagged juvenile fall Chinook salmon during July and early August were delayed as they approached Little Goose Dam. They found previously migrating fish milling in the forebay for days, or traveling back upstream for as much as ~8.7 miles (14 km) before returning to the dam (Beeman and Maule, 2001).

The use of voluntary spill to improve passage survival is based on data indicating that survival of juvenile salmonids passing dams is greatest at spillways, followed by juvenile bypass systems and then turbines (Muir et al. 2001). This benefit, however, could be offset by reduced survival due to the effects of gas bubble disease caused by increased total dissolved gas supersaturation when air entrained in spilled water dissolves under hydrostatic pressure in dam tailraces (Beeman and Maule, 2006).

Researchers have speculated that predation by populations of northern pikeminnow (*Ptychocheilus oregonensis*) downstream of dams may be a significant source of juvenile salmonid mortality. They found that predation is concentrated primarily in the tailrace immediately below a dam, often near the outfall site. Northern pikeminnow prefer slow-water habitat suggesting that they do not frequent the open stretch of faster water away from shore. High mortality due to predation in these areas has been attributed to high concentrations of both juvenile salmonids and northern pikeminnow in areas near the outfall and an increase in the vulnerability of bypassed juveniles to predation. If elevated levels of predation are not reduced near a bypass' release point, then the bypass system may not achieve its intended benefits (Den Bleyker et al., 1997).

To minimize the exposure of juvenile salmonids to predators subsequent to release from a bypass system, design criteria and methodologies have been developed to locate the outfall site strategically within a tailrace. Placing the outfall in a location where flow conditions are inhospitable to predators while providing favorable dispersion characteristics could limit predation. A concentrated, plunging outfall jet, which generates high shear velocities at its boundaries, may adversely affect the juveniles or place them in slower velocities near the river bottom inhabited by predators. Without improvements to the plunge characteristics of outfalls, significant numbers of juveniles may be lost as a direct or indirect consequence of the outfall plunge. Limited data describing and associating the local hydraulic and biological effects that a plunge may have on juvenile salmonids has made it difficult to assess related mortality (Den Bleyker et al., 1997).

To provide a basis for modifying the outfall structure, the following design criteria were established:

(1) the design should minimize the plunge depth of the outfall to avoid predation to the river bottom,

(2) the design should maximize the initial dispersion of water and fish into the river,

(3) supercritical flow within the outfall pipe should be maintained,

(4) the design should avoid excessive turbulence within the outfall pipe, and

(5) a depth of at least 1 foot must be maintained at the terminus of the modification.

By adhering to these criteria, it was thought that improvements could be made to an outfall plunge that could reduce juvenile mortality rates in the tailrace (Den Bleyker et al., 1997).

Based on hydraulic model tests, a flow spreader has been developed to improve the hydraulic characteristics of a bypass outfall plunge. With the flow spreader in place, plume widths were increased significantly and plunge depths were reduced significantly. The increased dispersion of the flow resulted in a decrease in the unit mass flow rate at the river surface. Although field tests have not been conducted, plunge characteristics with a flow spreader indicate that juveniles may be dispersed over a much greater area of the river and at relatively shallow depth. If discharged into a carefully selected area, inhospitable to predators, the juvenile salmonids may have an increased chance of survival (Den Bleyker et al., 1997).

In an effort to reduce in-river mortality, the U.S. Army Corps of Engineers (Corps) transported a large portion of smolts around lower Columbia River dams by barge, releasing them downstream of Bonneville Dam. NOAA Fisheries conducted several studies between 1968 and 1989 and, based upon smolt-to-adult returns, concluded that barged juvenile salmonids survived in higher proportions than their in-river counterparts. More recent data support this conclusion (NOAA Fisheries, 2000). However satisfactory the initial estimates of low direct mortality may be for the transportation program, the more important problems appear to be the extent of delayed mortality that is realized from transportation stressors (Budy et al., 2002). Comparing smolt-to-adult returns of transported fish with that of in-river migrants alone may not reveal the extent of delayed mortality (Schreck et al., 2006).

Whereas transportation reduces the direct mortality of spring-summer Chinook salmon to approximately 2 percent versus 6-14 percent per project per year in comparison with run-of-river fish, indirect or delayed mortality of barged fish may offset the balance in favor of run-of-river fish in some years (Budy et al., 2002). Congleton et al. (2000) reported high stress levels in spring-summer Chinook salmon that were correlated with barge-loading densities and presence of steelhead in the barge holds and concluded that survival rates for Chinook salmon could be most impacted during midseason transportation, when steelhead densities were high.

The physiological impacts of dam passage by run-of-river fish are more intuitive than for transported fish. Stress levels are known to increase as fish travel through the collection system at a dam (Maule et al. 1988). Barton et al. (1986) subjected juvenile Chinook salmon to sequential handling stresses and found that stress levels were cumulative. Maule et al. (1988) used a variety of physiological and performance tests to measure the effects associated with dam passage by run-of-river fish. They reported that stress levels increased sequentially as juvenile spring-summer Chinook salmon pass through the collection system of a dam but returned to precollection system levels within 24-48 hours.

Stress resulting from dam passage can compromise a fish’s energy reserves, immune system, ability to smolt, and propensity to migrate. Stress resulting from dam passage can be acute or chronic and accumulative and may lead to impaired physical abilities or even delayed mortality (Schreck et al., 2006). Smolt predators are known to frequent areas where smolts experience stress and become concentrated for prolonged periods of time. These areas include the forebays and tailraces of dams, where rheotaxic aberrations can cause smolts to aggregate, or stress from dam passage can be manifested (Budy et al. 2002).

In addition to physical changes at dams, the conditions that smolts face in tailraces may also have improved due to a predator control program that removed nearly one-million northern pikeminnow during the early 1990's (Beamesderfer et al., 1996); the use of bird wires across tailraces to discourage avian predation; the positioning of bypass outfalls exits in areas unattractive to predators (Shively et al. 1996). In a more recent study by Schreck et al., (2006), avian predation is estimated to consume 11-17 percent of all Columbia River smolts annually, mostly occurring downstream from Bonneville Dam by Caspian terns and double-crested cormorants.

Most Columbia River Basin juvenile anadromous salmon and steelhead tend to stay in the upper 10-20 feet of the water column as they outmigrate to the ocean. Juvenile fish passage routes at Columbia and Snake River dams cause juvenile fish to dive to depths of 50 to 60 feet to find passage routes because of the dam's configurations. Engineers and biologists have been pursuing new technologies that would provide more surface-oriented, less stressful passage routes for juvenile fish. Surface bypass structures are currently used at five of eight Corps dams on the lower Columbia and Snake rivers. Three types of surface bypass structures are installed – removable spillway weirs, temporary spillway weirs, and surface bypass channels.

Removable spillway weirs are installed at Lower Granite and Ice Harbor Dams and are nicknamed "fish slides." The fish slide is attached to the upstream side of the dam and fitted into a spill bay, raising the spillway opening to the salmon's preferred depth. Juvenile salmon and steelhead are safely passed over a raised spillway crest, similar to a waterslide. Testing at Lower Granite and Ice Harbor Dams noted an average of 98-percent survival for fish passing the dam via the fish slide.

Temporary spillway weirs were installed in two spillway bays at McNary Dam. The temporary spillway weir is a test device based on design elements of a removable spillway weir, however, positioned by the dam's gantry crane and not a pump-operated ballast system as used by the removable spillway weir. Initial testing also showed 98-percent survival. The third alternative bypass system is the surface bypass channel(s) that are used at two dams on the lower Columbia River. Bonneville Dam's "corner collector," completed in 2004, provides effective surface bypass – the ice and trash chute at the second powerhouse was modified for safer juvenile fish passage, and a 2,800-foot-long transport channel and 50-foot-long outfall channel were constructed to guide fish around the dam. Tests in 2004-2005 indicate a survival rate of nearly 100 percent for spring-fall Chinook and steelhead through the "corner collector." The ice and trash sluiceway at The Dalles Dam is also used by outmigrating fish as a surface bypass route and has similar survival rates (www.nww.usace.army.mil/spillway_weir/default.html.

Chapter 7 PRIEST RAPIDS LAKE WITHDRAWAL: DOWNSTREAM TEMPERATURE INFLUENCES AND WATER QUALITY MODELING

7.1 Introduction

We attempted to analyze downstream water temperature influences that may occur from withdrawing 6,000 cfs from Priest Rapids Lake for Reclamation's proposed Black Rock reservoir. We looked at two commonly used water temperature models to analyze potential temperature differences during salmonid adult spawning and smolt outmigration periods and during periods when discharge from Priest Rapids was near or exceeded water temperature standards. Existing water temperature data for the Priest Rapids Lake and concurrent downstream discharge and temperature data limited our time period scope to the data available (most data from the March to October period). However, this period encompassed most of the adult and juvenile migration periods as well as the mid-summer period when discharge temperatures were near or exceeded salmonid water quality standards. Both of the water temperature models, CE-QUAL-W2, and stream segment temperature (SSTEMP), may not work to predict possible water temperature changes due to the violation of model assumptions and the volume of water discharged as well as the methods in which water discharges are made from Priest Rapids Dam.

7.2 Temperature Modeling Scenarios

Priest Rapids Dam and Lake are very unique when compared to more typical mainstem Columbia River reservoirs primarily due to the powerhouse-spillway configuration and the volume and principal methods in which water is bypassed. The Priest Rapids Project is owned and operated by the Grant County Public Utility District No. 2 and is a run-of-the-river hydroelectric facility with limited water storage capacity. The impoundment extends 18.7 miles (20 km) upstream to Wanapum Dam and contains about 191,000 acre-feet of water. The dam is a reinforced concrete structure 2,450 feet (747 m) in length and has one powerhouse (consisting of 10 turbines) on the east side and one spillway (consisting of 22 bays) on the west side of the Columbia River. The depth and length of the stilling basin at Priest Rapids Dam are considerably smaller than other mainstem projects and the tailrace channel below is basalt bedrock and is considerably shallower than the stilling basin. The river conditions below the dam experience rapidly varying tailwater elevations and corresponding depths of flow. The top spill over spillway tainter gate 22 (nearest to powerhouse) is a design unique to the Priest Rapids Dam and is where bypass flows are most frequent. This top spill generates an aerated plume that is quite different from flow conditions below a conventional spillbay. A training wall located between the powerhouse and spillway limits the direct interaction between these project releases (Corps, 2003).

When we examined the feasibility of using the Corps' water quality model CE-QUAL-W2, commonly used by the Corps, we found that the discharge from Priest Rapids Dam violated the model's primary assumption. The CE-QUAL-W2 (2-D) model assumes lateral homogeneity. The model's governing equations are laterally and layer averaged. Lateral averaging assumes lateral variations in velocities, temperatures, and constituents are negligible. Therefore, this assumption may be inappropriate for large water bodies exhibiting significant lateral variations in water quality (Figure 7-1).

Figure 7-1. Aerated spillway flow from Priest Rapids Dam (Corps 2003).

Whether this assumption is met or not is often a judgment call by the user and depends, in part, on the questions being addressed. Eddy coefficients are used to model turbulence. With this model, the user must decide among several vertical turbulence schemes which one is most appropriate for the type of water body being simulated; however, no schemes approach the type or complexity of the Priest Rapids discharge scenario. The equations are written in the conservative form using the Boussinesq and hydrostatic approximations. Since vertical momentum is not included, the model will give inaccurate results where there is significant vertical acceleration (Cole, T. and Scott Wells, 2005). The operation of Priest Rapids relies on bypass spills through spillway tainter gate 22, thus creating significant vertical acceleration in this downstream area and is further compounded by the training wall located between the powerplant and spillway that limits the direct interaction between powerplant and spillway flows (Figure 7-2).

Figure 7-2. Priest Rapids Dam top spill bay 22 and standard spills at bays 17 to 21 (Corps, 2003).

We then examined the use of a more simplified water temperature model SSTEMP. SSTEMP is a steady-flow, physically-based, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. The model has been widely used in California’s Central Valley and associated basins since the mid-1980’s particularly; it has been used for preliminary simulations of water temperatures in the Sacramento River (USGS, 2000).

The SSTEMP model is unique as far as the range of capabilities offered by dealing with missing data and providing goodness-of-fit statistics as it computes “standard” applications. The SSTEMP model is composed of six modules: (1) Heat flux – predicts the energy balance between the water and its surrounding environment; (2) Heat transport – predicts average mean daily and diurnal water temperatures as a function of stream distance; (3) Solar model – predicts solar radiation penetrating the water as a function of latitude, time of year, and meteorological conditions; (4) Shade model – predicts interception of solar radiation due to topography and riparian vegetation; (5) Meteorological model–predicts changes in air temperature, relative humidity, and atmospheric pressure as a function of watershed elevation; and (6) Regression model–aids in filling missing water temperature data or smoothing of the data (USGS, 2000).

SSTEMP is divided into three broad functional areas: stream geometry, hydrology, and meteorology, and each requires a data set to run the model. Necessary geometry data include the stream network layout, site elevations, stream widths, shade estimates, and Manning's n or travel time. Meteorological data necessary are air temperature, relative humidity, wind speed, cloud cover, and solar radiation (generally from published data or assumed to be predictable by SSTEMP). Hydrologic data are from stream discharge coupled with water temperatures, both of which are generally available from USGS gages or field measurements (USGS, 2000).

The SSTEMP model is the "sister" model to SNTEMP and differs from the Network model in four distinct ways. The Segment model deals only with a single stream segment and not an entire dendritic network of tributaries or water withdrawals or return flows. Only one time period may be simulated for any given run. It is a manual process, but it is comparatively easy to change the time and space conditions. The SSTEMP model can perform an automated first-order sensitivity analysis and has the option of using either English or metric units. The SSTEMP model, given the time of year and latitude and longitude of the study site, computes the solar radiation likely to be available at the earth's surface. With SSTEMP, solar radiation is reduced by topographic shading and riparian vegetation. The radiation is combined with all other sources of heat exchange from the water to compute downstream water temperatures given upstream conditions. Given the lack of significant tributary influences on the Priest Rapids Lake and the run-of-the-river hydroelectric facility at the dam, the user-friendly SSTEMP model is more appropriate for a preliminary evaluation of the with- and without-water withdrawal scenario for the Black Rock water storage project.

Both the SSTEMP and SNTEMP models can be used in either an incremental, problem-solving decision environment or a standard setting addressing questions such as, "How much does the temperature change if I change the flow by a certain amount?" Or, "How many times is water quality parameter 'xyz' violated?" Both models work well with large volumes of water such as run-of-the-river reservoirs; however, neither can accurately simulate water temperatures when there are rapidly changing flows such as peaking or pulsating flows; flow fluctuations must be less than 10 percent of the total flow. Peaking flow conditions from Priest Rapids Dam may exceed 10 percent of the total flow during periods of high electrical demand. Both models rely on relatively constant 24-hour reservoir releases.

Both SNTEMP and SSTEMP version 2.0.8 models were used to simulate flow and water temperature conditions experienced at Priest Rapids Dam. Concurrent water temperature data for both in-pool and dam discharge for most recent years are available for the most of the April-through-October timeframe at http://www.gcpud.org/stewardship/waterquality.htm. Despite the model being user-friendly and known to work well with large volumes of water, it is limited to flows less than 100,000 cfs (2,832 cms), whereas, typical flows experienced at Priest Rapids Dam average around 150,000 cfs (4,242 cms). The model also allows for conversion of cubic-feet-per-second into cubic-meters-per-second (cms) where there would be less than five numerical characters and should therefore; be able to compute flows of 4,248 cms (150,000 cfs). However, the model automatically defaults back to flows less than 100,000 cfs (2,832 cms). Therefore, calculations made by the SSTEMP model must be less than 100,000 cfs (2,832 cms).

Select dates of water temperature and discharge data from the Priest Rapids Lake were entered into SSTEMP model where corresponding same-date weather and downstream water temperature data could be found. Weather data from the Hanford Meteorological Station at http://hms.pnl.gov and downstream water temperature data from the USGS national water information system at http://waterdata.usgs.gov were used for the preliminary results of water temperature predictions using the SSTEMP model. Downstream water temperature data from the USGS surface water quality station number 12472900 (Columbia River at Vernita Bridge, near Priest Rapids, Washington) was used to compare SSTEMP model results to the actual measured water temperature data.

Contemporary water temperature data from the USGS station 12472900 is limited to about 4 days per year and occurs about every 3 months as daily water quality measurements ceased in 1981. Both hydrologic and meteorological websites do not contain data going back to 1981, therefore, our preliminary analysis using SSTEMP is limited to 12 dates occurring from June 2001 to November 2004. Priest Rapids discharge data exceeded 100,000 cfs (2,832 cms)during 6 of the 12 dates so the discharge volume was scaled down to fit the model as was the Black Rock withdrawal amount.

The SSTEMP model was set to predict Columbia River water temperature 10 miles (16 km) downstream. The USGS station 12472900 is 9.2 miles (14.8 km) downstream from Priest Rapids Dam, and the Vernita Bar (critical spawning area for salmon) is just upstream of the Vernita Bridge; therefore, this segment of the Columbia River mainstem is vital for the regeneration of salmon stocks and is immediately influenced by Priest Rapids discharge. Model runs using the same dates and identical geometry, shading, and meteorology data from http://hms.pnl.gov were performed using no water withdrawal and using a 6,000-

cfs water withdrawal (maximum proposed withdrawal with the Black Rock Alternative). Downstream water temperature predictions with a 6,000-cfs water withdrawal were nearly identical to the predictions without a water withdrawal (Table 7-1 and Table 7-2). The downstream water temperature differences with and without a withdrawal ranged between 0.0 and 0.01 °C for individual dates. The mean difference between the two downstream temperature prediction data sets was also nearly identical and differed only by 0.0025 °C. Both downstream temperature prediction data sets (with and without water withdrawal) were not very different than the outflow temperature from Priest Rapids Dam (range -0.42 to 0.14 °C, mean 0.1 °C) or the actual measured water temperature at Vernita Bridge (-0.47 to 0.60 °C, mean 0.12 °C). No statistical differences using a t-Test were detected between the two data sets (with and without withdrawal) and outflow or Vernita Bridge river temperatures. However, the scaling down of discharge amounts to fit the model (<100,000 cfs) may have adversely affected the results.

The maximum amount of water that the Black Rock reservoir would withdraw from the Priest Rapids Lake is 6,000 cfs. From the data analyzed for the SSTEMP model, this amount of water would be an average of less than 6 percent of the instantaneous outflow from Priest Rapids Dam and would range between 2.68 and 8.67 percent. However, the data used for SSTEMP is very limited and may not be representative of the possible action. Also, the predicted downstream water temperature differences (ranges and means) are within 1.8 ^{o}F (1^{o}C), and the SSTEMP model may not be sensitive enough to predict minute changes in water temperature. The SSTEMP sensitivity analysis for all of the model runs (with and without water withdrawal) show that the inflow temperature is predominately the driving factor to downstream water temperature, with inflow and outflow amounts being second or third (inflow-to-outflow passage time is estimated to be about 45 minutes) (Corps, 2003). In addition, SSTEMP computes its downstream water temperature predictions using daily averages, but the current USGS data from Vernita Bridge are sampled during certain times of the day (these data are not daily averages) (see far right column in Table 7-1 and Table 7-2).

Table 7-1. Preliminary SSTEMP model calculations without maximum Black Rock reservoir withdrawal

Date	Total Discharge (cfs)	Modeled Discharge (cfs) (Scaled=%)	Black Rock Withdraw (cfs) w/wo (Scaled)	Outflow Temp °C	Predicted Mean Temp °C @ 10 mi. downstream	Predicted Minimum Temp °C @ 10 mi. downstream	Predicted Maximum Temp °C @ 10 mi. downstream	Measured Temp °C @ Vernita Bridge	Predcited versus (+/-) Measured	Measured Temp °C Time of Day
17-Nov-04	91,800		0	13.0	12.87	12.66	13.08	12.4	0.47	11:20
28-Jul-04	113,200	99616 (88%)	0	19.9	20.13	19.74	20.53	19.9	0.23	12:00
13-Apr-04	78,000		0	8.5	8.78	8.38	9.18	9.2	-0.42	9:50
10-Feb-04	97,900		0	3.0	3.07	2.84	3.31	3.2	-0.13	11:30
25-Sep-03	83,000		0	18.4	18.48	18.05	18.91	18.8	-0.32	11:20
17-Apr-03	148,300	99361 (67%)	0	7.3	7.44	7.19	7.7	7.8	-0.36	12:30
25-Sep-02	108,500	99820 (92%)	0	18.6	18.56	18.26	18.87	18.6	-0.04	12:20
26-Jun-02	223,700	98428 (44%)	0	15.2	15.62	15.12	16.12	15.8	-0.18	13:00
6-Mar-02	84,900		0	3.6	3.63	3.49	3.76	4.0	-0.37	11:55
11-Dec-01	117,900	99036 (84%)	0	8.5	8.4	8.35	8.44	9.0	-0.6	11:30
22-Aug-01	69,200		0	18.8	18.95	18.71	19.19	18.7	0.25	11:40
5-Jun-01	105,500	99170 (94%)	0	13.4	13.52	13.4	13.63	13.4	0.12	11:45

Table 7-2. Preliminary SSTEMP model calculations with maximum Black Rock Reservoir withdrawal

Date	Total Discharge (cfs)	Modeled Discharge (cfs) (Scaled=%)	Black Rock Withdraw (cfs) w/wo (Scaled)	Outflow Temp °C	Predicted Mean Temp °C @ 10 mi. downstream	Predicted Minimum Temp °C @ 10 mi. downstream	Predicted Maximum Temp °C @ 10 mi. downstream	Measured Temp °C @ Vernita Bridge	Predcited versus (+/-) Measured	Measured Temp °C Time of Day
17-Nov-04	91,800		6,000	13.0	12.86	12.64	13.08	12.4	0.46	11:20
28-Jul-04	113,200	99616 (88%)	5280 (88%)	19.9	20.14	19.74	20.54	19.9	0.24	12:00
13-Apr-04	78,000		6000	8.5	8.79	8.38	9.21	9.2	-0.41	9:50
10-Feb-04	97,900		6000	3.0	3.08	2.83	3.32	3.2	-0.12	11:30
25-Sep-03	83,000		6000	18.4	18.48	18.04	18.93	18.8	-0.32	11:20
17-Apr-03	148,300	99361 (67%)	4020 (67%)	7.3	7.45	7.19	7.71	7.8	-0.35	12:30
25-Sep-02	108,500	99820 (92%)	5520 (92%)	18.6	18.56	18.25	18.88	18.6	-0.04	12:20
26-Jun-02	223,700	98428 (44%)	2640 (44%)	15.2	15.61	15.12	16.1	15.8	-0.19	13:00
6-Mar-02	84,900		6000	3.6	3.63	2.92	4.33	4.0	-0.37	11:55
11-Dec-01	177,900	99036 (84%)	5040 (84%)	8.5	8.4	8.35	8.44	9.0	-0.6	11:30
22-Aug-01	69,200		6000	18.8	18.96	18.71	19.21	18.7	0.26	11:40
5-Jun-01	105,500	99170 (94%)	5640 (94%)	13.4	13.52	13.4	13.63	13.4	0.12	11:45

The first assumption—that the model is based upon by the possibility of having hydropeaking flows greater than 10 percent of the total flow—is violated.

The second assumption of the SSTEMP model assumes homogeneous and instantaneous mixing wherever two sources of water are combined. There is no lateral or vertical temperature distribution (dispersion or diffusion), represented in the model. The Priest Rapids Dam configuration with downstream training wall and operation constraints also violates this assumption.

Third, neither SSTEMP nor SNTEMP will accurately predict downstream temperatures from stratified reservoirs (USGS, 2000). Despite Priest Rapids Dam being a "run-of-the-river" hydroelectric facility, thermal stratification does occur during peak summer months. The top layer of water near the dam warms during daytime periods throughout the summer season. This layer of warmer water often extends to depths greater than 16.5 feet (5 m) and can be 36 to 37 ^{o}F (2 to 3 °C) warmer and is sometimes flushed downstream. This near-project phenomena creates warm water spikes downstream when flushed through the dam (Corps, 2003). On average, mean annual upstream/downstream temperature differences are 33 ^{o}F (0.3 °C), whereas inherent temperature prediction error ranges from 33 to 34 ^{o}F (0.4 to 0.6 °C) for SSTEMP/SNTEMP.

The fourth assumption of SSTEMP/SNTEMP that may be violated is that the model is not very reliable in very cold conditions when simulating water temperatures less than 39 ^{o}F (4 °C). Flows in the Columbia River during the winter period are often near, at, or below 39 ^{o}F (4 °C). (See available water temperature data for January to March period from Grant County PUD website.)

There are many other water temperature models in use in the Western United States (Deas and C. Lowney, 2000; Schneider et al., 2002). Some of these water quality models have been used to simulate water quality conditions in the mainstem Columbia River. Modeling water quality parameters, particularly temperature, can be a very challenging task on a river the size of the Columbia. For Priest Rapids Dam, the powerplant-spillway configuration, coupled with operational methods (where approximately 50 percent of the flow can be bypassed), presents a very daunting task when trying to simulate downstream temperatures using common water temperature models. The Priest Rapids scenario may be so unique that existing water quality models may not be able to simulate downstream water temperatures without significant model modification. However, it may be possible to develop a temperature model that is specific to the Priest Rapids scenario. This model would need to be extremely sensitive to resolve upstream and downstream temperature differences of less than 37 ^{o}F (0.3°C).

7.3 Recommendations

One recommendation would be to analyze other water quality models used for the Columbia mainstem and find out how/if one could incorporate river flows that range from 50,000 to 350,000 cfs and be sensitive enough to temperature differences of 0.3 °C or less. Some other water quality models used on the mainstem are MASS1, WQRRS, RBM-10, SYSTDG, MASS2, and EFDC (Schneider et al., 2002). A second suggestion would be to develop a temperature model that is specific to the Priest Rapids scenario. This would result is a very complex temperature model but may result in more robust temperature predictions. However, this effort would entail gathering field data at Priest Rapids and may still have an error rate greater than the actual temperature differences. A third suggestion would be to focus on withdrawing water during annual periods when downstream temperatures are not critical such as the late fall and winter periods. However, withdrawing water during this annual time period may contribute to the dewatering of redds in the Hanford Reach area which is already an issue resulting from the current operations of Priest Rapids Dam.

Chapter 8 HOMING BY PACIFIC SALMON AND FALSE ATTRACTION

There is sparse information on determination of chemical cues (odors) upon which salmon imprint and detection levels. The closest example of migration impacts by a project within Reclamation is the Umatilla Project; however, the origin of the restocked fish (after the project began operating) is unclear. Therefore, some of the impacts are also unclear.

Congress authorized the Umatilla Project in December 1905, and Reclamation started construction the next year, connecting many of the private canals to project facilities. Cold Springs Reservoir provided irrigation water by 1908; McKay Reservoir by 1927. The project converted nearly 45,000 acres of sagebrush into agricultural land. The Umatilla Project provides water for irrigation, recreation, fish, and wildlife. The project also reduces flood damage. The irrigation diversions, however, occasionally dried up the Umatilla River. Irrigation diversions and habitat damage in the early 1900s contributed to the decline of the once-productive salmon runs. Eventually, no salmon returned.

In the mid-1980s, some 70 years after the last Umatilla River salmon run, the Confederated Tribes, irrigators, Oregon Department of Fish and Wildlife (ODFW), the Corps of Engineers, Bonneville Power Administration (BPA), and Reclamation focused on resolving conflicting water needs in the lower Umatilla River. The Corps excavated a low-flow fish passage channel in the Umatilla River downstream from Three Mile Falls Diversion Dam. Reclamation and ODFW built fish screens, ladders, and trapping facilities using BPA funds. Congress passed the Umatilla Basin Project Act in 1988, authorizing a series of water exchange systems. Columbia River water would irrigate project lands in exchange for leaving an equal amount of water in the Umatilla River for the fishery. Reclamation began water exchanges in 1993. BPA provides the electricity to pump the exchange water and rate payers pay the pumping costs. The project remains successful today in irrigating crops while improving the Umatilla River fish habitat.

Along with habitat improvements, reintroduction using hatchery fish was selected as the most effective means to achieve a return goal of 11,000 adult salmon. In the Columbia River basin, a hatchery plan was designed to restore the extirpated population of Chinook salmon in the Umatilla River; however, it produced an unexpected and undesired result: high numbers of strays into the nontarget Snake River. Because adults that should have returned to the Umatilla River strayed at unusually high rates into the Snake River (home to an ESA-threatened Chinook stock), a conflict developed between two restoration plans.

Fall Chinook salmon were first stocked in the Umatilla River in the early 1980s and the Upriver bright stock (URB) was used each year, except for one brood. Upriver bright, or later spawning fall Chinook salmon, migrate through the lower Columbia River and are destined for areas above Bonneville Dam. The URB stock was developed from fish trapped at Bonneville Dam and represent mixed genetic characteristics. Managers released fish as subyearlings and yearlings because it was uncertain which rearing strategy would work best in the Umatilla River. Chinook salmon for the Umatilla have been reared at four different hatcheries that use both well and river water. Currently, most juveniles are reared at Umatilla or Bonneville hatcheries; neither of these hatcheries is situated on the Umatilla River.

By the early 1990s, straying of Umatilla releases into the Snake River was recognized as a continuing problem. NMFS launched an interim standard to limit the proportion of stray, nonnative hatchery fish to no more than 5 percent of any natural spawning population. Umatilla managers outlined several approaches with the potential to reduce straying by Umatilla releases and protect Snake River stock. Possible solutions included tagging, using acclimation ponds and new release locations, river flow enhancement, and development of a local brood stock. Some of these actions (acclimation and changes in release location) were already being implemented.

Because of the need to identify all fish, the costs of marking and tagging Umatilla releases increased above the costs of monitoring the fishery. It was also suspected that fish growth was reduced because of the extended tagging period in each raceway and the disturbance to fish in nearby raceways. However, records indicated that wire-tagging was effective for managing Umatilla strays. Between 1998 and 1999, more than 78 percent of migrants were detected and removed at Lower Granite Dam (LGD) on the Snake River.

The first recoveries of Umatilla salmon in the Columbia basin occurred in 1983. Annual adult returns fluctuated and were influenced by variable release numbers and survival rates. From 1983-1999, recoveries in the Umatilla River averaged 247±117 (95% CI) and 274±164 (95% CI) for subyearling and yearling releases, respectively. In comparison, strays averaged 842±461 (95% CI) from subyearling and 46±29 (95% CI) from yearling releases, which often outnumbered the Umatilla River recoveries. The estimated recovery data for Umatilla releases suggested that more than 500 salmon strayed into the Snake River in some years, subyearlings outnumbering the yearlings. Managers were concerned that non-endemic fish, principally Umatilla releases, were being incorporated into broodstock at Lyons Ferry Hatchery (Snake River). In addition, Umatilla fish that escaped past LGD had the potential to breed with naturally spawning Snake River stock, possibly reducing the fitness of the existing population.

Release location, release date, juvenile physiological development, and other factors are also thought to affect natal stream imprinting, return location, and homing fidelity of migrating adult salmonids. Prior to 1990, juvenile salmon were sometimes released at the mouth of the Umatilla River because of low flows, unsuitable water temperatures, and hazardous unscreened diversions. Because of the short time spent in the Umatilla River, fish released at the mouth may have failed to imprint and thus exhibited a poor homing instinct. After 1990, juveniles were released above river mile 42.5 (river kilometer 68.4) because of passage improvements. Release date was also a possible factor affecting straying. In general, subyearlings were released in May and June, at a time when flows in the Umatilla River were low, resulting in reduced water quality and higher temperatures. It was believed that fish released earlier would not reach size goals leading to reduced survival. Managers also agreed that acclimation or holding fish in river water prior to release might reduce straying. Facilities have since been built to hold and acclimatize fish.

River discharge may affect stray rates and was believed to hinder adult salmon from entering the Umatilla River. From the combination of natural rainfall patterns and irrigation diversions, low flows and high water temperatures often existed at the river mouth in September and October during the migration of URB stock. Inadequate flows in September were previously recognized as a passage concern within the Umatilla River and, by 1993, water from a storage reservoir was used to augment attraction flows. Since 1995, water from the Columbia River has been delivered to irrigators in place of Umatilla River water during critical life history periods for salmon. River flow has improved in recent years, but it is unclear if attraction is a problem. Although adult run timing to a collection facility in the lower Umatilla River appears similar for both groups (fish released as yearlings and subyearlings), information on run timing past the mouth of the Umatilla River is not available.

Local broodstock development is an essential part of restoration in the Umatilla River that may affect straying. Current Umatilla broodstock are composed of URB returns to the Umatilla River and Bonneville and Priest Rapids hatcheries on the Columbia River. Because the URB stock was developed from several genetic groups, the potential for Umatilla fish to stray may be greater than would normally occur if an endemic stock had been available. Straying is a natural part of the life history for Chinook salmon. On the other hand, salmon reared and released from Priest Rapids Hatchery have shown little tendency to stray into the

Snake River despite a genetic background similar to subyearlings released in the Umatilla River.

Since 1990, 50-100 percent of adults returning to the Umatilla River have been collected for broodstock. Although egg collection from Umatilla returns was inadequate to meet hatchery needs, Umatilla fish that strayed into Snake River collection facilities were not used. In recent years, most or all of the eggs for the yearling program originated from Umatilla releases, but the majority of eggs used for subyearling releases continue to be collected from Columbia River hatcheries, delaying the creation of a locally adapted stock. Further, salmon reared at remote hatcheries and transported to target streams may stray at higher rates and straying may be high for colonizing populations.

Biologists should be aware of the relationship between the environmental factors and straying. The environmental factors that caused the decline of a stock may still exist in waters that are candidates for restoration, creating the need for atypical management actions. Because of significant habitat alterations, Chinook salmon produced for the Umatilla River were often released in unusual locations (near the river mouth) or into conditions that were considered hazardous (low flow, warm temperatures, etc.). Although it cannot be known if the Umatilla releases are similar to historical patterns, releasing fish into unusual habitats may produce unusual or unexpected results. It has been suggested that changes in natural straying patterns should be suspected where enhancement measures include flow controls, selective breeding, and exposure of fry to various water sources (Labelle, 1992). Because the percentage of strays from all origins is limited to 5 percent of the escapement of Snake River stock past Lower Granite Dam, decisions for Umatilla managers are dependent on straying of other stocks and the recovery of salmon in the Snake River.

The Umatilla Project's impacts apply in a limited way to the planned operations and exchanges for the Black Rock Alternative. A more specific analysis with questions has been prepared for this report in the following paper, *Homing by Pacific Salmon, False Attraction and Distraction: Can Ariadne's Thread be Broken?* by A.H. Dittman and T.P. Quinn.

8.1 Introduction and Literature Review

Homing by Pacific Salmon, False Attraction and Distraction: Can Ariadne's Thread be Broken?

By A.H. Dittman and T.P. Quinn

There is evidence that astute observers living in Europe centuries ago surmised and even concluded that the Atlantic salmon they observed migrating and spawning in streams had been in those streams before, as juveniles and as adults spawning in previous years (Nordeng 1989). By the late 19th century, marking studies demonstrated homing to the site of previous spawning, and by the mid-20th century, there was a large body of research developing on homing by salmon (Hasler and Scholz, 1983; Quinn, 2005). Based on a wide variety of experiments, it is clear that salmon are guided to their home or "natal" stream by odors to which the juveniles were exposed while living in the stream and migrating from it years earlier. The exact nature of the odors that the fish learn has been the subject of considerable debate (Brannon and Quinn, 1990; Hasler and Scholz, 1983; Nordeng, 1977; Stabell, 1984), and there are probably complex mixtures of inorganic chemicals, organic chemicals from soil and plants, and also odors from fishes including juvenile salmon in the streams.

In addition to the question of which odors the salmon learn, there are two other, somewhat related, questions regarding homing: when (and, hence, where) are odors learned by salmon, and how are they used during the return migration when adult salmon are exposed to complex mixtures of familiar and unfamiliar odors. Many experiments have implicated the parr-smolt transformation as the critical period during which olfactory imprinting takes place (Dittman et al. 1996; Dittman et al. 1997; Hasler and Scholz, 1983; Morin et al. 1989a; Morin et al. 1989b; Morin and Doving, 1992; Nevitt et al. 1994; Scholz et al. 1976; Wagner, 1969), in concert with a suite of changes in physiology, morphology and behavior that prepare the salmon for the transition from fresh water to the ocean (Dickhoff and Sullivan, 1987; Hoar, 1976).

However, most of these experiments were conducted with salmon reared in hatchery environments that may not provide the environmental and migratory complexity that many juvenile salmon typically experience in the wild. Indeed, wild salmon and salmon species that demonstrate more complex juvenile rearing patterns (e.g. sockeye salmon) apparently also imprint near the time of emergence from the redd and perhaps at other periods prior to seaward migration, as evidenced by the movement patterns and population structure of various species

(Dittman and Quinn, 1996), marking experiments (Quinn et al. 2006), and laboratory experiments (Tilson et al. 1994; Tilson et al. 1995). Under natural circumstances, juvenile salmon emerge from redds in streams or lakes and move about in freshwater as the ecology of their species and population dictate, and then migrate to sea (Quinn 2005). Experimental disruptions of this natural sequence by transporting salmon from one hatchery to another prior to release (Candy and Beacham, 2000; Donaldson and Allen, 1957), or from one hatchery to a point along the migration corridor (Quinn et al., 1989a) have presented a complex picture of the imprinting process. Salmon taken from one hatchery as parr or smolts and brought to another hatchery on a different watershed tend to return to the point of release rather than the site where they were raised (Johnson et al. 1990); this may also occur for transplants within a watershed (Cramer 1981; Kenaston et al. 2001; Slaney et al. 1993). Salmon taken from a hatchery prior to migration and released downstream along part of the migratory route (e.g., around dams on the Columbia River) tend to return to the point of release or that vicinity (Vreeland et al. 1975), even if the odors from the natal hatchery are available nearby (Quinn et al. 1989a; Brannon and Quinn 1990). However, if the salmon are captured during their migration and transported farther downstream (e.g., past dams on the Columbia River or Snake River), they tend to return to their natal site (Ebel 1980; Ebel et al. 1973; Slatick et al. 1975). Taken together, these results support the conclusion that olfactory learning ("imprinting") in salmon is closely linked with migration, so that the act of migration may be necessary for imprinting to occur (Dittman et al. 1996).

The idea of sequential imprinting has been considered for some time (Harden-Jones, 1968), and it now seems clear that the salmon probably imprint at several ecologically important times in their lives, corresponding to periods of migration. The first is presumably the period at emergence from the gravel at the redd site and the last may be the point of seawater transition in the estuary or nearshore marine environment. When adult salmon return to spawn, their migrations at sea are probably controlled by a set of mechanisms that function in open water (Quinn 1980; Quinn and Brannon 1982), but when they reach coastal waters, they shift to olfaction-based homing mechanisms in some poorly understood period of interface between mechanisms (Craigie, 1926; Doving et al. 1985; Madison et al. 1972; Quinn et al. 1989b; Stasko et al. 1976). Salmon appear to use what is known as a "sign-stimulus" process for using odors to locate their home stream. That is, detection and recognition of an odor triggers a specific response - upstream swimming (Johnsen, 1982; Johnsen, and Hasler, 1980). However, there are also indications that the upstream migration may be more complex than just simple positive rheotaxis triggered by homestream waters, as migrating adult salmon have the ability to discriminate and choose waters containing higher concentrations of homestream water (Fretwell, 1989). Salmon demonstrate a certain amount of zig-zagging as they migrate upstream and will occasionally "over-shoot" their natal river, eventually moving back downstream to locate it after they can no longer detect their natal odors. There have been reports of this "overshooting" behavior for a long time (Ricker and Robertson, 1935) but the processes are not well understood. Some of the ascent into nonnatal streams may result from this "testing" process (Griffith et al. 1999) but environmental features such as temperature and habitat also affect locations where salmon hold during their migration period (Berman and Quinn, 1991; Goniea et al. 2006; High et al. 2006).

Given the history of research on salmon homing, remarkably little progress has been made toward determining the chemical nature of the odors upon which the salmon imprint. Early attempts to characterize the chemical properties of homestream odors (Fagerlund et al. 1963; Idler et al. 1961; McBride et al. 1964) were successful only in ascertaining some basic properties of the chemicals involved, and subsequent work (Bodznick, 1978) was not consistent with the earlier findings. More recent work has demonstrated that different combinations of amino acids present in natural stream waters act as chemoattractants for homing salmon, and it has therefore been suggested that these compounds may represent part of the chemical signature that salmon use to discriminate their homestream water (Shoji et al. 2000; 2003). One amino acid (L-Kynurenine) has also recently been identified as a sex pheromone released by ovulating female Pacific salmon to attract males (Yambe et al. 2006).

One reason that more scientific attention has not been directed at identifying the natural odors involved in imprinting and homing, may be partly due to a series of groundbreaking experiments by Arthur Hasler and his colleagues in the 1960s-1970s, utilizing artificial odors, especially morpholine and phenylethyl alcohol, to provide the first direct experimental evidence that salmon learn and utilize odors in homestream waters to guide their homing migrations (Cooper and Hasler, 1976; Cooper and Scholz, 1976; Hasler and Scholz, 1983; Scholz et al. 1978). Many subsequent studies have also focused on these compounds to elucidate the processes involved in olfactory imprinting (Nevitt et al. 1994, Dittman et al. 1996; Dittman et al. 1997). These studies also demonstrated that salmon are able to remember and identify a single component of a complex mixture of chemicals in stream water as an identifier of their home water. However, it appears that attraction to these imprinting compounds is most robust when tested in an unfamiliar background water (i.e., the only familiar scents are the artificial odorants; Dittman, personal communication).

Artificial imprinting compounds have also been utilized in field studies in efforts to enhance returns and improve homing fidelity. There was some evidence that this was successful in coho salmon (Hassler and Kucas, 1988) but not Chinook salmon (Hassler and Kutchins, 1990). However, these experiments did not account for possible differences in survival between exposed and unexposed fish. Another experiment on coho salmon found neither enhancement of homing to a hatchery by morpholine-exposed fish, nor deterrence of nonexposed fish (Rehnberg et al. 1985). Thus, it seems that if salmon have imprinted to the "background" odors of a site, the addition of another specific odorant such as morpholine does not improve their homing, and if they imprinted on the site without morpholine, the addition of that unfamiliar odor does not induce the fish to avoid the site.

One question that continues to challenge salmon biologists is, "what chemical components of potentially very dynamic river systems remain constant enough between seasons and over many years such that salmon are able to identify these waters as their natal stream?" In some cases, salmon return to spawn 4-5 years after leaving their natal stream and, in many cases, these homing migrations occur during a different season from when the fish last experienced (and imprinted to) their home waters as juveniles. Patterns of runoff, leaf litter, and other sources of chemicals likely differ between spring (when many salmon imprint and migrate) and fall (when many return), yet the salmon seem to be able to discern the home odors despite these differences. These questions, in part, led to a flurry of interest in the "pheromone hypothesis" (Nordeng, 1971; Nordeng, 1977) that population-specific odors from juvenile conspecifics residing year-round in the natal stream or migrating from it guide returning adults (Døving et al. 1980; Stabell, 1984; Stabell, 1992). Experiments demonstrated that juvenile salmonids can discriminate the odors of their own population from other populations (Courtenay et al., 1997; Groot et al., 1986; Quinn and Tolson, 1986), but they do not seem to play a critical role in homing (Brannon and Quinn, 1990). Others have suggested that minerals associated with the unique geology of different rivers might provide stable olfactory cues, and there is some evidence that such compounds may act as odorants (Bodznick, 1978; Plate, 2001), but their role in homing requires further study.

Under normal circumstances, the vast majority of salmon are able to successfully retrace the sequence of odors and return to the vicinity of their emergence site. The odors that guide them are still poorly understood. In particular, it is unclear how the salmon avoid distraction by chemicals that may be present on their return migration but were absent from the complex of odors on which they imprinted. It is equally unclear why they are not confused by the absence of chemicals on the return that were present during imprinting. Indeed, there do not seem to be any studies that explicitly investigated the changes in water chemistry and effects on homing from season to season and year to year. Anecdotal studies indicate that even massive changes in water quality such as those associated with the eruption of Mt. St. Helens in Washington did not mask the home odors, though the salmon seemed inclined to avoid the ash-laden water (Leider, 1989; Whitman et al. 1982).

The natural homing process eventually interfaces with spawning site selection by female salmon and the search for mates by males (Blair and Quinn, 1991). This period is not well known, and there is presumably a blend of habitat selection and responses to competition as well as homing that determines how close to their actual natal site (i.e., redd location) they eventually settle. In some cases, the salmon can home to precise areas within small streams, demonstrating truly exceptional powers of discrimination (Quinn et al. 2006). However, it is also well-known that a fraction of the surviving adult salmon does not home but stray to nonnatal rivers. Much of the quantitative data on straying is from salmon tagged and released from hatcheries (Candy and Beacham, 2000; Hard and Heard, 1999; Pascual and Quinn, 1994; Quinn and Fresh, 1984; Quinn et al. 1991; Thedinga et al., 2000), and it is not entirely clear whether these data are representative of wild fish or not (Labelle, 1992; McIsaac, 1990; Quinn, 1993).

By way of conclusion, the literature on salmon homing and imprinting is vast and not without some contradictions. However, the overall body of knowledge is consistent with the hypothesis that salmon imprint, not once at the smolt transformation period, but rather at a series of life history transitions that are marked by migration. Of these migrations, the smolt period is normally a critical one and is most clearly demonstrated experimentally, but imprinting also occurs at emergence from the gravel. Disruptions in the normal migration (e.g., by moving smolts by truck from their rearing site to a release site elsewhere) generally result in migration back to the release site, especially if it is distant from the rearing site. The analogy of the thread given by Ariadne to Theseus that allowed him to retrace his path out of the labyrinth after he defeated the Minotaur fits this situation. Had the thread been broken, he could only have gone back as far as the break.

8.2 Black Rock Alternative

Homing is thus a critical aspect of the basic biology of salmon, yet many aspects of the process are uncertain. The odors which allow salmon to discriminate one stream from another, the sequence in which they are learned by juveniles and "replayed" by returning adults, and the ways in which the quantity and quality of water also affect homing, are all poorly understood. These uncertainties are not merely items of scientific interest, but rather, they may profoundly affect the ways in which salmon respond to artificial disturbances in the natural flow patterns of rivers. How do salmon "decide" whether to ascend a stream that has familiar odors but minimal flow and warm water or an unfamiliar stream with greater discharge and more suitable temperatures? If water is diverted from one stream to another stream after the salmon have migrated to sea, will it deter them from ascending the recipient stream as adults because it no longer smells familiar? Will salmon native to the first stream enter the second stream because they smell familiar odors, despite the fact that there are also unfamiliar odors mixed in? These are related questions have come to the forefront of discussion because of proposals to divert significant volumes of water (3,000 to 6,000 cfs) from the Columbia River, above its confluence with the Yakima River, into a new storage reservoir and from there into the Yakima River system.

The Yakima River Basin Water Storage Feasibility Study is investigating the potential to exchange Columbia River water for Yakima River water to help satisfy irrigation, fisheries, and future municipal water requirements in the Yakima River basin. The proposed Black Rock dam and reservoir would be filled using Columbia River water pumped from the Priest Rapids Lake, and delivered directly into the Roza and Sunnyside irrigation canals. Some Columbia River water would enter the Yakima River through various canal overflow drops and return ditches located downstream from Parker Dam (RM 104), and, thus, the chemical composition of the Yakima River would be altered. Alternative proposals are under consideration, but they, too, would involve diversion of water from the Columbia River into the Yakima River system.

Estimated mixing of irrigation return flows with the Yakima River during project operations was performed using RiverWare model software. Table 8-1 presents the percentage of mixing in 8 months. Between .05 and 1.5 percent of the Yakima flow could be from the Black Rock reservoir irrigation returns.

Table 8-1. Percent of Black Rock reservoir water mixed with Yakima River water at the Kiona-Benton gage (RM 29.9) by month during the irrigation season as a result of direct operational spill from Roza and Sunnyside Canals

Month	Kiona-Benton gage monthly median flow (cfs)	Total monthly median Roza and Sunnyside Canal operational spill of Black Rock reservoir water (cfs)	Percent of Black Rock reservoir water mixed with Yakima River water
March	4,507	2.2	0.049
April	5,162	17.5	0.34
May	4,933	24.4	0.49
June	4,428	29.0	0.65
July	1,932	30.1	1.53
August	1,845	30.4	1.62
September	1,939	24.5	1.25
October	2,206	20.9	0.94

8.3 Possible Effects on Salmon Migration

The question at hand is, "How might the proposed water diversion, storage, and delivery operations affect the migrations of salmon originating in the Yakima River or elsewhere in the Columbia River system?" In reality, there appear to be two classes of questions. The first set of questions concern the possible differences in behavior as a function of the origin of the salmon—those from the Yakima River system vs. those originating further up the Columbia River system. The second set of questions concerns the time period—the behavior of salmon that imprinted and went to sea under the "status quo" and returned after the diversion began vs. those that imprinted and returned after the diversion project had been completed. Thus, there are four questions, stated explicitly below:

- How does the infusion of Columbia River water into the Yakima River affect the homing/straying patterns of Yakima River salmon that migrated to sea before the diversion was completed and thus were not exposed to an admixture of Yakima-Columbia river water prior to returning as adults?

- How does the infusion of Columbia River water into the Yakima River affect the homing/straying patterns of subsequent generations of Yakima River salmon that migrated to sea after the diversion was completed and thus were exposed to an admixture of Yakima-Columbia river water prior to returning as adults?

- How does the infusion of Columbia River water into the Yakima River affect the homing/straying patterns of upper Columbia River salmon populations that migrated to sea before the diversion was completed and thus were not exposed to an admixture of Yakima-Columbia river water at the mouth of the Yakima River prior to returning as adults?

- How does the infusion of Columbia River water into the Yakima River affect the homing/straying patterns of subsequent generations of upper Columbia River salmon populations that migrated to sea after the diversion was completed and thus were exposed to an admixture of Yakima-Columbia river water at the mouth of the Yakima River prior to returning as adults?

Regarding the first question, it is suggested that juvenile Yakima River system salmon would imprint on the waters of the river or its tributaries at one or more developmental stages (e.g., emergence from the gravel, downstream movement in the fall to wintering habitat, and migration out of the river and down to sea as smolts the next spring). During the period when they are out to sea (typically 2 years for steelhead and 2-4 years for Chinook salmon), the diversion would be completed and on their return migration they would leave the ocean and home to the Columbia River system, and continue past the confluence with the Snake River. When they reached the mouth of the Yakima River, they would detect the familiar odors of that river but they would also detect water from the mainstem Columbia River that had been altered (to some unknown extent, from the standpoint of homing) by storage in a reservoir, transfer along canals and other conveyances, and seepage through the ground after use for irrigation. Would the salmon be less likely to enter the Yakima River and either delay near the mouth or continue up the Columbia River to spawn elsewhere? Either of these results would be unequivocally viewed as undesirable as they would decrease the spawning population in the Yakima River system and possibly also result in interbreeding with other discrete populations.

At a qualitative level, the likelihood of disorientation by the salmon is probably related to the proportional contribution of the unfamiliar water (i.e., the proportion of the discharge that they would detect that was “pure” Yakima River system water and what proportion was from the Columbia River upstream from the Yakima River). The smaller the proportion of unfamiliar water, the less likely the salmon would be to experience delay or disorientation. However, this assumes that all water is equivalent in terms of olfactory recognition, and this is probably not the case. Water from the Columbia River that had seeped through the ground in the Yakima basin would presumably be changed during that period to become more similar to “pure” Yakima River system water than the Columbia River water was before it was diverted. It seems likely that the longer the Columbia River water is within the Yakima River system, and the higher the proportion of that water that seeps through the ground before returning to the Yakima River and thence into the Columbia, the less likely the fish are to be confused. However, at present there does not seem to be an objective way of evaluating the relative importance of these factors—the proportion of imported water and extent to which that imported water would become "naturalized" to the Yakima River system. These issues are broadly similar for subsequent generations of Yakima River fish, except that they would have been exposed to some of the diverted water during their lives, thus, they are less likely to be affected than "first generation" salmon.

The first generations of salmon returning to the spawning areas in the Columbia River system above the confluence with the Yakima River after the diversion would encounter Columbia River water (including, presumably, some water from their natal system) in both the mainstem and also the Yakima River itself. In general, it seems likely that the Columbia River will be sufficiently modified by the reservoir system that it will probably not cause the fish to detour into the Yakima River, though they might delay briefly there. In subsequent generations, salmon that migrated downstream and passed the confluence with the Yakima River on their way downstream would probably imprint on that area as part of their overall sequence of learning, and so be less likely to be confused than the first generations. Therefore, the likelihood of disorientation seems to be greater for the first generations (i.e., those salmon that went to sea before the diversion was completed) than subsequent generations (fish that migrated as smolts under the new set of conditions).

However, there are clearly two major uncertainties. First, what is the relationship between proportion of Columbia River water in the Yakima River and proportion of salmon disoriented? There may be some threshold, below which no salmon are disoriented, followed by a linear or an accelerating proportion of salmon disoriented as the proportion of Columbia River water increases (see Figure 8-1). Alternatively, even small amounts of Columbia River water may be sufficient to disorient most of the salmon. Secondly, little is known about the process by which Columbia River water would come to be indistinguishable from Yakima River water. Is it a function of residence time in the system, is residence in the reservoir equivalent to time seeping through the soil, does the season of the year matter, etc. The relationship between percentage of foreign water and disorientation is not known, and curves A, B, and C shown in Figure 8-1 represent three possible scenarios that reflect this uncertainty.

The complex relationship between the residence time of foreign water within a watershed and potential impacts on olfactory mediated migrations are also not known (see Figure 8-2). Fundamentally, we know very little about the ways in which odors important to salmon homing vary from season to season and year to year, and we do not even know how to characterize the odors that fish use to distinguish one river from another. This lack of understanding about basic olfaction and water chemistry hampers our ability to foresee how the fish will react to some future set of conditions. The process and timing by which out-of-basin water acquires the olfactory characteristics of Yakima River water are not known, and the three possible relationship curves (A, B, and C) shown in Figure 8-2 reflect this uncertainty.

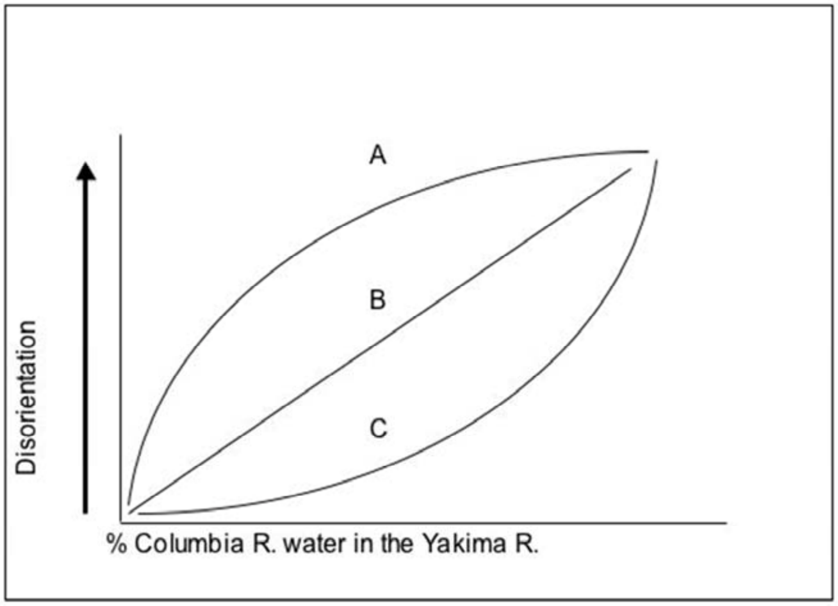


Figure 8-1. Hypothetical relationships between the percentage of Columbia River water released into the Yakima River and the degree of migratory disorientation experienced by homing adults.

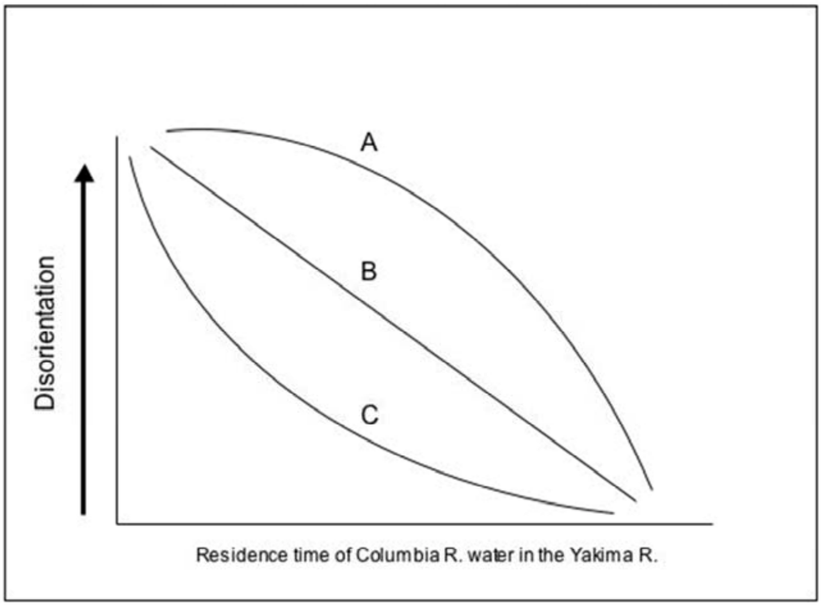


Figure 8-2. Hypothetical relationships between the amount of time diverted Columbia River water resides in the Yakima River basin before being released into the Yakima River and the degree of migratory disorientation experienced by homing adults.

It should also be noted that the previous discussion assumes that the proportion of diverted Columbia River water relative to Yakima River water would remain constant seasonally (i.e., the amount of diverted water released into the Yakima River would be proportionally equivalent during both the juvenile outmigration and the subsequent adult homing migration). In reality, most water diversion projects, especially those used for irrigation, are operated seasonally such that water is collected during periods of high natural runoff (spring) and released for irrigation during low-flow periods (summer/fall). Depending on the species of salmonid and their particular migratory patterns, this could mean that the water homing adults experience may be very different than the water learned as outmigrating juveniles. This suggests that it is important that all operational planning for the water divergence project anticipate potential problems associated with seasonal variation of operations and the migratory life histories of Yakima and upper Columbia River salmonids.

The magnitude of the proposed diversion is very great, and there are clearly uncertainties as to whether there will be any deleterious effects on salmon homing, along with the other issues that will pertain to this proposed project. Water diversion projects have been implemented in many places for many purposes around the world, and fisheries biologists have raised concerns about the general impact of water transfer projects on fisheries resources (e.g. Meador, 1996). In some cases, “false attraction” has been raised as a concern, either because the temperature, flow, odor, or some other property of one water source that might attract fish from another river. Such projects are not generic, like laboratory experiments, but rather are unique to the situation in which they are planned or occur. Anecdotal or correlative reports of straying or migration delay have been reported at water diversions (e.g. Unwin and Quinn, 1993), but despite the large numbers of water diversion projects throughout the regions occupied by anadromous salmonids, there appear to be relatively few well-documented cases of straying related to false attraction or masking of homestream odors by diversion projects. This might be interpreted to mean that such projects have little impact on homing but is probably more indicative of a lack of careful monitoring and studies directly examining these questions.

One especially well-characterized and, therefore, particularly informative example of the effects of water diversion on salmon homing was provided by a detailed study of adult migratory behavior of sockeye and pick returning to Seton Creek, a tributary of the Fraser River, British Columbia (Fretwell, 1989). The Seton Lake hydroelectric project was designed to divert water from a dam constructed at the outlet of Seton Lake, along a diversion canal, and through the Seton hydroelectric facility for power production (see Figure 8-3.) The spillway of the hydroelectric facility released 100% Seton Lake water into the Fraser River at a location approximately .6 mile (1 km) downstream of the natural outlet for Seton Creek. At certain times during operation of the facility, so much Seton Lake water (homestream water) was diverted through the powerplant that the majority of water flowing into the Fraser River out of Seton Creek was actually originating from Cayoosh Creek, a tributary of Seton Creek downstream from the diversion dam (Figure 8-3). As a result, Seton Lake sockeye salmon adults migrating up the Fraser River experienced a higher percentage of Seton Lake water at the powerplant tailrace vs. Seton Creek outlet.

During these periods, the normal homing migration of Seton Lake salmon was disrupted because they were attracted to the tailrace of the powerplant rather than their natal stream. Through a combination of radio telemetry studies under different diversion regimes and direct laboratory testing of homing behavior, it was demonstrated that salmon preferred the tailrace water containing 100-percent homestream water (diverted for power generation) vs. the natural stream channel containing home water diluted with significant amounts of water from a nonnatal stream. Ultimately, by seasonally altering the flow regimes and controlling the composition of water in the natal stream channel, the disruptive effects of the hydroelectric project have subsequently been minimized (Fretwell, 1989).

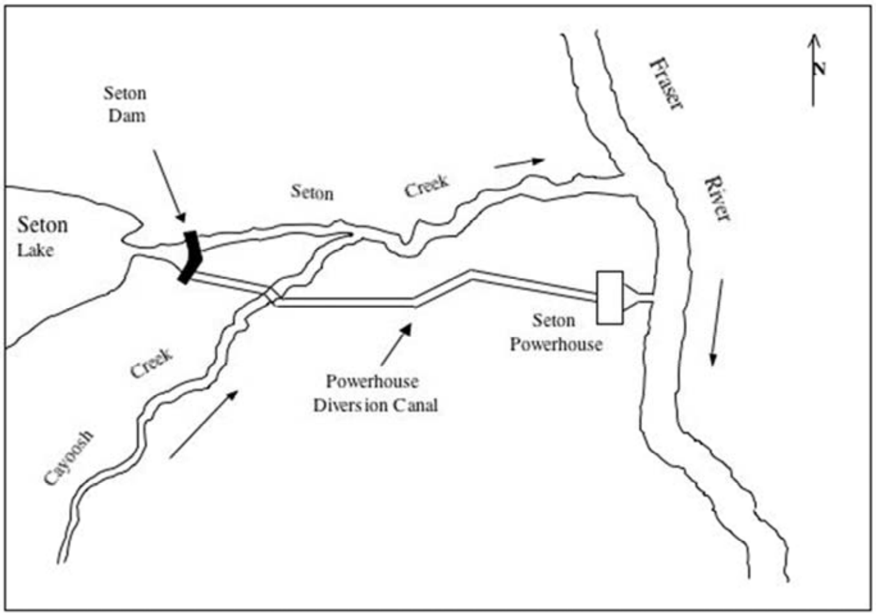


Figure 8-3. Map of Seton Creek hydroelectric facility and diversion canal.

These studies directly demonstrated that migrating adult salmon can distinguish between different dilutions of homestream water, and that relatively small increases in the percentage of non-homestream water in test waters could have profound effects on water discrimination and attractiveness (Figure 8-4). Data represent behavioral experiments comparing responses of Seton Lake sockeye salmon to 100-percent homestream water versus mixtures of home-and non-homestream water. Lake sockeye salmon demonstrate no preference for home water versus test water until non-home water percentage equals 10 percent. As the non-home water percentage increases to 33 percent, virtually all fish discriminate between the waters and prefer pure homestream water. (Figure 8-4 is adapted from Fretwell (1989) by pooling data across all years of his study.)

Furthermore, this work showed that discrimination and attraction to different dilutions of homestream water was both species- and population-specific, and changed over the course of the spawning migration. These findings demonstrate that water diversion has the potential for profound adverse effects on salmon homing and suggest a cautionary note that the effects on migratory behavior may be complex, potentially changing seasonally and affecting populations and species differently.

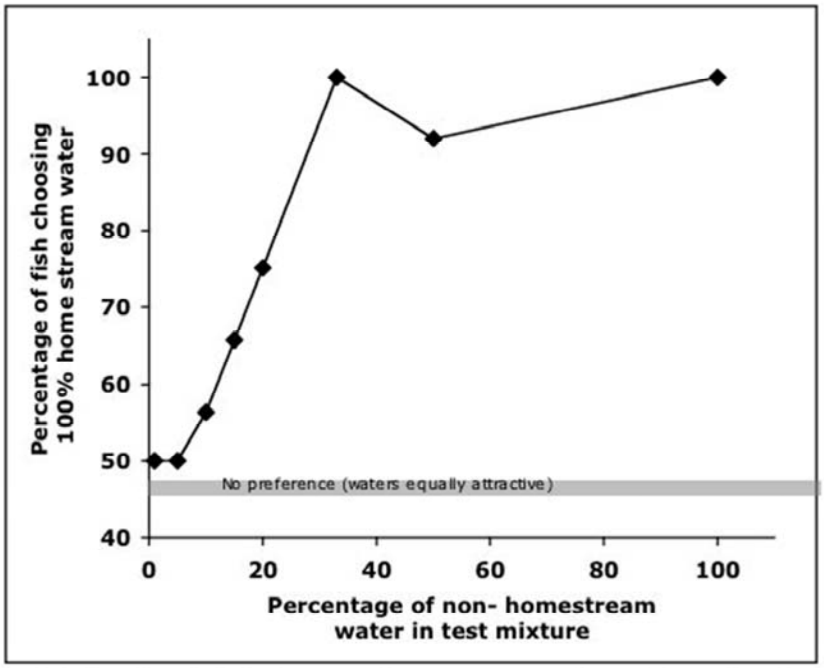


Figure 8-4. Homing salmon discriminate between pure homestream water and mixtures of home- and non-homestream water.

In summary, many aspects of salmon homing are still poorly understood. In particular, the nature of the odorous chemicals that allow salmon to identify their natal stream and the complex relationship of a river's geology and ecology in developing a river's odor qualities are not known. These uncertainties make it difficult to anticipate the effects of major water diversions on salmon homing, but the scale of the proposed Black Rock Alternative and previous studies indicating complex and sometimes unanticipated effects of homestream dilution or alteration, suggest that careful consideration of these potential effects are warranted.

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