APPENDIX F
ENVIRONMENTAL

PART 1 — FISH MITIGATION AND RESTORATION

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to
PART 1, Fish Mitigation and Restoration

PREFACE

NOTE TO READERS: *At the original writing of this Appendix F, Part 1, the discussion reflected the HHD AWS Project, and potential impacts, at mid-1997. During the fall of 1997, negotiations with resource agencies and tribal representatives resulted in a change in the project. The project now includes storage under Section 1135 of 5,000 ac-ft on a yearly basis beginning in Phase I of the project: previously, the 5,000 ac-ft was considered a 1-in-5 year event until initiation of Phase II when it would become yearly. Part F1 has been revised to reflect this change; however, there may be some omissions. These omissions, if any, will be corrected in the final edition.*

Appendix Overview

This Appendix F, Part 1, is divided into ten sections. The appendix sections are organized by 1) watershed location, headwaters and project area first and lower watershed last; and 2) project impact or issue. The opening section discusses the theme of adaptive management and its relation to operation of Howard Hanson Dam before and during the Additional Water Storage Project. The third to last section, Section 8, contains the selected restoration and mitigation plan. The second to last section, Section 9, describes the process and parameters used to model 32 years of historic data under Baseline, Phase I and Phase II conditions. Selected results of this modeling are used to assess project impacts and benefits. The entire modeling results sections are available upon request. The last section, Section 10, contains the framework for an adaptive management monitoring and evaluation program. A schedule and initial cost estimate for monitoring and evaluation during the first 15 years of the Additional Water Storage Project are included.

Definitions of Baseline, Phase I, and Phase II:

Baseline is the operation of Howard Hanson Dam (HHD) utilizing the existing 98 percent rule curve, and assuming Pipeline 5 is operational in accordance with, "Agreement Between The Muckleshoot Indian Tribe and The City of Tacoma Regarding the Green/Duwamish River System, 1995" (the Agreement). In addition, the 5,000 acre-feet (ac-ft) from the HHD Section 1135 Environmental Restoration project is assumed to be available for drought years. Total storage volume in normal years is 25,400 ac-ft, pool elevation is 1141 ft, and total storage volume in drought years is 30,400 ac-ft, elevation 1147 ft. For modeling purposes, 5,000 ac-ft was stored in non-drought years (4 of 5 years) to mimic annual debris clearing activities that require surcharging storage to elevation 1147 ft to access flat terrace areas to store and dispose of collected debris. This additional storage was not held for use in augmenting flows but quickly dumped over a one week period.

Phase I of the Additional Water Storage Project (AWSP) adds to Baseline the fish passage facility at the dam, a larger volume of storage behind the dam in the spring to store water for augmenting fish flows at Auburn, 20,000 ac-ft of additional Municipal and Industrial (M&I) water storage collected by storing Tacoma's Second Supply water right, and four habitat restoration projects. The 20,000 ac-ft of M&I storage is roughly equivalent to 100 days of storing the 100 cfs Second Supply Water Right. Note: diversion of Pipeline 1 occurs during spring refill but diversion for Pipeline 5 does not, instead this water is stored for Phase I additional storage and released during the low flow period to meet higher summer water supply demand. In addition, recent negotiations have resulted in adding yearly storage of the Section 1135 5,000 ac-ft beginning in year one of Phase I. Total storage volume in Phase I (Baseline + Phase I M&I + yearly storage of Section 1135 water) is 50,400 ac-ft equivalent to elevation 1167 ft. This storage volume is a revision following negotiations to include Section 1135 yearly storage in Phase I, prior to these negotiations flow modeling occurred with definition of Phase I only including Section 1135 storage in drought years. Total storage volume varied in flow modeling between normal years (non drought) with 45,400 ac-ft (Baseline + M&I) at 1162 ft elevation and drought years with 50,400 ac-ft (Baseline + M&I and Section 1135). We have not remodeled Phase I to include the annual storage of Section 1135.

As originally planned, Phase II of the AWSP replaced the Phase I storage with 14,600 ac-ft of water for fish use in the summer and fall (yearly storage of Section 1135 water) and an additional 2,400 ac-ft for M&I for a total additional volume of 37,000 ac-ft. Total storage volume (Baseline + Phase II) all years is 62,400 ac-ft, pool elevation 1177 ft. Since negotiations, the 14,600 ac-ft has been reduced to 9,600 ac-ft as the Section 1135 project is assumed to be operating yearly beginning in Phase I. We have not remodeled Phase II to reduce the annual storage of flow augmentation water.

Definitions of Green River watershed areas:

Watershed Area	Description	River Miles
Headwaters	Howard Hanson to Headwaters	64.5-88
Upper Green River	Lower Gorge to HHD	45.5-64.5
Middle Green River	Hwy 18 to Lower Gorge	33.8-45.5
Lower Green River	Tidal Influence to Hwy 18	11-33.8
Duwamish	area of tidal influence	0-11

SECTION 1 ADAPTIVE MANAGEMENT AND OPERATION OF HOWARD HANSON DAM

1.0 INTRODUCTION

Adaptive management is a form of natural resource management that states explicitly that uncertainty is inherent in all decisions related to management of natural systems. It is a management form that uses scientific information to develop management strategies in order to learn from programs or projects so that subsequent improvements can be made in creating both successful policy and managed programs and projects (Lee and Lawrence 1986). As such, adaptive management is managing by experimentation where "experimentation is not just a study," but is a major process of organizational change. Fluharty and Lee (1988) describe four essential elements to implement adaptive management:

1. The possibility of failure must be acknowledged and included in policy decisions.
2. Front end costs for planning, experimental design, and baseline measurement of natural systems must be incurred, and a long-term commitment to continue is necessary.
3. Interventions must be large, but should not be applied universally.
4. Information must be collected, analyzed, and reflected in program and project redesign, over time periods greater than the terms of policy or program managers.

1.A EXISTING STORAGE AND ADDITIONAL WATER STORAGE PROJECT

The Howard Hanson Dam (HHD) original operational storage strategy, generally followed from 1962 to 1983, delayed the start of reservoir refill until June. Early spring run-off is often fairly turbid, and delaying refill until after the snowmelt runoff peak enhanced the quality of water for municipal use (Tacoma Public Utilities, TPU). Once refill was initiated, all inflow was stored except that required to satisfy instream flow requirements. Storing the water as fast as possible, once refill began, minimized the duration but exacerbated the magnitude of downstream impacts. An analysis of refill strategies, conducted by the Corps, determined that refill under this strategy reduced flows from the project from an average of 1140 cfs to 234 cfs per week, using 1967 as a base year (DEIS, 1995). This strategy reduced flows in the river below the dam to extreme levels and eliminated freshets or pulses from the dam during the refill period. Impacts to juvenile outmigrants originating above the project are minimized using this strategy, but impacts to salmonids downstream of the project can be significant.

HHD operated from 1984-1992 under a passive adaptive management direction. Under passive adaptive management, it is assumed that the best information available is correct. Learning occurs through inadvertent management mistakes and inevitable natural variations. This type of management is akin to incrementalism; accumulating knowledge through gradual bits of information, and making marginal adjustments as you go.

An example of the information learned from inadvertent management mistakes comes from 1987, a summer/fall drought year. During that year, the Corps delayed spring refill as long as possible to allow for the outmigration of salmon and steelhead smolts through the project. By delaying refill, the reservoir did not reach full pool; and with the drought during the summer and fall, the project could not maintain minimum flows below the project which resulted in steelhead redd dewatering and stranding of adult salmon. The Washington Department of Fish and Wildlife (WDFW) documented that one-half of the native winter steelhead population was killed that year from dewatering of redds. The WDFW and Muckleshoot Indian Tribe (MIT) had to use heavy equipment to physically excavate areas of the lower Green to provide passage for upstream migrating adult chinook salmon. Management practices in refill of the reservoir have changed as a result of 1987 management decisions. Since 1992, the reservoir has been operated to ensure refill of the pool and protection of downstream resources by following the refill rule curve -- beginning refill on or before April 15.

From 1991-1996, HHD operated under a compromise of passive and active adaptive management. Active adaptive management treats all management actions as deliberate experiments in order to understand system processes. By implementing planned experimental management policies or project operation changes, better information is expected for long-term management, especially in situations where nature does not provide sufficient differences.

Since 1992, the operational storage refill strategy has involved periodic adjustments to meet a variety of resource needs (passive). Although refilling the reservoir to the summer conservation pool of 1141 feet MSL is the overriding consideration, the start date of refilling the reservoir in the spring and HHD releases during the refill period may be adjusted. Releases from HHD during spring storage refill are adjusted to protect fisheries resources, and in consideration of whitewater recreation opportunities and specific community activities (DEIS, 1995).

To protect fisheries resources, the spring storage refill strategy reflects a compromise between protection of juvenile salmonids outmigrating through the project and protection of downstream fisheries resources. During 1994, refill began in mid-April in response to input provided by the Green River Fisheries Management Coordination Committee (GRFMCC). The passive adaptive management strategy maintains the objective of refilling the reservoir pool, but allows the timing and rate of storage refill to be adjusted in response to additional fisheries information and current weather and runoff conditions.

As an outgrowth of the 1994 earlier refill, to further minimize project impacts to outmigrating smolts and steelhead spawning, the GRFMCC's 1996 refill strategy was an even earlier refill -- occurring in late March. Future use of this early refill strategy should include an evaluation of anticipated spring inflow, project outflows, and pool elevations to ensure protection of outmigrating juveniles.

As part of baseline studies scoped for the Additional Water Storage Project (AWSP), a limited series of experiments affecting outmigration of salmon and steelhead smolts was implemented beginning in 1991 (active adaptive management). In May of 1991, a planned experiment was implemented during spring refill whereby the reservoir was filled to full pool in a two-week period during the peak of outmigration for salmon and steelhead juveniles. This refill test showed a significant drop in juvenile coho outmigration associated with decreased <u>outflow</u> from the project (r^2=0.95). The results from this test were incorporated in the AWSP in designing the fish passage facility to handle the greatest outflow capacity *(Hydraulics and Hydrology Appendix*) and in modeling future refill strategies for maximum outflow during the peak salmon outmigration period in Phase I (*Section 9).*

A second AWSP experiment was a study to measure the amount of time it takes for coho salmon and steelhead juveniles to traverse (a.k.a. travel time) the reservoir under three different pool sizes and varying reservoir conditions. In the spring of 1995, this planned experiment measured the travel times of the juvenile fish and found that <u>pool size</u> did not significantly affect the travel times of tagged fish; however, findings did suggest that <u>refill rate</u> may affect travel time. We have already incorporated these active adaptive management results in our AWSP impact analysis and modeling of refill strategies (*Section 2B, Reservoir Outmigration of Juvenile Salmonids).*

The two experiments described above and conducted under the AWSP, were part of a larger series of baseline fish passage studies scoped as part of the project: results of these studies are described in more detail in Section 2, all technical reports from these studies are provided in *Appendix F, Part F2, Wildlife*. These studies were scoped through coordination and cooperation with all participating resource agencies, USFWS, WDFW, Washington Department of Ecology, and the Muckleshoot Indian Tribe and are being conducted over a series of 11 years, from 1990 to 2000.

1.A.1 Howard Hanson Dam Section 1135 Adaptive Management Refill and Release Strategy

For the recently completed HHD Section 1135 Restoration Project, an adaptive management process was selected, providing an active evaluation of the consequences of storing an additional 5000 ac-ft of water (HHD Section 1135 Final Project Modification Report, 1996). Implementing an adaptive process when considering frequency, refill, and release of additional storage provides a high level of flexibility regarding the need to store additional water while ensuring that potential impacts are minimized. An adaptive storage, refill and release schedule can be accomplished through annual coordination with the GRFMCC. By monitoring snowpack conditions, timing and quantity of steelhead escapement, and changing weather and inflow conditions, the potential benefits of storing additional water to augment downstream releases can be weighed against potential impacts. The Corps currently coordinates with members of the GRFMCC to plan short and long-term flow releases on a year-by-year basis. Providing the opportunity to improve downstream fisheries by storing additional water on an as-needed basis ensures an ongoing balancing of benefits and potential impacts using current information.

1.B AGENCY RESOLUTION PROCESS PROPOSAL

During the fall of 1995 and winter of 1996, the Seattle District and the Tacoma Public Utilities (TPU) convened a series of resource agency meetings between technical and policy level appointees to discuss outstanding issues and concerns related to the current state of the AWSP feasibility study. An outgrowth of these series of meetings (Agency Resolution Process) was the Corps and TPU policy decision to propose a phased implementation of the AWSP. Phases are described in the AWSP Feasibility Report. This phased approach was to 1) provide time to study further issues identified by the Agency Resolution Process that were not identified during earlier agency meetings in the feasibility study; and 2) to provide a means (adaptive management) to isolate and address specific management issues related to the AWSP. The Corps and Tacoma presented a proposal to the agency directors on February 9, 1996, that described the phased approach and the commitment by the Corps and TPU to implement adaptive management principles and agreements. The state and federal resource agencies gave conditional support to the AWSP based on this proposal.

Under the Agency Resolution Process, the Corps and Tacoma agreed to an adaptive management plan for the AWSP. The key elements of the Plan include experimentation, monitoring and analysis, and synthesis of results, followed by adaptive management practices responsive to the scientific results of those efforts. The AWSP Adaptive Management Plan involves: 1) phased implementation, so changes in the ecosystem can be studied with long-term monitoring; 2) incorporation of potential changes in project design and management/operation as we learn from phased implementation studies and monitoring; 3) implement changes in program structure if monitoring results and outcomes justify changes; and 4) ongoing coordination with agencies and the MIT throughout the project to ensure that good science is incorporated into management strategies and decision making.

1.C ECOSYSTEM RESTORATION AND ADDITIONAL WATER STORAGE

Halbert (1993) states that for effective implementation and evaluation of management actions there is a "need to develop quantitatively explicit hypotheses about how the system functions." For the Green River and the effect Howard Hanson Dam has on the aquatic environment, existing operation and the AWSP, there are two main competing hypotheses on life-history limiting factors during the freshwater rearing phase of anadromous salmon:

1. The older, generally accepted hypothesis: The summer and fall low-flow period limits production of juvenile coho, steelhead, and to an extent, chinook; so increasing low-flow habitat (through flow augmentation) will increase production of these stocks.

2. The newer, less understood and less accepted hypothesis: Reduction in spring flows (increased storage volume and/or refill rate) limits the production of chum, chinook, and to a limited extent coho and steelhead, by increasing disconnection of important lateral and off-channel habitat and decreasing flow volume used for smolt outmigration; so maintaining spring flows will maintain production.

1.C.1 Objectives and Performance Targets for Adaptive Management (Phase I and II)

Effective adaptive management requires the development of clearly defined goals, objectives, and performance measurements (decision criteria or targets) to evaluate whether objectives have been met. After meeting with WDFW Assistant Directors Martin Baker and David Mudd on January 31, 1996, the Corps and TPU would consider preliminary objectives and performance targets for Phase I and Phase II (as described in February 9, 1996 Proposal):

Phase I

- Maximize smolt survival through the reservoir and dam outlet.
- Initiate efforts to establish self-sustaining runs of historical upper Green River anadromous stocks (steelhead, coho salmon, and potentially, fall chinook).
- Establish baseline conditions (through inventory and monitoring) for middle and lower Green River anadromous stocks (habitat availability and use, migration/flow survival relationships).

Phase II

- Optimize the (potentially) competing objectives of 1) maximum smolt survival through the project, 2) maximum flow-augmentation and municipal water supply, and 3) minimizing impacts to lower watershed fish resources.
- Establishment of self-sustaining runs of upper Green River anadromous stocks (steelhead, fall chinook and coho salmon).

Performance Targets for Phase I:

- The Corps and Tacoma will immediately work with agency and tribal staff to identify appropriate targets and monitoring methods to measure project performance against agreed upon Phase I and II objectives.
- The Corps and Tacoma will also establish a scientific peer-review workgroup to develop identified appropriate targets and measurement methods.
- Performance measurement for Objective 1 of Phase I includes stock specific survival targets for the reservoir and dam outlet (including latent mortality) and potential refinements necessary to meet these targets. Further, performance targets from other water storage projects could be used as a starting point for discussion purposes.
- Performance measurement for Objective 2 of Phase I includes establishment of upper watershed smolt production and adult escapement estimates (necessary to create self-sustaining runs).

Performance Targets for Phase II:

- As of the last Agency Resolution meeting, February 9, 1996, no performance measures had been established for Phase II; however, monitoring of downstream areas was begun: a side-channel inventory of the middle Green River was completed during the fall and winter of 1996/1997 (discussed below).

1.C.2 Commitment to Adaptive Management and Delineation of Performance Targets

The first target and monitoring plan efforts were directed to the issues of 1) connection of the mainstem river to off-channel habitats (side-channels), and 2) survival of juvenile salmon and steelhead outmigrants through the reservoir. In response to issue No. 1, immediately following the February 9, 1996 Agency Resolution Process final meeting, the Corps and Tacoma initiated efforts to identify and establish appropriate targets and monitoring methods for lower and middle watershed side-channel connectivity. Through a series of interagency meetings between February and September 1996, a physical habitat monitoring plan was developed to inventory Green River side-channel habitat. In the fall of 1996, an interdisciplinary team from the Corps and Tacoma, with agency assistance, completed a low-flow and high-flow inventory. The results of the physical habitat inventory, recommendations on flow targets to maintain floodplain connectivity, and outcomes from modeling baseline, Phase I and Phase II refill strategies are presented in *Section 7, Green River Side Channel Inventory*. In 1997, the Corps and Tacoma are beginning efforts to collect available data on fish use of off-channel habitats. Initial tasks have included working with 1) WDFW and Muckleshoot Indian Tribe to identify specific off-channel habitat areas for steelhead and salmon (chum) spawning, and 2) assisting King County in trapping of juvenile outmigrants in selected side channels.

In response to issue No. 2, during the summer and fall of 1996, Tacoma and the Corps established an independent scientific peer-review panel to review available information and establish appropriate targets for reservoir survival of juvenile salmon and steelhead outmigrants. This workgroup is being polled on various questions about reservoir survival through an approach known as the Delphi Process. Description of the process and initial results of the polling are presented in *Section 2C, Assessment of Reservoir Success Through the Delphi Process*. As this is an iterative approach, one or more rounds of questions will be presented to the panel and results will not be available until the Final Report is complete.

1.D ADAPTIVE MANAGEMENT SUMMARY

The operation of Howard Hanson Dam has gone through an evolution of management policy from 1962 to 1997. This evolution has rapidly evolved to an active adaptive management process. Central to this rapid change to active adaptive management is the AWSP. The AWSP planning process has provided a dynamic forum for an active exchange of management philosophies or paradigms (Agency Resolution Process), a storehouse of new information gathered through planning, design, and baseline measurement (baseline studies), and a potential vehicle to continue information gathering and analysis beyond the normal lifespan of project managers (performance measures and commitment to monitoring).

The AWSP reflects the four essential elements necessary for successful adaptive management (described in Section 1A).

1. The possibility of failure was acknowledged and was partially responsible for the creation and proposed implementation of Phase I and Phase II.
2. The front end costs for planning, experimentation, and baseline studies, and a commitment to long-term monitoring were executed or were agreed to under AWSP.
3. Large interventions are planned for various aspects of the AWSP, two examples -- 1) a state of the art fish passage facility is planned under restoration to address the existing dam passage problems; and 2) additional water storage is phased (Phase I 60-67% increase in total storage, Phase II a 100% increase).
4. To date, all available information collected and analyzed has been incorporated into the AWSP with planned monitoring to continue through implementation and operation of the project.

1.E LITERATURE CITED

Castleberry, D.T., J.J. Cech Jr., D.C. Erman, D. Hankin, M. Healey, G.M. Kondolf, M. Mangel, M. Mohr, P.B. Moyle, J. Nielsen, T.P. Speed, and J.G. Williams. Uncertainty and instream flow standards. Fisheries 21:20-21.

Fluharty, D. and K.N. Lee. Neither wilderness nor factory: learning from natural resource management. Proceedings of the First Annual Meeting on Puget Sound Resources 1:256-265.

Halbert, C.L. 1993. How adaptive is adaptive management? Implementing adaptive management in Washington state and British Columbia. Reviews in Fisheries Science 1:261-283.

Lee, K.N., and J. Lawrence. 1986. Adaptive management: learning from the Columbia River basin fish and wildlife program. Environmental Law 16:431-460.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17, 36.

SECTION 2 JUVENILE SALMON AND STEELHEAD PASSAGE THROUGH THE HOWARD HANSON DAM PROJECT

2.0 INTRODUCTION

At the beginning of the Howard Hanson Dam (HHD) Additional Water Storage Project (AWSP), the Corps and the City of Tacoma recognized that raising the existing HHD pool for additional water storage would cause unavoidable adverse impacts to juvenile fish on their downstream migration to Puget Sound. Since 1982, between 2 to 4 million juvenile salmon and steelhead annually have been released upstream of the dam to utilize the 106 miles of accessible stream habitat. In response to this adverse impact, the Corps and Tacoma developed a fish passage technical committee (FPTC) composed of broad-based group of public and private individuals experienced in design and evaluation of fish passage facilities. The FPTC is composed of the following members:

Milo Bell	Independent Consultant
Ken Bates	Washington Department of Fish and Wildlife
Steve Rainey	National Marine Fisheries Service
Phil Hilgert	Beak and R2 Resource Consultants
Ed Donahue	FishPro, Inc.

The initial purpose of the FPTC was to provide a planning document for use in development of a permanent, downstream fish passage facility at HHD under the AWSP. The FPTC completed an initial report in 1990, entitled *"Howard A. Hanson Dam Fish Passage Alternatives for the Proposed New Operating Rule Curve."* This report provided a variety of juvenile fish passage options and recommended biological screening criteria that became the starting point for the 3 year design phase (1993-1996) in development of the AWSP preferred fish passage alternative. Throughout the design phase, the FPTC supervised, guided and modified design options developed by the Corps. Design of the facility is discussed in the *Hydraulics and Hydrology Appendix* and incremental analysis of 9 passage alternatives is presented in *Section 8, Fish Mitigation and Restoration Plan and the Economics Appendix*. The FPTC made some basic assumptions:

Fish passage below the 1080 ft pool is satisfactory.

They concluded that adequacy of fish passage through the existing outlet structure is a function of vertical head, gate opening, and flow. Studies by the Washington Department of Fisheries (Seiler and Neuhauser 1985) indicated that juvenile downstream passage is adequate through the existing sluice (radial) gates when the pool is below 1080 ft.

Fish passage is required between pool elevation 1080 to 1177 ft.

Improved fish passage is needed for the period of refill and full storage. It is also assumed that fish passage through the existing sluice gate in conjunction with an operating fish collection facility will be adequate during the short duration of winter flood peak flows.

There is no need to screen fish above the 1177 ft pool.

The short duration peak flows (flood flows) that fill the reservoir above elevation 1177 ft are brief enough that full screening will not be necessary.

Appropriate water circulation patterns occur near the outlet.

Appropriate flow patterns may be necessary to effectively attract and collect fish under a variety of flow and pool elevation conditions.

Besides consideration of passage alternatives, the FPTC report also provided a framework of Baseline studies necessary to assess the existing state of downstream fish passage at HHD as well as provide insights into potential changes in passage with the AWSP. In their report, the FPTC provided a recommended list of studies necessary to evaluate each of the proposed fish passage options and to verify the aspects of the assumptions presented above. These recommended studies were:

- Evaluation of attraction by juvenile fish by species to the existing outlet at selected pool evaluations.
- Study depth (vertical) and lateral (horizontal) distribution of juvenile fish near the outlet as functions of reservoir temperature, pool elevation and outflow.
- Study passage of juveniles through the reservoir to determine if delay (increased travel time) is a function of reservoir elevation (pool size) and outflow.
- Study flow circulation near the outlet as a function of temperature, outflow and pool elevation.
- Evaluate attraction flow (required to pass fish) at selected pool elevations.
- Evaluate constructed feasibility; verify attraction flow requirements, collection and passage efficiency and operating procedures for safe passage.

These recommended fish studies became the basis for a series of Baseline interagency monitoring studies performed the U.S. Fish and Wildlife Service (USFWS), Washington Department of Fish and Wildlife (WDFW), the Muckleshoot Indian Tribe (MIT), the Corps and the City of Tacoma. These studies were initiated in 1990 and will continue through the year 2000. The studies performed in relation to each of the recommendations were:

Evaluate attraction by juvenile fish and attraction flows; resulted in two years of study and two USFWS reports:

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Study vertical and horizontal distribution; resulted in a one year study and USFWS report:

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Study passage through the reservoir; resulted in a one year study and report by the USFWS:

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Additional studies beyond the FPTC report were scoped through interagency cooperation with the USFWS, MIT, and WDFW. These additional studies included 1) monitoring of instream habitat that would be inundated by the pool raise; 2) long-term adult survival studies utilizing paired releases of tagged coho and steelhead smolts above and below the dam to fully measure the effects of the existing project on the survival of juvenile salmon and steelhead; and 3) long-term adult survival studies of chinook salmon utilizing releases (unpaired) of fingerlings in the Headwaters watershed above HHD. These studies have resulted in two reports to date:

Wunderlich, R.C. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. Western Washington Fishery Resource Office, Olympia, Washington.

Aitkin, K. 1996. Progress report on the Howard Hanson Project Adult Return Rate Study for CWT coho and chinook salmon, 1994 and 1995.

The following paragraph 2.1 provides a brief summary of these Baseline anadromous fish studies. The rest of this Section 2, *Juvenile Salmon and Steelhead Passage Through the Howard Hanson Dam Project*, will discuss the results, conclusions, and Corps recommendations from these monitoring studies.

2.1 RECAP OF BASELINE USFWS ANADROMOUS FISH STUDIES

Following is a brief summary of salient points related to the Baseline studies performed by the U.S. Fish and Wildlife Service (USFWS). Section 2 provides more detail on the studies related to important aspects of the AWSP and Appendix __ contains all reports in their entirety.

2.1.1 Tributary Inundation

Full Report Title: *Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam*

- single year study completed in 1991; contained in the original study plan
- provided stream habitat data for areas within the proposed inundation zone (1147 to 1177 ft elevation)
- study costs combined with 1991 outmigration study above

RESULTS:

- results used to establish baseline stream condition, and a basis for impact analysis
- 2.9 miles of stream will be inundated up to 6 months with loss of riparian zone structure and function
- inundation of stream habitat could result in lost production of an estimated 11,700 coho smolts, 1800 steelhead smolts, and between 21,000 to 210,000 chinook smolts

CONCLUSIONS

- coho may adapt best to increased reservoir area (they utilize pond/lake habitat elsewhere) and chinook least
- to minimize impacts, the Corps/Tacoma will use a variety of habitat improvements to address the impacts from the Phase I pool raise 1.9 miles of habitat, and the Phase II pool, an additional 1 mile. These improvements include, but are not limited too – removal of migration barriers (culverts); stabilization of the affected 1.9 to 2.9 stream miles through addition of large woody debris and boulders; placement of floating debris islands throughout the reservoir, and creation of off-channel habitat above and below the inundation zone.
- besides mitigating impacts to the 1.9 to 2.9 miles of stream habitat affected, the Corps/Tacoma have selected management measures to improve instream habitat in major tributaries of Howard Hanson reservoir up to the 1240 ft elevation, and will be restoring a ¾ mile long side-channel in the lower river that could be important as

Upper Watershed juvenile overwintering habitat (fish that have migrated through the new fish passage facility).

2.1.2 Outmigration Study

Full Title of Reports: *Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington 1991 and 1992*

- two year study in 1991 and 1992
  - 1st year contained in the original feasibility study plan
  - 2nd year was an additional study requested by agencies and tribe
  - 3rd year requested but not undertaken
- provided numbers and timing of fish movement through the reservoir and dam by species: steelhead, coho and fall chinook
- study costs > $250k

RESULTS:

- 1991 study monitored refill during late May and June, 1992 study had refill begin in early April: a test refill period was also monitored and evaluated in 1991
- results used to establish baseline juvenile fish outmigration patterns, numbers, and survival through the existing project (dam only)
- few steelhead were captured during the outmigration studies, this is probably due to inefficiency of equipment and size and swimming ability of steelhead smolts
- refill in April delayed or entrapped most outmigrating smolts until drawdown in fall; for example, entrapped chinook increased in size from 46 mm in February to 180 mm by late November
- 97% of the decline in passage of coho smolts could be explained by the decrease in outflow and increase in pool height during refill
- the radial (or flood) gates caused minimal or no injury while the 48 inch bypass (used during low flow) caused greatest injury
- chinook smolts had the highest injury and mortality rates: up to 30% of chinook were killed in all 1992: this is only a measurement of direct mortality through the bypass pipe; CWT of coho smolts suggests total mortality through the entire project (dam + reservoir impacts, including entrapment in the reservoir) may be between 75-95%
- chinook fry to smolt survival varied greatly in two years of study, from 1.1 % in 1991 to 14.5% in 1992, the change in chinook survival is probably related to climatic changes or stocking practices
- over 30,000 smolt-sized coho fry (>100 mm) outmigrated during the reservoir drawdown in fall

CONCLUSIONS:

- coho smolt outmigration is significantly related to outflow and shallow exit depth, therefore a surface collection facility is required for their successful outmigration and all acceptable fish passage alternatives include a surface exit

- as part of any fish passage alternative considered, the 48 inch bypass will be fixed to meet velocity and bend radius criteria provided by the Fish Passage Technical Committee
- differences in survival of outmigrating smolts can be heavily influenced by factors outside the Howard Hanson project
- Howard Hanson Reservoir could provide excellent rearing habitat for coho fry and potentially for chinook
- the travel time study completed in 1995 provided additional information on steelhead outmigration

2.1.3 ATPase

- originally a single year analysis conducted in conjunction with the outmigration study; contained in the original study plan
- expanded in conjunction with multiple year fish travel/migration studies requested in 1991 by the agencies and tribe
- provided "smolt readiness" information based on increased enzyme levels
- costs distributed within related studies

RESULTS:
- results used to correlate fish movement with fish physiological condition
- chinook captured in the reservoir forebay were found to be smolt ready from mid-May to early September, coho were smolt ready between April and late June
- coho and chinook smolts lost "smolt readiness" if they were held in the reservoir beyond their normal outmigration "window"
- coho fry that reared in the reservoir and reached smolt size by the end of summer were not smolt ready

CONCLUSIONS:
- providing smolts a surface exit during their outmigration period is necessary to maintain smolt readiness

2.1.4 Gillnet Study

- single year snap shot of fish horizontal and vertical location at the forebay of the existing intake tower; not contained in the original study plan or requested by the agencies but a Corps/Tacoma decision to gather this information

RESULTS:
- provided an indication of fish distribution within the influence of the existing intake tower's flow net
- results used to correlate fish distribution with water passage through low level outlets
- no technical report completed
- study costs approx. $5k

2.1.5 Horizontal/Vertical Distribution Study

Full Report Title: *Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir*

- single year study requested in 1991 by the agencies and tribe and completed in 1993; not contained in the original study plan
- provided seasonal information (April-July) of fish reservoir distribution away from the flow influences of the existing intake structures outlets
- results used to determine fish location during critical outmigration periods, and aid in the design of the fish passage facility
- study costs > $60k

RESULTS:

- 80-97% of all juvenile salmon found in the upper 15 m of the water column
- coho smolts were found higher in the water column than chinook
- all smolts showed a strong preference for shoreline areas
- no predatory fish were found in the lower reservoir

CONCLUSIONS:

- results confirmed need for surface exit for outmigrating smolts first indicated in 1991 and 1992 outmigration studies
- results used in developing criteria for the fish passage facility, i.e., the screen "fishes" shallow depths between 5-20 ft, and the screen/intake tower is located near the shoreline

2.1.6 Adult Return Rate Study

First report title: *Progress report on the Howard Hanson Project Adult Return Rate Study for CWT Coho and Chinook Salmon, 1994 and 1995*

- multiple year study requested in 1991 by the agencies and tribe, most tagging completed in 1993-1995; not contained in the original study plan
- adult returns are expected through the year 2000 (chinook)
- designed to provide pre-project adult survival/return rates
- study costs > $600k

RESULTS:

- coho smolts tagged (40,000/yr) and released in 1993, 1994, and 1995, releases occurred above and below the reservoir, returns reported in first progress report
- preliminary 1993 coho release adult return rates for test (release above dam) and control were: release group 1 test -- 5.5 %, control 6.1%; release group 2 test 1.8%, control 7.8%
- preliminary 1994 coho release adult return rates for test and control were: release group 1 test 0.1%, control 0.9%; release group 2 test 0.03%, control 0.6%.

- chinook fingerlings tagged (400,000/yr) in 1994 and 1995 with a third year planned for 1996, returns to begin in fall of 1996
- as of March 12, 1997, approximately 25 adult chinook had been collected from the 1994 outplants
- steelhead fry and smolt releases were less than planned: 1) fry (55,000/yr) released in 1993 and 1994, returns should still give an indication of steelhead return rates; 2) one year of smolt releases (120,000) occurred in 1995, returns to began in fall of 1996 with collection by Muckleshoot and WDFW
- tag returns will be used as baseline adult survival/return condition

CONCLUSIONS:

- preliminary 1993 and 1994 coho returns were analyzed by the Corps against major reservoir physical variables: 1) radial gates were in operation throughout 1993 outmigration period, 1994 the bypass gate was used beginning May 12, this may partially the greater differential in between-year survival (1993 Vs 1994), and 2) regression analysis revealed a significant relationship between test survival and average inflow (r^2=0.95) and test survival and average outflow (r^2=0.89)
- the results of this initial analysis appear to be in agreement with the 1991 and 1992 outmigrant studies where outflow explained most variation in daily passage and the bypass gate was found to have the highest injury and mortality rates
- results will also be used for future comparison with post-project adult survival/return conditions to verify success of restoration (mitigation) measures
- Corps/Tacoma are developing monitoring plans to assess post-project adult survival/return as the feasibility study progresses
- plans include -- fish passage facility will have PIT-tag sensors, hydroacoustic monitoring equipment, and a sampling station where juveniles can be evaluated

2.1.7 Smolt Reservoir Migration Study

Full Report Title: *Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington*

- single year study of steelhead smolt travel time requested in 1991 by the agencies and tribe; not contained in the original study plan
- study completed in spring of 1995 using coho salmon and steelhead smolts (and a limited number of chinook smolts) to determine travel patterns and duration in the reservoir during outmigration
- results used to document baseline travel time under three pool conditions (low, medium, and high) and migration patterns and to predict the affects of increased storage on juvenile fish travel
- study costs > $100k

RESULTS:

- low and high pool had relatively slow refill rates or stable pool conditions, medium pool had highest refill rate or greatest change in reservoir conditions

- a site-visit by the telemetry contractor prior to and at initiation of the study showed that detection rate at the could be poor due to rapidly changing pool elevation and from high background "noise"
- at high pool or largest reservoir area, the greatest number of smolts were detected at the dam and were presumed to successfully transit the project: 72-84% of coho and 88% of steelhead smolts, mid pool had the lowest detection rate: 39% for coho
- steelhead mean travel time at high pool (2.5 days) was virtually equal to low pool (2.7 days) or near riverine conditions and 4 days less than medium pool (7.4 days)
- coho mean travel time at high pool (6.0 days) was seven days longer than at low pool (3.0 days), but 1.4 days less than medium pool (11.4 days)
- smolts were found closely associated with large woody debris throughout the reservoir

CONCLUSIONS:

- the objective of the study was to evaluate a performance measure, travel rate, the study was not meant to consider reservoir survival as measured by detection rate
- the study was conducted under much worse than normal refill conditions (existing condition), with low and mid pool inflows less than lower quartile (75% exceedance) and high pool inflow near lowest minimum for that period (99% exceedance)
- outflow was regulated for mid to high pool for steelhead redd protection necessitating reduced outflows especially during the mid-pool refill period
- multivariate regression analysis indicated refill rate may have greater impact on travel time than size of the reservoir -- although either measure appears to have a minor influence on outmigrant timing compared to entrapment within the reservoir from lack of a surface outlet facility
- much of the refill under additional storage will occur in March and April, prior to outmigration of most smolts, with average refill rates in late April and May not exceeding 4-500 ac-ft per day, equal to or less than baseline refill rates
- for steelhead and coho, the additional storage pool while larger probably will not increase overall smolt travel time beyond 2-3 days
- the Corps/Tacoma are considering mitigation plans that include restoration of inundated stream channels to provide more instream cover, addition of "floating islands" to provide shoreline cover in the reservoir, monitoring of predator populations (and if necessary removal), supplementation of selected stocks to maintain Headwaters production potential.

2.1.8 Literature Cited

Aitkin, K. 1996. Progress report on the Howard Hanson Project Adult Return Rate Study for CWT coho and chinook salmon, 1994 and 1995.

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Wunderlich, R.C. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. Western Washington Fishery Resource Office, Olympia, Washington.

SECTION 2A PRODUCTION POTENTIAL OF THE HEADWATERS GREEN RIVER WATERSHED

NOTE TO READERS: At the original writing of this Appendix F, Part 1, the discussion reflected the HHD AWS Project, and potential impacts, at mid-1997. During the fall of 1997, negotiations with resource agencies and tribal representatives resulted in a change in the project. The project now includes storage under Section 1135 of 5,000 ac-ft on a yearly basis beginning in Phase I of the project: previously, the 5,000 ac-ft was considered a 1-in-5 year event until initiation of Phase II when it would become yearly. Part F1 has been revised to reflect this change; however, there may be some omissions. These omissions, if any, will be corrected in the final edition.

2A.1 INTRODUCTION

The purpose of this report is to provide estimates of the anadromous fish production potential of the Headwaters Green River above Howard Hanson Dam. The entire section of river above HHD (RM 64.5) will be referred to as the Headwaters watershed. Anadromous salmon and steelhead historically used the headwaters watershed, and thus a large level of the Green River fish production was lost as a result of the completion of the Tacoma Diversion Dam at RM 61, 1911-1912, and finally with the completion of HHD in 1962. This report provides an estimate of the level of production which could be recovered (restored) through restoration of anadromous fish runs into the watershed.

Production potential of each species is defined as the number of fish able to be produced through restoration. The objective of this section is to estimate the number of juveniles which could be produced by each species in the Headwaters. These estimates will then be combined with the information provided in *Section 8, Fish Mitigation and Restoration Plan,* to estimate the proportion of fish which could be successfully passed through HHD during outmigration under baseline and the AWSP. An estimate of the juvenile to adult (ocean) survival rate for each species will be used to predict total adult returns, and, together with an estimated escapement goal, to evaluate if enough returns will be available on an annual basis to establish self-sustaining runs and support a directed harvest. Production potential estimates will be provided for coho salmon, steelhead, and fall and spring chinook salmon. No historical records are available on historical runs of sea-run cutthroat trout. This species is not addressed in this report.

It should be noted that the Headwaters Green River watershed could sustain total fish populations equal to the sum of the individual species' production potential estimates provided in this report. The estimates for individual species generally reflect values selected from systems known to produce numbers of one or more of the particular species. The exact mix of species ultimately selected for restoration and that can be successfully restored will have a strong influence on the individual production which can be anticipated from each species. When data was available, the effects of inter-specific interactions in terms of anticipated production were evaluated.

Several investigators have previously estimated production potential of the Headwaters watershed. The first attempt, by Chapman (1981), estimated production potential in smolt production and adult escapement of coho, chinook and steelhead using weighted useable area for selected streams (Table 1). This author uses the term "pristine" for his salmon and steelhead production estimates; in this section we will be using estimates of pre-dam available habitat, the term pristine is a "loaded" term that has very different connotations to different readers and will not be used to describe pre-dam estimates. The second estimate, by Seiler and Neuhauser (1985), provided coho smolt production potential using an estimate of smolts per watershed area. The Washington Department of Fish and Wildlife (WDFW) has produced three estimates, of which two are reported below. Gerke (1987) estimated adult returns (catch + escapement) for coho, chinook, and steelhead, while Cropp (1994) estimated steelhead parr, smolts, and adult escapement using the Maximum Sustained Harvest methodology.

Historical information on the Headwaters anadromous fish assemblage and the potential number of returning adults comes from trapping of adults (for hatchery egg take) in the early part of the century. There was approximately three years of trapping below the Diversion Dam, from 1911-1914, with trap counts for coho and steelhead. The average return for coho during those years was 5600 adults while steelhead was 1600 adults. Grette and Salo (1986) reported that historical escapement estimates ranged from 9,000 to 25,000 for coho, 500 to 5200 for steelhead, and from 150 to 300 for spring chinook. The authors researched Washington Department of Game records and concluded that harvest and seasonal blockages below the trap could have resulted in underestimates of total returns.

The current effort to estimate production potential was undertaken for three reasons. First, most earlier efforts were selective, using one method for a particular species (or unknown method) and were based on a limited number of streams or available habitat information. Better estimates could be provided if one or more currently accepted methods could be used with a better quantification of available habitat. Second, more reliable estimates of production from other system have become available, and this new data will allow a better comparison of the Headwaters to other watersheds. Third, as part of the Additional Water Storage Project (AWSP), extensive and varied fish restoration and mitigation facilities have been, or are being considered, and estimates of production potential will influence the type and extent of facilities required. Having the best production potential estimates will permit a fair incremental evaluation of the fish passage and habitat restoration options being considered, and result in the greatest overall probability of success.

Since 1992, a temporary fish ladder and trap and haul program has been cooperatively administered by the City of Tacoma, WDFW, Muckleshoot Tribe and Trout Unlimited. During this time adult steelhead have been collected for the broodstock program stocking steelhead fry in the Upper Watershed. As a pilot program, between 20-133 adult steelhead have been released annually into the Upper Watershed. Salmon collection at the fish trap has been variable; the trap has not been operated every year during the fall migration season. A pilot program to release salmon into the Upper Watershed may be initiated in the near future if the AWS Project is approved to move forward to construction. Without successful downstream fish passage at HHD, WDFW and MIT staff expect that outplanting of hatchery reared juvenile salmon and steelhead will cease in the near future.

TABLE 1. PREVIOUS ESTIMATES OF SMOLT PRODUCTION AND ADULT ESCAPEMENT/RETURN FOR ANADROMOUS SALMONIDS FOR THE HEADWATERS ABOVE HOWARD HANSON DAM.

Chapman (1981). Estimated smolt yield and adult return, Green River, above Tacoma Diversion without Howard Hanson Dam under pre-dam conditions (the author titled the estimate as "pristine" we use pre-dam). Using weighted useable habitat area.

Species	Smolt Yield	Adult Escapement	Total Adult Return[a]	Adult Return Rate (%)
Coho	213,516	4,270	17,081	8
Chinook[b]	128,644	1,286	4,632	3.6
Steelhead	20,079	437	2,008	10
Total	362,239	5,993	23,721	6.5

a. Adult Return includes escapement needs and harvestable surplus: 1) for coho escapement = 4270, harvest = 12,811 or 17,081; 2) chinook escapement = 1286, harvest = 3346 or 4,632; and 3) steelhead escapement = 437, harvest = 1571 or 2,008.
b. Includes fall and spring chinook.

Cropp (1994). Green River wild steelhead escapement requirements above HHD. Using estimated habitat areas and the Maximum Sustained Harvest methodology.

Steelhead Parr Yield reported was 20,998 and Adult Escapement of 582. The estimated habitat areas are less than those used for the Corps production estimates.

Gerke, B. 1987. Counteroffer regarding mitigation for fishery losses due to the Green River Diversion Plan. Washington Department of Fisheries Draft Letter. Method of calculation unknown but is not based on natural production.

Species	Smolt Yield[a]	Total Adult Return	Adult Return Rate (%)
Coho	280,000[b]	37,240	N/A
Chinook	800,600	8,006	1
Steelhead	35,000	3,500	10
Total	N/A	48,746	N/A

a. Assumes initial hatchery development for all species to build-up runs. For chinook, this assumes all fingerling plants, for steelhead this is a combination of fingerling plants and natural production.
b. Gerke and Woodin (1982) in Fox 1995.

Seiler and Neuhauser (1985). Estimate of coho smolt yield using total watershed area.

Coho Smolt Yield of 120,000, using estimate of the upper Green River Watershed area (220 sq. miles) or 61% of the area of the South Fork Skykomish. Multiplied the number of smolts trapped annually out of the South Fork times 61%.

2A.2 METHODS FOR PRODUCTION POTENTIAL

Our approach was to estimate potential natural smolt production in the upper watershed, consistent with the Ecosystem Restoration Goal, to assess the overall benefits to our different restoration alternatives. This approach was primarily for downstream fish passage alternatives (how many fish survive through the alternatives and return as adults), but was also applied to habitat restoration projects as well. Given that ocean conditions are experienced by all juveniles leaving the Green River Basin, the simple assumption for this analysis is that the number of juvenile fish produced in the upper watershed is a measure of the potential for adult returns once downstream and upstream fish passage is completed. The stocks considered for the restoration goal and the life stages considered for passage through the project are as follows:

Species	**Life Stage**
Coho	1+ (yearling)
Steelhead	1+ and 2+
Fall Chinook	0+
Spring Chinook	0+ (90%), 1+ (10%)[a]

a. Currently, since there no viable source of stock to re-introduce spring chinook to the Green River, spring chinook smolt and adult returns are estimated but are not included in the final outputs for incremental analysis of the fish passage facility. Sea-run cutthroat were originally considered in production and fish passage survival but were removed because of high uncertainty over restoration potential.

Although we have attempted to use the best available information to estimate smolt and adult returns, predicting salmon and steelhead numbers is a risky business. As Hunter and Gerke (1992) note:

> "... fish productivity estimation is an imprecise science. The use of different productivity methodologies routinely result in estimates differing by factors of 3 or more. There are too many variables that significantly influence fish productivity, and no reliable, universal method exists. There is no real substitution for data collection and evaluation of actual fish use in the basin of concern."

Overview of Different Methods Available for Salmon Production Estimates. The following is not a complete list of means to estimate smolt and adult production, but is a general discussion.

- Historical <u>adult</u> spawning escapement numbers (maximum or average) from trapping or redd counts. Records for the Upper Green from 1911-1914 were available for coho and steelhead, the average was used (Grette and Salo 1985).
- Smolt yield based on outmigration trapping. Records are available for other watersheds. The quality of data varies by species based on the effectiveness of smolt capture. Coho yield is the most reliable, while fall chinook and steelhead can be highly suspect. Trapping data for coho from nine watersheds was provided by Dave Seiler, WDFW. Data was used two ways, 1) weighted average of all watersheds with the average number of smolts/mi^2 of watershed, and 2) linear regression of watershed area on smolt number.
- Habitat based production estimates for <u>smolts</u> or <u>adults</u>. This is the most widely used method(s), primarily because of the limitations of the previous methods (lack of available data, large variation, etc.). This method has already been used by Chapman, Cropp, and Gerke (Table 1) to estimate smolt production and adult returns. The precise application varies by lifestage, smolt or adult, and by species, spring chinook, fall chinook, steelhead, and coho. Many of these methods incorporate a measure of 1) total accessible stream length (yards/meters, kilometers/miles) below impassable barriers; 2) average stream width; and 3) average stream gradient (discussed below).

For the Green River, historical distribution (smolt or adult) of the anadromous species in the upper Green was unavailable. Accessible stream miles from stream blockage location and type was available from the WDFW. Data on individual stream widths was available for larger tributaries but was missing for some smaller streams. This data was collected from the U.S. Forest Service, Plum Creek Timber, U.S. Fish and Wildlife Service, from Hatfield and Associates (1981), and Chapman (1981). In addition, the Corps of Engineers took spring wetted width measurements on 40 stream segments in May of this year. Stream gradient has been calculated from U.S. Geological Survey topographic maps in 1% increments for all accessible stream miles.

Methods that were used. Following the Corps' Ecosystem Restoration Authority, and our stated project-goal of natural production of the historical anadromous fish runs above Howard Hanson Dam -- to estimate the natural production of the upper Green River:

- We used habitat-based methods to estimate natural smolt production of coho, steelhead, cutthroat, fall and spring chinook.
- Smolt production estimates were appropriate for our study because of 1) the lack of available data for use in other methods, and 2) the applicability of smolt production to assess survival of most restoration alternatives above HHD, fish passage and habitat restoration.
- We used different methodologies (density estimate by period and habitat-type) appropriate for each species and race of salmon.
- We assumed for all available habitat information that: 1) there is no difference in overall quality (for example, pre-dam conditions vs. current); 2) natural anadromous barrier locations are reliable; and 3) the distribution of spring and fall chinook in the White River would be similar (by percent gradient) in the Green River.

Lastly, we developed adult returns using 1) the most recent, available literature, and 2) assumptions on ocean survival, harvest and in-river survival. The information on adult returns is used in the evaluation of the fish passage facility alternatives and is presented in *Section 8, Fish Mitigation and Restoration Plan, and the Economics Appendix.*

Habitat-Based Smolt and Adult Escapement Methodologies. Coho Production Estimates. We used the method Baranski (1989) developed for estimating smolt production in Puget Sound streams which uses gradient, low flow channel width, and channel length. Density estimates applied vary by stream width and gradient: tributaries less than 5.5 m width, gradients <1%=0.11 smolts/m^2; 1-2%=0.23; 2-3%=0.11. Hunter and Gerke (1992) assume that gradients >3% do not produce coho, we followed this same assumption.

Beechie et al. (1994) developed a well-researched and documented method of estimating smolt production for the Skagit River. It incorporates potential production estimates (smolt density/unit area) for different temporal and spatial scales: 1) winter or summer; 2) by habitat unit type -- pool, riffle, side channel, and distributary slough; 3) mainstem or tributary; and 4) pond or lake. We used winter densities in estimating the smolt production potential for the two sloughs considered for habitat restoration and lake density to estimate production in the reservoir.

Chapman (1981) used a value of 0.42 smolts/yd^2 times the weighted useable habitat area in the upper Green to calculate coho smolt production. His habitat values may underestimate the total available area. This is also the density estimate used by the WDFW to estimate smolt production throughout western Washington (Zillges 1978).

<u>Steelhead Production Estimates.</u> Cropp (1994) used the Maximum Sustained Harvest Methodology to estimate smolt production in the upper Green River, for selected reaches of from RM 68-89 (2.44-4.31 parr/100m^2), and for tributaries (7.17 parr/100m^2). He also estimated adult escapement. Similar to Cropp, we used MSH to estimate parr density at low flow (using values from Gibbons et al. 1985, and assuming higher production for the mainstem Green), and adult escapement. Unlike Cropp, we used more streams, and included gradients up to 5%. We also used parr to smolt survival estimates of 50%, the same values used by Hosey and Associates (1988) for the Elwha and by Wunderlich and Toal (1992) for HHD. The parr to smolt survival was necessary to assess survival through the project.

Chapman (1981) used a value of 0.022 smolts/yd^2 times the weighted useable habitat area in the upper Green to calculate steelhead smolt production. His habitat values may underestimate the total available area.

<u>Fall Chinook Salmon.</u> There is no currently accepted habitat based method to calculate fall chinook production in the state of Washington (Seiler 1994). For the lower Green River, WDFW uses previous escapement record from the 1970's (5750 adults). We calculated adults/mile (140/mile) using distribution records from the SASSI and Grette and Salo (1985) to calculate escapement for the upper Green. I also used values reported from the Big Qualicum and the Elwha River (120/mile). We finally used the 120 adults/mile to estimate minimum escapement for the upper Green.

Wunderlich and Toal (1992) used smolt density (0.14 smolt/m2 low flow, and 1.4 smolts/m2 spring flow) x useable habitat area for the 1141-1177 ft inundation zone in estimating potential mitigation requirements. We used these values in combination with spring wetted area and low-flow wetted area to estimate fall chinook smolt density.

Since historical distribution data is not available for the upper Green, we defined accessible area as tributaries greater than 18 ft low-flow width and gradients of 1% or less. The 18 ft width for streams follows the definition of large tributaries used in the WDFW coho methodology. The 1% gradient or less follows where fall chinook are found in the White River (reported in the SASSI and measured off USGS maps).

Spring Chinook Salmon. Warren (1994) has completed a literature review of production methods for spring chinook and reported on a number of means to calculate smolt and adult number. We used this reference for estimates of smolt density (0.361 smolt/yd2) and adult escapement (40 adults/mile). Note: currently, since there no viable source of stock to re-introduce spring chinook to the Green River, spring chinook smolt and adult returns are estimated but are not included in the final outputs for incremental analysis of the fish passage facility.

In non-glacial rivers (like the Green), both Warren (1994) and Hunter and Gerke (1992) state that rearing habitat limits spring chinook production in most rivers, not spawning habitat. Thus, rearing habitat production estimates may be more appropriate for spring chinook. Since historical distribution data is not available for the upper Green, we defined accessible area as tributaries greater than 18 ft low-flow width and gradients of 3% or less. The 18 ft width for streams follows the definition of large tributaries used in the WDFW coho methodology. The 3% gradient or less follows where spring chinook are found in the White River (reported in the SASSI and measured off USGS maps).

Barrier Information and Total Accessible Stream Miles in the upper Green River. The only published source of information available on **natural barriers** in the upper Green River comes from the WRIA (1975), Duwamish Basin, Water Resource Inventory Area 09, from the Washington Department of Fisheries. The inventory includes a listing of five possible barriers, both impassable and passable: 1) falls; 2) cascades; 3) beaver dams; 4) log jams; and 5) dams.

We obtained the stream blockage type and blockage location for the upper Green in GIS format from the Washington Rivers Information System (WARIS) database, Washington Department of Fish and Wildlife (1:100,000 scale). This data was incomplete for the upper Green, and we had to do some major revisions using the original WRIA (1975) maps. Figure 1 shows our revised GIS with streams and anadromous fish barriers for the Upper Green River. Using stream segments in the GIS, and only identified impassable barriers (natural) for anadromous fish, we estimated the length of inaccessible and accessible miles of stream habitat for all identified tributaries in the database.

There is limited data available on natural and artificial barriers from U.S. Forest Service stream surveys, Plum Creek Timber, and Wunderlich and Toal (1992). There was no rating of any of these barriers for passage of adult or juvenile anadromous fish, and we have not included these barriers in our total accessible miles database. The Habitat Division of the Muckleshoot Indian Tribe provided us with their initial measurements of accessible miles (from the WRIA (1975) for anadromous fish in the upper Green. Comparing their estimates with ours, there was general agreement on stream length.

With any of the barrier information, there has been no recent review of the reliability of information, and whether the identified barrier is passable for: 1) all anadromous species historically present in the basin; 2) all life stages; 3) all seasons; 4) is still present. Hunter and Gerke (1992) discussed the reliability of barrier information in the upper Cowlitz River, and noted that their information source was "poorer than that available for anadromous streams elsewhere in the state." This was in light of several reported (original) sources of barrier information throughout the basin for a period of 50 years. With this in mind, we would consider the quality of information for the upper Green to be suspect, but the only source available at this time.

Habitat Data and Information for the upper Green River. The only published source of information available on total stream miles, accessible miles, and watershed area for the upper Green River comes in GIS format from the Washington Rivers Information System (WARIS) database, Washington Department of Fish and Wildlife (1:100,000 scale). Details were discussed under the Barrier Section. Additional sources of information were:

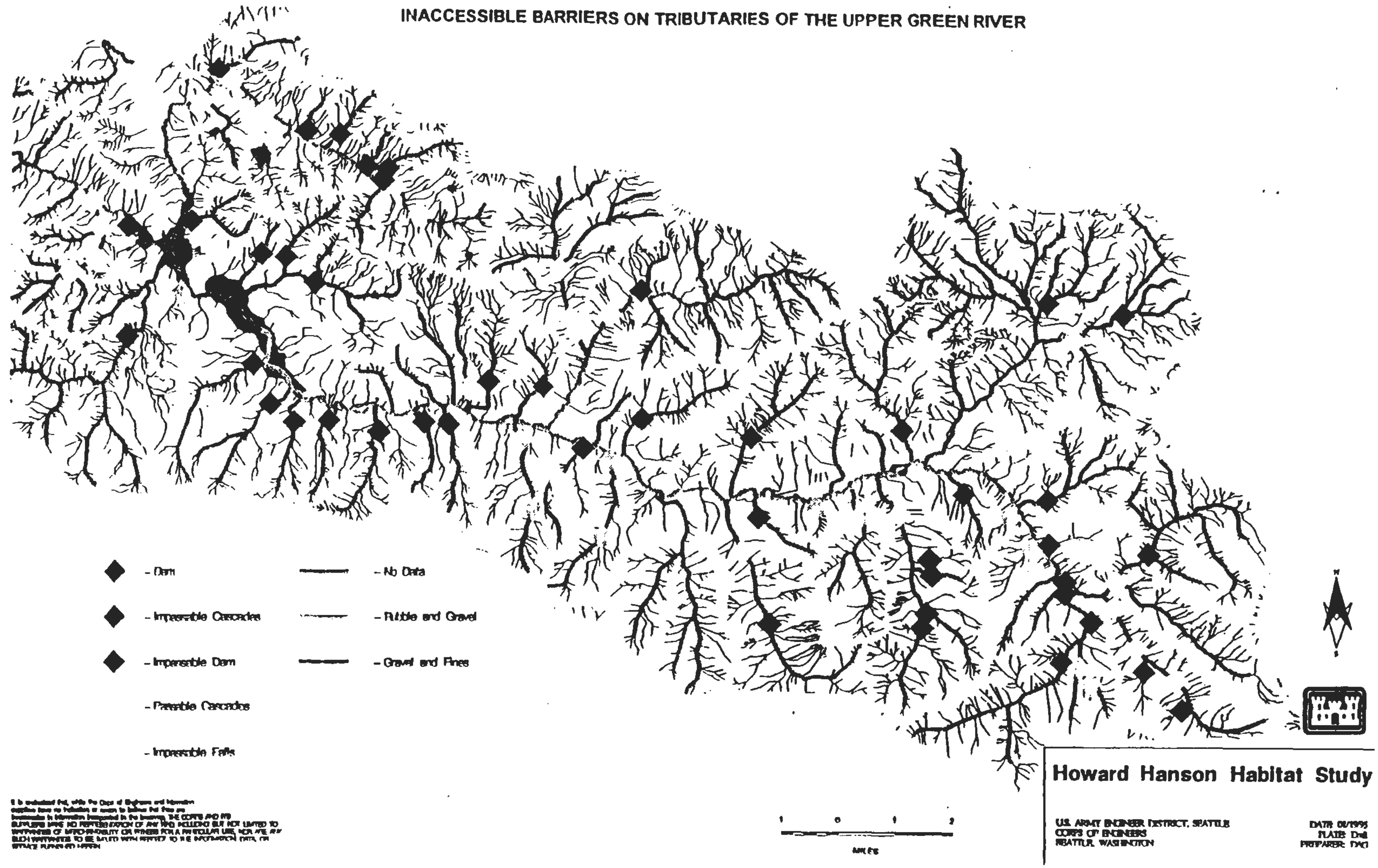


FIGURE 1. PASSABLE AND IMPASSABLE ANADROMOUS FISH BARRIERS IN THE HEADWATERS WATERSHED OF THE GREEN RIVER BASIN.

- Plum Creek Timber Preliminary Watershed Analysis of the Middle Green, Lester Administration Unit and bull trout surveys of the Green River above Lester. Bull trout surveys included 12 100 m reference sites within 10 km segments (Chapman and Associates Methodology) on several streams: Intake Creek, Sawmill Creek, Bald Creek, Tacoma Creek, Pioneer Creek, Twin Camp Creek, upper Green River above Sunday Creek. Stream and riparian surveys were also conducted for the watershed assessment by the Muckleshoot Tribe for Plum Creek Timber on McCain Creek, Friday Creek, Morgan Creek, Bald Creek, Champion Creek, Rock Creek, Lester Creek, Sawmill Creek, and the upper Green. The watershed analysis stream summary data will be more complete on each of the streams than the bull trout survey data.
- Forest Service Stream Surveys were completed in the upper Green River using Hankin and Reeves (1988) methodology accepted for use by Region 6. The surveys were systematic surveys of the entire stream, unlike many of the following habitat references. Smolt production estimates were not calculated from these surveys. Streams surveyed were: Tacoma Creek, Twin Camps Creek, Sawmill Creek, Sunday Creek, East Creek, Snow Creek, and the upper 6 miles of the Green River, from the confluence with Sunday Creek to the headwaters.

Fish and Wildlife Service (Wunderlich and Toal 1992) completed stream surveys of the 10 tributaries draining into Howard Hanson Reservoir from elevation 1141 ft (baseline normal year full pool) to 1177 ft (expected additional pool). Discussed in *Section 3* with the complete report available as part of *Appendix Part F2, Wildlife.* These surveys were completed in the lower sections of most streams and may not be representative of the entire stream length. They also estimated smolt production using several available literature sources, as well as potential steelhead spawning. The streams they surveyed were: 1) Large tributaries -- mainstem Green, North Fork Green (09-0163), Page Creek (tributary of the North Fork), Charley Creek (09-0181), Gale Creek (09-0196); 2) Small tributaries -- Cottonwood Creek (09-0197), Piling Creek, Unnamed Creeks, 09-0202, 09-0212, 09-0215.

- <u>Tom Cropp (1994)</u> presented data on total habitat available on the mainstem Green and larger tributaries for wild steelhead escapement. Data for larger tributaries was noted that steelhead use and average widths need verification. Data on stream length and width were presented for: 1) mainstem Green, RM 68.0-75.2, and 2) lower reaches of major tributaries -- Tacoma Creek (1.0 miles), Twin Camp Creek (1.0), Sunday Creek (3.5), Friday Creek (0.8), and Smay Creek (1.8).
- <u>Smith and Hatfield (1981)</u> reported valley width, channel width, wetted width, depth, velocity, slope, pool/riffle ratio for 11 stream reaches above HHD. This data was collected during October only at selected points on: 1) mainstem Green, RM , and 2) for larger tributaries -- Sunday Creek (09-0277), Snow Creek (09-0281), and Tacoma Creek (09-0326).
- <u>Chapman (1981)</u> estimated total available habitat at low flow in August for a number of tributaries in the upper Green River basin (habitat totals were distributed to you in Enclosure 1 of the 23 February, 1995 memo). Total weighted useable habitat available and smolt production was reported for: 1) mainstem Green, RM 66-88; 2)

named tributaries -- North Fork Green (09-0163), Charley Creek (09-0181), Gale Creek (09-0196), Smay Creek (09-0216), West Fork of Smay Creek (09-0217), Champion Creek (09-0242), Rock Creek (09-0245), McCain Creek (09-0268), Sawmill Creek (09-0257), Friday Creek (09-0269), Intake Creek (09-0308), Tacoma Creek (09-0326), Sunday Creek (09-0277), Snow Creek (09-0281); and 3) Unnamed -- 09-0215, 09-0233, 09-0234, 09-0243, 09-0244, 09-0271, 09-0288.

2A.3 RESULTS

2A.3.1 Habitat database of all stream segments in the upper Green River with gradients of 10% or less

Appendix Table A-2 has all unmeasured streams removed from the database at the end of Section 2A.. This database includes all stream segments of 10% or less gradient in the upper Green River above Howard Hanson Dam. This database was further refined for use in estimating total habitat available for each anadromous species. The appendix tables following A-2 show the final stream area available, by species (Tables B1-B3 coho, C1-C3 steelhead, D1-D3 fall chinook, and E1-E3 spring chinook).

Accessible segment lengths of each stream were measured off the Washington Department of Fish and Wildlife Stream Catalog. The Corps used the Department of Natural Resources hydrographic layer as the base layer (1:24,000) and overlaid the WDFW Anadromous Fish Layer over this. Segments were measured from the confluence to the first identified inaccessible barrier (see Figure 1). Streams were broken into segments of varying gradients from 0-10% (in 1% increments). Gradient measurements were made from U.S. Geological Survey topographic maps. Low flow width data for tributaries and the mainstem Green were collected from Forest Service stream surveys of 1991-1992, U.S. Fish and Wildlife surveys in 1991, Plum Creek Timber surveys of 1993-1994, and from Chapman 1981 and Hatfield 1981.

Spring wetted width data was collected from U.S. Fish and Wildlife stream surveys of May, 1991 and from U.S. Army Corps of Engineers width measurements from May of 1995. Please note that unmeasured streams were removed from this table, these represent streams with accessible area but with no actual width measurements. These streams are listed in Appendix Table A-1 and show potential anadromous habitat that has not been surveyed. However, these stream segments are removed from following appendix tables used in estimated total habitat area by species. The low flow width (9.7 ft) and spring width (14.4 ft) are the average of all measured accessible tributaries.

Habitat Summary. Table 2 and Figure 2 provide a summary of accessible stream habitat by percent gradient. There are 267 miles of stream habitat in the Headwaters watershed. Of this number, 106 miles is considered accessible with 65.8 miles found at gradients of 5% or less. Low-flow area is heavily weighted to lower gradient sections, for stream segments of 0-10% gradient, 79% of the 13 million sq ft of total habitat is at gradients of 2% or less. Using measures of spring wetted width, April or May, can increase the estimate of total habitat by 50% or more. Comparison of Headwaters low-flow wetted area for gradients 5% or less (range utilized by steelhead) to a similar sized watershed, the Elwha above Glines Canyon Dam (246 sq miles), shows the Headwaters has an almost equal total area 1.38 million sq yds vs 1.31 million above Glines Canyon (Hosey and Associates 1988).

TABLE 2. TOTAL ACCESSIBLE STREAM LENGTH AND LOW-FLOW WETTED AREA BY PERCENT GRADIENT FOR THE HEADWATERS WATERSHED OF THE GREEN RIVER.

Gradient	Accessible Length	Accessible Miles of Measured Streams	Low Flow Area (ft2)	Percent of Total Low Flow Area (<10%)	Accessible Miles of Missing Stream Widths
0.0-0.01	58500	11.1	4086300	30.7%	0.0
1%	71100	13.5	4081330	30.7%	0.0
2%	97750	18.5	2331630	17.5%	0.5
3%	31800	6.0	430110	3.2%	0.3
4%	56820	10.8	966190	7.3%	0.6
5%	31100	5.9	559520	4.2%	1.0
6%	6900	1.3	95140	0.7%	0.7
7%	13500	2.6	153430	1.2%	0.1
8%	11970	2.3	161650	1.2%	0.4
9%	12200	2.3	241090	1.8%	0.0
10%	17300	3.3	207160	1.6%	1.1
Subtotal	408940	77.5	13313550	100.0%	4.7
Missing Stream Widths		4.7			
10-18%	126050	23.9	761595 or 1439105[a]		
Total Accessible Miles		106.0			
Inaccessible Miles		161.0			

a. Estimate for unmeasured streams can vary by 2x or more depending on how estimate is calculated.

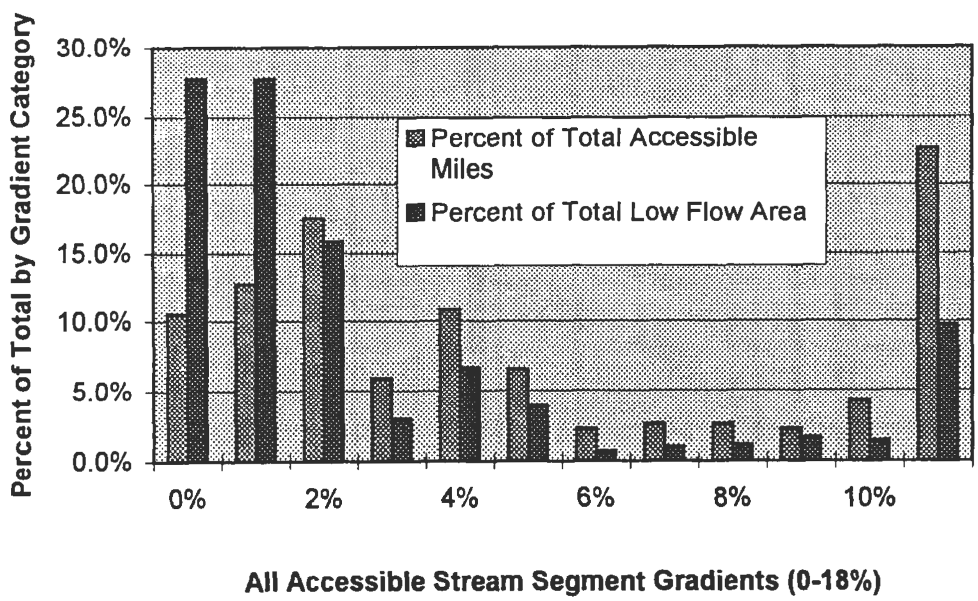


FIGURE 2. SUMMARY OF ACCESSIBLE HABITAT GRADIENT CATEGORY FOR ALL STREAM SEGMENTS FOR THE HEADWATERS WATERSHED.

2A.3.2 Smolt Production Estimates for the Headwaters Green River

Section 2A.2 described how we conducted our smolt production estimates using stream survey data and density estimates of smolts unit/area. This Section, 2A.3.2., contains the results of smolt production estimates for the Headwaters watershed area above Howard Hanson Dam. Calculation of the estimates and assumptions used in calculation are provided in Tables 2 through 21 at the end of the report. Literature references and assumptions are listed in footnotes below each table. I also estimated smolt production for coho above and below the upstream collector, the stream area is listed in the Appendix Tables. This production estimate was used for input in Fish Passage alternatives 8 and 9 (upstream collector, otherwise labeled alternatives B1 and B2, discussed in *Section 8, Fish Mitigation and Restoration Plan.* A similar method was used for smolt production estimates above and below the upstream collector for the other salmon stocks. Actual calculation of the smolt production above the proposed upstream collector are available upon request.

Coho Smolt Production Estimates. All smolt estimates will be presented together (Tables 2 to 6). All habitat based production estimates are in smolts per sq meter, therefore Appendix tables were transformed from sq ft to sq meters. The methods used were: 1) Baranski (1989); 2) Beechie et al. (1994); and 3) Zillges (1977). Estimates for Baranski (1989) are broken into three production totals, Table 2 for all streams with no inundation (without existing and AWSP), Table 3 for all streams including inundation with existing pool, and Table 4 for all streams with existing and AWSP pool. Table 5 provides an estimate of potential reservoir production using Beechie et al. (1994). Table 6 presents the standard WDFW estimate method (Zillges 1978). Estimate of total production by watershed area, WUA, and unknown method was already listed in Table 1 (Seiler and Neuhauser 1985; Chapman 1981; Gerke 1987). We selected the estimate from Table 4, Baranski for existing and AWSP, for use in evaluating the fish passage facilities. Comparison to the estimate for existing inundation, there is a potential loss of 13,000 smolts from the total AWSP inundation. The results from all the methods are presented below:

Method	Estimate Area	Total Smolts Above HHD
Baranski	No Inundation	194,314
	Existing Pool	175,708
	Existing and AWSP	**161, 705**
Zillges	Existing and AWSP	192,685
Seiler		120,000
Chapman		213,516
Gerke		280,000

Steelhead Smolt Production Estimates. We used the Maximum Sustained Harvest (MSH) methodology to estimate parr and adult escapement. Calculating parr production potential (PPP) is the first step in estimating the overall steelhead production potential of the Headwaters. The data provided in Tables 7 through 11 were stratified by size of stream and gradient zone and the parr density values provided by Gibbons et al. (1985) were applied as required. Parr production estimates were not applied for the reservoir, although other researchers have done so for similar sized reservoir (Hosey and Associates 1988). For inundated stream areas, we used a similar approach to coho with estimates of total smolt production by increments of inundation, from no pool (Table 7), to existing pool (Table 8), to the AWSP (Table 9). Tables 10 and 11 are comparison estimates using parr to smolt survival estimates from long-term monitoring of Snow Creek, Olympic Peninsula, and different estimates of total stream habitat based on gradient (4% and less vs 5% and less). We used the estimate from Table 9 for the Existing and AWSP for evaluation of the fish passage facility alternatives.

Method	Estimate Area	Total Smolts Above HHD
MSH	No Inundation	29,767
	Existing Pool	27,983
	Existing and AWSP	**25,257**
Snow Creek	4% No Inundation	8628
Snow Creek	5% No Inundation	15,220
Chapman		20,079
Cropp		20,998
Gerke		35,000

Chinook Smolt Production Estimates. A predominately sub-yearling outmigration pattern is assumed for fall chinook planted in the Headwaters, although 3% or more of outmigrants have been documented as yearling (Dilley and Wunderlich 1993). Spring chinook are presumed to follow a similar outmigration pattern, 90% as underyearling, they will be presented with fall chinook totals. Tables 12 through 17 present assumptions and estimates for fall chinook production and Tables 18 through 20 provide estimates for spring chinook. We took the estimate from Table 17 for fall chinook and Table 20 for spring chinook to use in evaluation of the fish passage facility alternatives.

Method	Estimate Area	Total Smolts Above HHD
Fall Chinook		
Graybill	No Inundation	563,527
	No Inundation and Proportioned-Outmigration	518,327
Wunderlich and Toal	No Inundation	1,230,523
	Existing Pool	1,050,524
	Existing and AWSP	
Chapman[a]		128,644
Gerke		800,600
Spring Chinook		
Warren	No Inundation	348,495
	Existing	306,483
	Existing and AWSP	**279,971**

a. Includes both fall and spring chinook.

Escapement Goal Estimates for Coho Salmon. The number of adults required to fully see the Headwaters watershed (161,700 smolts) under alternate scenarios of (Baranski estimate and Zillges) is provided below (a 50:50 sex ratio is assumed in both cases) (Table 21). The estimated escapement goal (total number of spawning adults) selected for the fish passage evaluation, 6468 adults, is near the historical average from the original fish trap data.

TABLE 21. REQUIRED ESCAPEMENTS FOR COHO SALMON (ADULTS REQUIRED FOR FULL SEEDING) WITH PROJECT (1177 POOL) CONDITION (ASSUMING 100% DAM PASSAGE) USING TWO SMOLT PRODUCTION ESTIMATES. THE ESTIMATE OF 6468 ADULTS WAS USED FOR FISH PASSAGE INCREMENTAL ANALYSES

Watershed Condition	Methodology	Escapement Equation	Smolt Methodology	Smolt Estimate	Required Escapement
With Project	Hosey and Associates	(Smolt/50)*2.0		161700	**6468**
		(Smolt/50)*2.0		192685	7707

a. The Hosey method is a deviation from the normal WDFW method (Zillges 1977) that assumes 100 smolts/female. Data from Snow Creek (43 smolts/female) and from Chehalis River (48 smolts/female, Seiler 1989) suggests using 50 smolts/female is a better number.
b. The smolt production numbers are from the Baranski (1989) method (161700) and the Zillges (1977) method (192685).

Coho Escapement Estimates

Method	**Estimate Area**	**Escapement Goal Above HHD**
Hosey/Baranski	**Existing and AWSP**	**6,468**
Zillges	Existing and AWSP	7,707
Chapman		4,270
Fish Trap (Grette and Salo)	No Inundation	5,600
Gerke	Total Adult Return Not Escapement	37,240

Escapement Goal Estimates for Steelhead. Escapement goals under an MSH management scenario were calculated directly from the PPP estimates listed in Table 22 (provided from Table 9, smolt production). The MSH escapement goal is thus 1339 adults, which was used in the fish passage evaluation. The three year historical average from 1911-1914 was 1600 adults.

TABLE 22. HEADWATERS GREEN RIVER STEELHEAD MAXIMUM SUSTAINED HARVEST ESCAPEMENT GOALS WITH THE AWSP. ESCAPEMENT IS 1339 AND RUN SIZE IS 3128.

Estimate	Equation	Parr Production Potential	Product
MSH Escapement	PPP * 0.0265	50514	1339
MSH Run Size	R1=S/(((12.2355*S)/PPP)+0.3857)		1886
	R2=S/(((12.2355*S)/PPP)+0.2766)		4371
	AVERAGE OF TWO ESTIMATES	**TOTAL MSH RUN SIZE**	**3128**

a. Parr number is from Table 9. Steelhead parr and smolt production.

Escapement Goal Estimates for Chinook. Escapement goals for fall chinook using an estimate of adults per/mile from Olympic Peninsula streams is presented under Table 23. Alternates fall chinook estimates are provided in Tables 24 and 26: using adults/mile from the lower Green (Table 24) and a cross-check on smolt production estimate using various egg-fry survival estimates (Table 26). Spring chinook estimates using adults/mile are provided in Table 27. Estimated escapement goal for fall chinook, 2277, and spring chinook, 1342, were used in the fish passage evaluation. These estimates are far and above the historical estimates from 1911-1914 of 150-300 spring adults. The historical average could be an under-representation due to poor attraction to the trap, harvest, and lower river barriers (Grette and Salo 1985). Fall chinook stocks have been introduced to the Headwaters since 1982, from lower Green River stock and the only available native spring chinook stock from the White River are currently severely depressed. Fall chinook have also been introduced to headwater areas of the next basin, the White River.

TABLE 23. FALL CHINOOK ESCAPEMENT ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING ADULT SPAWNING CAPACITY ESTIMATES FROM OLYMPIC PENINSULA STREAMS (WDFW 1981) AND FOR ELWHA FROM HOSEY AND ASSOCIATES (1988) WITH PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1177 FT ELEVATION.

Watershed Location	Accessible Length (miles)	Adults/Mile	Correction Factor	Escapement Goal
Above 1177 ft Zone	18.2	120		2184
1070-1141 ft Zone	4.5	120	0.1	54
1141-1177 ft Zone	1.3	120	0.25	39
			Total Escapement	2277

a. WDFW (1981) (*In* Hosey) and Hosey and Associates (1988) estimated number of adults/mile (120).
b. Table 23 shows estimate if adults/mile from the lower Green is used (140/mile).

TABLE 27. SPRING CHINOOK ESCAPEMENT ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING ADULT SPAWNING CAPACITY ESTIMATES FROM OLYMPIC PENINSULA STREAMS FROM HOSEY AND ASSOCIATES (1988) WITH PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1177 FT ELEVATION

Watershed Area	Accessible Length (miles)	Adults/Mile	Correction Factor	Adult Escapement Goal
Above 1177 ft Zone	32	40		1296
1070-1141 ft Zone	6	40	0.1	22
1141-1177 ft Zone	2	40	0.25	24
			Total Escapement	1342

a. The 40 adults/mile is the same value used by Warren (1994) in estimating escapement requirements for the White River.

Chinook Escapement Estimates

Method	Estimate Area	Escapement Goal Above HHD
Fall Chinook		
Adults/Mile	**Existing and AWSP**	**2,277**
Chapman[a]		1,286
Gerke	Not Escapement	
	Total Return	8,006
Spring Chinook		
Adults/Mile	**Existing and AWSP**	**1,342**
Fish Trap (Grette and Salo)	No Inundation	150-300

a. Includes fall and spring chinook.

2A.3.3 Fish Passage Facility Evaluation

The smolt production and adult escapement goal estimates for coho, steelhead, and fall chinook salmon were used to evaluate 9 distinct fish passage alternatives. Spring chinook were used in the model but were not included in the final accounting of total run size and adult escapement for selection of the preferred alternative. NOTE: Currently, since there no viable source of stock to re-introduce spring chinook to the Green River, spring chinook smolt and adult returns are estimated but are not included in the final outputs for incremental analysis of the fish passage facility. Discussion of the passage model, with incremental and total adult escapements, used for evaluation of the alternatives is presented in *Section 8, Fish Mitigation and Restoration Plan and the Economics Appendix.*

Selected AWSP Smolt Production and Adult Escapement Estimates

	Smolts	Adult Escapement
Coho	161,705	6468
Steelhead	25,257	1339
Fall Chinook	890,000	2277
Spring Chinook	279,971	1342

In comparison to the established watershed areas below the dam, the potential production of the Headwaters is exceptional. These estimates were based on a measurement of existing available stream habitat (post-dam quantity, with no assumption of habitat quality): estimates for coho and steelhead used low-flow conditions, fall chinook used an average estimate incorporating spring and summer flow conditions. Successful fish passage through the dam, in combination with the planned fish ladder/trap and haul adult passage facility at the Diversion Dam, could lead to realization of the greatest aquatic restoration benefit for the entire Green River Basin, reconnection of the Headwaters to the lower river (Table 28).

TABLE 28. GENERAL WATERSHED FACTS FOR THE GREEN RIVER BASIN, KING COUNTY, WASHINGTON.

	Lower/Middle Green	**Headwaters Green**
Watershed Area	263 sq miles	220 sq miles
Accessible Stream Length	125 miles	106 miles*
Native Anadromous Species	Coho, Chum, Chinook, Steelhead[a]	Steelhead, Coho Chinook
Natural Production (Escapement)	11,800-15,800	9,900 (potential)

*A small sockeye salmon run is found below the Diversion Dam.

The Headwaters watershed is more productive than WDFW trapping indicates (35,000 coho), Seiler and Neuhauser (1985) estimated that it should produce 120,000 smolts based on area. However, there are several factors explaining the low production of the hatchery planted coho: fry planted at very small size lead to low survival (700-1400/lb); 2) fry were planted early in spring (mid-March to Mid-April) therefore -- cold temperatures and lack of food; 3) fry distribution is limited by road access; and 4) hatchery stocks used may not be optimal for natural rearing. They recommend that "any successful, cost-effective natural production from the upper (Headwaters) Green River should be based on natural spawning."

2A.4 LITERATURE CITED OR REFERENCES USED TO DEVELOP ANALYSIS

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Chapman, D.W. 1981. Pristine production of anadromous salmonids -- Green River. Final Report (Contract POOC 14206454) to U.S. Department of the Interior, Bureau of Indian Affairs, Portland, Oregon.

Cropp, T. 1994. Green River system wild steelhead escapement requirements. Unpublished data presented at Tacoma Diversion Dam fish passage conceptual meeting, July 1994.

Gaia Northwest. 1993. Cowlitz Falls project fisheries management plan: anadromous reintroduction program, December 17, 1993. Technical report prepared for Bonneville Power Administration.

Gerke, B. 1987. Counteroffer regarding mitigation for fishery losses due to the Green River Diversion Plan. Washington Department of Fisheries Draft Letter.

Grette, G, and E. Salo. 1986. The status of anadromous fishes of the Green River/Duwamish River system. Evans Hamilton, Inc. Report to the Seattle District, U.S. Army Corps of Engineers.

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Hosey and Associates. 1988. Elwha Project, FERC No. 2683, Glines Project, FERC No. 588, Appendix 6: Fish production potential. Draft response to request for additional information of May 28, 1987.

Hunter, M.A. and B. Gerke. 1992. Identification of anadromous barriers and a review of the productivity estimates for the upper Cowlitz River basin. Draft report from the Washington Dept. of Fisheries, October 1992.

Johnson, R. 1986. Assessment of the Skagit River system's coho rearing potential. Washington Department of Fisheries Technical Report 95.

Natural Resource Consultants. 1991. Review of the draft environmental impact statement, Glines Canyon, (FERC No. 588) and Elwha (FERC No. 2683) Hydroelectric Projects, Washington. *In:* Comments on FERC's DEIS of February, 1991, Elwha Project and Glines Canyon Project, prepared by Harza Northwest, Inc.

Pentec Environmental. 1993. Sunday Creek Basin Fish Habitat Improvement Project. Conceptual Plan Project 139-001, Prepared for Mt. Baker-Snoqualmie National Forest, Mountlake Terrace, Washington.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. U.S. Forest Service General Technical Report PNW-245.

Reeves, G.H., J.D. Hall, T.D. Roelofs, T.L. Hickman, and C.O. Baker. 1991. Responses of salmonids to habitat change. American Fisheries Society Special Publication 19:483-518.

Seiler, D. 1994. Conversation with F. Goetz on 20 October, 1994, on coho smolt production.

Seiler, D. and S. Neuhauser. 1985. Evaluation of downstream passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984, Howard Hanson Dam, 1984. Progress Report No. 235. Washington Department of Fisheries.

Smith, G.M. and C.T. Hatfield. 1981. An assessment of fish resource management options in relation to the development of a comprehensive water management plan for the Green River, Washington state (Phase I). Report submitted to Charles Howard and Associates by Hatfield Consultants Limited, West Vancouver, British Columbia.

Warren, B. 1994. Estimated escapement goal for White River spring chinook. Puyallup Indian Tribe Technical Report.

Wunderlich, R. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, pre-season run size prediction and in-season run assessment. Washington Department of Fisheries Technical Report 28.

APPENDIX A-1 SMOLT PRODUCTION ESTIMATES FOR COHO, STEELHEAD, AND CHINOOK, TABLES 2-20, ADDITIONAL ADULT ESCAPEMENT ESTIMATES, TABLES 24-26.

TABLE 2. COHO SMOLT PRODUCTION POTENTIAL FOR STREAMS IN THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM USING THE BARANSKI (1989) METHOD. FOR STREAMS WITH GRADIENT OF 3% OR LESS AND ASSUMING FULL PRODUCTION FOR INUNDATION AREAS.

Stream Gradient	Density Estimate (smolt/m2)	Low Flow Surface Area (m2)	Total Smolt Number
Mainstem River (RM 65.5-83)	0.18	688370	123907
0.01-0.02	0.23	287011	66013
0.03	0.11	39957	4395
Total		1015338	194314

a. Mainstem smolt value is from Beechie et al. (1994). We felt the mainstem value reported in Baranski (1989) was inappropriate for the upper Green River.
b. Smolt values for tributaries to the upper Green River and the mainstem Green (RM 83-88) are from Baranski (1989).
c. No assumption is made for decreased production caused by inundation.
d. Stream gradients of 3% or less were used, this follows the assumption of Gerke and Hunter (1992) for Cowlitz production estimates.

TABLE 3. COHO SMOLT PRODUCTION POTENTIAL FOR STREAMS IN THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM USING THE BARANSKI (1989) METHOD. FOR STREAMS WITH GRADIENT OF 3% OR LESS, ASSUMING PARTIAL PRODUCTION (25%) FOR INUNDATED STREAMS UP TO 1141 FT, AND PRODUCTION IN THE RESERVOIR POOL ITSELF.

Stream Gradient	Density Estimate (smolt/m2)	Low Flow Surface Area (m2)	Correction Factor	Total Smolt Number
Mainstem River (RM 68.5-83)	0.18	559657		100738
0.01-0.02	0.23	266224		61232
0.03	0.11	32934		3623
			Smolt Subtotal	165593
Mainstem River (RM 65.5-68.5)	0.18	128713	0.25	5792
0.01-0.02	0.23	20787	0.25	1195
0.03	0.11	7023	0.25	193
			Smolt Subtotal	7180
Reservoir Pool	0.0025	1174000		2935
			Smolt Total	175708

a. Mainstem smolt value is from Beechie et al. (1994). We felt the mainstem value reported in Baranski (1989) was inappropriate for the upper Green River.
b. Smolt values for tributaries to the upper Green River and the mainstem Green (RM 83-88) are from Baranski (1989).
c. Partial production (25%) is assumed for inundation areas up to elevation 1141 ft.
d. Production for the reservoir area uses smolt density for lakes from Beechie et al. (1994) and surface area in m2 from Wunderlich and Toal (1992).

TABLE 4. COHO SMOLT PRODUCTION POTENTIAL FOR STREAMS IN THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM USING THE BARANSKI (1989) METHOD. FOR STREAMS WITH GRADIENT OF 3% OR LESS, ASSUMING PARTIAL PRODUCTION (25% AND 10%) FOR STREAMS INUNDATED UP TO 1177 FT AND PRODUCTION IN THE DIFFERENT RESERVOIR POOLS. THIS IS THE PRODUCTION POTENTIAL ESTIMATE USED FOR ASSESSING FISH PASSAGE AND HABITAT RESTORATION PROJECTS.

Stream Gradient	Density Estimate (smolt/m2)	Low Flow Surface Area (m2)	Correction Factor	Total Smolt Number
Mainstem River (RM 70-83)	0.18	507067		91272
0.01-0.02	0.23	251560		57859
0.03	0.11	32141		3536
		790768	Smolt Subtotal	152666
Mainstem River (RM 65.5-68.5)	0.18	128713	0.10	2317
0.01-0.02	0.23	20787	0.10	478
0.03	0.11	7023	0.10	77
Reservoir Pool (1105)	0.0025	1174000		2935
			Smolt Subtotal	5807
Mainstem River (RM 68.5-70)	0.18	52591	0.25	2367
0.01-0.02	0.23	14663	0.25	843
0.03	0.11	793	0.25	22
Reservoir Pool (1123)	0.0025	729000		1823
			Smolt Subtotal	3232
			Smolt Total	161705

a. Mainstem smolt value is from Beechie et al. (1994). We felt the mainstem value reported in Baranski (1989) was inappropriate for the upper Green River.
b. Smolt values for tributaries to the upper Green River and the mainstem Green (RM 83-88) are from Baranski (1989).
c. Partial production is assumed for areas inundated with additional pool (25% for newly inundated areas and 10% for previously inundated areas).
d. Previously inundated areas have a lower production value because they are inundated for a longer period of time with the additional pool.
e. Production from the reservoir is estimated using smolt density/hectare from Beechie et al. (1994) and surface areas for avg. pool height is reported for current pool (using area at avg. elevation 1105 ft) and additional pool increment (additional area from 1105 to 1123).

TABLE 5. COHO SMOLT PRODUCTION POTENTIAL FOR HOWARD HANSON DAM FOR THE CURRENT POOL AND THE ADDITIONAL STORAGE POOL USING DENSITY ESTIMATES/HECTARE FROM BEECHIE ET AL. (1994).

Pool Level	Density Estimate (smolt/hectare)	Average Surface Area (hectare	Total Smolt Number
Current Storage Pool (using avg. elevation 1105 ft)	25	117.4	2935
Addition Pool (using avg. elevation 1123 ft)	25	190.3	4758
		Incremental Increase	1823

a. Density estimate for smolts/hectare for lakes is from Mainstem smolt value is from Beechie et al. 1994.
b. Surface acres is from Wunderlich and Toal (1992). The average surface acres for each pool condition is used because of the extreme fluctuation in lake level
c. Incremental increase is the additional smolt production potential with the increase in pool area from the current pool to the 1177 ft pool.

TABLE 6. COHO POTENTIAL PRODUCTION ESTIMATES FOR SMOLTS USING ZILLGES (1977) METHODOLOGY FOR AREA OF MAINSTEM AND SMALL TRIBUTARIES (USING STREAMS OF 3% OR LESS GRADIENT).

Watershed Location	Stream Type	Stream Length (yds)	Area (sq yds)	Density Factor	Correction Factor	Smolt Production
Total Watershed	Mainstem	77826		2.5 smolts/lineal yd		194565
	Small Tributary		59773	0.42 smolts/sq yd		25105
PRE-DAM CONDITION PRODUCTION ESTIMATE					TOTAL SMOLTS	**219670**
Above the inundation zone	Mainstem	56953		2.5 smolts/lineal yd		142383
	Small Tributary		57207	0.42 smolts/sq yd		24027
					SMOLT SUBTOTAL	**166409**
1070-1141 ft elevation	Mainstem	8833		2.5 smolts/lineal yd	0.1	2208
	Small Tributary		1617	0.42 smolts/sq yd	0.1	68
	Lake Production	7800		1.25 smolts/yd shoreline		9750
					SMOLT SUBTOTAL	**12026**
1141-117 ft elevation	Mainstem	4240		2.5 smolts/lineal yd	0.25	2650
	Small Tributary		949	0.42 smolts/sq yd	0.25	100
	Lake Production	9200		1.25 smolts/yd shoreline		11500
					SMOLT SUBTOTAL	**14250**
WITH PROJECT ESTIMATE					**TOTAL SMOLTS**	**192685**

TABLE 7. POTENTIAL STEELHEAD SMOLT PRODUCTION IN STREAMS OF THE UPPER GREEN RIVER WITH GRADIENT OF 5% OR LESS. INCLUDING PRODUCTION AT 100% OF POTENTIAL FOR INUNDATED TRIBUTARIES IN HOWARD HANSON RESERVOIR.

Stream Type	Parr Density	Low Flow Wetted Area (100 m2)	Potential Parr Production	Parr to Smolt Survival	Smolt Number
Mainstem	4.1	6884	28224	50%	14112
Tributary	6.68	4687	31309	50%	15655
		Potential Parr Production	59534	Total Smolt	29767

a. Using Gibbons et al. (1985) values of parr density for mainstem and tributaries.
b. Using Parr to Smolt Survival estimates from long-term studies (14 yrs) on Snow Creek (Johnson et al. 1992).
c. All stream segments with gradients of 5% or less were included in this production estimate (Gibbons et al. 1985).
d. Includes Production Estimates for HHD Inundation Zone at full production potential, Tables 6 and 7 show reduced production.

TABLE 8. POTENTIAL STEELHEAD SMOLT PRODUCTION IN STREAMS OF THE UPPER GREEN RIVER WITH GRADIENT OF 5% OR LESS. INCLUDING PRODUCTION AT 25% OF POTENTIAL FOR INUNDATED TRIBUTARIES IN HOWARD HANSON RESERVOIR UP TO 1141 FT.

Stream Type	Parr Density	Low Flow Wetted Area (100 m2)	Potential Parr Production	Parr to Smolt Survival	Correction Factor	Smolt Number
Mainstem	4.1	5597	22948	50%		11474
Tributary	6.68	4409	29452	50%		14726
		Potential Parr Production	52400		Smolt Number	26200
Mainstem	4.1	1287	5277	50%	0.25	660
Tributary	6.68	278	1857	50%	0.25	232
		Potential Parr Production	7134		Smolt Number	892
		Total Parr Production	66667	TOTAL SMOLT NO.		27983

a. Using Gibbons et al. (1985) values of parr density for mainstem and tributaries.
b. Using Parr to Smolt Survival estimates from long-term studies (14 yrs) on Snow Creek (Johnson et al. 1992).
c. All stream segments with gradients of 5% or less were included in this production estimate (Gibbons et al. 1985).
d. Subsection includes parr and smolt production from inundated areas (1141), production is estimated at 25% of normal.

TABLE 9. POTENTIAL STEELHEAD SMOLT PRODUCTION IN STREAMS OF THE UPPER GREEN RIVER WITH GRADIENT OF 5% OR LESS. INCLUDING PRODUCTION AT 25% (1177 FT) AND 10% (1141 FT) OF POTENTIAL FOR INUNDATED TRIBUTARIES IN HOWARD HANSON RESERVOIR UP TO 1177 FT. THIS IS THE PRODUCTION POTENTIAL ESTIMATE USED FOR ASSESSING FISH PASSAGE AND HABITAT RESTORATION PROJECTS..........

Stream Type	Parr Density	Low Flow Wetted Area (100 m2)	Potential Parr Production	Parr to Smolt Survival	Correction Factor	Smolt Number
Mainstem	4.1	5071	20791	50%		10396
Tributary	6.68	4213	28143	50%		14071
		Potential Parr Production	48934		Smolt Number	24467
Mainstem	4.1	1287	5277	50%	0.10	264
Tributary	6.68	278	1857	50%	0.10	93
		Potential Parr Production	7134		Smolt Number	357
Mainstem	4.1	526	2157	50%	0.25	270
Tributary	6.68	196	1309	50%	0.25	164
		Potential Parr Production	3466		Smolt Number	433
		Total Parr Production	59534	TOTAL SMOLT NO.		25257

a. Using Gibbons et al. (1985) values of parr density for mainstem and tributaries.
b. Using Parr to Smolt Survival estimates from long-term studies (14 yrs) on Snow Creek (Johnson et al. 1992).
c. All stream segments with gradients of 5% or less were included in this production estimate (Gibbons et al. 1985).
d. Subsections includes parr and smolt production from inundated areas, production is estimated at 25% (1177) and 10% (1141) of normal.

TABLE 10. POTENTIAL PARR PRODUCTION IN STREAMS OF THE UPPER GREEN RIVER WITH GRADIENT OF 4% OR LESS AND POTENTIAL SMOLT NUMBER.

Stream Type	Parr Density	Low Flow Wetted Area (100 m2)	Parr to Smolt Survival	Smolt Number
Mainstem	4.1	6678	16%	4381
Tributary	6.68	3974	16%	4247
			Total Smolt	8628

a. Using Gibbons et al. (1985) values of parr density for mainstem and tributaries.
b. Using Parr to Smolt Survival estimates from mark and recapture studies (4 years) on Snow Creek (Johnson and Cooper 1991).
c. Only stream segments of 4% gradient or less were included in this production estimate.

TABLE 11. POTENTIAL PARR PRODUCTION IN STREAMS OF THE UPPER GREEN RIVER WITH GRADIENT OF 5% OR LESS AND POTENTIAL SMOLT NUMBER.

Stream Type	Parr Density	Low Flow Wetted Area (100 m2)	Potential Parr Production	Parr to Smolt Survival	Smolt Number
Mainstem	4.1	6678	27380	27%	7393
Tributary	6.68	4340	28991	27%	7828
		Potential Parr Production	56371	Total Smolt	15220

a. Using Gibbons et al. (1985) values of parr density for mainstem and tributaries.
b. Using Parr to Smolt Survival estimates from long-term studies (14 yrs) on Snow Creek (Johnson et al. 1992).
c. All stream segments with gradients of 5% or less were included in this production estimate (Gibbons et al. 1985).

TABLE 12. POTENTIAL FALL CHINOOK SMOLT PRODUCTION FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON FOR STREAMS WITH LESS THAN 1% GRADIENT AND STREAM WIDTH GREATER THAN 18 FT AT LOW FLOW AND USING THE MEAN OF THE LOW FLOW AND SPRING FLOW SMOLT DENSITY ESTIMATES.

Stream Type	Density Estimate (smolts/yd2)	Square Yds	Totals
Low Flow Area	0.1	904004	90400
Spring Area	0.6	1577089	946253
		Mean Smolt Estimate	563527

a. The low flow and spring flow estimates give a range of values, from low 90400 smolts to a high of 946253: the mean value is calculated from the low flow and spring flow.
b. Smolt density estimates are from Graybill (1978) for rearing areas in the Skagit River Basin.
c. Stream gradient of 1% or less was selected as a criterion from distribution and gradient data from habitat use in the upper White River system. Fall Chinook are not found in any stream segment greater than 1%.
d. Density estimates were not made for Spring Chinook in streams <1%, this assumes no interaction between the races.
e. Only streams with greater than 18 ft low flow width were used, this is the distinction used between small and large tributaries in calculation of coho smolt density estimates (Baranski 1989).

TABLE 13. POTENTIAL FALL CHINOOK SMOLT PRODUCTION FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM FOR STREAMS WITH LESS THAN 1% GRADIENT AND STREAM WIDTH GREATER THAN 18 FT AT LOW FLOW AND USING THE PROPORTIONED VALUES OF SPRING AND LOW FLOW SMOLT DENSITY.

Outmigration Periods	Smolt Production Estimate	Proportion of Outmigration Period	Total Smolts
May 15-June 10	946253	25%	236563
June 11-July 7	660969	25%	165242
July 8-August 3	375685	25%	93921
August 3-September 1	90400	25%	22600
		Proportioned Smolt Estimate	518327

a. The proportioned smolt production estimate was developed by proportioning the density values over the outmigration period. We used the 106 day outmigration period, proportion it into quarters, 27 days/quarter, as we did with the smolt density estimate. This assumes a 90% decline in survival of presmolts from May 15 to September 1, an amount cited from several sources (Healy 1991). The outmigration period was defined from ATPase samples taken during the 1992 outmigration report (below). The August 3-September 1 period corresponds to the timeframe when low flow widths were measured for most streams. The May 15-June 10 period corresponds to the timeframe when spring flow widths were measured for most streams.

b. Chinook captured below the dam in the scoop trap in 1992 were found with ATPase levels exceeding 25 from May 15-September 1. Peak ATPase levels were found from June 15-August 1 (>45) (Table 3).

c. We will assume this is the outmigration period for fall chinook from Howard Hanson Dam for estimates of smolt production and for assessment of survival through the fish passage alternatives considered for ecosystem restoration.

TABLE 14. MEAN ATPASE VALUES FROM SUBYEARLING CHINOOK SALMON COLLECTED FROM THE SCOOP TRAP BELOW HOWARD HANSON DAM IN 1991 AND 1992.

1991		1992	
Date	ATPase Level	Date	ATPase Level
9-Jul	32.9	28-Feb	6.6
16-Jul	28.1	27-Mar	8.3
23-Jul	30.4	10-Apr	11.4
30-Jul	32.3	8-May	19.8
27-Sep	21.1	22-May	29.3
		9-Jun	37.5
		23-Jun	55.9
		7-Jul	43.3
		21-Jul	43.2
		23-Sep	17.4
		6-Oct	20.9
		22-Oct	15.8
		6-Nov	14

TABLE 15. POTENTIAL FALL CHINOOK SMOLT PRODUCTION FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON FOR STREAMS WITH LESS THAN 1% GRADIENT AND STREAM WIDTH GREATER THAN 18 FT AT LOW FLOW AND USING THE MEAN OF THE LOW FLOW AND SPRING FLOW SMOLT DENSITY ESTIMATES. ASSUMES FULL PRODUCTION.

Stream Type	Density Estimate (smolts/yd2)	Square Yds	Totals
Low Flow Area	0.14	904004	126561
Spring Area	1.4	1577089	2207925
		Mean Smolt Estimate	1230523

a. The low flow and spring flow estimates give a range of values, from a low **126,561** to a high of **2,207,925**: the mean value **(1,230,523)** is calculated from the low flow and spring flow.
b. Smolt density estimates are from Northwest Resource Associates (1991) used by Wunderlich and Toal (1992) in assessing mitigation requirements for the additional pool raise in tributaries of Howard Hanson Dam.
c. Stream gradient of 1% or less was selected as a criterion from distribution and gradient data from habitat use in the upper White River system. Fall Chinook are not found in any stream segment greater than 1%.
d. Density estimates were made for Spring Chinook in streams <1%, this assumes no interaction between the races.
e. Only streams with greater than 18 ft low flow width were used, this is the distinction used between small and large tributaries in calculation of coho smolt density estimates (Baranski 1989).
f. This is the full production estimate for the upper Green River from the confluence of the North Fork upstream.

TABLE 16. POTENTIAL FALL CHINOOK SMOLT PRODUCTION FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON FOR STREAMS WITH LESS THAN 1% GRADIENT AND STREAM WIDTH GREATER THAN 18 FT AT LOW FLOW AND USING THE MEAN OF THE LOW FLOW AND SPRING FLOW SMOLT DENSITY ESTIMATES. ASSUMES PARTIAL PRODUCTION IN INUNDATED TRIBUTARIES.

Stream Type	Density Estimate (smolts/yd2)	Square Yds	Correction Factor	Totals
Low Flow Area	0.14	726816		101754
Spring Area	1.4	1269671		1777539
		Mean Smolt Estimate		990524
Low Flow Area	0.14	177189	0.25	6202
Spring Area	1.4	307418	0.25	107596
		Mean Smolt Estimate		60000
		TOTAL SMOLT ESTIMATE		**1050524**

a. Smolt density estimates are from Northwest Resource Associates (1991) used by Wunderlich and Toal (1992) in assessing mitigation requirements for the additional pool raise in tributaries of Howard Hanson Dam.
b. Stream gradient of 1% or less was selected as a criterion from distribution and gradient data from habitat use in the upper White River system. Fall Chinook are not found in any stream segment greater than 1%.
c. Density estimates were made for Spring Chinook in streams <1%, this assumes no interaction between the races.
d. Only streams with greater than 18 ft low flow width were used, this is the distinction used between small and large tributaries in calculation of coho smolt density estimates (Baranski 1989).
e. This is the partial production estimate for the upper Green River with inundated tributaries estimated at 0.25% of natural production.

TABLE 17. POTENTIAL FALL CHINOOK SMOLT PRODUCTION FOR THE UPPER GREEN RIVER WATERSHED ABOVE AND BELOW THE UPSTREAM COLLECTOR, FOR STREAMS WITH LESS THAN 1% GRADIENT AND STREAM WIDTH GREATER THAN 18 FT AT LOW FLOW AND USING THE MEAN OF THE LOW FLOW AND SPRING FLOW SMOLT DENSITY ESTIMATES. ASSUMES PARTIAL PRODUCTION IN INUNDATED TRIBUTARIES UP TO 1177 FT.

Watershed Location	Stream Type	Density Estimate (smolts/yd2)	Square Yds	Correction Factor	Totals
Above Upstream Collector	Low Flow Area	0.14	663916		92948
	Spring Area	1.4	1158671		1622139
			Mean Smolt Estimate		857544
			Smolt Estimate Above Collector		857544
Below Upstream Collector	Low Flow Area	0.14	177189	0.1	2481
1141 Inundation Zone	Spring Area	1.4	307418	0.1	43039
			Mean Smolt Estimate		22760
1141-1177 Inundation Zone	Low Flow Area	0.14	111000	0.25	3885
	Spring Area	1.4	62900	0.25	22015
			Mean Smolt Estimate		12950
			Smolt Estimate Below Collector		35710
			TOTAL SMOLT ESTIMATE		893253

a. The low flow and spring flow estimates give a range of values, from low 90400 smolts to a high of 946253: the mean value is calculated from the low flow and spring flow.

b. Smolt density estimates are from NWRA (1991) used in the tributary inundation report by USFWS.

c. Stream gradient of 1% or less was selected as a criterion from distribution and gradient data from habitat use in the upper White River system. Fall Chinook are not found in any stream segment greater than 1%.

d. Density estimates were not made for Spring Chinook in streams <1%, this assumes no interaction between the races.

e. Only streams with greater than 18 ft low flow width were used, this is the distinction used between small and large tributaries in calculation of coho smolt density estimates (Baranski 1989).

f. This is the partial production estimate for the upper Green River with inundated tributaries estimated at 25% (1177) and 10% (1141) of natural production.

TABLE 18. SPRING CHINOOK SMOLT PRODUCTION ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING SMOLT DENSITY ESTIMATE FROM WARREN (1994) AND WILL FULL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR..

Low Flow Surface Area (m2)	Smolt Density	Smolt Production Estimate
965361	0.361	348495

a. Low flow area is for accessible streams identified from the Washington Department of Fisheries Stream Catalog. Only streams with gradients of 3% or less and with stream widths greater than 18 ft were included.
b. Streams equal to or less than 1% were used in the fall chinook estimate, this assumes no interaction between the races.
c. The density estimate used is from Warner (1994); an average value of 22 streams (in Smith et al. 1985).
d. Stream gradient and width criteria were selected from: 1) gradient was from the highest gradient section that spring chinook are found in streams of the upper White River; 2) width is from the size distinction between small (<18 ft width) and large (> 18 ft width) streams used in coho smolt estimates.

TABLE 19. SPRING CHINOOK SMOLT PRODUCTION ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING SMOLT DENSITY ESTIMATE FROM WARREN (1994) AND WITH PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1141 FT ELEVATION.

Low Flow Surface Area (m2)	Smolt Density	Correction Factor	Smolt Production Estimate
810190	0.361		292479
155171	0.361	0.25	14004
		Total Smolt Production	306483

a. Low flow area is for accessible streams identified from the Washington Department of Fisheries Stream Catalog. Only streams with gradients of 3% or less and with stream widths greater than 18 ft were included.
b. Streams equal to or less than 1% were used in the fall chinook estimate, this assumes no interaction between the races.
c. The density estimate used is from Warner (1994); an average value of 22 streams (in Smith et al. 1985).
d. Stream gradient and width criteria were selected from: 1) gradient was from the highest gradient section that spring chinook are found in streams of the upper White River; 2) width is from the size distinction between small (<18 ft width) and large (> 18 ft width) streams used in coho smolt estimates.
e. The correction factor assumes that inundated habitat in the reservoir is only 25% as productive as regular stream habitat.

TABLE 20. SPRING CHINOOK SMOLT PRODUCTION ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING SMOLT DENSITY ESTIMATE FROM WARNER (1994) AND WILL PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1177 FT ELEVATION.

Low Flow Surface Area (m2)	Smolt Density	Correction Factor	Smolt Production Estimate
742936	0.361		268200
155171	0.361	0.1	5602
67254	0.361	0.25	6070
		Total Smolt Production	279871

a. Low flow area is for accessible streams identified from the Washington Department of Fisheries Stream Catalog. Only streams with gradients of 3% or less and with stream widths greater than 18 ft were included.
b. Streams equal to or less than 1% were used in the fall chinook estimate, this assumes no interaction between the races.
c. The density estimate used is from Warner (1994); an average value of 22 streams (in Smith et al. 1985).
d. Stream gradient and width criteria were selected from: 1) gradient was from the highest gradient section that spring chinook are found in streams of the upper White River; 2) width is from the size distinction between small (<18 ft width) and large (> 18 ft width) streams used in coho smolt estimates.
e. This is the partial production estimate for the upper Green River with inundated tributaries estimated at 25% (1177) and 10% (1141) of natural production.

TABLE 24. FALL CHINOOK ESCAPEMENT ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM, USING ADULT SPAWNING CAPACITY ESTIMATES FROM THE LOWER GREEN RIVER (140 ADULTS/MILE) WITH PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1177 FT ELEVATION.

Watershed Location	Accessible Length (miles)	Adults/Mile	Correction Factor	Adult Escapement Goal
	18.2	140		2548
Above 1177 ft Zone	4.5	140	0.1	63
1070-1141 ft Zone	1.3	140	0.25	46
1141-1177 ft Zone			Total Escapement	2657

a. Two calculations of adults/mile for the lower Green are presented in Table 24, below.

TABLE 25. LOWER GREEN RIVER FALL CHINOOK ADULTS/MILE USING ESCAPEMENT ESTIMATE AND TWO MEASUREMENTS OF SPAWNER DISTRIBUTION, FROM GRETTE AND SALO (1985).

Green River Escapement	RM Length	Total Miles	Adults/Mile
5750	24-61	37	140
	4 miles lower Neuwakum	4	
5750	29.6-47 and 56-61	22.4	257

a. Adults/mile row 1 assumes equal distribution between all spawnable areas.
b. Adults/mile row 2 assumes clumped distribution in two main spawning areas.

TABLE 26. CROSS-CHECK ON FALL CHINOOK ESCAPEMENT ESTIMATE FOR THE UPPER GREEN RIVER WATERSHED ABOVE HOWARD HANSON DAM. USING SMOLT DENSITY ESTIMATE FROM WUNDERLICH AND TOAL (1992) AND GRAYBILL ET AL. (1978) AND WITH PARTIAL PRODUCTION FROM INUNDATED TRIBUTARIES IN THE RESERVOIR UP TO 1177 FT ELEVATION. EGG TO SMOLT SURVIVAL IS FROM HOSEY AND ASSOCIATES, FECUNDITY FROM GRETTE AND SALO (1985).

Smolt Density	Smolt No.	Egg-to-fingerling(smolt) Survival	Average Fecundity (egg/female)	No. of Females	Male Sex Ratio	Escapement Goal
0.14 and 1.4	893253	0.15	5048	1180	1	2359
0.14 and 1.4	893253	0.07	5048	2528	1	5056
0.1 and 0.6	397011	0.15	5048	524	1	1049
0.1 and 0.6	397011	0.07	5048	1124	1	2247

a. Smolt density estimates of 0.14-1.4 were used by Wunderlich and Toal (1992) in estimating mitigation requirement for inundation of stream habitat above HHD. This range was considered by NWRA (1991) to be a "reasonable" range for estimating smolt production for the Elwha.
b. The lower density estimate (0.1-0.6) was used for comparison to the higher estimates, these values were from Skagit River in the mid-70's (Graybill et al. 1979).
c. The conclusion is the higher the smolt density and the lower the egg-smolt survival rate, the higher the escapement required.
d. It maybe more appropriate to use the lower density estimate, if that is true – our adult returns for fish passage are 50% too low.
e. The escapement number we used was 2277, this may be low unless we have high egg-to-smolt survival.

APPENDIX TABLES OF HABITAT AREA

Table A-2. Habitat database of all stream segments in the upper Green River with gradients of 10% or less.
Table B-1 to B-3. Coho smolt production habitat area.
Table C-1 to C-3. Steelhead smolt production habitat area.
Table D-1 to D-3. Fall Chinook smolt production habitat area.
Table E-1 to E-3. Spring Chinook smolt production habitat area.

Appendix Table A-2. Habitat database of all stream segments in the upper Green River with gradients of 10% or less. Appendix Table A-2 has all unmeasured streams removed from the database. This database includes all stream segments of 10% or less gradient in the upper Green River above Howard Hanson Dam. This database was further refined for use in estimating total habitat available for each anadromous species. The appendix tables show the final stream area available, by species (Tables B-1 to E-3).

River or Tributary	WDFW No.	Low Flow Width (ft)	[illegible] Width (ft)	Segment Length [illegible] (ft)	Low Flow Area (ft2)	[illegible]
Green River (RM [illegible])	1	65	[illegible]	[illegible]	[illegible]	[illegible]
Green River (75-83)	2	64	111.5	42200	2700800	0.005
				58500	**4086300**	
Green River (RM [illegible])	1	65	150	[illegible]	[illegible]	0.01
Green River (RM 68.5-70.0)	1	65	150	5660	566100	0.01
Foggy Creek (a)	[illegible]	[illegible]	25	1800	[illegible]	0.01
Gale Creek (a)	[illegible]	22	30	1600	35200	0.01
North Fork Green (a)	163	30	47.2	5800	174000	0.01
Sawmill Creek (a)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.01
Sunday Creek (a)	277	25.8	43.1	7600	196080	0.01
Sunday Creek (b)	277	23.5	38.9	5500	129250	0.01
Sunday Creek (c)	277	22.8	[illegible]	6900	157320	0.01
				[illegible]	[illegible]	
*	215	5	5	640	3200	0.02
*	234	6.3	6	3000	18900	0.02
*	[illegible]	[illegible]	[illegible]	100	[illegible]	0.02
Champion Creek (a)	242	[illegible]	[illegible]	2000	[illegible]	0.02
Cottonwood Creek (a)	197	7	30	480	3360	0.02
East Creek (a)	202	10.6	16.5	4750	50350	0.02
Gale Creek (b)	196	22	30	2080	45760	0.02
Gold Creek (a)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02
Green River (83-[illegible]) (a)	3	[illegible]	27.1	[illegible]	[illegible]	0.02
Intake Creek (a)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02
North Fork Green (b)	163	30	47.2	2150	64500	0.02
North Fork Green (c)	163	30	47.2	42150	1264500	0.02
Page Creek	4	26	26	1830	47580	0.02
Page Mill Creek	4	[illegible]	[illegible]	570	14820	0.02
[illegible] Creek (a)	179	10	[illegible]	800	8000	0.02
[illegible] Creek (a)	216	26.5	[illegible]	[illegible]	[illegible]	0.02
Snow Creek	231	22.4	[illegible]	[illegible]	[illegible]	0.02
Twin Camp Creek (a)	317	19.2	[illegible]	7900	151680	0.02
[illegible] Creek	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02
	101	[illegible]	[illegible]	800	[illegible]	0.02
				[illegible]	[illegible]	

River or Tributary	WDFW No.	Low Flow Width (ft)	Spring Wetted Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Gradient
a	192	7.5	9.8	1800	13500	0.03
a	233	7	9	2400	16800	0.03
c	234	6.3	8	2300	14490	0.03
Champion Creek (b)	242	23.9	39.7	2300	54970	0.03
Charley Creek (a)	181	27	35	2800	75600	0.03
Charley Creek (d)	181	27	35	1400	37800	0.03
Cottonwood Creek (b)	197	7	8	1220	8540	0.03
Cottonwood Creek (c)	197	7	20	4580	32060	0.03
Eagle Creek	169	6.8	8.7	1500	10200	0.03
Sawmill Creek (a)	257	11.7	17.9	2400	28080	0.03
Sawmill Creek (c)	257	11.7	17.9	1200	14040	0.03
Twin Camp Creek (b)	317	15.7	25	7900	124030	0.03
				31800	**430110**	
Boundary Creek	197	8.2	11	1800	14760	0.04
Charley Creek (b)	181	27	35	1500	40500	0.04
Charley Creek (e)	181	27	35	1500	40500	0.04
Friday Creek (d)	269	18.1	29	900	16290	0.04
From Chapman	288	5.7	7.1	3200	18240	0.04
Gale Creek (c)	196	22	30	2320	51040	0.04
Green Canyon Creek (a)	241	10.1	13.5	2400	24240	0.04
Green River (83-88)(b)	3	26.2	43.8	4200	110040	0.04
Green River (83-88)(c)	3	16	25.6	7900	126400	0.04
Green River (83-88)(d)	3	14.4	22.7	3700	53280	0.04
Green River (83-88)(e)	3	10.8	16.3	4700	50760	0.04
McCain Creek (a)	247	17.8	28.8	5500	97900	0.04
Rock Creek (a)	245	22.1	36.5	2900	64090	0.04
Rock Creek (c)	245	22.1	36.5	1100	24310	0.04
Sawmill Creek (e)	257	11.7	17.9	1000	11700	0.04
Sawmill Creek (i)	257	11.7	17.9	1900	22230	0.04
Sawmill Creek (l)	257	11.7	17.9	1000	11700	0.04
Smay Creek (b)	216	26.5	45	4900	129850	0.04
West Fork Smay Creek (a)	217	17.1	27	3000	51300	0.04
	227	4.4	5	500	2200	0.04
	300	5.4	6.5	900	4860	0.04
				56820	**966190**	
a	336	10	13.3	800	8000	0.05
b	215	5	5	730	3650	0.05
c	215	5	5	1670	8350	0.05
Champion Creek (c)	242	23.9	39.7	1500	35850	0.05
Champion Creek (d)	242	23.9	39.7	2400	57360	0.05
Friday Creek (b)	269	18.1	29	800	14480	0.05
Gold Creek (b)	235	15.1	23.2	800	12080	0.05
Intake Creek (a)	329	12.9	23.1	2800	36120	0.05
Rock Creek (d)	245	22.1	36.5	2500	55250	0.05
Rock Creek (e)	245	22.1	36.5	4200	92820	0.05
Sunday Creek (d)	277	20	32.7	3700	74000	0.05
Sunday Creek (e)	277	17.5	28.2	6400	112000	0.05
Tacoma (a)	326	17.7	28.6	2800	49560	0.05
				31100	**559520**	
a	202	8	12	260	2080	0.06
b	202	8	12	940	7520	0.06
McCain Creek (b)	247	17.8	28.8	600	10680	0.06
Pilings Creek (b)	179	10	12	600	6000	0.06
Pilings Creek (c)	179	10	12	630	6300	0.06
Pilings Creek (d)	179	10	12	470	4700	0.06
Rock Creek (b)	245	22.1	36.5	700	15470	0.06
Sawmill Creek (b)	257	11.7	17.9	700	8190	0.06

River or Tributary	WDFW No.	Low Flow Width (ft)	Spring Wetted Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Gradient
West Fork Smay Creek (b)	217	17.1	27	2000	34200	0.06
				6900	**85140**	
a	228	5.9	7.4	900	5310	0.07
a	230	7.1	9.2	900	6390	0.07
c	230	7.1	9.2	600	4260	0.07
c	233	7	9	1200	8400	0.07
Charley Creek (c)	181	27	35	600	16200	0.07
Cougar Creek	212	7.6	10	2200	16720	0.07
Lester Creek (a)	254	16.8	27	700	11760	0.07
Sawmill Creek (g)	257	11.7	17.9	2700	31590	0.07
Smay Creek (c)	216	12.4	18	900	11160	0.07
Tacoma (c)	326	17.7	28.6	2200	38940	0.07
	298	4.5	5	600	2700	0.07
				13500	**153430**	
b	233	7	9	500	3500	0.08
b	234	6.3	8	500	3150	0.08
c	212	4	10	2270	9080	0.08
c	221	11.7	15.6	600	7020	0.08
Friday Creek (e)	269	18.1	29	500	9050	0.08
Gale Creek (d)	196	22	22	2600	57200	0.08
Green Canyon Creek (b)	241	10.1	13.5	1500	15150	0.08
McCain Creek (c)	247	17.8	28.8	500	8900	0.08
Sawmill Creek (d)	257	11.7	17.9	500	5850	0.08
West Fork Smay Creek (d)	217	17.1	27	2500	42750	0.08
				11970	161650	
Champion Creek (e)	242	23.9	39.7	7400	176860	0.09
Lester Creek (c)	254	16.8	27	2200	36960	0.09
Sylvester Creek (b)	211	8.2	11	900	7380	0.09
	226	11.7	16.7	1700	19890	0.09
				12200	241090	
a	212	4	10	320	1280	0.1
b	212	4	10	330	1320	0.1
b	258	6.8	8.6	400	2720	0.1
Intake Creek (c)	329	12.9	23.1	2000	25800	0.1
Sawmill Creek (j)	257	11.7	17.9	800	9360	0.1
Sunday Creek (f)	277	15	23.8	6400	96000	0.1
West Fork Smay Creek (c)	217	17.1	27	500	8550	0.1
West Fork Smay Creek (e)	217	17.1	27	1800	30780	0.1
	244	6.6	8.7	4750	31350	0.1
				17300	207160	
				408940	13313550	

Appendix B-1. Habitat summary of low flow area for tributaries to Howard Hanson Dam used in calculating coho smolt production. Current and future inundated habitat areas are summarized under Appendix Tables B-2 and B-3. Habitat areas were broken into mainstem and tributary areas, and by percent gradient.

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (M2)	Gradient
Green River (RM 65.5-68.5)	1	85	16300	1385500	128713	0
Green River (75-83)	2	64	42200	2700800	250904	0.005
Green River (RM 65.5-75)	1	85	32440	2757400	256162	0.01
Green River (RM 68.5-70.0)	1	85	6660	566100	52591	0.01
					688370	
Friday Creek (a)	269	18.1	1900	34390	3195	0.01
Gale Creek (a)	196	22	1600	35200	3270	0.01
North Fork Green (a)	163	30	5800	174000	16165	0.01
Sawmill Creek (m)	257	11.7	2700	31590	2935	0.01
Sunday Creek (a)	277	25.8	7600	196080	18216	0.01
Sunday Creek (b)	277	23.5	5500	129250	12007	0.01
Sunday Creek (c)	277	22.8	6900	157320	14615	0.01
a	215	5	640	3200	297	0.02
a	234	6.3	3000	18900	1756	0.02
a	258	6.8	100	680	63	0.02
Champion Creek (a)	242	23.9	2000	47800	4441	0.02
Cottonwood Creek (a)	197	7	480	3360	312	0.02
East Creek (a)	282	10.6	4750	50350	4678	0.02
Gale Creek (b)	196	22	2080	45760	4251	0.02
Gold Creek (a)	235	15.1	1300	19630	1824	0.02
Green River (83-88)(a)	3	16.9	5900	99710	9263	0.02
Intake Creek (b)	329	12.9	1800	23220	2157	0.02
North Fork Green (b)	163	30	2150	64500	5992	0.02
North Fork Green (c)	163	30	42150	1264500	117472	0.02
Page Creek	4	26	1830	47580	4420	0.02
Page Mill Creek	4	26	570	14820	1377	0.02
Pilings Creek (a)	179	10	800	8000	743	0.02
Smay Creek (a)	216	26.5	11500	304750	28311	0.02
Snow Creek	281	22.4	6500	145600	13526	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	14091	0.02
West Creek	288	9.7	1500	14550	1352	0.02
	191	3.8	800	3040	282	0.02
					287011	
a	192	7.5	1800	13500	1254	0.03
a	233	7	2400	16800	1561	0.03
c	234	6.3	2300	14490	1346	0.03
Champion Creek (b)	242	23.9	2300	54970	5107	0.03
Charley Creek (a)	181	27	2800	75600	7023	0.03
Charley Creek (d)	181	27	1400	37800	3512	0.03
Cottonwood Creek (b)	197	7	1220	8540	793	0.03
Cottonwood Creek (c)	197	7	4580	32060	2978	0.03
Eagle Creek	169	6.8	1500	10200	948	0.03
Sawmill Creek (a)	257	11.7	2400	28080	2609	0.03
Sawmill Creek (c)	257	11.7	1200	14040	1304	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	11522	0.03
					39957	

Appendix B-2. Habitat summary of low flow area for tributaries to Howard Hanson Dam used in calculating coho smolt production. Subtotal of habitat area in inundated areas (1070-1141 ft) is included.

River or Tributary	*WDFW No.*	*Low Flow Width (ft)*	*Segment Length (accessible in ft)*	*Low Flow Area (ft2)*	*Low Flow Area (M2)*	*Gradient*
AREA ABOVE THE INUNDATION ZONE						
Green River (75-83)	2	64	42200	2700800	250904	0.005
Green River (RM 70-75)	1	85	32440	2757400	256162	0.01
Green River (RM 68.5-70.0)	1	85	6660	566100	52591	0.01
					559657	
Friday Creek (a)	269	18.1	1900	34390	3195	0.01
Sawmill Creek (m)	257	11.7	2700	31590	2935	0.01
Sunday Creek (a)	277	25.8	7600	196080	18216	0.01
Sunday Creek (b)	277	23.5	5500	129250	12007	0.01
Sunday Creek (c)	277	22.8	6900	157320	14615	0.01
a	234	6.3	3000	18900	1756	0.02
a	258	6.8	100	680	63	0.02
Champion Creek (a)	242	23.9	2000	47800	4441	0.02
East Creek (a)	282	10.6	4750	50350	4678	0.02
Gale Creek (b)	196	22	2080	45760	4251	0.02
Gold Creek (a)	235	15.1	1300	19630	1824	0.02
Green River (83-88)(a)	3	16.9	5900	99710	9263	0.02
Intake Creek (b)	329	12.9	1800	23220	2157	0.02
North Fork Green (b)	163	30	2150	64500	5992	0.02
North Fork Green (c)	163	30	42150	1264500	117472	0.02
Page Creek (a)	4	26	1830	47580	4420	0.02
Page Creek (b)	4	26	570	14820	1377	0.02
Smay Creek (a)	216	26.5	11500	304750	28311	0.02
Snow Creek	281	22.4	6500	145600	13526	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	14091	0.02
West Creek	288	9.7	1500	14550	1352	0.02
	191	3.8	800	3040	282	0.02
					266224	
a	192	7.5	1800	13500	1254	0.03
a	233	7	2400	16800	1561	0.03
c	234	6.3	2300	14490	1346	0.03
Champion Creek (b)	242	23.9	2300	54970	5107	0.03
Charley Creek (d)	181	27	1400	37800	3512	0.03
Cottonwood Creek (b)	197	7	1220	8540	793	0.03
Cottonwood Creek (c)	197	7	4580	32060	2978	0.03
Eagle Creek	169	6.8	1500	10200	948	0.03
Sawmill Creek (a)	257	11.7	2400	28080	2609	0.03
Sawmill Creek (c)	257	11.7	1200	14040	1304	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	11522	0.03
					32934	
AREA BELOW THE INUNDATION ZONE						
Green River (RM 65.5-68.5)	1	85	16300	1385500	128713	0
					128713	
Gale Creek (a)	196	22	1600	35200	3270	0.01
North Fork Green (a)	163	30	5800	174000	16165	0.01

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (M2)	Gradient
a	215	5	640	3200	297	0.02
Cottonwood Creek (a)	197	7	480	3360	312	0.02
Pilings Creek (a)	179	10	800	8000	743	0.02
					20787	
Charley Creek (a)	181	27	2800	75600	7023	0.03
					7023	

Appendix B-3. Habitat summary of low flow area for tributaries to Howard Hanson Dam used in calculating coho smolt production. Subtotal of habitat area in inundated areas at 1141 ft and 1177 ft is included.

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (M2)	Gradient
AREA ABOVE THE INUNDATION ZONE						
Green River (75-83)	2	64	42200	2700800	250904	0.005
Green River (RM 70-75)	1	85	32440	2757400	256162	0.01
					507067	
Friday Creek (a)	269	18.1	1900	34390	3195	0.01
Sawmill Creek (m)	257	11.7	2700	31590	2935	0.01
Sunday Creek (a)	277	25.8	7600	196080	18216	0.01
Sunday Creek (b)	277	23.5	5500	129250	12007	0.01
Sunday Creek (c)	277	22.8	6900	157320	14615	0.01
a	234	6.3	3000	18900	1756	0.02
a	258	5.8	100	580	63	0.02
Champion Creek (a)	242	23.9	2000	47800	4441	0.02
East Creek (a)	282	10.6	4750	50350	4678	0.02
Gold Creek (a)	235	15.1	1300	19630	1824	0.02
Green River (83-88)(a)	3	16.9	5900	99710	9263	0.02
Intake Creek (b)	329	12.9	1800	23220	2157	0.02
North Fork Green (c)	163	30	42150	1264500	117472	0.02
Page Creek (b)	4	26	570	14820	1377	0.02
Smay Creek (a)	216	26.5	11500	304750	28311	0.02
Snow Creek	281	22.4	6500	145600	13526	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	14091	0.02
West Creek	288	9.7	1500	14550	1352	0.02
	191	3.8	800	3040	282	0.02
					251560	
a	192	7.5	1800	13500	1254	0.03
a	233	7	2400	16800	1561	0.03
c	234	6.3	2300	14490	1346	0.03
Champion Creek (b)	242	23.9	2300	54970	5107	0.03
Charley Creek (d)	181	27	1400	37800	3512	0.03
Cottonwood Creek (c)	197	7	4580	32060	2978	0.03
Eagle Creek	169	6.8	1500	10200	948	0.03
Sawmill Creek (a)	257	11.7	2400	28080	2609	0.03
Sawmill Creek (c)	257	11.7	1200	14040	1304	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	11522	0.03
					32141	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)						
Green River (RM 65.5-68.5)	1	85	16300	1385500	128713	0

River or Tributary	*WDFW No.*	*Low Flow Width (ft)*	*Segment Length (accessible in ft)*	*Low Flow Area (ft2)*	*Low Flow Area (M2)*	*Gradient*
					128713	
Gale Creek (a)	196	22	1600	35200	3270	0.01
North Fork Green (a)	163	30	5800	174000	16165	0.01
a	215	5	640	3200	297	0.02
Cottonwood Creek (a)	197	7	480	3360	312	0.02
Pilings Creek (a)	179	10	800	8000	743	0.02
					20787	
Charley Creek (a)	181	27	2800	75600	7023	0.03
					7023	
AREA BELOW THE INUNDATION ZONE (1141-1177 FT)						
Green River (RM 68.5-70.0)	1	85	6660	566100	52591	0.01
					52591	
North Fork Green (b)	163	30	2150	64500	5992	0.02
Gale Creek (b)	196	22	2080	45760	4251	0.02
Page Creek (a)	4	26	1830	47580	4420	0.02
					14663	
Cottonwood Creek (b)	197	7	1220	8540	793	0.03
				10929370	**793**	

Appendix C-1. Habitat summary of low flow area for tributaries to Howard Hanson Dam used in calculating steelhead smolt production. Current and future inundated habitat areas are summarized under Appendix Tables C-2 and C-3. Habitat areas were broken into mainstem and tributary areas.

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (100m2)	Gradient
Green River (RM 65.5-68.5)	1	85	16300	1385500	1287	0
Green River (75-83)	2	64	42200	2700800	2509	0.005
Green River (RM 70-75)	1	85	32440	2757400	2562	0.01
Green River (RM 68.5-70.0)	1	85	6660	566100	526	0.01
				7409800	**6884**	
Friday Creek (a)	269	18.1	1900	34390	32	0.01
Gale Creek (a)	196	22	1600	35290	33	0.01
North Fork Green (a)	163	30	5800	174000	162	0.01
Sawmill Creek (m)	257	11.7	2700	31590	29	0.01
Sunday Creek (a)	277	25.8	7600	196080	182	0.01
Sunday Creek (b)	277	23.5	5500	129250	120	0.01
Sunday Creek (c)	277	22.8	6900	157320	146	0.01
a	215	5	640	3200	3	0.02
a	234	6.3	3000	18900	18	0.02
a	258	6.8	100	680	1	0.02
Champion Creek (a)	242	23.9	2000	47800	44	0.02
Cottonwood Creek (a)	197	7	480	3360	3	0.02
East Creek (a)	282	10.6	4750	50350	47	0.02
Gale Creek (b)	196	22	2080	45760	43	0.02
Gold Creek (a)	235	15.1	1300	19630	18	0.02
Green River (83-88)(a)	3	16.9	5900	99710	93	0.02
Intake Creek (b)	329	12.9	1800	23220	22	0.02
North Fork Green (b)	163	30	2150	64500	60	0.02
North Fork Green (c)	163	30	42150	1264500	1175	0.02
Page Creek	4	26	1830	47580	44	0.02
Page Mill Creek	4	26	570	14820	14	0.02
Pilings Creek (a)	179	10	800	8000	7	0.02
Smay Creek (a)	216	26.5	11500	304750	283	0.02
Snow Creek	281	22.4	6500	145600	135	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	141	0.02
West Creek	288	9.7	1500	14550	14	0.02
	191	3.8	800	3040	3	0.02
a	192	7.5	1800	13500	13	0.03
a	233	7	2400	16800	16	0.03
c	234	6.3	2300	14490	13	0.03
Champion Creek (b)	242	23.9	2300	54970	51	0.03
Charley Creek (a)	181	27	2800	75600	70	0.03
Charley Creek (d)	181	27	1400	37800	35	0.03
Cottonwood Creek (b)	197	7	1220	8540	8	0.03
Cottonwood Creek (c)	197	7	4580	32060	30	0.03
Eagle Creek	169	6.8	1500	10200	9	0.03
Sawmill Creek (a)	257	11.7	2400	28080	26	0.03
Sawmill Creek (c)	257	11.7	1200	14040	13	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	115	0.03
Boundary Creek	197	8.2	1800	14760	14	0.04
Charley Creek (b)	181	27	1500	40500	38	0.04
Charley Creek (e)	181	27	1500	40500	38	0.04
Friday Creek (d)	269	18.1	900	16290	15	0.04
From Chapman	288	5.7	3200	18240	17	0.04
Gale Creek (c)	196	22	2320	51040	47	0.04
Green Canyon Creek (a)	241	10.1	2400	24240	23	0.04
Green River (83-88)(b)	3	26.2	4200	110040	102	0.04
Green River (83-88)(c)	3	16	7900	126400	117	0.04

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (100m2)	Gradient
Green River (83-88)(d)	3	14.4	3700	53280	49	0.04
Green River (83-88)(e)	3	10.8	4700	50760	47	0.04
McCain Creek (a)	247	17.8	5500	97900	91	0.04
Rock Creek (a)	245	22.1	2900	64090	60	0.04
Rock Creek (c)	245	22.1	1100	24310	23	0.04
Sawmill Creek (e)	257	11.7	1000	11700	11	0.04
Sawmill Creek (i)	257	11.7	1900	22230	21	0.04
Sawmill Creek (l)	257	11.7	1000	11700	11	0.04
Smay Creek (b)	216	26.5	4900	129850	121	0.04
West Fork Smay Creek (a)	217	17.1	3000	51300	48	0.04
	227	4.4	500	2200	2	0.04
	300	5.4	900	4860	5	0.04
a	336	10	800	8000	7	0.05
b	215	5	730	3650	3	0.05
c	215	5	1670	8350	8	0.05
Champion Creek (c)	242	23.9	1500	35850	33	0.05
Champion Creek (d)	242	23.9	2400	57360	53	0.05
Friday Creek (b)	269	18.1	800	14480	13	0.05
Gold Creek (b)	235	15.1	800	12080	11	0.05
Intake Creek (a)	329	12.9	2800	36120	34	0.05
Rock Creek (d)	245	22.1	2500	55250	51	0.05
Rock Creek (e)	245	22.1	4200	92820	86	0.05
Sunday Creek (d)	277	20	3700	74000	69	0.05
Sunday Creek (e)	277	17.5	6400	112000	104	0.05
Tacoma (a)	326	17.7	2800	49560	46	0.05
			347070	5045280	4687	
				5045280		

Appendix C-2. Habitat Summary of low flow area for tributaries to Howard Hanson Dam used in calculating steelhead smolt production. Inundated tributaries (1070-1141 ft) of Howard Hanson Reservoir are broken out separately.

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (100m2)	Gradient
AREA ABOVE THE INUNDATION ZONE						
Green River (75-83)	2	64	42200	2700800	2509	0.005
Green River (RM 70-75)	1	85	32440	2757400	2562	0.01
Green River (RM 68.5-70.0)	1	85	6660	566100	526	0.01
				6024300	5597	
Friday Creek (a)	269	18.1	1900	34390	32	0.01
Sawmill Creek (m)	257	11.7	2700	31590	29	0.01
Sunday Creek (a)	277	25.8	7600	196080	182	0.01
Sunday Creek (b)	277	23.5	5500	129250	120	0.01
Sunday Creek (c)	277	22.8	6900	157320	146	0.01
a	234	6.3	3000	18900	18	0.02
a	258	6.8	100	680	1	0.02
Champion Creek (a)	242	23.9	2000	47800	44	0.02
East Creek (a)	282	10.6	4750	50350	47	0.02
Gale Creek (b)	196	22	2080	45760	43	0.02
Gold Creek (a)	235	15.1	1300	19630	18	0.02
Green River (83-88)(a)	3	16.9	5900	99710	93	0.02
Intake Creek (b)	329	12.9	1800	23220	22	0.02
North Fork Green (b)	163	30	2150	64500	60	0.02
North Fork Green (c)	163	30	42150	1264500	1175	0.02
Page Creek (a)	4	26	1830	47580	44	0.02
Page Creek (b)	4	26	570	14820	14	0.02
Smay Creek (a)	216	26.5	11500	304750	283	0.02
Snow Creek	281	22.4	6500	145600	135	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	141	0.02

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (100m2)	Gradient
West Creek	288	9.7	1500	14550	14	0.02
	191	3.8	800	3040	3	0.02
a	192	7.5	1800	13500	13	0.03
a	233	7	2400	16800	16	0.03
c	234	6.3	2300	14490	13	0.03
Champion Creek (b)	242	23.9	2300	54970	51	0.03
Charley Creek (d)	181	27	1400	37800	35	0.03
Cottonwood Creek (b)	197	7	1220	8540	8	0.03
Cottonwood Creek (c)	197	7	4580	32060	30	0.03
Eagle Creek	169	6.8	1500	10200	9	0.03
Sawmill Creek (a)	257	11.7	2400	28080	26	0.03
Sawmill Creek (c)	257	11.7	1200	14040	13	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	115	0.03
Boundary Creek	197	8.2	1800	14760	14	0.04
Charley Creek (b)	181	27	1500	40500	38	0.04
Charley Creek (e)	181	27	1500	40500	38	0.04
Friday Creek (d)	269	18.1	900	16290	15	0.04
From Chapman	288	5.7	3200	18240	17	0.04
Gale Creek (c)	196	22	2320	51040	47	0.04
Green Canyon Creek (a)	241	10.1	2400	24240	23	0.04
Green River (83-88)(b)	3	26.2	4200	110040	102	0.04
Green River (83-88)(c)	3	16	7900	126400	117	0.04
Green River (83-88)(d)	3	14.4	3700	53280	49	0.04
Green River (83-88)(e)	3	10.8	4700	50760	47	0.04
McCain Creek (a)	247	17.8	5500	97900	91	0.04
Rock Creek (a)	245	22.1	2900	64090	60	0.04
Rock Creek (c)	245	22.1	1100	24310	23	0.04
Sawmill Creek (e)	257	11.7	1000	11700	11	0.04
Sawmill Creek (i)	257	11.7	1900	22230	21	0.04
Sawmill Creek (l)	257	11.7	1000	11700	11	0.04
Smay Creek (b)	216	26.5	4900	129850	121	0.04
West Fork Smay Creek (a)	217	17.1	3000	51300	48	0.04
	227	4.4	500	2200	2	0.04
	300	5.4	900	4860	5	0.04
a	336	10	800	8000	7	0.05
b	215	5	730	3650	3	0.05
c	215	5	1670	8350	8	0.05
Champion Creek (c)	242	23.9	1500	35850	33	0.05
Champion Creek (d)	242	23.9	2400	57360	53	0.05
Friday Creek (b)	269	18.1	800	14480	13	0.05
Gold Creek (b)	235	15.1	800	12080	11	0.05
Intake Creek (a)	329	12.9	2800	36120	34	0.05
Rock Creek (d)	245	22.1	2500	55250	51	0.05
Rock Creek (e)	245	22.1	4200	92820	86	0.05
Sunday Creek (d)	277	20	3700	74000	69	0.05
Sunday Creek (e)	277	17.5	6400	112000	104	0.05
Tacoma (a)	326	17.7	2800	49560	46	0.05
			318650	**4745920**	**4409**	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)						
Green River (RM 65.5-68.5)	1	85	16300	1385500	1287	0
				1385500	**1287**	
Gale Creek (a)	196	22	1600	35200	33	0.01
North Fork Green (a)	163	30	5800	174000	162	0.01
Charley Creek (a)	181	27	2800	75600	70	0.03
a	215	5	640	3200	3	0.02
Cottonwood Creek (a)	197	7	480	3360	3	0.02
Pilings Creek (a)	179	10	800	8000	7	0.02
			28420	**299360**	**278**	

Appendix C-3. Habitat Summary of low flow area for tributaries to Howard Hanson Dam used in calculating steelhead smolt production. Inundated tributaries of Howard Hanson Reservoir are broken out separately for 1141 and 1177 ft pools.

River or Tributary	*WDFW No.*	*Low Flow Width (ft)*	*Segment Length (accessible in ft)*	*Low Flow Area (ft2)*	*Low Flow Area (100m2)*	*Gradie nt*
AREA ABOVE THE INUNDATION ZONE						
Green River (75-83)	2	64	42200	2700800	2509	0.005
Green River (RM 70-75)	1	85	32440	2757400	2562	0.01
				5458200	**5071**	
Friday Creek (a)	269	18.1	1900	34390	32	0.01
Sawmill Creek (m)	257	11.7	2700	31590	29	0.01
Sunday Creek (a)	277	25.8	7600	196080	182	0.01
Sunday Creek (b)	277	23.5	5500	129250	120	0.01
Sunday Creek (c)	277	22.8	6900	157320	146	0.01
a	234	6.3	3000	18900	18	0.02
a	258	6.8	100	680	1	0.02
Champion Creek (a)	242	23.9	2000	47800	44	0.02
East Creek (a)	282	10.6	4750	50350	47	0.02
Gold Creek (a)	235	15.1	1300	19630	18	0.02
Green River (83-88)(a)	3	16.9	5900	99710	93	0.02
Intake Creek (b)	329	12.9	1800	23220	22	0.02
North Fork Green (c)	163	30	42150	1264500	1175	0.02
Page Creek (b)	4	26	570	14820	14	0.02
Smay Creek (a)	216	26.5	11500	304750	283	0.02
Snow Creek	281	22.4	6500	145600	135	0.02
Twin Camp Creek (a)	317	19.2	7900	151680	141	0.02
West Creek	288	9.7	1500	14550	14	0.02
	191	3.8	800	3040	3	0.02
a	192	7.5	1800	13500	13	0.03
a	233	7	2400	16800	16	0.03
c	234	6.3	2300	14490	13	0.03
Champion Creek (b)	242	23.9	2300	54970	51	0.03
Charley Creek (d)	181	27	1400	37800	35	0.03
Cottonwood Creek (c)	197	7	4580	32060	30	0.03
Eagle Creek	169	6.8	1500	10200	9	0.03
Sawmill Creek (a)	257	11.7	2400	28080	26	0.03
Sawmill Creek (c)	257	11.7	1200	14040	13	0.03
Twin Camp Creek (b)	317	15.7	7900	124030	115	0.03
Boundary Creek	197	8.2	1800	14760	14	0.04
Charley Creek (e)	181	27	1500	40500	38	0.04
Friday Creek (d)	269	18.1	900	16290	15	0.04
From Chapman	288	5.7	3200	18240	17	0.04
Gale Creek (c)	196	22	2320	51040	47	0.04
Green Canyon Creek (a)	241	10.1	2400	24240	23	0.04
Green River (83-88)(b)	3	26.2	4200	110040	102	0.04
Green River (83-88)(c)	3	16	7900	126400	117	0.04
Green River (83-88)(d)	3	14.4	3700	53280	49	0.04
Green River (83-88)(e)	3	10.8	4700	50760	47	0.04
McCain Creek (a)	247	17.8	5500	97900	91	0.04
Rock Creek (a)	245	22.1	2900	64090	60	0.04
Rock Creek (c)	245	22.1	1100	24310	23	0.04
Sawmill Creek (e)	257	11.7	1000	11700	11	0.04
Sawmill Creek (i)	257	11.7	1900	22230	21	0.04
Sawmill Creek (l)	257	11.7	1000	11700	11	0.04
Smay Creek (b)	216	26.5	4900	129850	121	0.04
West Fork Smay Creek (a)	217	17.1	3000	51300	48	0.04
	227	4.4	500	2200	2	0.04

River or Tributary	WDFW No.	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (100m2)	Gradient
	300	5.4	900	4860	5	0.04
a	336	10	800	8000	7	0.05
c	215	5	1670	8350	8	0.05
Champion Creek (c)	242	23.9	1500	35850	33	0.05
Champion Creek (d)	242	23.9	2400	57360	53	0.05
Friday Creek (b)	289	18.1	800	14480	13	0.05
Gold Creek (b)	235	15.1	800	12080	11	0.05
Intake Creek (a)	329	12.9	2800	36120	34	0.05
Rock Creek (d)	245	22.1	2500	55250	51	0.05
Rock Creek (e)	245	22.1	4200	92820	86	0.05
Sunday Creek (d)	277	20	3700	74000	69	0.05
Sunday Creek (e)	277	17.5	6400	112000	104	0.05
Tacoma (a)	326	17.7	2800	49560	46	0.05
			302480	**4535390**	**4213**	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)						
Green River (RM 65.5-68.5)	1	85	16300	1385500	1287	0
				1385500	**1287**	
Gale Creek (a)	196	22	1600	35200	33	0.01
North Fork Green (a)	163	30	5800	174000	162	0.01
Charley Creek (a)	181	27	2800	75600	70	0.03
a	215	5	640	3200	3	0.02
Cottonwood Creek (a)	197	7	480	3360	3	0.02
Pilings Creek (a)	179	10	800	8000	7	0.02
			28420	**299360**	**278**	
AREA BELOW THE INUNDATION ZONE (1141-1177 FT)						
Green River (RM 68.5-70.0)	1	85	6660	566100	526	0.01
				566100	**526**	
Gale Creek (b)	196	22	2080	45760	43	0.02
North Fork Green (b)	163	30	2150	64500	60	0.02
Page Creek (a)	4	26	1830	47580	44	0.02
Cottonwood Creek (b)	197	7	1220	8540	8	0.03
Charley Creek (b)	181	27	1500	40500	38	0.04
b	215	5	730	3650	3	0.05
				210530	**196**	

Appendix D-1. Habitat Summary of low flow and spring flow for tributaries to Howard Hanson Dam used in calculating fall chinook smolt production Current and future inundated habitat areas are summarized under Appendix Tables D-2 and D-3.

River or Tributary	WDFW No.	Low Flow Width	Spring Width	Segment Length(accessible)	Spring Surface Area (yd2)	Low Flow Surface Area (yd2)	Gradient
Green River (RM 65.5-68.5)	1	85	150	16300	271667	153944	0
Green River (75-83)	2	64	111.5	42200	522811	300089	0.005
Friday Creek (a)	269	18.1	29	1900	6122	3821	0.01
Gale Creek (a)	196	22	30	1600	5333	3911	0.01
Sunday Creek (c)	277	22.8	37.7	6900	28903	17480	0.01
Sunday Creek (b)	277	23.5	38.9	5500	23772	14361	0.01
Sunday Creek (a)	277	25.8	43.1	7600	36396	21787	0.01
North Fork Green (a)	163	30	47.2	5800	30418	19333	0.01
Green River (RM 70-75)	1	85	150	32440	540667	306378	0.01
Green River (RM 68.5-70.0)	1	85	150	6660	111000	62900	0.01
				126900	**1577089**	**904004**	

Appendix D-2. Habitat Summary of low flow and spring flow for tributaries to Howard Hanson Dam used in calculating fall chinook smolt production (partial with 1141 inundation).

River or Tributary	WDFW No.	Low Flow Width	Spring Width	Segment Length(accessible)	Spring Surface Area (yd2)	Low Flow Surface Area (yd2)	Gradient
AREA ABOVE THE INUNDATION ZONE							
Green River (75-83)	2	64	111.5	42200	522811	300089	0.005
Friday Creek (a)	269	18.1	29	1900	6122	3821	0.01
Sunday Creek (c)	277	22.8	37.7	6900	28903	17480	0.01
Sunday Creek (b)	277	23.5	38.9	5500	23772	14361	0.01
Sunday Creek (a)	277	25.8	43.1	7600	36396	21787	0.01
Green River (RM 70-75)	1	85	150	32440	540667	306378	0.01
Green River (RM 68.5-70.0)	1	85	150	6660	111000	62900	0.01
				103200	**1269671**	**726816**	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)							
Green River (RM 65.5-68.5)	1	85	150	16300	271667	153944	0
Gale Creek (a)	196	22	30	1600	5333	3911	0.01
North Fork Green (a)	163	30	47.2	5800	30418	19333	0.01
					307418	**177189**	

Appendix D-3. Habitat Summary of low flow and spring flow for tributaries to Howard Hanson Dam used in calculating fall chinook smolt production (partial with 1141 and 1177 inundation).

River or Tributary	WDFW No.	Low Flow Width	Spring Width	Segment Length(accessible)	Spring Surface Area (yd2)	Low Flow Surface Area (yd2)	Gradient
AREA ABOVE THE INUNDATION ZONE							
Green River (75-83)	2	64	111.5	42200	522811	300089	0.005
Friday Creek (a)	269	18.1	29	1900	6122	3821	0.01
Sunday Creek (c)	277	22.8	37.7	6900	28903	17480	0.01
Sunday Creek (b)	277	23.5	38.9	5500	23772	14361	0.01
Sunday Creek (a)	277	25.8	43.1	7600	36396	21787	0.01
Green River (RM 70-75)	1	85	150	32440	540667	306378	0.01
				96540	**1158671**	**663916**	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)							
Gale Creek (a)	196	22	30	1600	5333	3911	0.01
Green River (RM 65.5-68.5)	1	85	150	16300	271667	153944	0
North Fork Green (a)	163	30	47.2	5800	30418	19333	0.01
					307418	**177189**	
AREA BELOW THE INUNDATION ZONE (1141-1177 FT)							
Green River (RM 68.5-70.0)	1	85	150	6660	111000	62900	0.01
					111000	**62900**	

Appendix E-1. Habitat Summary of low flow area for tributaries to Howard Hanson Dam used in calculating spring chinook smolt production. Current and future inundated habitat areas are summarized under Appendix Tables E-2 and E-3.

River or Tributary	WDFW No.	Low Flow Width	Segment Length(accessible)	Surface Area (yd2)	Gradient
Green River (RM 65.5-68.5)	1	85	16300	128713	0
Green River (75-83)	2	64	42200	250904	0.005
Friday Creek (a)	269	18.1	1900	3195	0.01
Gale Creek (a)	196	22	1600	3270	0.01
Sunday Creek (c)	277	22.8	6900	14615	0.01
Sunday Creek (b)	277	23.5	5500	12007	0.01
Sunday Creek (a)	277	25.8	7600	18216	0.01
North Fork Green (a)	163	30	5800	16185	0.01
Green River (RM 70-75)	1	85	32440	256162	0.01
Green River (RM 68.5-70.0)	1	85	6660	52591	0.01
Twin Camp Creek (a)	317	19.2	7900	14091	0.02
Gale Creek (b)	196	22	2080	4251	0.02
Snow Creek	261	22.4	6500	13526	0.02
Champion Creek (a)	242	23.9	2000	4441	0.02
Page Creek	4	26	1830	4420	0.02
Page Mill Creek	4	26	570	1377	0.02
Smay Creek (a)	216	26.5	11500	28311	0.02
North Fork Green (b)	163	30	2150	5992	0.02
North Fork Green (c)	163	30	42150	117472	0.02
Champion Creek (b)	242	23.9	2300	5107	0.03
Charley Creek (a)	181	27	2800	7023	0.03
Charley Creek (d)	181	27	1400	3512	0.03
			83180	**965361**	

Appendix E-2. Habitat Summary of low flow area for tributaries to Howard Hanson Dam used in calculating spring chinook smolt production. Subtotal of habitat area in inundated areas (1070-1141 ft) is included.

River or Tributary	WDFW No.	Low Flow Width	Segment Length(accessible)	Surface Area (m2)	Gradient
AREA ABOVE THE INUNDATION ZONE					
Green River (RM 68.5-70.0)	1	85	6660	52591	0.01
Gale Creek (b)	196	22	2080	4251	0.02
Page Creek (a)	4	26	1830	4420	0.02
North Fork Green (b)	163	30	2150	5992	0.02
Green River (75-83)	2	64	42200	250904	0.005
Friday Creek (a)	269	18.1	1900	3195	0.01
Sunday Creek (c)	277	22.8	6900	14615	0.01
Sunday Creek (b)	277	23.5	5500	12007	0.01
Sunday Creek (a)	277	25.8	7600	18216	0.01
Green River (RM 70-75)	1	85	32440	256162	0.01
Twin Camp Creek (a)	317	19.2	7900	14081	0.02
Snow Creek	281	22.4	6500	13526	0.02
Champion Creek (a)	242	23.9	2000	4441	0.02
Page Creek (b)	4	26	570	1377	0.02
Smay Creek (a)	216	26.5	11500	28311	0.02
North Fork Green (c)	163	30	42150	117472	0.02
Champion Creek (b)	242	23.9	2300	5107	0.03
Charley Creek (d)	181	27	1400	3512	0.03
				810190	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)					
Gale Creek (a)	196	22	1600	3270	0.01
Green River (RM 65.5-68.5)	1	85	16300	128713	0
North Fork Green (a)	163	30	5800	16165	0.01
Charley Creek (a)	181	27	2800	7023	0.03
			2800	**155171**	

Appendix E-3. Habitat Summary of low flow area for tributaries to Howard Hanson Dam used in calculating spring chinook smolt production. Subtotal of habitat area in inundated areas at 1141 ft and 1177 ft is included.

River or Tributary	WDFW No.	Low Flow Width	Segment Length(accessible)	Surface Area (m2)	Gradient
AREA ABOVE THE INUNDATION ZONE					
Green River (75-83)	2	84	42200	250904	0.005
Friday Creek (a)	269	18.1	1900	3195	0.01
Sunday Creek (c)	277	22.8	6900	14615	0.01
Sunday Creek (b)	277	23.5	5500	12007	0.01
Sunday Creek (a)	277	25.8	7600	18216	0.01
Green River (RM 70-75)	1	85	32440	256162	0.01
Twin Camp Creek (a)	317	19.2	7900	14091	0.02
Snow Creek	281	22.4	6500	13526	0.02
Champion Creek (a)	242	23.9	2000	4441	0.02
Page Creek (b)	4	26	570	1377	0.02
Smay Creek (a)	216	26.5	11500	28311	0.02
North Fork Green (c)	163	30	42150	117472	0.02
Champion Creek (b)	242	23.9	2300	5107	0.03
Charley Creek (d)	181	27	1400	3512	0.03
				742936	
AREA BELOW THE INUNDATION ZONE (1070-1141 FT)					
Gale Creek (a)	196	22	1600	3270	0.01
Green River (RM 65.5-68.5)	1	85	16300	128713	0
North Fork Green (a)	163	30	5800	16165	0.01
Charley Creek (a)	181	27	2800	7023	0.03
			2800	**155171**	
AREA BELOW THE INUNDATION ZONE (1141-1177 FT)					
Green River (RM 68.5-70.0)	1	85	6660	52591	0.01
Gale Creek (b)	196	22	2060	4251	0.02
Page Creek (a)	4	26	1830	4420	0.02
North Fork Green (b)	163	30	2150	5892	0.02
			6060	**67254**	

SECTION 2B RESERVOIR OUTMIGRATION OF JUVENILE SALMONIDS

2B.1 OVERVIEW OF SECTION 2B

There are two project goals for the Additional Water Storage Project (AWSP) -- one is to store 32,000 ac ft of additional water for flow augmentation and municipal water supply, and the second is for ecosystem restoration, to restore the historical anadromous fish runs to the Headwaters watershed. There is a clear interaction between these goals within the bounds of the reservoir. When additional water is stored there are two major changes to environmental resources found within the proposed pool raise area: 1) upland and tributary stream habitat is inundated (discussed in the *Wildlife Appendix* and *Section 3*); and 2) free-flowing stream corridors used by juvenile salmonids as they migrate towards the ocean is replaced by the slack-water reservoir pool. Tributary stream habitat inundation is a clear impact of the pool raise that can be measured, however, the change from a free-flowing migratory corridor to slackwater corridor is not as obvious an impact and is not as easily accounted for.

This section describes several aspects of the AWSP and is divided into five sub-sections:

1) the first subsection (2B-1) provides measured or modeled changes in various reservoir features from low pool to the full Phase II AWSP,

2) the second subsection (2B-2) compares Howard Hanson Reservoir (Baseline, Phase I, and Phase II) to other reservoirs and lakes found in Oregon and Washington,

3) the third subsection (2B-3) presents the results of the only performance measurement of juvenile salmonid travel through the reservoir (reservoir travel time of radio-tagged smolts), and

4) the fourth subsection (2B-4) contains an analysis of variance (ANOVA) of physical variables faced by smolts as they migrated through the reservoir, results from this section are used in 2B-3, and

5) the fifth and last subsection (2B-5), is the reservoir outmigration success incremental analysis, changes in reservoir travel time, for the AWSP.

The next section, 2C, describes a further analysis of reservoir survival the Corps and Tacoma are completing utilizing a team of independent scientists (through the Delphi Process) to review existing information and to provide their professional opinion on possible impacts of the AWSP.

Following is a restatement of definitions for Baseline, Phase I, and Phase II conditions presented in the Introduction to the Appendix:

Definitions of Baseline, Phase I, and Phase II:

Baseline is the operation of Howard Hanson Dam (HHD) utilizing the existing 98 percent rule curve, and assuming Pipeline 5 is operational in accordance with, *"Agreement Between The Muckleshoot Indian Tribe and The City of Tacoma Regarding the Green/Duwamish River System, 1995"* (the Agreement). In addition, the 5,000 acre-feet (ac ft) from the HHD Section 1135 Environmental Restoration project is assumed to be available for drought years. Total storage volume in normal years is 25,400 ac ft, pool elevation is 1141 ft, and total storage volume in drought years is 30,400 ac ft, elevation 1147 ft.

Phase I of the Additional Water Storage Project (AWSP) adds to Baseline the fish passage facility at the dam, a larger volume of storage behind the dam in the spring to store water for augmenting fish flows at Auburn, and 20,000 ac ft of additional active Municipal and Industrial (M&I) water storage collected by storing Tacoma's Second Supply water right. Total storage volume (Baseline + Phase I) is 50,400 ac ft, pool elevation 1167 ft.

Phase II of the AWSP replaces the Phase I storage with 9,600 ac ft of water for fish use in the summer and fall and an additional 22,400 ac ft for M&I for a total additional volume of 32,000 ac ft. Total storage volume (Baseline + Phase II) all years is 62,400 ac ft, pool elevation 1177 ft.

SUBSECTION 2B-1 HOWARD HANSON RESERVOIR PHYSICAL MEASUREMENTS

2B-1.1 PROJECT PURPOSE AND SCOPE

In this sub-section we present several physical measurements that have been assumed to be associated with the production and survival of juvenile anadromous salmonids that are found to rear and migrate through Howard Hanson Reservoir.

The objective of this sub-section is to:

1. to provide the background of physical conditions in the reservoir,
2. compare these physical conditions to smolt production potential,
3. provide a brief discussion of water particle travel time vs. smolt travel and adult survival.

2B-1.2 RESERVOIR MORPHOMETRICS

Table 1 provides measurements of reservoir surface area, storage volume, reservoir length and shoreline perimeter. Appendix Table A-1. has modeled water velocities at 16 cross-sections from the dam to the edge of the Phase II pool over a broad range of flows and for several pool elevations. Modeled changes in outflow and refill rate are presented in sub-section 2B-5 and are used in the incremental analysis of changes in reservoir travel time. Some of the measurements in Tables 1 and Appendix Table A-1 have been previously provided to the resource agencies and to the Delphi Workgroup. Also, in 1995, the U.S. Fish and Wildlife Service (USFWS) cooperated in a study with the Corps measuring smolt travel time through the reservoir under various pool conditions. The report summarizing the study results incorporated existing reservoir measurements for that year in a multivariate analysis (Aitkin et al. 1996). The results of that report and additional analysis performed by the Corps is presented in sub-sections 2B-3. and 2B-4. Table 3 shows the incremental change for several reservoir variables going from Baseline to Phase I, Baseline to Phase II, and Phase I to Phase II.

The Seattle District mapped the reservoir basin area at scales of 1 in = 200 ft in 1961, and 1 in = 400 ft in 1972. Surface area was measured by the original survey crew and storage volumes were estimated by Hydraulics Hydrology using conical volume models. A planimeter and map wheel were used to measure reservoir length and shoreline perimeter off the large scale topographic maps. The Corps modeled water particle travel time (WPTT) for various pool elevations for Baseline, Phase I, and Phase II. The results of this modeling is shown in Appendix Table A-1, water velocity, which was used to calculate

WPTT (Figure 3). The Hydraulics and Hydrology Section of the Corps completed the modeling using results from existing HEC-2 and HEC-6 models to calculate velocities and travel times. Cross-sections used in the velocity calculations were from reservoir cross-sections measured in 1961 and remeasured in 1979 and 1993. The model is a steady-state model where outflow must equal inflow, therefore this model cannot account for differences in refill rate. Table 3 shows a simple comparison of WPTT for a median May (1250 cfs; inflow to HHD for years 1964-1995) for Baseline to Phase I and Baseline to Phase II.

TABLE 1. HOWARD HANSON RESERVOIR (POOL) PHYSICAL MEASUREMENTS -- SURFACE AREA, VOLUME, LENGTH, AND SHORELINE PERIMETER AT VARIOUS POOL ELEVATIONS.

Pool Elevation, Surface Area, and Volume (at 15 ft increments)

Pool Elevation	Surface Acres	Total Volume (ac-ft)	Description
1035	0	0	Run of River
1070	100	1200	Low Pool (Turbidity Pool)
1085	165	2675	
1100	255	6300	
1115	385	10290	
1130	560	17265	
1141	763	25400	Baseline Conservation Pool
1147	871	30400	Drought Year Pool
1162	1077	45400	
1167	1134	50400	Phase I Pool
1177	1254	62400	Phase II Conservation Pool
1206	1750	102764	Flood Storage Reservation

Pool Elevation, Pool Length, and Shoreline Perimeter (at 10 ft increments)

Pool Elevation	Length (miles)	Perimeter (miles)	Description
1035	0	0.0	Run of River
1070	1.5	3.1	Low Pool (Turbidity Pool)
1080	1.8	3.7	
1090	2.5	5.0	
1100	2.8	6.8	
1110	3.1	7.5	
1120	3.4	9.0	
1130	3.9	11.2	
1140	4.3	12.0	
1141	4.3	12.2	Baseline Conservation Pool
1150	4.7	13.5	Drought Year Pool
1160	5.1	14.9	
1162	5.1	15.2	
1167	5.4	15.9	Phase I Pool
1170	5.5	16.3	
1177	5.7	17.3	Phase II Conservation Pool
1180	5.8	17.9	

TABLE 3. COMPARISON OF THE INCREMENTAL INCREASE IN RESERVOIR VARIABLES AT FULL POOL FOR BASELINE (1147)-PHASE I, BASELINE-PHASE II, AND PHASE I TO PHASE II.

	Baseline-Phase I	Baseline-Phase II	Phase I-Phase II
Surface Area (acres)	263	406	120
Reservoir Length (miles)	0.7	1.0	0.3
Shoreline Perimeter (miles)	2.9	4.3	1.4
Total Volume (ac-ft)	20,000	32,000	12,000
Water Particle T.Time (hr) at 1250 cfs[a]	204	345	141

a. Modeled water particle travel time for a median May=1250 cfs: Baseline 1141=235 hr; Phase I 1162=439 hr; Phase II 1175=580 hr.

2B-1.3 RESULTS AND DISCUSSION

Smolt production. Of all stocks found in the Headwaters, coho salmon may be best adapted to rearing in the slower velocity water of ponds and lakes, and therefore reservoirs (Reeves et al. 1989; Wunderlich and Toal 1992). However, an emerging paradigm of juvenile rearing and outmigration (spiraling) of salmon in the Columbia River states that chinook juveniles may spend considerable time rearing in reservoirs as they outmigrate (Williams et al. 1996). Spiraling suggests that various life history types of chinook can find quality rearing habitat in selected reservoir areas. USFWS studies of Howard Hanson Reservoir (Dilley and Wunderlich 1992 and 1993; Dilley 1994) found tremendous growth rates for chinook juveniles in lower and upper reservoir areas. These juveniles were presumably trapped in the reservoir because the dam lacks a surface fish passage outlet. Figures 1 through 2 show the differences in reservoir size between low pool, 1070 ft elevation, Baseline normal year full pool, 1141 ft, Phase I drought year pool (1 in 5 years), 1167 ft, and Phase II full pool, 1177 ft. Discussion in this section uses existing full pool elevation of 1141 ft, and does not incorporate the Section 1135 5,000 ac ft storage.

Surface area has been correlated with the production of juvenile coho by various authors (Beechie et al. 1994; Reeves et al. 1989). In a study estimating the coho rearing habitat production of the Skagit River basin, biologists from the Skagit Tribe Fisheries Cooperative estimated that lakes in the Skagit Basin could produce 25 smolts per hectare (2.53 acres/hectare). Howard Hanson Reservoir is not a lake, having an extreme annual variation in surface area (and volume) from 100 to 763 acres for Baseline (1141 ft), and going from 100 to 1254 acres in Phase II. However, even with this extreme variation in surface area, the AWSP will have a greater surface area available for a longer period of time (over Baseline) that should have significant rearing potential. Dilley and Wunderlich (1992 and 1993) found up to 30,000 coho fry rearing in the existing reservoir that had reached smolt size (114 mm) by the end of the summer. A simple index estimation of the potential increase in coho smolt production for full pool shows that 1) for Baseline to Phase I, approximately 3400 more smolts could be produced; 2) for Baseline to Phase II, about 4850 more smolts could be produced. These estimates in increased production are off-set by the losses in tributary stream habitat inundated (*Section III*) and could be off-set by increases in resident fish production, especially resident trout, a potential predator of juvenile coho (Bennet 1970; Hamilton et al. 1970).

The Washington Department of Fish and Wildlife has also used a simple estimation of coho production in lakes by measuring total shoreline perimeter (Zillges 1977). They applied a production factor of 1.25 smolts per yard of lakeshore in Puget Sound. Baranski (1989) felt that this number needed updating and refinement. Applying this estimator to the full pool shoreline perimeter shows a potential incremental increase of 1) Baseline to Phase I, approximately 6600 more smolts could be produced; and 2) Baseline to Phase II, about 11220 more smolts could be produced. These values are almost 2 times greater than the estimates using smolts per surface area unit. As noted above, shoreline perimeter or surface area with the variation in pool area/volume may prevent "meaningful" estimation of coho production related to the larger AWSP pool and can only off-set losses from stream habitat inundation. Lastly, no associated value for chinook juvenile production in small reservoirs or in lakes has been developed so no estimate of additional production from the AWSP is available.

Even with uncertain estimates of additional smolt production, we presume the excellent rearing conditions documented under existing conditions for coho and chinook will be enhanced with the larger pool along with the associated habitat improvements from planned restoration and mitigation (*Section 8. Restoration and Mitigation Plan Summary*). One means of estimating total reservoir production potential is described below for resident fish in a nearby reservoir.

Production Potential for a Nearby Reservoir. Changes in reservoir size, whether in terms of area or volume can lead to increases in resident or anadromous fish number. Stables et al. (1990) assessed the effect of reservoir enlargement, at Spada Lake, Sulton River, Washington, on a natural trout fishery. Using creel survey and water quality survey they found yield increased from less than 1,000 kg/year before enlargement to nearly 5,000 kg/year after enlargement and then declined. Natural production in stream spawning and rearing areas was sufficient to maintain production but it appears harvest exceeded sustainable lucustrine production. Estimation of lake production capacity through the morphoedaphic index (total dissolved solids/mean lake depth) predicted total potential yield (kg/year) increased 84% after enlargement. Only limitations on natural production were moderate trout growth rates, compared to other lakes, and a diet consisting primarily of small invertebrates. Cutthroat trout yield was improved relative to rainbow trout.

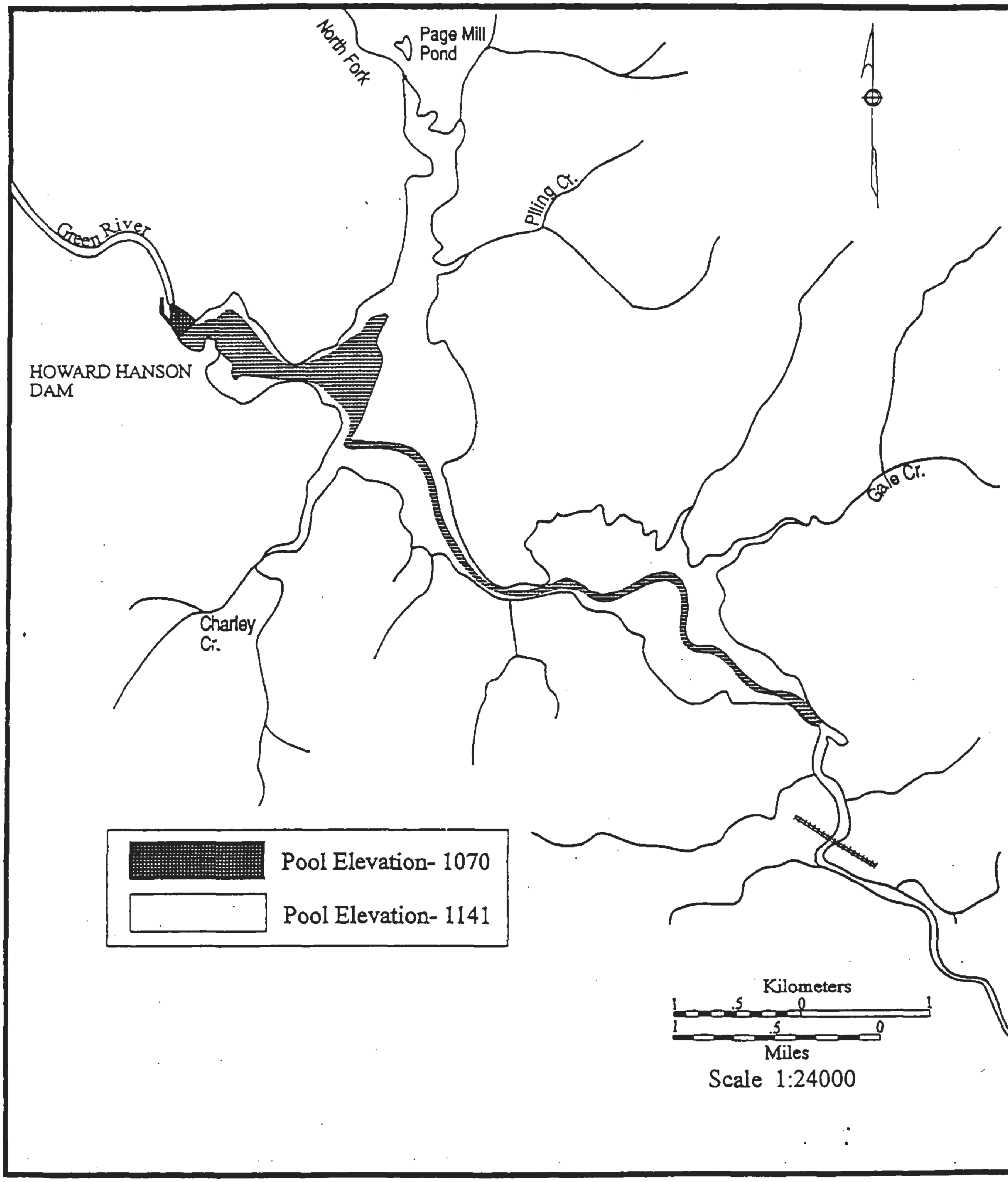


FIGURE 1. EXISTING RANGE OF HOWARD HANSON DAM RESERVOIR SIZE FROM LOW POOL, 1070 FT ELEVATION, TO NORMAL YEAR FULL POOL, 1141 FT ELEVATION.

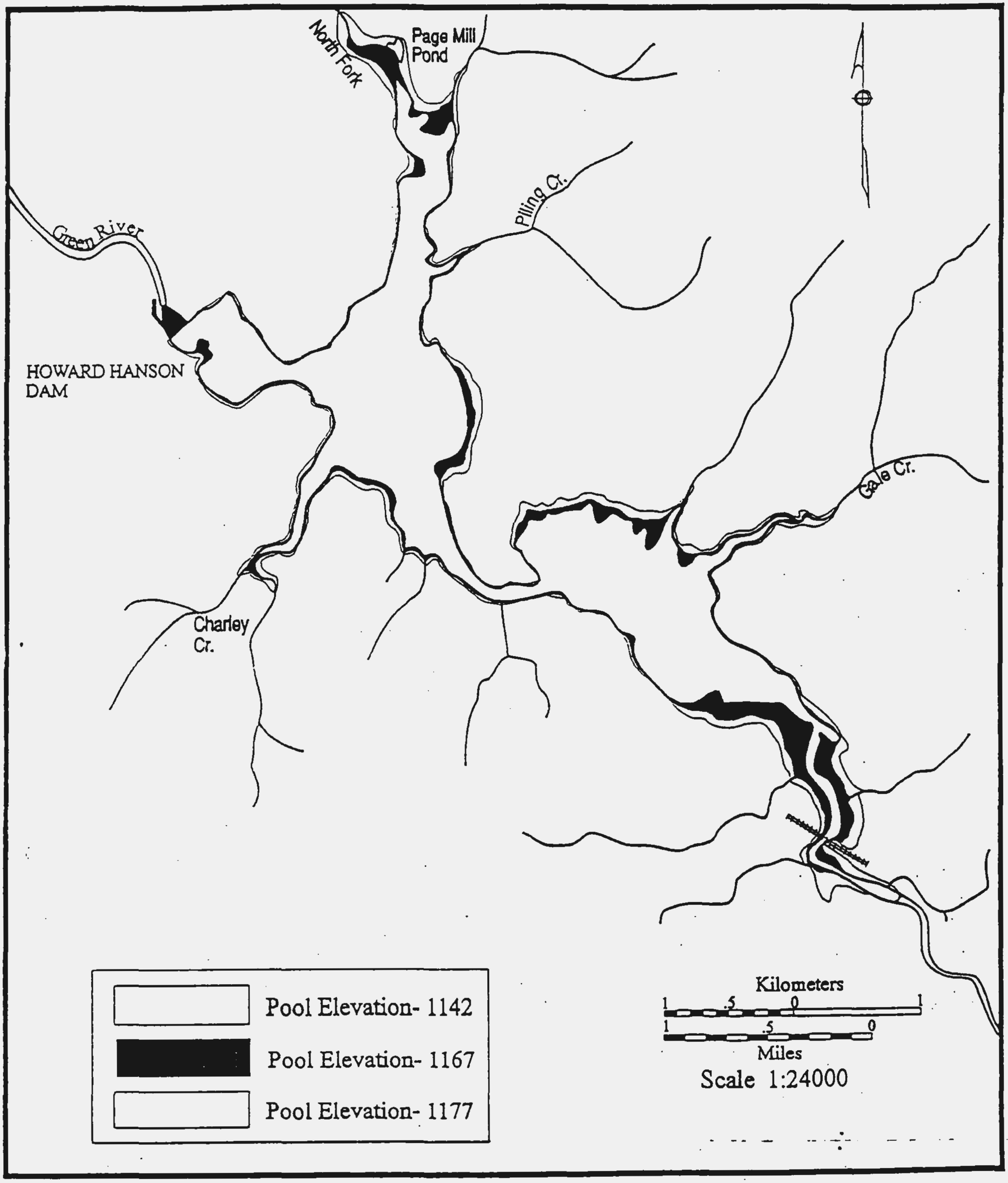


FIGURE 2. RANGE OF RESERVOIR POOL SIZE BETWEEN BASELINE FULL POOL, 1141(2) FT ELEVATION, AND PHASE I DROUGHT YEAR POOL, 1167 FT, AND PHASE II FULL POOL, 1177 FT.

Spada Lake is a multiple-use reservoir created in 1965 by impoundment of the Sultan River at RKM 27. It is operated for water supply and hydroelectric power and provides a sport fishery for wild populations of rainbow and cutthroat trout. Spada Lake was enlarged in 1984, surrounding lands were clearcut and slash was burned. The maximum pool elevation was raised from 1___-1420 ft depending on the state of drawdown while surface area at full pool increased from 789 to 1915 acres, and shoreline length increased from 23.9 to 44.1 miles.

Howard Hanson reservoir shares many similarities to Spada Lake. A similar estimation of reservoir productivity could be made for Howard Hanson Reservoir using morphoedaphic index. Conductivity data (uS/cm) can be used to estimate total dissolved solids (TDS, mg/L) an indicator of lake productivity. TDS range from 55 to 90% of conductivity in fresh water (APHA et al. 1985). Stables et al. (1990) used the general equation TDS=0.65(conductivity). This equation was used to estimate TDS for use in Ryder's 1965 morphoedaphic index (MEI) of potential fish production. The MEI was created with data collected from a series of northern temperate lakes. The MEI equation is described as:

log 10 (annual yield)=0.0407 + 0.446 log 10 MEI (annual yield is in kg/hectare, and MEI=TDS/mean lake depth (m)).

This model can be applied globally if used within available climatic conditions and fundamental model assumptions are met (Jenkins 1982; Ryder 1982; Schlessinger and Regier 1982). Spada Lake and Howard Hanson Reservoir are within Ryder's (1965) range of data for size, mean depth, climate, and mean TDS. In Spada Lake, specific conductance did not change after enlargement -- average 24.2 (uS/cm) before enlargement and 25.3 after. Total TDS was estimated at 16.3 mg/L; mean lake depth at full pool was 13.5 m before and 25 m after. The sustainable annual yield was predicted to be 1.19 kg/hectare before and 0.90 kg/hectare after enlargement. Converting this to total yield on the basis of lake surface area shows 371 kg/year before and 681 kg/year after enlargement. Most MEI predictions for Spada Lake were lower than actual harvest, which ranged from 2.22-2.56 kg/hectare before and 0.53-6.47 kg/hectare after enlargement, or MEI was exceeded by a factor of 2 before and by a factor of 7 after enlargement. Average annual lake surface fluctuation was less after enlargement varying from 2 to 15 m before and from 5 to 10 m after enlargement.

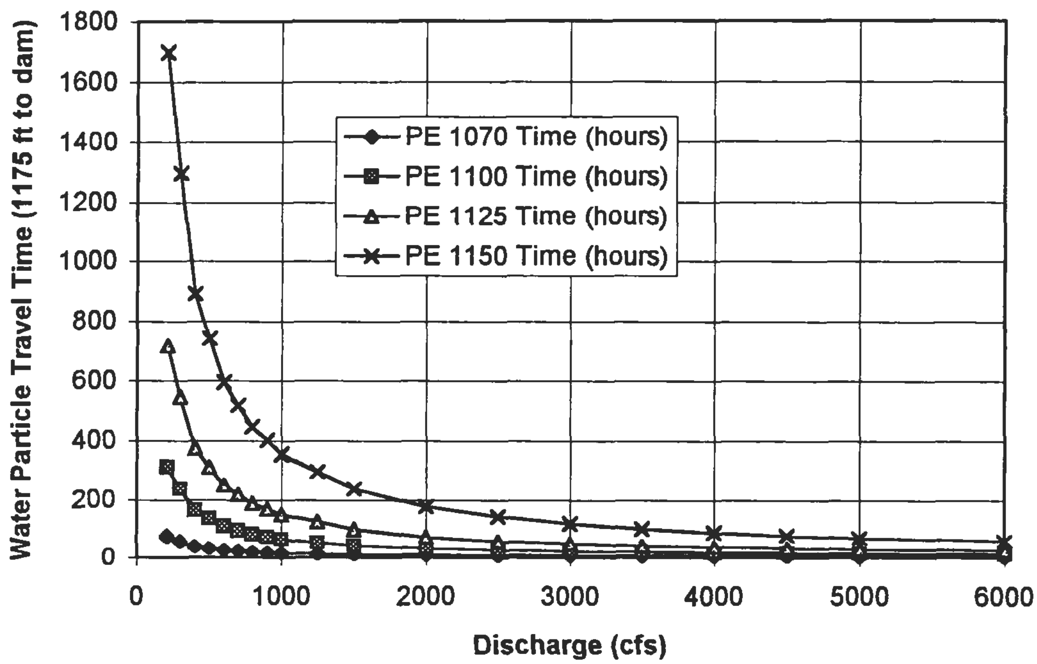
Eight km of stream were inundated after reservoir enlargement, it appears that rainbow trout have been more impacted than cutthroat by the loss of spawning and rearing area possibly because cutthroat trout spawn higher in the tributaries and thus loss less useable area. Water level fluctuations could reduce fish production by decreasing the abundance and diversity of benthic invertebrates in littoral areas exposed during drawdown (Fillion 1967; Benson and Hudson 1975; Bryan 1982). No estimate was made at Spada Lake before or after enlargement although the range of lake level fluctuation was greater before. The increased pelagic and littoral trout habitat due to lake enlargement should have lead to a higher total fish yield. However, there were off-setting factors such as the doubling of lake depth increasing the capacity of the lake as a nutrient and heat sink. Also a predicted increase in nutrient availability did not occur and the lake remains highly oligotrophic.

Changes in Smolt Travel Time. Most studies of the survival of outmigrating juvenile salmon and steelhead through reservoirs have been conducted on the Columbia River and its impoundments, few studies have been completed on small impoundments. The Corps considers that general results of Columbia River studies have application to Howard Hanson Reservoir but that specific results (such as travel rate/day) are not applicable (discussed further in the following sub-sections). Some of these studies have concluded that there is a relationship between the survival of smolts and how quickly they can reach the ocean. Although a more recent paradigm for the outmigration of juvenile salmonids, spiraling, suggests that certain life history types spend a considerable period of time rearing in the river (or in reservoirs) during their migration to the ocean (Williams et al. 1996). Original studies of impoundments on the Columbia River found that smolts move through impoundments on the Columbia River at 1/2 to 1/3 as fast as they do through free-flowing river sections of the same length (Raymond 1968; 1969; 1979). The timing and size of smolt appear to be affected differently by the reduction in how fast they traveled to the ocean. Two studies concluded that early run fish are larger, migrate faster, and may be more affected by flow than late runs such as subyearling chinook (Miller and Sims 1984; Sims et al. 1984).

Sims and Ossiander (1981) is the classic study that has created a polarization in understanding of smolt migration and survival. These authors stated that mortality was inversely correlated with flow. This study has resulted in some researchers who have a deterministic view of juvenile outmigration, that is, they believe that the survival of most if not all smolts is determined by the flow volume in the river and/or reservoir. A variety of researchers, including the Independent Scientific Review Group of the Northwest Power Planning Council, consider that there is a suite of physical and biological factors influencing the migration and survival of juvenile anadromous salmonids although flow is still considered one of the most important physical factors affecting the migration success of juvenile salmonids (Williams et al. 1996).. Work following that of Sims and Ossiander (1981) has tried to identify what features of flow, for what species and life stages, was affecting smolt survival. Water particle travel time, (WPTT), the speed at which a water particle travels a distance, has been discussed by various authors as a more relevant variable related to smolt travel time than simple measures of flow (Smith et al. 1993).

In 1995, we (USFWS and Corps) measured the travel time of smolts migrating through Howard Hanson Reservoir (sub-section 2B-3). We found that there was no correlation between the travel rate of coho or steelhead and the modeled WPTT. In fact, smolts appeared to swim much more quickly than WPTT in the reservoir. At full pool, outflow and inflow were near equal, inflow averaged 500 cfs (Table 2, subsection 2B-4) which equals a WPTT of 589 hours (24.5 days) at 1141 ft pool. Steelhead travel time at the pool level was 2.5 days, 10.2% of the WPTT, and coho travel time was 6 days, 24.5% of the WPTT. Chinook were timed at a later high pool under more adverse inflow conditions. These smaller tagged fish performed as well or better than tagged coho under lower inflow, mean inflow was 300 cfs (Table 2, sub-section 2B-4) -- WPTT was 1029 hr (42.8 days) while chinook travel time was 6.8 days, 15.9% of WPTT. An analysis of variance of coho and chinook travel time showed there was no significant difference even with the lower inflow and much slower WPTT faced by the chinook smolts.

Although WPTT may be related to smolt travel time (and possibly to smolt survival) in studies of the Columbia River, smolts in Howard Hanson Reservoir appear to swim much faster than WPTT when the pool is filling slowly or is stable. Instead, measures of flow appear to be more relevant physical factors than modeled WPTT: inflow to the reservoir is highly correlated with faster smolt travel rate (sub-section 2B-3) and overall adult survival of coho salmon (Section 2E.), while outflow from the project may be the strongest factor explaining daily passage at the dam (Section 2D.).



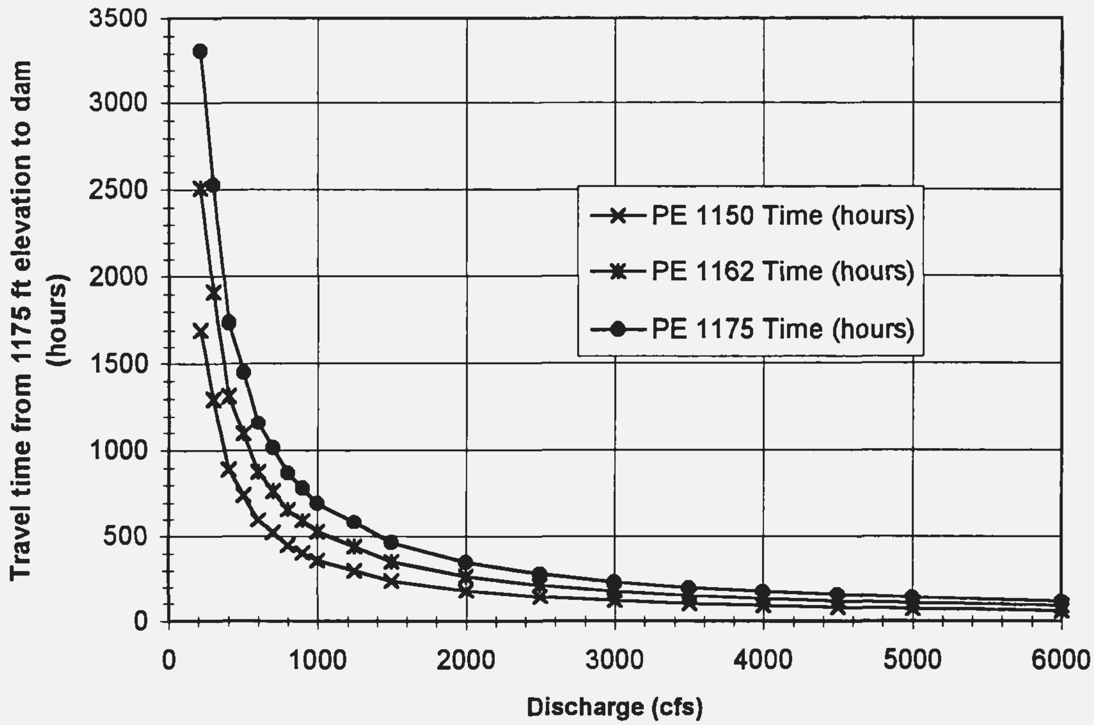


FIGURE 3. MODELED WATER PARTICLE TRAVEL TIMES FOR SPRING REFILL AND LOW-FLOW RANGE OF FLOWS (200-6,000 CFS OUTFLOW) FOR BASELINE CONDITIONS (TOP FIGURE: POOL ELEVATION=PE, 1070 FT TO 1150 FT) AND AWSP PHASE I AND II (BOTTOM FIGURE: PE= BASELINE DROUGHT 1150 FT, PE=1162 FT, PHASE I NORMAL YEAR, AND 1175 FT).

2B-1.4 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1985. Standard methods for the examination of water and wastewater, 16th edition. American Public Health Association, Washington, D.C.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Benson, N.G., and P.L. Hudson. 1975. Effects of reduced fall drawdown on benthos abundance in Lake Francis Case. Transactions of the American Fisheries Society 104:526-528.

Bryan, K.A. 1982. An investigation of some factors influencing the performance of a recreational trout fishery. Journal of Applied Ecology 19:113-131.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Harr, R.D., and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run watershed, Oregon. Water Resources Bulletin 24:1103-1111.

Jenkins, R.M. 1982. The morphoedaphic index and reservoir fish production. Transactions of the American Fisheries Society 111:133-140.

Miller, D.R., and C.W. Sims. 1984. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Report (contract DE-AI179-83BP39645) to Bonneville Power Administration, Portland, Oregon.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. U.S. Forest Service General Technical Report PNW-245.

Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Transactions of the American Fisheries Society 94:214-218.

Ryder, R.A. 1982. The morphoedaphic index--use, abuse, and fundamental concepts. Transactions of the American Fisheries Society 111:154-164

Sims, C.W., A.E. Giorgi, R.C. Johnsen, and D.A. Brege. 1984. Migrational characteristics of juvenile salmon and steelhead in the Columbia River basin-1983. Report (contracts DACW68-78-0051 and DACW57-81-F-0342) to U.S. Army Corps of Engineers, Portland, Oregon.

Sims, C.W., and F.J. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead in the Snake River, from 1973 to 1979, a research summary. Report (contract DACW68-78-C-0038) to U.S. Army Corps of Engineers, Portland, Oregon.

Stables, T.B., G.L. Thomas, S.T. Thiesfeld, G.B. Pauley, and M.A. Wert. 1990. Effects of reservoir enlargement and other factors on the yield of wild rainbow and cutthroat trout in Spada Lake, Washington. North American Journal of Fisheries Management 10:305-314.

Wunderlich, R. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, pre-season run size prediction and in-season run assessment. Washington Department of Fisheries Technical Report 28.

Appendix Table A-1. Howard Hanson Reservoir modeled velocities at reservoir cross-sections (sedimentation cross-sections) for incremental reservoir elevations (pools 1070, 1100, 1125, 1150, 1175 ft) and flow rates (200-6,000 cfs) from HEC-2 model, sections used from Ed Zapel's HHD Reservoir sedimentation resurvey HEC-6 model (Section no 800-2300).

BOLD and ***ITALICIZED flow values are averages from previous and following calculated velocities.***
OUTLINED sections represent reservoir extents for given pool elevation:
Reservoir Cross-Section Numbers correspond to pool elevations: 1400=1070 ft pool extent, 1800=1000, 2000=1125, 2100=1150, 2300=1177 ft pool (actual elevation is 1175 ft).
BOLD velocities anomalous due to excessive reach lengths and channel section

Channel Velocities in fps

								1070				1100		1125	1150	1160	1175
Pool Elev	Flow (cfs)	800	900	1000	1100	1200	1300	1400	1500	1600	1700	180	1900	2000	2100	2200	2300
1070	210	0.02	0.02	0.01	0.02	0.02	0.05	4.79	0.75	0.56	**7.43**	1.02	2.15	1.17	**4.06**	0.84	2.54
	300	0.03	0.03	0.02	0.03	0.03	0.08	5.17	0.86	0.69	**8.07**	1.14	2.30	1.21	**3.86**	0.98	2.71
	400	0.04	0.03	0.03	0.03	0.04	0.10	5.54	0.97	0.81	**8.71**	1.25	2.45	1.24	**3.65**	1.11	2.87
	500	0.05	0.04	0.04	0.04	0.05	0.13	5.76	1.06	0.92	**9.08**	1.35	2.54	1.29	**3.73**	1.22	2.93
	600	0.05	0.05	0.04	0.05	0.06	0.15	5.98	1.15	1.02	**9.44**	1.44	2.62	1.34	**3.80**	1.32	2.99
	700	0.06	0.06	0.05	0.06	0.07	0.18	6.14	1.22	1.11	**9.67**	1.52	2.65	1.40	**3.90**	1.41	3.10
	800	0.07	0.06	0.06	0.07	0.08	0.21	6.30	1.29	1.20	**9.89**	1.59	2.67	1.46	**3.99**	1.50	3.21
	900	0.08	0.07	0.07	0.08	0.09	0.24	6.45	1.35	1.28	**10.0**	1.65	2.62	1.48	**4.02**	1.58	3.30
	1000	0.09	0.08	0.07	0.08	0.10	0.26	6.59	1.41	1.35	**10.16**	1.71	2.56	1.49	**4.04**	1.66	3.38
	1250	0.11	0.10	0.09	0.11	0.12	0.33	6.88	1.54	1.52	**10.5**	1.71	2.39	1.36	**3.77**	1.88	3.48
	1500	0.13	0.12	0.11	0.13	0.14	0.39	7.17	1.66	1.69	**11.00**	1.70	2.21	1.22	**3.49**	2.09	3.58
	2000	0.18	0.15	0.14	0.17	0.19	0.51	7.42	1.87	1.96	**10.25**	1.49	1.99	1.36	**3.52**	2.42	3.87
	2500	0.22	0.19	0.18	0.21	0.24	0.64	7.46	2.04	2.21	**10.18**	1.42	1.95	1.44	**3.73**	2.66	4.17
	3000	0.27	0.23	0.21	0.25	0.29	0.77	7.55	2.19	2.43	**10.18**	1.38	1.95	1.52	**3.96**	2.87	4.45
	3500	0.31	0.27	0.25	0.29	0.34	0.90	8.02	2.33	2.65	**10.59**	1.45	1.99	1.56	**4.30**	3.02	4.73
	4000	0.36	0.31	0.29	0.33	0.39	1.03	8.31	2.47	2.85	**10.96**	1.51	2.03	1.58	**4.61**	3.17	4.96
	4500	0.40	0.35	0.32	0.38	0.43	1.16	8.58	2.60	3.04	**10.25**	1.58	1.97	1.60	**4.84**	3.33	5.14
	5000	0.45	0.39	0.36	0.42	0.48	1.29	8.85	2.73	3.22	**9.71**	1.60	1.96	1.65	**5.00**	3.15	5.04
	6000	0.54	0.46	0.43	0.50	0.58	1.54	9.24	2.96	3.56	**9.08**	1.70	2.04	1.75	**5.39**	3.27	5.33
1100	210	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.12	1.17	2.22	1.05	1.70	1.45	1.02	1.70
	300	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.09	0.17	1.70	3.78	0.99	1.95	1.55	1.20	1.80
	400	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.12	0.22	2.22	5.34	0.93	2.20	1.65	1.38	1.90
	500	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.15	0.28	2.78	3.48	1.53	1.82	2.40	1.37	2.35
	600	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.18	0.33	3.34	1.61	2.12	1.43	3.14	1.36	2.80
	700	0.03	0.03	0.02	0.03	0.03	0.04	0.06	0.21	0.39	3.90	1.66	2.18	1.47	3.39	1.44	2.96
	800	0.03	0.03	0.02	0.03	0.03	0.04	0.07	0.24	0.45	4.45	1.70	2.23	1.51	3.64	1.52	3.12
	900	0.04	0.04	0.03	0.04	0.04	0.05	0.08	0.27	0.51	5.00	1.75	2.26	1.53	3.73	1.60	3.23
	1000	0.04	0.04	0.03	0.04	0.04	0.05	0.08	0.30	0.56	5.55	1.80	2.28	1.54	3.82	1.68	3.33
	1250	0.05	0.05	0.04	0.05	0.05	0.07	0.11	0.38	0.70	6.92	1.83	2.26	1.38	3.68	1.89	3.46
	1500	0.06	0.05	0.05	0.06	0.05	0.08	0.13	0.45	0.83	8.28	1.86	2.24	1.21	3.53	2.09	3.59
	2000	0.08	0.07	0.06	0.07	0.07	0.10	0.17	0.60	1.10	10.17	1.50	1.99	1.36	3.52	2.42	3.87
	2500	0.10	0.09	0.08	0.09	0.09	0.13	0.21	0.75	1.37	10.29	1.41	1.95	1.44	3.73	2.66	4.17
	3000	0.12	0.11	0.09	0.11	0.11	0.15	0.25	0.90	1.63	10.66	1.37	1.97	1.52	3.98	2.86	4.46

Pool Elev	Flow (cfs)	800	900	1000	1100	1200	1300	1400	1500	1600	1700	180	1900	2000	2100	2200	2300
	3500	0.15	0.12	0.11	0.13	0.13	0.18	0.29	1.05	1.88	10.94	1.44	2.00	1.56	4.32	3.02	4.73
	4000	0.17	0.14	0.12	0.15	0.14	0.20	0.34	1.19	2.13	10.86	1.51	2.02	1.58	4.60	3.18	4.95
	4500	0.19	0.16	0.14	0.17	0.16	0.23	0.38	1.34	2.37	10.24	1.58	1.97	1.60	4.84	3.33	5.14
	5000	0.21	0.18	0.15	0.19	0.18	0.25	0.42	1.49	2.60	9.81	1.60	1.96	1.65	5.01	3.15	5.04
	6000	0.25	0.21	0.18	0.22	0.22	0.31	0.50	1.78	3.04	9.21	1.70	2.04	1.75	5.40	3.26	5.33
1125	210	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.03	0.02	0.07	**5.90**	1.11	2.04	1.42
	300	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.06	0.05	0.03	0.10	**6.14**	1.17	2.07	1.54
	400	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.07	0.06	0.04	0.13	**6.38**	1.23	2.10	1.65
	500	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.09	0.08	0.05	0.17	**6.73**	1.29	2.16	1.77
	600	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.05	0.11	0.09	0.05	0.20	**7.08**	1.35	2.21	1.88
	700	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.13	0.11	0.06	0.23	**7.35**	1.44	2.29	2.00
	800	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.07	0.15	0.13	0.07	0.26	**7.62**	1.52	2.37	2.11
	900	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.17	0.15	0.08	0.30	**7.84**	1.59	2.46	2.23
	1000	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.09	0.18	0.16	0.09	0.33	**8.06**	1.65	2.55	2.34
	1250	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.11	0.23	0.20	0.12	0.41	**8.48**	1.78	2.72	2.59
	1500	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.13	0.28	0.24	0.14	0.49	**8.89**	1.90	2.88	2.83
	2000	0.06	0.05	0.04	0.05	0.05	0.05	0.06	0.17	0.37	0.31	0.18	0.65	**8.83**	2.12	3.14	3.22
	2500	0.07	0.06	0.05	0.06	0.06	0.06	0.07	0.21	0.46	0.39	0.23	0.80	**5.86**	2.45	3.24	3.64
	3000	0.08	0.07	0.06	0.07	0.07	0.08	0.09	0.26	0.55	0.47	0.27	0.94	**4.52**	2.79	3.32	4.01
	3500	0.10	0.08	0.07	0.08	0.08	0.09	0.10	0.30	0.65	0.55	0.32	1.08	**2.93**	2.99	3.49	4.28
	4000	0.11	0.10	0.08	0.09	0.09	0.10	0.12	0.34	0.74	0.63	0.36	1.21	**2.47**	3.35	3.56	4.58
	4500	0.12	0.11	0.09	0.10	0.10	0.11	0.13	0.39	0.83	0.70	0.41	1.33	**3.38**	3.75	3.62	4.86
	5000	0.14	0.12	0.10	0.11	0.11	0.13	0.15	0.43	0.92	0.78	0.45	1.44	**2.86**	4.09	3.70	5.09
	6000	0.17	0.14	0.11	0.14	0.14	0.15	0.18	0.52	1.11	0.93	0.54	1.63	**2.34**	4.71	3.42	5.19
1150	210	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.48	**5.74**	0.93
	300	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.01	0.01	0.02	0.70	**5.76**	1.16
	400	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.02	0.01	0.01	0.02	0.91	**5.77**	1.39
	500	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.05	0.02	0.01	0.01	0.03	1.14	**3.98**	1.62
	600	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.06	0.02	0.01	0.01	0.03	1.37	**2.18**	1.85
	700	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.07	0.03	0.02	0.02	0.04	1.61	**2.08**	2.10
	800	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.08	0.03	0.02	0.02	0.04	1.84	**1.98**	2.34
	900	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.04	0.09	0.04	0.02	0.02	0.05	2.08	**1.98**	2.56
	1000	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.04	0.10	0.04	0.02	0.02	0.05	2.31	**1.97**	2.77
	1250	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.06	0.12	0.05	0.03	0.03	0.07	2.93	**2.03**	3.18
	1500	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.07	0.14	0.06	0.03	0.03	0.08	3.54	**2.08**	3.59
	2000	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.09	0.19	0.08	0.04	0.05	0.10	4.86	**2.23**	4.19
	2500	0.05	0.04	0.03	0.04	0.04	0.03	0.03	0.11	0.24	0.10	0.06	0.06	0.13	6.36	**2.37**	4.67
	3000	0.06	0.05	0.04	0.05	0.05	0.04	0.04	0.13	0.29	0.11	0.07	0.07	0.15	8.36	**2.49**	5.09
	3500	0.07	0.06	0.05	0.06	0.06	0.05	0.05	0.15	0.34	0.13	0.08	0.08	0.18	9.00	**2.64**	5.34
	4000	0.08	0.07	0.05	0.06	0.06	0.06	0.05	0.18	0.39	0.15	0.09	0.09	0.20	9.37	**2.51**	5.19
	4500	0.09	0.08	0.06	0.07	0.07	0.06	0.06	0.20	0.43	0.17	0.10	0.10	0.23	9.68	**1.45**	5.33
	5000	0.10	0.09	0.07	0.08	0.08	0.07	0.07	0.22	0.48	0.19	0.11	0.11	0.25	9.98	**1.21**	5.51
	6000	0.12	0.11	0.08	0.10	0.10	0.08	0.08	0.26	0.58	0.23	0.13	0.14	0.30	10.5	**0.96**	5.83
1175	210	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.23
	300	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.02	0.05	0.34
	400	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.02	0.07	0.44
	500	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.03	0.01	0.01	0.01	0.01	0.03	0.09	0.56
	600	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.04	0.01	0.01	0.01	0.01	0.03	0.10	0.67
	700	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.01	0.01	0.01	0.01	0.04	0.12	0.78
	800	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.01	0.01	0.01	0.01	0.04	0.13	0.89

Pool Elev	Flow (cfs)	800	900	1000	1100	1200	1300	1400	1500	1600	1700	180	1900	2000	2100	2200	2300
	900	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.06	0.02	0.01	0.01	0.01	0.05	0.15	1.00
	1000	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.06	0.02	0.01	0.01	0.01	0.06	0.17	1.11
	1250	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.04	0.08	0.03	0.02	0.01	0.02	0.07	0.21	1.39
	1500	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.04	0.09	0.03	0.02	0.01	0.02	0.08	0.25	1.66
	2000	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.05	0.12	0.03	0.02	0.02	0.03	0.11	0.33	2.20
	2500	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.06	0.15	0.04	0.03	0.02	0.04	0.14	0.42	2.74
	3000	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.08	0.18	0.05	0.03	0.03	0.04	0.17	0.50	3.26
	3500	0.06	0.05	0.04	0.04	0.04	0.03	0.02	0.09	0.21	0.06	0.04	0.03	0.05	0.20	0.58	3.77
	4000	0.06	0.05	0.04	0.05	0.05	0.03	0.03	0.10	0.24	0.07	0.04	0.04	0.06	0.22	0.66	4.27
	4500	0.07	0.06	0.05	0.05	0.05	0.04	0.03	0.11	0.27	0.08	0.05	0.04	0.07	0.25	0.75	4.74
	5000	0.08	0.07	0.05	0.06	0.06	0.04	0.04	0.13	0.30	0.09	0.05	0.05	0.07	0.28	0.83	5.20
	6000	0.09	0.08	0.06	0.07	0.07	0.05	0.04	0.15	0.36	0.10	0.06	0.06	0.09	0.34	0.99	6.06

SUBSECTION 2B-2 COMPARISON OF HOWARD HANSON RESERVOIR TO OTHER LAKES AND RESERVOIRS FOUND IN OREGON AND WASHINGTON

2B-2.1 PROJECT PURPOSE AND SCOPE

The previous sub-section presented some measures of change in Howard Hanson Reservoir size and flow properties. This sub-section continues that presentation with a comparison of Howard Hanson Reservoir to other lakes and reservoirs found in Oregon and Washington. This comparison is important to provide context to the anticipated change in pool size from the AWSP and to consider whether Howard Hanson Reservoir, Baseline or the AWSP, is a large enough impediment to outmigrating smolts that it could adversely affect their overall survival even with an improved fish passage facility.

Objectives of this sub-section are:

1. provide a list of selected lakes and reservoirs in Oregon and Washington, with physical characteristics, that have had or still have components of the historical anadromous fish runs found in the Upper and Headwaters watershed of the Green River (Tables 1 and 3),

2. compare physical characteristics of various reservoirs in Washington with Howard Hanson Reservoir, Baseline to AWSP (Tables 2 and 3), and

3. discuss the natural history of anadromous salmonids in relation to impoundments, lakes or reservoirs, and the potential for establishment of natural reproducing runs above Howard Hanson Reservoir (Table 4 and 5).

2B-2.2 METHODS

A variety of references were used to compile a list of lakes and reservoirs, with physical characteristics, that historically included one or more of the anadromous salmonid stocks found in the Upper and Headwaters Green River; coho, summer/fall chinook, spring chinook, and winter steelhead. The Atlas of Oregon Lakes was used for most lakes and reservoirs in Oregon (Johnson et al. 1985). A number of references were used to compile lake and reservoir characteristics for Washington (Corps Water Control Manual; Goodwin and Westley 1967; Westley and Goodwin 1967; Wolcott 1973; Dion et al. 1976a, 1976b, 1976c, 1976d; Stober and Bell 1986; Edmundson 1991).

The physical characteristics of the lakes and reservoirs considered for comparison were primarily measures of lake morphometry: lake elevation; thalweg length (length of channel); shoreline length (or perimeter); total storage capacity (volume); surface area; shoal area; volume factor (Oregon lakes); shape factor; retention time (volume/flow); maximum depth; average depth (lakes); ratio of average to maximum depth (lakes); mean inflow (lakes, where available); and mean outflow (reservoirs, where available). Most measurements were available from the references cited above. Thalweg length and shoreline perimeter were not available for all lakes and reservoirs: these variables were measured off the largest scale topographic map available for those impoundments. If no value is reported for a variable, then no reference or means of measurement was available. Table 3 outflow values are actual values for reservoirs other than Howard Hanson. Howard Hanson outflow and reservoir storage volume are modeled based on actual inflow from 1994. Modeling parameters and refill characteristics are fully described in *Section IX. Modeling Parameters for Baseline, Phase I, and Phase II.*

In Tables 2 and 3, the storage volume of Lake Washington, 159,000 ac ft, as reported, is inaccurate. This storage volume represents the upper 7 ft of water depth that is managed as reservoir storage volume. The Corps manages total lake storage from MSL 15 to 22 ft. The 15 ft elevation is the lower depth of the spillway gates while 22 ft is the top of the spillway dam. Total storage capacity for Lake Washington is not available from the references reviewed, but should be considered an order of magnitude greater than 159,000 ac ft as the maximum lake depth is 219 ft. For example, shoal area is the area of the lake less than 10 ft deep, the value for Lake Washington is 7.8%.

Species distribution of anadromous stocks was compiled from references used for the morphometrics comparison and from the Washington Department of Fish and Wildlife Stock Status Report for Salmon and Steelhead (SASSI 1992). The SASSI provides species status reports from river basins and includes a distribution map of natural spawning areas. These distribution maps were used to identify stocks that spawn above natural lakes in Washington. In some cases distribution maps were not clear in the end point of spawning, or where one stock may end and another begins. Table 1 provides of list of natural lakes and anadromous stocks found above these lakes. A question mark follows some stocks where information was not available to confirm distribution for a particular stock. Tables 4 and 5 provide a list of lakes and reservoirs in Washington that anadromous stocks are found above.

2B-2.3 RESULTS AND DISCUSSION

Physical Characteristics of Lakes and Reservoirs. Table 1 provides a list of the physical characteristics of natural lakes in Oregon and Washington that have had or still have components of the Upper and Headwaters Green River anadromous fish stocks; the anadromous stocks found above these lakes is also provided. Table 2 lists physical characteristics of reservoirs in Oregon and Washington found on anadromous bearing streams, including Howard Hanson Reservoir. Table 3 provides a more detailed comparison of various Washington reservoirs, including HHD Baseline and AWSP, for selected morphometrics.

During outmigration to the ocean, juvenile anadromous salmonids either follow the shoreline or the thalweg of rivers or lakes. Smaller fish typically are found closer to the shoreline, while larger juveniles tend towards the thalweg (center) of the channel (Williams et al. 1996). Even within a species or stock, both variants of channel position, shoreline or thalweg, can be observed. In Howard Hanson Reservoir, juveniles have been observed close to shore (within 1/4 mile) in the lower reservoir, but as smolts are presumed to travel primarily along the old river channel (thalweg) as this is the channel location with the highest velocities (Dilley 1994; Aitkin et al. 1996). Howard Hanson Reservoir is also atypical in shoreline configuration having several "pinchpoints" where fish are funneled through natural areas of river confinement (gorge areas or bedrock outcropping) where there are accelerated velocities and little or no difference between shoreline and channel position. There are four such locations throughout the reservoir: 1) at the head of the proposed AWSP project; 2) through Eagle Gorge -- the separation point of the upper and lower reservoir; 3) 0.5 miles above the dam; and 4) at the forebay of the dam. These pinchpoints are not much wider than bankful width of the river and represent natural "training" areas for outmigrants to be guided downstream.

Thalweg length and shoreline perimeter of the listed natural lakes and reservoirs with anadromous salmonids vary tremendously: the actual length of shoreline outmigrants must traverse should be considered about half the shoreline perimeter. Lake Washington (a natural lake managed as a reservoir) for example, has a shoreline perimeter of 90 miles and a total lake length of 20.7 miles. Unlike any other reported lake, the Lake Washington watershed is actually a multi-lake or tri-lake system. Lake Sammamish is joined to Washington by the Sammamish Slough and Washington is linked to Lake Union and Puget Sound by the Lake Washington Ship Canal. Within this one watershed, the actual thalweg length outmigrants have to traverse either by shoreline or thalweg route is additive (one or more lakes) depending on the starting point. The greatest distance would occur for smolts originating on Issaquah Creek, the major tributary to Lake Sammamish. Using thalweg length, these outmigrants would have to travel the entire length of Sammamish (8.4 miles), up to half the distance of Washington (10.3 miles), and the entire length of the Ship Canal (8.6 miles, managed as a continuous waterbody with Lake Washington) or a total of 27.3 miles. This great distance smolts must traverse has not proven a hindrance to productivity of the system. Prior to the 1980s, the adult survival rate or production of coho, steelhead, and chinook in Lake Washington equaled or exceeded that of surrounding riverine watersheds, including the lower Green River. Various factors have been hypothesized to be limiting current production but reservoir distance traveled, or travel rate, has not been put forth as a limiting factor.

Most lakes are substantially smaller than the Lake Washington system. Lakes in Washington varied in length from 0.9 to 20.7 miles and perimeter from 5 to 90.5 miles. Oregon lakes were generally within this range, with lengths from 3 to 43 miles, perimeters from 3.6 to 87.8 miles. Klamath Lake had the greatest perimeter, 87.8 miles. For lakes in both states, storage volume ranged from 7700 to 850,000 ac ft and surface area from 300 to 61,500 acres. By comparison, Howard Hanson Reservoir for Baseline to Phase II is 4.3-5.9 miles long, has a perimeter of 12-17 miles, with storage volume of 25,400 to 62,400 ac ft, and surface area of 750 to 1250 acres.

Reservoirs in both states tend to be substantially larger than the natural lakes. Several of these natural lakes have been converted to reservoir storage for one or more purposes including flood control, water supply, navigation and hydroelectric power. In Washington, Baker, Kachess, Keechelus, Cle Elum, Lake Washington, and Lake Union are now managed as reservoirs. In Oregon, two or more of the Coast Range lakes have dams on the outlet of the lake but are not actively managed as reservoirs. Klamath Lake is also managed as a storage reservoir. Except for Lake Washington, all of the Washington lakes managed as reservoirs have been enlarged in size.

Shoreline length and perimeter distance for Oregon and Washington reservoirs are generally longer than Howard Hanson Reservoir ranging from 2.5-23.9 miles in length and 3.1 to 62.2 miles in perimeter (excluding Lake Washington). Total storage volume and surface area are also substantially greater than Hanson, varying from 9800 to 1,435,000 ac ft in volume and 90 to 11,680 acres in area.

Table 3 gives a more detailed comparison Howard Hanson Baseline, Phase I, and Phase II, to other Washington reservoirs for a sample year, 1994: reservoir volume, area, and retention time for 3 months. All of the reservoirs considered in this comparison either have had outmigration studies or still have outmigrating populations of naturally reared anadromous salmonids. Compared to 9 other reservoirs, Hanson Baseline full pool has the second smallest reservoir volume, third smallest area, and near medium retention time. Phase I full pool has the third smallest volume, fourth smallest area, and near median retention time. Phase II full pool follows the same pattern. The retention times reported for Howard Hanson Reservoir should be considered much longer than average, 1994 is considered a very dry to average year for the months presented. For 32 years of record, exceedance flows show May of 1994 flow was exceeded 95% of the time, June flow was exceeded 70%, and July flow near 50%.

Based on physical size and water retention time, Howard Hanson Reservoir should be considered a small to medium reservoir. It is within the size bounds of other lakes that have had or still have naturally reared populations of anadromous salmonids. The Corps considers that the increase in reservoir size from Baseline to the AWSP storage pool should not prevent the restoration of the historical anadromous fish stocks found in the Headwaters Green River watershed. However, there will be an incremental decline in at least one performance measure, travel time, through the project from Baseline to Phase I and Phase II, results are presented in Section 2B.5.

Natural History of Anadromous Salmonids and Lakes. Table 1 provides a list of 24 natural lakes in Oregon and Washington where one or more stocks of historical anadromous fish species found in the Headwaters Green River are or were present. These stocks were discussed in *Section 2A. Production Potential of the Headwaters Green River Watershed* and include coho, steelhead, spring chinook, and sea-run cutthroat trout. Summer-fall chinook stock from the lower Green River have been introduced to the Headwaters since 1982 and will be considered representative of the historical fish assemblage for this report. There is little available information on the history of Headwaters sea-run cutthroat trout, and they will not be discussed.

Of the 24 lakes listed in Table 1, 63% of the lakes have had coho salmon populations (15 of 24), 83% have had steelhead (20 of 24), and 46% have had chinook salmon (11 of 24): these numbers includes stocks that were unconfirmed, with ? following stock name in Table 1. Of the lakes with chinook, 6 have had spring chinook and 5 fall chinook salmon. A more detailed breakdown of the historical distribution of salmon and steelhead and presence above Washington lakes is presented in Table 4: additional smaller lakes are listed in Table 4 not provided in Table 1. Lake location is categorized by geomorphic province, Coast, Puget Sound, and Upper Columbia Province (Franklin and Dryness 1973). As in the listing of Oregon and Washington lakes, steelhead and coho are represented in greater numbers than chinook salmon above Washington lakes. Steelhead were found above 86% of lakes (13 of 15), coho above 100% (10 of 10), fall chinook above 13% (2 of 16), and spring chinook 31% (5 of 16).

A final listing is presented for historical Headwaters Green River species found above reservoirs in Table 5. These stocks are maintained either through natural reproduction or hatchery outplanting of juveniles. Reservoirs tallied are non-Columbia River reservoirs found in western Washington and Oregon. The percentages of stocks persisting above reservoirs closely parallels that of natural lakes -- steelhead and coho above 5 of 6 reservoirs, summer/fall chinook above 1 of 6, and spring chinook persist above 2 of 7 reservoirs.

The distribution of stocks found above natural lakes and persisting above reservoirs is one indicator of the potential for restoration of salmon stocks above Howard Hanson Reservoir. From the tally of lakes and reservoirs, steelhead and coho salmon seem to have naturally pioneered river basins with lakes and to have successfully adapted to outmigrate through the lakes at critical life-stages as juveniles or smolts. The lower number of lakes with chinook stocks should not be considered a fatal condition limiting their restoration potential. Chinook pioneering of many of the lakes considered may never have occurred for at least two reasons: 1) the lakes that were not pioneered and colonized by chinook may be above natural barriers that are passable by coho and steelhead but not chinook; and 2) chinook habitat (often larger rivers and streams) is usually distinct from coho and steelhead (smaller rivers and streams), and in some river systems there maybe little or no overlap in habitat use.

The number of reservoirs where chinook stocks persist or are artificially maintained may be a relic of management policies, geographic setting and siting of the reservoirs. For example, Wynoochee Dam and Reservoir appear to have been sited in the main spawning area of a small spring chinook salmon population (<250 adults). Within a few years of dam construction, few or no adult spring chinook were observed in the system. Spring chinook stock from a nearby population were introduced briefly for 1 to 2 years but a systematic long-term recovery program has not be pursued. This stock is not considered extirpated (SASSI 1992). In contrast, small numbers of summer/fall chinook stock from the lower Wynoochee are trapped, hauled and released above the dam each year although they were not historically present in this headwaters area (Corps 1996). Some reservoirs are used as rearing areas for chinook juveniles. In the Willamette Valley, some Corps reservoirs (Fall Creek for example) are heavily planted each year with fingerling spring chinook that experience good growth and good fry to smolt survival.

As discussed in the first subsection (2B.1) coho salmon may be best adapted to use of slack-water habitat, whether it be a pond, lake or artificial lake -- reservoir. In addition to the numerous ponds and lakes where coho juveniles rear, at least one study has described morphological distinctions between lake-rearing and stream-rearing populations of coho salmon (Swain and Holtby 1989). The body-type and behavior of the lake-rearing juveniles was clearly distinct from those of stream-rearing juveniles. The authors suggest that the differences in body-type represent a physical differentiation between the two stocks based on rearing location.

Exceptional growth rates for coho juveniles rearing in Howard Hanson Reservoir have been described by Washington Department of Fish and Wildlife (WDFW) and USFWS researchers (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992, 1993; Dilley 1994). These same USFWS researchers also noted extremely high growth rates for chinook juveniles and smolts rearing and/or entrapped in the reservoir. It has also been speculated that there are lake-rearing strains of rainbow and cutthroat trout, including adult trout, in Howard Hanson Reservoir although studies of the lower reservoir found no large trout (Wunderlich and Toal 1991; Dilley 1994). WDFW biologists did find large numbers of juvenile trout in surveys of the upper reservoir (T. Cropp, undated).

2B-2.4 LITERATURE CITED

Cropp, T. Undated. Howard Hanson Reservoir fish population study, July-August, 1989. Washington Department of Wildlife.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dion, N.P., G.C. Bortleson, J.B. McConnell, and L.M Nelson. 1976a. Reconnaissance data on lakes in Washington: Volume 1, Clallam, Island, Jefferson, San Juan, Skagit, and Whatcom Counties. Washington Dept. of Ecology Water Supply Bulletin No. 43.

Dion, N.P., G.C. Bortleson, J.B. McConnell, and L.M Nelson. 1976b. Reconnaissance data on lakes in Washington: Volume 2, King and Snohomish Counties. Washington Dept. of Ecology Water Supply Bulletin No. 43.

Dion, N.P., G.C. Bortleson, J.B. McConnell, and L.M Nelson. 1976c. Reconnaissance data on lakes in Washington: Volume 4, Clark, Cowlitz, Grays Harbor, Lewis, Pacific, Skamania, and Thurston Counties. Washington Dept. of Ecology Water Supply Bulletin No. 43.

Dion, N.P., G.C. Bortleson, J.B. McConnell, and L.M Nelson. 1976d. Reconnaissance data on lakes in Washington: Volume 5, Chelan, Ferry, Kittitas, Klickitat, Okanogan, and Yakima Counties. Washington Dept. of Ecology Water Supply Bulletin No. 43.

Edmondson, W.T. 1991. The uses of ecology: Lake Washington and beyond. University of Washington Press, Seattle. 329 pp.

Goodwin, C.L. and R.E. Westley. 1967. Limnological survey of Kachess, Keechelus, and Cle Elum Reservoirs. Washington Dept. of Fisheries, U.S. Bureau of Fisheries, Fish Passage Research Program.

Johnson, D.M, R.R. Petersen, D.R. Lycan, J.W. Sweet, and M.E. Neuhaus. 1985. Atlas of Oregon Lakes. Oregon State University Press, Corvallis. 317 pp.

Seiler, D., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia.

Stober, Q.C., and M.C. Bell. 1986. The feasibility of anadromous fish projects above the Alder/La Grande hydroelectric projects on the Nisqually River. Final Report to the Nisqually Indian Tribe. University of Washington Fisheries Research Institute, FRI-UW-8609. 50 pp.

Swain, D.P. and L.B. Holtby. 1989. Differences in morphology and behavior between juvenile coho salmon (Oncorhynchus kisutch) rearing in a lake and in its tributary stream. Canadian Journal of Fisheries and Aquatic Sciences 46: 1406-1414.

U.S. Army Corps of Engineers. 1996. Wynoochee Dam Section 1135 Environmental Restoration Project Management Report. Final Report Submitted to North Pacific Division.

Westley, R.E. and C.L. Goodwin. 1967. Limnological study of Mayfield Reservoir. Washington Dept. of Fisheries, U.S. Bureau of Fisheries, Fish Passage Research Program.

Wolcott, E.E. 1973. Lakes of Washington: Volume 1, Western Washington. Washington Dept. of Ecology Water Supply Bulletin No. 14.

Wunderlich, R.C. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. Western Washington Fishery Resource Office, Olympia, Washington.

TABLE 1. CHARACTERISTICS OF NATURAL LAKES THAT HISTORICALLY INCLUDED ONE OR MORE OF THE ANADROMOUS SALMONID STOCKS FOUND IN THE HEADWATERS AND UPPER GREEN RIVER; STEELHEAD, COHO, SUMMER/FALL CHINOOK, SPRING CHINOOK, AND SEA-RUN CUTTHROAT TROUT.

State	Geomorphic Province	County	River Basin	River or Stream	Lake	Stocks[1]
Washington	North Cascades	Whatcom	Skagit	Baker	Baker[4]	SO, SH, CO
	North Cascades	Chelan	Wenatchee	Wenatchee	Wenatchee	SO, SH, SCH
	North Cascades	Kittitas	Yakima	Kachess	Kachess[4]	SO, SH, SCH
	North Cascades	Kittitas	Yakima	Yakima	Keechelus[4]	SO, SH, SCH
	North Cascades	Kittitas	Yakima	Cle Elum	Cle Elum[4]	SO, SH, SCH
	Puget Sound	King	Duwamish	Green	Lake Sawyer	SCT?, CO?, SH?
	Puget Sound	King	Lake Washington	Cedar	Lake Sammamish	SO, CO, SH, FCH, SCT
	Puget Sound	King	Lake Washington	Cedar	Lake Washington[4]	SO, CO, SH, FCH, SCT
	Puget Sound	King	Lake Washington	Ship Canal	Lake Union	SO, CO, SH, FCH, SCT
	Olympic	Clallam	Ozette	Ozette	Ozette	CO,FCH,SO,SH,CH
	Olympic	Clallam	Quillayute	Lake Cr/Soleduk	Pleasant	CO,FCH,SO,SH?
	Olympic	Clallam	Quillayute	Dickey	Dickey	CO.SH
	Puget Sound	Mason	Mason	Sherwood Ck	Mason	CO, SH?
	Olympic	Grays Harbor	Quinault	Quinault	Quinault	CT,SO,DV
Oregon	Coast Range	Douglas	Mid-Coast Basin	Siltcoos River	Siltcoos	CT, SH, CO
	Coast Range	Douglas	Mid-Coast Basin	Siltcoos	Woahink	CO,CT
	Coast Range	Douglas	Mid-Coast Basin	Tahkenitch Creek	Tahkenitch	SH, CO
	Coast Range	Coos	South Coast	Tenmile Creek	Tenmile	CO,SH,CT
	Coast Range	Coos	South Coast	N. Tenmile Creek	N. Tenmile	CO
	Cascades	Klamath	Deschutes	Little Deschutes	Crescent	SH
	Cascades	Deschutes	Deschutes	Upper Deschutes	Cultus	SH
	Cascades	Jefferson	Deschutes	Metolius	Suttle	SH,SO
	Basin and Range	Klamath	Klamath	Klamath	Upper Klamath	PI, FCH, SCH, SH?
	Blue Mountains	Wallowa	Grande Ronde	Wallowa	Wallowa	SO, SH, SCH

Lake	Lake Elevation (ft)	Thalweg Length (miles)	Shoreline Length (miles)	Total Storage Capacity (ac-ft)	Area (acres)	Shoal Area	Volume Factor	Shape[2] Factor	Retention Time (days)	Maximum Depth (ft)	Average Depth (ft)	Av/Max Ratio	Mean Inflow
Baker[4]	674	N/A	N/A	100,676	2375				53.0	190			1890
Wenatchee	1868	5.2	13	360000	2500			1.9	205.7	240	150	0.60	1750
Kachess[4]	2221	N/A	N/A	N/A	N/A				N/A	374	272	0.73	N/A
Keechelus[4]	2456	N/A	N/A	44000	N/A				N/A	249	119	0.48	N/A
Cle Elum[4]	2101	N/A	N/A	N/A	N/A				N/A	171	121	0.71	N/A
Lake Sawyer	512	1.3	7	7700	300			2.9	N/A	58	26	0.45	N/A
Lake Sammamish	28	8.4	19		4897					100			305
Lake Washington[4]	22	20.71	90.5	159390	23464	7.8%			985.5	219	108	0.49	1261
Lake Union	22	5.7	6.1	20000	580			1.8	18.0	50	34	0.68	1261
Ozette	29	7.8	31	960000	7300			2.6	N/A	320	130	0.42	N/A
Pleasant	390	2.1	4.9	16000	500			1.6	N/A	50	32	0.64	N/A
Dickey	193	0.9	5	13000	500			1.6	N/A	45	25	0.56	N/A
Mason	195	4.8	11	49000	1000			2.4	N/A	90	48	0.53	N/A
Quinault	182	4	11.7		3729					156			2825
Siltcoos	8	5.8	27.8	33900	3164	32.0%	1.46	3.5	2.0	22	11	0.49	
Woahink	38	3.4	14.2	26700	820	17.0%	1.44	3.5	14.0	68	33	0.48	
Tahkenitch	11	3.1	25.5	18,200	1674	36.0%	1.42	4.4	2.0	23	11	0.47	
Tenmile	9	4.9	22.9	16,200	1627	42.0%	1.36	4.1	1.0	22	10	0.45	
N. Tenmile	9	4.6	19.3	12,100	1,098	41.0%	1.66	4	2.0	23	11	0.48	
Crescent	4839	4.7	12.4	566,000	4547	5.0%	1.41	1.4	156.0	265	124	0.47	
Cultus	791	3	6.8	62900	792	6.0%	1.13	1.7	48.0	211	80	0.38	
Suttle	3438		3.6	11200	253	10.0%	1.77	1.6	62.0	75	44	0.59	
Upper Klamath	4139	43	87.8	849300	61543	14.0%	0.83	2.5	15.0	50	14	0.28	
Wallowa	4383	3.7	8.2	243500	1508	3.0%	1.62	1.5	30.0	299	161	0.54	

1. Fish species: CO=coho, SCT, sea-run cutthroat, SH=steelhead, FCH=fall chinook, SCH=spring chinook, SO=sockeye
2. Shape factor is the same as shoreline configuration=ratio of length of shoreline to circumference of a circle having an area equal to that of the lake.
3. Length from north to south end, length from inlet (Cedar or Sammamish) to outlet is 13.9 miles.
4. LAKES BAKER, CLE ELUM, KACHES, AND KEECHELUS WERE ORIGINAL LAKES NOW MODIFIED WITH A DAM THAT HAS RAISED THE POOL, ORIGINAL LAKE MORPHOMETRICS WERE NOT AVAILABLE. LAKE WASHINGTON WAS LOWERED 9 FEET AND IS NOW REGULATED BY A DAM.

TABLE 2. CHARACTERISTICS OF VARIOUS IMPOUNDMENTS (FLOOD CONTROL, HYDROELECTRIC, AND MUNICIPAL WATER SUPPLY) ON ANADROMOUS BEARING STREAMS IN THE PACIFIC NORTHWEST (WASHINGTON AND OREGON).

State	River Basin	River or Stream	Dam	Lake Name	Reservoir Level
Washington	Skagit	Baker	U.Baker	Baker Lake	Low
			U.Baker		Full
	Skagit	Baker	L. Baker	Lake Shannon	Low
			L. Baker		Full
	Skagit	Skagit	Ross	Ross Lake	Full
	Skagit	Skagit	Diablo	Diablo Lake	Full
	Skagit	Skagit	Gorge	Gorge Lake	Full
	Duwamish	Green	Howard Hanson	Howard Hanson	Low
			Howard Hanson		Mid
			Howard Hanson		Full
			Howard Hanson	Proposed	Phase I
			Howard Hanson	Proposed	Phase 2
	Lake Washington	Cedar	LW Ship Canal	Lake Washington	Full
	Lake Washington	Ship Canal	LW Ship Canal	Lake Union + Ship Canal	Full
	Puyallup	White	Mud Mountain	Mud Mountain	Full
	Snohomish	Sultan	Sultan	Sultan	Full
	Nisqually	Nisqually	Alder	Alder	Full
	Elwha	Elwha	Glines	Lake Mills	Full
			Elwha	Lake Aldwell	Full
	Chehalis	Wynoochee	Wynoochee	Wynoochee	Low
			Wynoochee		Mid
			Wynoochee		Full
	Lower Columbia	Cowlitz	Mayfield	Mayfield	Full
			Riffe	Riffe	Full
	Lower Columbia	Lewis	Merwin	Merwin	Full
	Columbia	White Salmon	Condit	Northwestern Lake	Full
	Columbia	Yakima	Kachess	Kachess	Full
	Columbia	Yakima	Yakima	Keechelus	Full
	Columbia	Yakima	Cle Elum	Cle Elum	Full
Oregon	Willamette	South McKenzie	Cougar	Cougar	Full
	Willamette	North Santiam	Detroit	Detroit	Full
	Willamette	South Santiam	Foster	Foster	Full
	Willamette	Middle Santiam	Green Peter	Green Peter	Full
	Willamette	Long Tom	Fern Ridge	Fern Ridge	Full

	Willamette	Clackamas	North Fk Clackamas	North Fork Reservoir	Full
	Willamette	McKenzie	Blue River	Blue River	Full
	Willamette	Willamette	Dexter	Dexter	Full
	Willamette	Willamette	Lookout Point	Lookout Point	Full
	Willamette	M. Fk Willamette	Hills Creek	Hills Creek	Full
	Willamette	Willamette	Fall Creek	Fall Creek	Full
	Willamette	Coast Fk Willamette	Cottage Grove	Cottage Grove	Full
	Deschutes	Lower Deschutes	Pelton	Simtustus	Full
	Deschutes	Metolius	Round Butte	Billy Chinook	Full
	Rogue	Rogue River	Lost Creek	Lost Creek	Full
	Rogue	Rogue River	Applegate	Applegate	Full

Lake Name	Reservoir Level	Pool Elevation (ft)	Thalweg Length (miles)	Shoreline Length (miles)	Total Storage Capacity (ac-ft)	Surface Area (acres)	Shoal Area	Volume Factor	Shape[1] Factor	Outlet Depth or Maximum Head	Juvenile Bypass Type	Mean Outflow	Retention Time (days)	Maximum Depth (ft)
Baker Lake	Low	674	N/A	N/A	100,676	2375					Gulper	1890	53.3	190
	Full	724	12.2	26.9	285,473	4985				69	Gulper	1890	151.0	240
Lake Shannon	Low	363.6	N/A	N/A	28,123	1330						2670	10.5	185
	Full	438.6	8.3	19.5	159,470	2218				83.6		2670	59.7	260
Ross Lake	Full	1602.5	23.9	62.2	1,435,000	11,680					None	3814	376.2	
Diablo Lake	Full	1,205	4.2	14.6	90,000	910					None	4426	20.3	
Gorge Lake	Full	875	4.4	9.1	9,760	241					None	4426	2.2	
Howard Hanson	Low	1070	1.5	3.1	790	100				35	None	993	0.8	54
	Mid	1105	2.9	7.1	7305	300				70	None	993	7.4	89
	Full	1141	4.3	12.2	25400	763				106	None	993	25.6	125
Proposed	Phase I	1167	5.4	16.2	50400	1157				132	MIS/Proposed	993	50.8	153
Proposed	Phase II	1177	5.7	17.3	62400	1254				142	MIS/Proposed	993	62.8	161
Lake Washington	Full	22	20.71	90.5	159390	23464	7.8%			27	Overflow Weir	1261	839.5	219
Lake Union + Ship Canal	Full	22	5.7	14.4							Overflow Weir			50
Mud Mountain	Full										None			
Sultan	Full										None			
Alder	Full	1207	7.5	28	232,000	3,065					None	1400	62.9	285
Lake Mills	Full	590	2.8	5.8	40000	415					Eicher	1494	26.8	
Lake Aldwell	Full	200	2.5	5.3	8100	267						1494	5.4	
Wynoochee	Low	762.1	N/A	N/A	34,034	855					MultiLevel	535	63.6	132

Lake Name	Reservoir Level	Pool Elevation (ft)	Thalweg Length (miles)	Shoreline Length (miles)	Total Storage Capacity (ac-ft)	Surface Area (acres)	Shoal Area	Volume Factor	Shape[1] Factor	Outlet Depth or Maximum Head	Juvenile Bypass Type	Mean Outflow	Retention Time (days)	Maximum Depth (ft)
											Outlets			
	Mid	776.1	N/A	N/A	45,443	975					MultiLevel Outlets	535	84.9	146
	Full	800	4.4	10.4	69,405	1,122					MultiLevel Outlets	535	129.7	170
Mayfield	Full	425	10.6	24.8	133,700	2200					6 Floating Fish Traps/Gulper	6171	21.7	
Riffe	Full	770	23.5	51.7	1586285	11000					None	4823	328.9	
Merwin	Full	239.6	14	23.3	420,000	6,000				170	Gulper	4500	93.3	180
Northwestern Lake	Full	295	2	4.3	1302	92						1450	0.9	55
Kachess	Full	2262	7.3	15.4	239000	4540				374	None	150	1593.3	415
Keechelus	Full	2517	6	13.3	157000	2560				249	None	240	654.2	310
Cle Elum	Full	2240	8.5	18.5	436900	4878				171	?			310
Cougar	Full	1699	5.3	17	219300	1280	3.0%	1.19	3.8		Skimmer		120.0	425
Detroit	Full	1569	10	35.5	455,000	3580	5.0%	1.10	4.1		None		90.0	440
Foster	Full	641	5.9	19.7	61000	1220	10%	1.36	4.1		Overflow Weir		30.0	110
Green Peter	Full	1015	10.5	48	430000	3720	6.0%	0.98	6.4		Skimmer		144.0	315
Fern Ridge	Full	374	4.6	30.1	101200	9360	52%	1.00	2.6		Surface Spill		90.0	33
North Fork	Full	665	4.4	8.0	19000	324	12%	1.08	3.2		Pump		<7	120
Blue River	Full	1350	6.1	17	85,000	935	6.0%	1.10	4.3		MIS		90.0	248
Dexter	Full	695	2.9	7	27500	1025	21%	1.27	1.8				30.0	56
Lookout Point	Full	929	13.2	34.8	453000	4360	3.0%	1.24	4		Gulper		57.0	234
Hills Creek	Full	1543	8.7	32	356,000	2735	5.0%	1.00	3.9		None		42.0	299
Fall Creek	Full	834	9	22.4	125000	1860	10%	1.16	3.7		Skimmer		105.0	161
Cottage Grove	Full	790	3.6	7.6	33500	1139	17%	1.20	2.1				60	73
Simtustus	Full	1580	7.8	19.6	33200	637	12%	1.01	5.5		Skimmer		60.0	155
Billy Chinook	Full	1945	13	62.3	400,000	3916	5.0%	0.74	7.1		Skimmer		60.0	415
Lost Creek	Full	1872	9.8	31.1	465,000	3428	5.0%	1.26	3.8		None		120.0	322
Applegate	Full	1987	3	18.5	82,200	988	5.0%	1.10	4.3		None		210.0	225

1. Shape factor is same as shoreline configuration=ratio of shoreline length to circumference of a circle having an area equal to that of the lake.

TABLE 3. COMPARISON OF RETENTION TIME FOR A SAMPLE YEAR, 1994, DURING MAY, JUNE, AND JULY FOR VARIOUS IMPOUNDMENTS ON ANADROMOUS BEARING STREAMS IN WASHINGTON: ALL OF THE RESERVOIRS HAVE EITHER HAD OUTMIGRATION STUDIES OR STILL HAVE OUTMIGRATING POPULATIONS OF NATURAL REARED SMOLTS. VOLUME AND OUTFLOWS FOR HOWARD HANSON FULL (BASELINE), PHASE I (NORMAL YEAR), AND PHASE II ARE MODELED BASED ON 1994 INFLOWS.

Lake Name	Level	Reservoir Capacity (ac-ft)	Total Storage Area (acres)	May Outflow	May Retention Time (days)	June Outflow	June Retention Time (days)	July Outflow	July Retention Time (days)
Baker	Full	285,473	4985	2998	95.2	2351	121.4	2299	124.2
Lake Shannon	Full	159,470	2218	2998	53.2	2351	67.8	2299	69.4
Howard Hanson[1]	Full	24200	763	439	55.1	573	42.2	335	72.2
Proposed	Phase I	45400	1157	671	67.7	511	88.8	417	108.9
Proposed	Phase II	58000	1254	706	82.2	480	120.8	368	157.6
Lake Washington[2]	Full	159390	23464	882	180.7	771	206.7	369	432.0
Lake Mills	Full	40000	415	1407	28.4	1164	34.4	821	48.7
Lake Aldwell	Full	8100	267	1537	5.3	1311	6.2	913	8.9
Wynoochee	Full	69,405	1,122	215	322.8	279	248.8	279	248.8
Mayfield	Full	133,700	2200	5077	26.3	3907	34.2	3225	41.5
Riffe	Full	1586285	11000	5018	316.1	3600	440.6	2451	647.2

1. The 32 year percent exceedance flows for inflow in May and June show May of 1994 near 95% values, June near 70%, July near 50%.
2. Edmundson (1991) has previously calculated overall lake turnover rate as 2.3 years, numbers presented here are for a standard comparison of retention time and are only using the upper 7 ft of the lake that is managed as active storage (see Methods).

TABLE 4. HISTORICAL DISTRIBUTION OF NATIVE, WILD, ANADROMOUS SALMON FOUND ABOUT NATURAL LAKES IN COAST, NORTH CASCADES, AND SOUTH CASCADES GEOMORPHIC PROVINCES: WITH PERCENT OF POPULATIONS FOUND ABOVE THESE LAKES (ALL DATA FROM SASSI 1992).

Species	Coast Percentage	Total No. of Lakes	Puget Sound Percentage	Total No. of Lakes	U. Columbia Percentage	Total No. of Lakes	Total Percentage	Number of All Lakes
Summer/Fall Chinook	33	3	14	7	0[1]	6	12.5	16
Spring Chinook	33	3	0	7	67[2]	6	31.2	16
Coho	100[3]	3	100	7	?	?	100	10
Steelhead	67	3	86	7	100	5	86.7	15

1. Two Non-native stocks are found above lakes but are not counted here.
2. For two of the lakes reported, spring chinook above are questionable but counted here.
3. For one lake, fall coho are found above it, summer coho are not.

TABLE 5. RESERVOIRS WITH HISTORICAL HEADWATERS AND UPPER GREEN RIVER SPECIES STILL EXISTING IN THE UPPER WATERSHED THROUGH NATURAL REPRODUCTION OR COMBINATION WITH OUTPLANTING (NON-COLUMBIA RIVER RESERVOIRS IN WESTERN WASHINGTON AND OREGON).

Species	Reservoir Number	Reservoir Percentage
Summer/Fall Chinook	6	17
Spring Chinook	7	29
Coho	6	83
Winter Steelhead	6	83

SUBSECTION 2B-3 TRAVEL TIME AND FLOW RELATIONSHIPS OF COHO SALMON AND STEELHEAD SMOLTS MIGRATING THROUGH HOWARD HANSON RESERVOIR, A SMALL IMPOUNDMENT ON THE GREEN RIVER, WASHINGTON

2B-3.1 PROJECT PURPOSE AND SCOPE

This study was an addition to the original list of studies scoped for the Additional Water Storage Project (AWSP). It was added under a supplemental request for funding and schedule adjustment in 1992. The goal of the study, as listed in the SACCAR, was to gather data on the length of time juvenile fish require to migrate through Howard Hanson Reservoir and to use this information to predict travel time associated with increased storage.

Specifically, the travel time information was to be used to evaluate if the existing reservoir has a significant impact on the survival of outmigrating smolts. A measure of performance (travel time) was necessary in order to evaluate potential changes in the AWSP pool size and reservoir refill conditions. Successful passage through the entire HHD project, reservoir and dam passage, depends on the ability of fish to pass through the project safely, but also within their natural outmigration period, a time window or biological window.

If fish require additional time to exit the project beyond their normal outmigration period their survival can be affected. Some species of salmon can be expected to residualize if held too long beyond their emigration period, others have been found to re-smoltify up to certain limits beyond their emigration window. In selected rivers and reservoirs, an increase in migration time can provide additional opportunities for predators to prey on juvenile fish. There are three potential means that the existing and/or AWSP could increase travel time that could lead to delaying smolts beyond their normal emigration period: 1) migration through the reservoir, 2) delay in finding the dam outlet, and 3) actual entrapment by lack of a suitable dam outlet.

This study documents travel time through the known distances of the existing reservoir. It also provides variation in travel time, over known distances, with changes in reservoir refill operations. Information from these two areas, time by distance, and time by distance and refill conditions, was used to evaluate travel and potential survival through the existing project and to predict travel times under the AWSP. This section reviews existing travel time against reservoir refill operations and evaluates travel time in relation to specific biological windows of juvenile salmon and steelhead. Subsection 2B-5 provides estimated travel times under the AWSP.

2B-3.2 INTRODUCTION

This study is a compilation of the U.S. Fish and Wildlife Service report --

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. 1996. *Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington.* U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

and includes results from *Section 2B-4. Reservoir Outmigration of Juvenile Salmonids: Subsection: Analysis of Smolt Travel Time, Reservoir Physical Variables and Biological Variables.*

This study was presented at a scientific conference, the American Fisheries Society Western Division Annual Meeting, in July of 1996 by the following authors -- Fred Goetz, J. Kevin Aitkin, Jeff Dillon, and Carrie K. Cook-Tabor, and Robert Wunderlich: U.S. Army Corps of Engineers, Seattle, and U.S. Fish and Wildlife Service, Olympia, Washington under the Section 2B-2 title. This paper will be submitted for publication in a peer-reviewed scientific journal in the fall of 1997 following peer review and acceptance by contributing authors. Additional authors may be recognized under submission of the manuscript including but not limited to Eric Warner, Muckleshoot Indian Tribe (MIT), and Travis Shaw, Corps of Engineers. The presented abstract is as follows:

Abstract. In the Pacific Northwest, thousands of miles of productive stream habitat is isolated above tributary storage impoundments and is largely inaccessible to anadromous salmonids. Over several decades fish passage for outmigrating smolts was provided at the dam outlet to several of these impoundments, but with limited success. To date, little information has been available on the outmigration of Pacific salmonids through these small impoundments. At Howard Hanson Reservoir, on the Green River, we radio-tagged 110 coho salmon and 106 steelhead smolts to assess whether reservoir pool size affects the travel time of outmigrating smolts and what factors might influence their travel time. We released tagged smolts at three pool levels, low (1.7-2.8 mile long pool), mid (2.9-4.0 miles), and high pool (4.0-4.3 miles). We found that by itself, pool size did not influence the mean travel time of steelhead or coho. Travel time varied by species with coho mean travel time significantly greater than steelhead for mid and high pool ($P<.001$). Using a General Linear Model analysis (for all releases), the best model showed a weak direct relationship between refill rate, fish weight, and travel time ($R^2=0.47$). Within a pool release group (low, mid, or high), there was an inverse relationship between inflow and travel time ($R^2=0.82$). We hope to use these results in a project to restore self-sustaining runs of coho, fall chinook, and steelhead in the watershed above the reservoir.

Howard Hanson Dam and Reservoir Authorized Project Purposes. Originally Authorized as Eagle Gorge Dam and Reservoir by the Flood Control Act of 1950. Construction of the dam was completed in 1962 at river mile 64.5 on the Green River. Primary authorized use of the project is flood control. Three secondary authorized uses: low flow augmentation of the Green River, irrigation, and water supply. The project was not built with adequate downstream fish passage facilities. At high pool, smolts must sound between 70 to 106 ft to exit the project (*Section 2D.*). To provide fish passage, feasibility work is progressing on design of a surface collector and fish lock to be operational in 2003 (discussed in various sections of *Appendix F Fish Restoration and Mitigation* and the *Hydraulics and Hydrology Appendix*).

Under current operation, refill of HHD begins each spring at or around April 15, pool elevation 1070 ft, and is progressively filled to high pool, elevation 1141 to 1147 ft (depending on debris clearing or drought operations), by the end of May or early June. As the pool fills the reservoir increases in size from about 1.5 miles length at low pool to 4.7 miles (1147 ft) at high pool (Figure 1). For a two-week period in most years the pool is filled an additional 6 feet to 1147 ft (and for longer periods in drought years under Section 1135 authority) to provide a cushion to clear debris around the reservoir. The AWSP would increase pool size from Baseline length 4.7 miles, 1147 ft elevation, to 5.4 miles in Phase I, 1167 ft elevation, and to 5.7 miles in Phase II, 1177 ft elevation. The measured and modeled changes in reservoir physical variables are discussed in subsection 2B-1 with the incremental increase in selected reservoir variables presented in Table 1 (below).

TABLE 1. COMPARISON OF THE INCREMENTAL INCREASE IN RESERVOIR VARIABLES AT FULL POOL FOR BASELINE (1147)-PHASE I, BASELINE-PHASE II, AND PHASE I TO PHASE II.

	Baseline-Phase I	Baseline-Phase II	Phase I-Phase II
Surface Area (acres)	263	383	120
Reservoir Length (miles)	0.7	1.0	0.3
Shoreline Perimeter (miles)	2.9	4.3	1.4
Total Volume (ac-ft)	20,000	32,000	12,000
Water Particle T.Time (hr) at 1250 cfs[a]	204	345	141

a. Modeled water particle travel time for a median May=1250 cfs: Baseline 1141=235 hr; Phase I 1162=439 hr; Phase II 1175=580 hr.

The Headwaters watershed of the Green River may have exceptional potential to provide for additional production of anadromous salmonids in the Green River basin. Historically, the Headwaters provided over 106 miles of potential spawning and rearing habitat for coho salmon, spring chinook salmon, winter steelhead, and sea-run cutthroat trout (Table 2 and Section 2A). Since construction of the Tacoma Diversion Dam in 1911-12 and Howard Hanson Dam in 1962 the 220 mi^2 of Headwaters has been isolated from the rest of the Green River Basin. Beginning in 1982, the Muckleshoot Indian Tribe (MIT), Washington Department of Fish and Wildlife (WDFW), and Trout Unlimited have released juvenile hatchery coho, fall chinook salmon, and winter steelhead in the watershed above Howard Hanson Dam. Since 1991, the City of Tacoma has begun a pilot program to restore natural salmon and steelhead spawning in the Headwaters with initial releases of 20-130 adult steelhead per year

TABLE 2. GENERAL WATERSHED FACTS FOR THE GREEN RIVER BASIN, KING COUNTY, WASHINGTON.

	Lower Green River	Upper Green River
Watershed Area	263 mi^2	220 mi^2
Accessible Stream Length	125 miles	106 miles*
Native Anadromous Species	Coho, Chum, Chinook, Steelhead	Steelhead, Coho Chinook
Natural Production (Escapement)	11,800-15,800	9,900* (potential)

*Estimated from Section 2A: will require adequate downstream fish passage to realize the potential.

Because the outlets of HHD were not designed to collect fish near the surface, outmigrating juveniles may become delayed at the dam or are entrapped in the reservoir well beyond the seasonal "biological window" within which they would normally reach the ocean (Dilley and Wunderlich 1992, and 1993). An additional concern, which was not studied by the USFWS during their two years of dam passage monitoring, is that juvenile salmonids could require additional time (travel time) to traverse the larger AWSP reservoir pool. The additional travel time could result in positive or negative effects to the outmigrating fish. Negative effects include the potential for increased residualism or predation which both could lead to decreased adult survival and diminished restoration potential. Positive effects include a longer residence and rearing period which can lead to larger, more robust smolts and potential increased adult survival.

Because of the concern over the potential negative effects related to increased travel time with the AWSP, the Corps and Tacoma proposed, scoped and executed this study with interagency participation to monitor the existing travel times of smolts migrating through Howard Hanson Reservoir and, if possible, assess the effects of the larger AWSP on travel time. This study is considered an active adaptive management experiment (Section 1), the second of two experiments evaluated under the AWSP (test refill in 1991 was the second experiment). As an experiment, a study plan was laid out, reservoir operation was coordinated under the study plan with participating resource agencies, and the performance of marked fish was measured (travel time=performance measure). As presented in the discussion, results of this study have already been incorporated in the AWSP impact analysis and modeling of refill strategies.

The study objectives were:

- For three pool levels, low, medium, and high, determine if reservoir pool size controls the travel time of coho salmon and steelhead smolts migrating through the Howard Hanson Reservoir project area.

- Characterize the relationship between observed travel times of coho salmon and steelhead smolts and the associated reservoir conditions during the period of reservoir passage.

- Develop a predictive model to assess potential changes in smolt travel time with 1) operational changes (refill); and 2) a larger pool size.

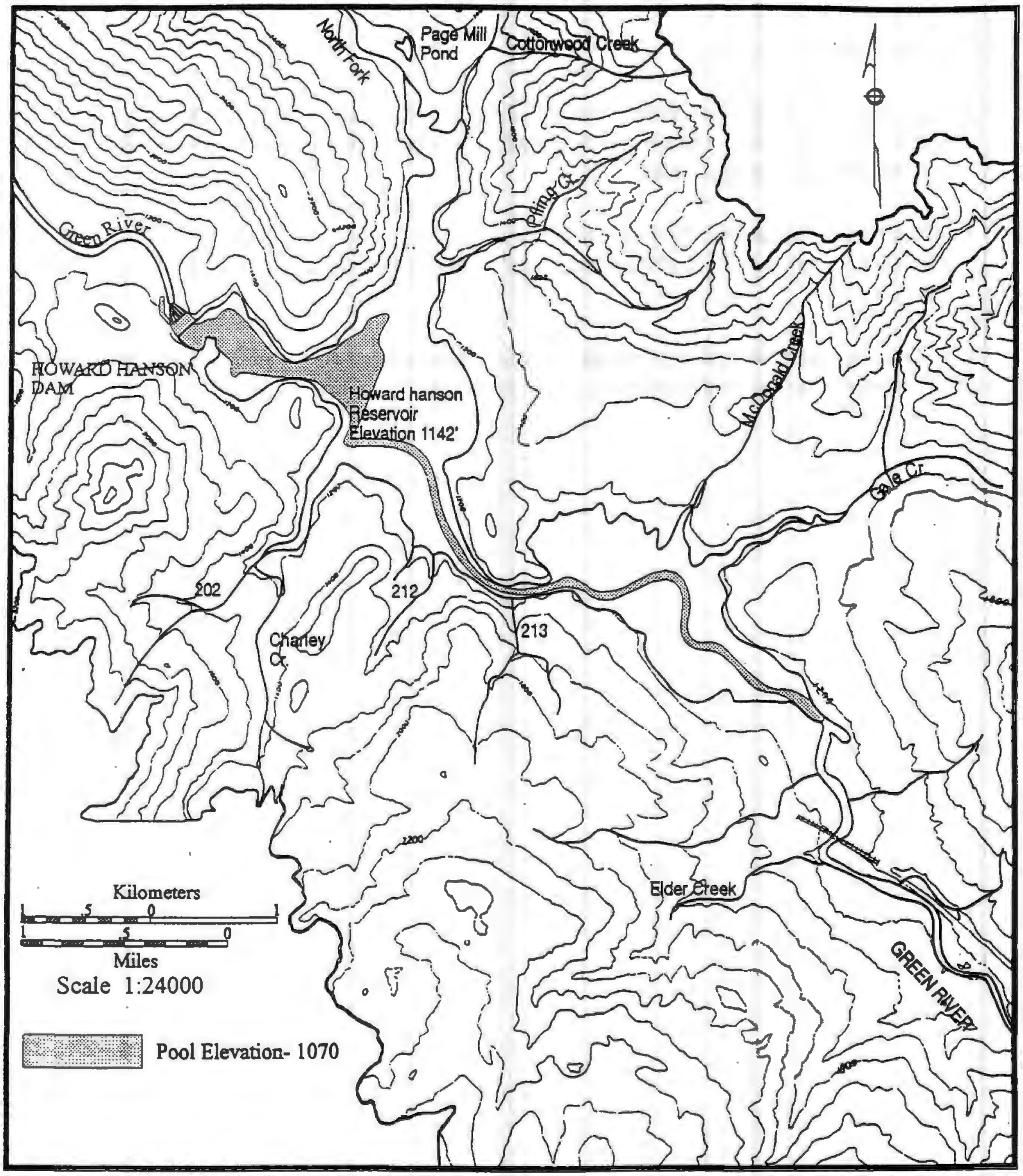


FIGURE 1. HOWARD HANSON RESERVOIR AT THREE POOL ELEVATIONS, 1070 FT LOW POOL (LIGHT GRAY SHADING), 1100 FT - MID POOL (WHITE), AND 1141 FT HIGH POOL (DARK GRAY).

2B-3.3 METHODS

Radio telemetry (tags and receivers) was used to monitor the movement and travel time of steelhead, coho and chinook salmon smolts during the spring and early summer refill period of 1995. Smolt release was planned and timed to coincide with the spring refill period at Howard Hanson Dam such that smolts would encounter the broadest range of reservoir conditions, primarily pool size (length and volume), that could affect smolt travel time and would still be within their outmigration window. Table 3 provides a general description of test conditions, monitoring periods, and the release plan for coho and steelhead. A detailed description of tagging, release, equipment, monitoring, and data analysis can be found in Aitkin et al. (1996).

TABLE 3. TEST CONDITIONS, MONITORING, AND RELEASE PLAN FOR RADIO-TAGGED COHO SALMON AND STEELHEAD SMOLTS.

		Reservoir Pool Test Condition	
	Low	**Mid**	**High**
Monitoring Period	April 11-May 2	May 2-22	May 23-June 9
Pool Elevation (ft)	1077-1103 ft	1105-1136 ft	1137-1142 ft
Pool Length (miles)	1.6-2.8	2.9-4.0	4.0-4.3
Mean Pool Vol. (ac-ft)	3228	15970	24030
Replicates	3	3	3
Total Tag No. Coho	n=36	n=36	n=38
Steelhead	n=36	n=36	n=34
ATPase Samples	n=15	n=15	n=15

Two smaller release groups of fall chinook salmon were released later than the coho and steelhead high pool release groups (June 14 and 22: late high pool release). These smolts were released at the same location as coho and steelhead: group size of 7 and 11 (pooled n=18). As these smolts were released outside the study design monitoring period, these smolts were not included in regression analysis, but are discussed in comparing travel times at high pool.

Coho and chinook were inserted with ATS model 379: 1.1-1.3 g air weight; 0.8 g water wt; 33-35 pulse/minute (ppm); 150 MHz band; 20 day battery life; minimum fish size for coho was 130 mm fork length, 105 mm for chinook. Steelhead were inserted with Lotek SFM-2: 2.3 g air weight; 1.1 g water wt; rates of 41, 49 & 61 ppm; 148 MHz band; 26-37 day battery life; minimum fish size of 170 mm fork length. Gastric implants were used, and fish were held for 24 hr prior to release. The radio transmitter was implanted in the fish's stomach using a plastic pipette as a plunger. The pipette acted to enclose and protect the antenna during tag insertion (N. Adams, NBS, pers. comm.). The transmitters antenna was then crimped so it trailed posteriorly from the fishes mouth. During initial coho tagging, tag regurgitation was a problem. To prevent further regurgitation by coho, a small piece of sponge was tied to the tag prior to insertion (Moser et al. 1991). All tagged fish were held for 24 hours before release.

Migratory tendency of smolts was assessed by measurement of ATPase units (umles ATP hodrolyzed per mg protein per hr, Zaugg 1982). During each day of tagging, five fish from the release group population were sacrificed for ATPase assessment, or a total of 15 fish per species per release condition. Pre-study ATPase criteria for smolt readiness were 12-30 units for coho (Schroder and Fresh 1992) and above 10 units for steelhead (Chrisp and Bjornn 1978).

Smolts were released about 0.8 miles above the full pool, at elevation 1156 ft on the mainstem Green River. Receiver locations were below the dam; at the dam forebay (within 600 ft of the intake tower); and at pool elevation 1100 ft, near the mid-point of the reservoir. Automatic data loggers were Lotek SRX_400. Mobile tracking included land and boat locations. The dam forebay was considered the true "finish line" for the all three pool levels. The finish line was equipped with two 6 element yagi antennas, line amplifier, and line splitter to create a master/auxiliary antenna system. The line splitter was added for mid pool and high pool. Antenna direction, receiver gain and power settings were calibrated at set-up and at two week intervals. Calibration used a Lotek or ATS tag suspended in the water at 3 and 18 ft depths at various points up to 1500 ft from the dam intake. The mid pool receiver location was not calibrated and travel times for this station are not reported here. Mobile tracking occurred periodically throughout the study. Mobile tracking was intended to provide: additional data on migration routes, migratory behavior of smolts, and act as secondary detection system.

Monitoring periods for travel time estimation ranged from 18-20 days for low, mid and high pool. Additional monitoring occurred for up to 36 days after release at high pool. Data was reduced using a series of 6 sorting criteria (see Aitkin et al. 1996). Once reduced, data was manually error-checked to find the first valid detection of each tagged fish at each fixed receiver location. All "ghost" frequencies or detections were removed. A "ghost tag" frequency was an erroneous detection by the receiver of a known tag frequency before its release. MIT reduced all mobile tracking data and provided detections at the forebay site, which supplemented the fixed data set.

Data Analysis. Travel times from release site to the forebay and to reservoir mid-point were computed for each fish by subtracting release date and time from the first validated detection at a site. Differences in mean travel times among and between release groups were then tested with analysis of variance (ANOVA).

Factors considered in predicting travel times included: fish species, forklength, weight, K-factor (condition), ATPase level, and environmental factors; reservoir content (storage volume), surface area, refill rate, pool elevation, and elevation change, inflow, outflow, the ratio of outflow to inflow (outflow/inflow), inflow turbidity, outflow turbidity, temperature, and water particle travel time from release site to the dam (see Appendix A Table 1 in Aitkin et al. 1996).

Environmental data for individual fish were generated by calculating the averages of the available environmental measurements (hourly or daily) over the fish's travel time. ATPase levels used were a surrogate measure of the degree of smoltification of a group per day of release. Fish were assigned the average ATPase level of the group sampled for ATPase on the day of tagging.

A generalized linear model (GLM) is a linear predictor based on a linear combination of explanatory variables. Generalized linear models do not depend on normality and constancy of variance. The set of potential appropriate distributions in describing travel time through a reservoir includes the exponential, lognormal, gamma, Weibull, and inverse Guassian (Lee 1991). The gamma probably function was selected because travel time data, being essentially waiting time data, are typically modeled with gamma distribution. These data, are always positive and the distribution of values are skewed to the left. A gamma distribution with a log-link was used in the GLM analysis. The log-link was chosen to convert the multiplicative effects of the GLM model to an additive structure.

Generalized linear models of the travel time data were developed using SASS, SPLUS, and XLISP-STAT. First, pairwise linear correlations were determined between the independent variables and travel time. Stepwise forward selection and backward elimination for adding or dropping factors were employed in developing the models. The criterion for adding or deleting a variables was the F statistic at a p-value of 0.05. The AIC statistic (Newman 1995) and the C^p criterion (Zar 1984) were used in determining the best models. Release group was not initially used as a predictor variable because is was assumed the variation in environmental, physiological, and morphological variables would sufficiently explain smolt travel times. It was added following modeling without release group, where the best model poorly explained travel times.

Analysis of variance (ANOVA) was also used to better explain differences in environmental, physiological and morphological variables between release groups. This analysis was completed after the initial regression analysis showed that combining all release groups provided a poor model in explaining travel time. Release group as a predictor variable improved the relationship but resulted in distinct models for each pool period. The ANOVA was used to evaluate differences in variables between pool periods. A full discussion of the ANOVA results is presented Section 2B-4, a summary of those results is presented in this section.

Travel times of individual species at the three different pool levels were tested for compliance with the assumptions of ANOVA. Homogeneity of variance was tested with a Levene's Test, while normalcy was evaluated with probability plots. When a data set failed to meet the assumptions of ANOVA, the data was rank-transformed and re-tested. If the transformation failed to eliminate heteroscedasticity, the ANOVA was conducted with a more stringent significance level (I=0.01 rather than I=0.05). Violation of ANOVA's assumptions leads to a loss of confidence in the Type I error rate of the test (Keppel, 1991, pp. 107). Type I error rate is the probability of rejecting a null hypothesis that is actually true and is set by the investigator. The reduction in the significance level protects against committing an error while preserving the parametric test's ability to the make inferences about populations.

Each of the physical parameters was analyzed using a one-way ANOVA with the three different pool levels serving as discrete levels. Each of the variables was tested for compliance with the assumptions of ANOVA in the same way as the biological data. The normalcy of each parameter's distribution was inspected visually with probability plots, and the assumption of homoscedasticity was tested using the Levene's test. If the specific parameter failed to meet the assumptions of ANOVA, the data were rank-transformed and retested. In several instances, the transformation failed to correct deviations from homoscedasticity and were tested at a reduced significance level (I=0.01). Parameters that yielded significant statistical results were further tested with Tukey's multiple range test to determine which treatment means were significantly different from each other.

2B-3.4 STUDY RESULTS

2B-3.4.1 Site Visit and Receiver Set-up

One of the greatest constraints of this study was the possibility of non-detection of fish at the dam. Because of this concern, two acoustic companies, Lotek and Advanced Telemetry Systems, visited the dam detection site prior to and during the set-up of equipment. Both companies provided concepts of a "finish line" for detecting fish in the forebay. Two main ideas were, a series above-water antennas pointed at the water-surface, or a series of underwater cables strung across the log-boom at the forebay entrance. Through coordination with agency representatives, the final selected antenna array was a series of two antennas placed at the face of the dam utilizing a line amplifier.

The dam antenna set-up proved problematic. An acoustic engineer from Lotek found that noise (including additional radio frequencies in our selected tag frequency range) was very full at the dam and at points upstream in the reservoir. This noise obliterated some frequencies from detection and resulted in "ghost tag" detections of non-fish. For this reason and others listed in the discussion section of Aitkin et al. (1996) receiver detection is only used for travel times, not as a measure of smolt survival to the dam. In addition, the antenna set-up resulted in detections of fish outside the desired finish line. At low pool, tags were recorded from 1000-2500 ft upstream of the needed detection range (500-600 ft from the intake). To correct this problem and return to the original study design of a discrete, identified detection line at the edge of the flownet of the dam, a line-splitter was added at mid and full pool. The splitter created two separate antennas, a master and auxiliary. The auxiliary antenna detection range was limited to the areas within 5-600 ft of the intake. The original set-up therefore underestimated travel times of smolts at low pool vs. mid and full pool.

The installation of the line-splitter occurred one day before the first mid pool release of tagged fish. There are concerns by the Corps that the system may not have been operated properly for the first few days and thus early movement to the dam by tagged fish could have gone undetected. The distribution of tag detections shows one of two conclusions: 1) refill rate or high Green River flows delayed smolts for 1 or more days following release; or 2) the dam receiver was not operating properly for 1 or more days following line-splitter installation. Appendix Figures A-1 and A-2 show frequency histograms of coho and steelhead travel times. Mid pool travel times show a clear shift in the distribution of dam detections by 5-6 days for greater than 90% of detections. Either fish were delayed by high refill and/or high inflow, or there was a problem in detection of signals at the dam. The Corps has accepted the travel times for mid pool as accurate and the USFWS conclusion that refill rate delays reservoir travel, but we still consider further monitoring and evaluation during the AWSP as the definitive means to define reservoir travel and ultimately reservoir survival of smolts.

2B-3.4.2 Travel Times

The total distance smolts traveled under all three pool levels was constant, 4.9 miles, but the reservoir and riverine portions of this distance were dynamic (Figure 2). At low pool, 34-58% of the travel distance was through the reservoir. During mid pool, 58-82% of the travel distance was through the reservoir and at full pool, 82-88% of the distance was through the reservoir. The increasing reservoir length was one of several measures of morphometry that was tested under this study. One limitation of this study was our inability to measure travel time from the first point when smolts reached the reservoir pool to the time they reached the finish line. The constantly changing elevation of the pool prevented use of an automatic receiver at the edge of the reservoir, hence the use of a standard length, 4.9 miles, but with constantly changing portions of reservoir and riverine length.

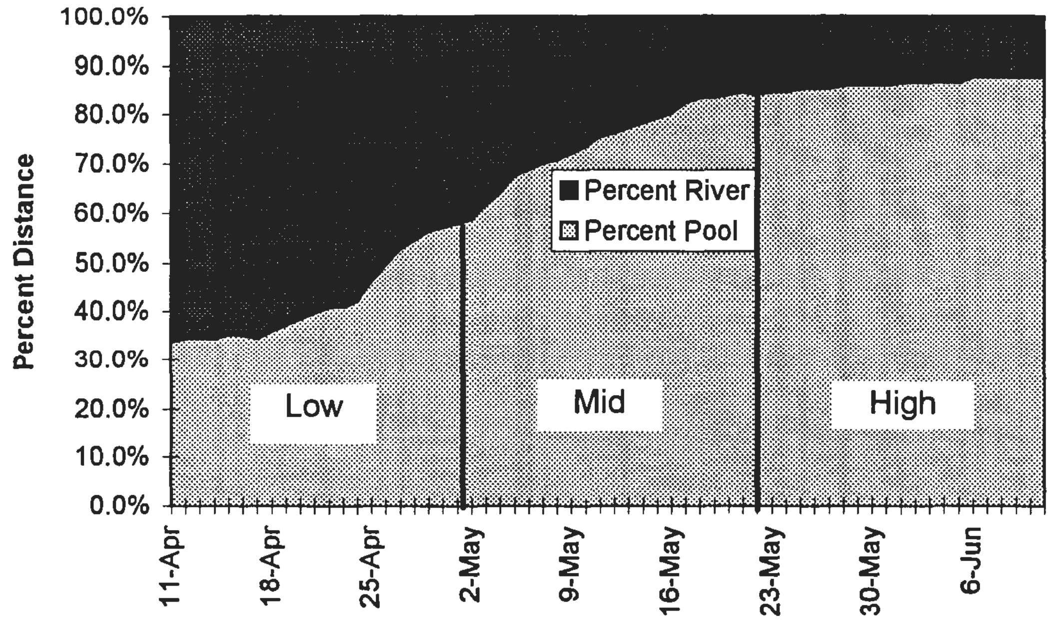


FIGURE 2. TRAVEL DISTANCE (4.9 MILES) (AS MEASURED BY RESERVOIR THALWEG LENGTH) APPORTIONED INTO RIVERINE AND RESERVOIR POOL COMPONENTS.

<u>Within species travel time comparison.</u> The longest mean travel time for all species occurred at mid pool. Coho travel time at mid pool (11 days) was significantly greater than at either low (3.1 days) or full pool (6 days). Full pool travel time was also significantly greater than low pool. Steelhead travel time at mid pool (7.4 days) was significantly greater than either low pool (2.9 days or full pool (2.7 days). No difference was detected between low and full pool. Chinook travel time at the second full pool release, was 6.8 days (Figure 3).

Frequency histograms of coho and steelhead travel times are presented in Appendix Figures A-1 and A-2. Low pool had a fairly tight distribution of times, following a gamma distribution (see Methods). Mid pool appears that over 90% of all tagged fish were "delayed" for 5-6 days. These fish either 1) held at the release site during the period of high inflow (mid pool release occurred during highest inflow for entire study period); or 2) experience increased travel times from effect of high refill rates (discussed below). Coho at high pool had a much more variable distribution of travel times with 5 fish coming in after the 20 day monitoring period. Steelhead still showed a tight distribution of travel times, again following the assumed gamma distribution.

The mean transit time of salmonids used in this study was not the same at each pool level. The mean travel time of salmonids was significantly slower at mid pool (8.6 days) than mean transit time at both low and full pool levels. Mean transit times at full pool (4.3 days) were significantly higher than at low pool (2.9 days).

Between species comparison. There was a significant difference in mean travel time between coho and steelhead. The mean travel time (all pool levels) for coho measured during this study was 6.2 days which was significantly slower than winter steelhead with a mean transit time of 4.4 days. Coho travel times were longer at both mid and full pool.

We also compared travel times for all species (coho, steelhead, and chinook) at high pool. There was a significant difference in mean rank transformed transit time between species at high pool (I=0.05). The mean reservoir transit time of coho (6.0 days) and fall chinook (6.8 days) were not significantly different from each other, but were significantly longer than winter steelhead (2.7 days) (Figure 4). Winter steelhead transited the reservoir significantly faster than coho or chinook.

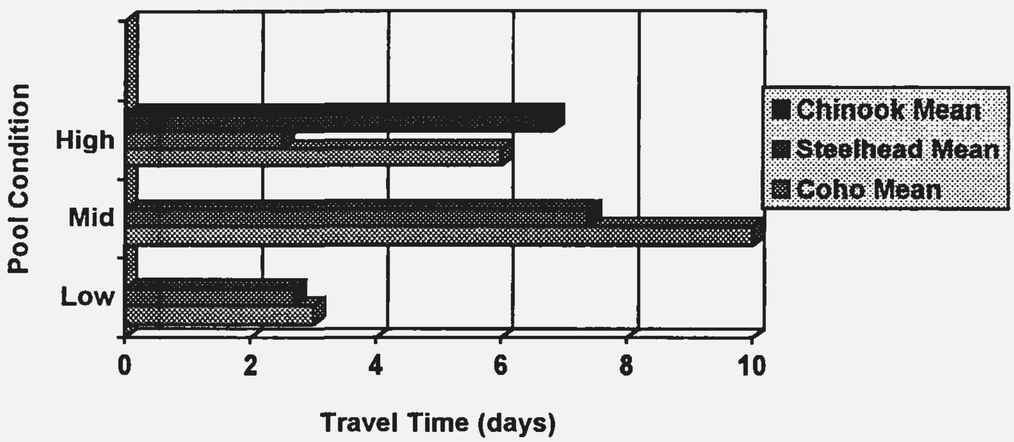


FIGURE 3. MEAN TRAVEL TIMES OF COHO, CHINOOK AND STEELHEAD SMOLTS THROUGH THREE POOL CONDITIONS.

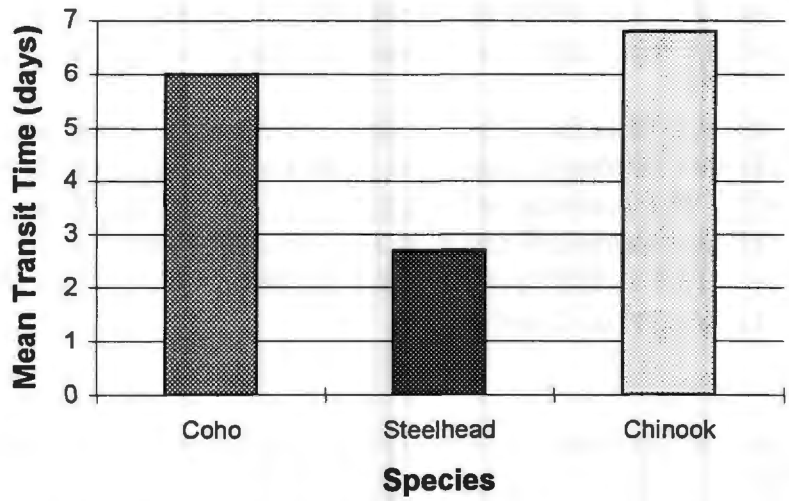


FIGURE 4. MEAN TRANSIT TIMES (ALL POOL LEVELS COMBINED) FOR DIFFERENT SPECIES OF RADIO TAGGED SMOLTS RELEASED INTO THE HOWARD HANSON DAM RESERVOIR AT HIGH POOL.

Tag detection (or recovery) rates varied by pool level and by species. Of 110 tagged coho, 62 were detected at the dam forebay. An additional 5 coho smolts reached the dam after the official monitoring period ended. Of 106 tagged steelhead, 76 were detected at the dam forebay. Of 18 tagged chinook, 7 were detected at the dam forebay (Table 4).

TABLE 4. TAG RECOVERY RATES (PERCENT DETECTION RATE) AT THE DAM FOREBAY (FINISH LINE) FOR ALL RELEASE GROUPS: R1=RELEASE GROUP 1.

	Coho Recovery				Steelhead Recovery				Chinook Recovery		
Pool	**R1**	**R2**	**R3**	**Total**	**R1**	**R2**	**R3**	**Total**	**R1**	**R2**	**Total**
Low (%)	58	50	50	56	67	42	50	53			
Mid (%)	50	33	33	39	75	83	67	75			
High (%)	100	92	36*	74*	92	100	70	88	30	45	38
Average			61*				72				

* Five coho smolts were detected after the end of the monitoring period; if included would increase detection to 74% for R3 and 87% for total.

We assumed tag detection time at the dam was an indicator of smolt day or night movement: day defined as sunrise to sunset. Of 62 coho detected at the dam forebay, 77% were found during the day. Similarly, of 73 steelhead detected, 70% were found during the day. Chinook detection times were not available -- to be added. For all release groups but one, most detections occurred during the day. Steelhead release at low pool was the exception, with 74% of the fish detected at night (Table 5). Peak detection time occurred in later afternoon for coho and at midday for steelhead (Figure 5 in Aitkin et al. 1996).

TABLE 5. DIEL TIMING OF COHO AND STEELHEAD SMOLT DETECTIONS AT THE DAM FOREBAY.

	Coho detections		Steelhead detections	
	Day (%)	Night (%)	Day (%)	Night (%)
Low pool	12 (60)	8 (40)	5 (26)	14 (74)
Mid pool	8 (80)	2 (20)	22 (92)	2 (8)
High pool	28 (88)	4 (12)	24 (80)	6 (20)
Total	48 (77)	14 (23)	51 (70)	22 (30)

2B-3.4.3 Statistical Analysis of Travel Times vs Biological and Reservoir Conditions

Regression Analysis

The significant pairwise linear correlations between travel time for all the potential predictor variables are listed in Table 6. The variables pertaining to reservoir refill, such as the ratio of outflow to inflow, refill rate, and the difference between outflow and inflow, have the highest correlations with travel time besides release group (pool level). The reservoir refill variables are highly correlated, as are the physiological and morphological variables, such as weight, length, K-factor, and ATPase level, and environmental variables, such as pool elevation, surface area, content and water particle travel time.

TABLE 6. PAIRWISE LINEAR CORRELATION (R) BETWEEN TRAVEL TIME AND POTENTIAL PREDICTOR VARIABLES. ONLY SIGNIFICANT CORRELATES ARE REPORTED.

Variable	Correlation	Variable	Correlation
Outflow/Inflow	0.476	Average Elevation	0.316
Release Group	0.461	Minimum Elevation	0.310
Refill Rate1	0.442	Maximum Inflow	0.237
Refill Rate2	0.442	Surface Area	0.218
Inflow-Outflow	0.424	Fork length	0.214
Inflow Turbidity	0.373	Weight	0.208
Pool Elev. Change	0.371	Average Inflow	0.207
1/Average Inflow	0.342	Species	0.203
1/Average Inflow	0.342	Pool Content	0.203
Maximum Elevation	0.310	Minimum Inflow	0.184

Note: Correlation is significant at the two-sided 0.05 level ($P_{Ho}(r \geq 0.167, n=138) = 0.05$)

Using stepwise, forward selection, a regression model containing the ratio of outflow/inflow (OF/IF), fish weight (WT), and outflow turbidity (OT) was developed when release group (RG) was not used as a potential predictor variable (Table 7). The best subsets regression analysis yielded the same model. The best models containing 1, 2, or 3 variables are listed in Table 7. The coefficients for the variables OF/IF, WT, and OT, are negative, suggesting as the ratio of outflow to inflow, fish weight, and outflow turbidity increases, smolt travel time decreases. When refill rate, which is highly negatively correlated (0.95) with the ratio of outflow to inflow, was used as a predictor variable, the coefficients indicate that travel time increases as refill rate increases.

TABLE 7. SUMMARY OF FORWARD STEPWISE MODEL SELECTION FOR TRAVEL TIMES WITHOUT RELEASE GROUP (RG) AS A POTENTIAL PREDICTOR.

1 Variable Models.	**R^2**
Outflow/Inflow (OF/IF)	0.23
Refill Rate 1 (RR1)	0.19
2 Variable Models.	
OF/IF, Weight (WT)	0.34
RR2, WT	0.36

Variable Models.	**R^2**
OF/IF, WT, O. Turbidity	**0.47**
R2, WT, OT	0.39
RR1. WT. OT	0.39

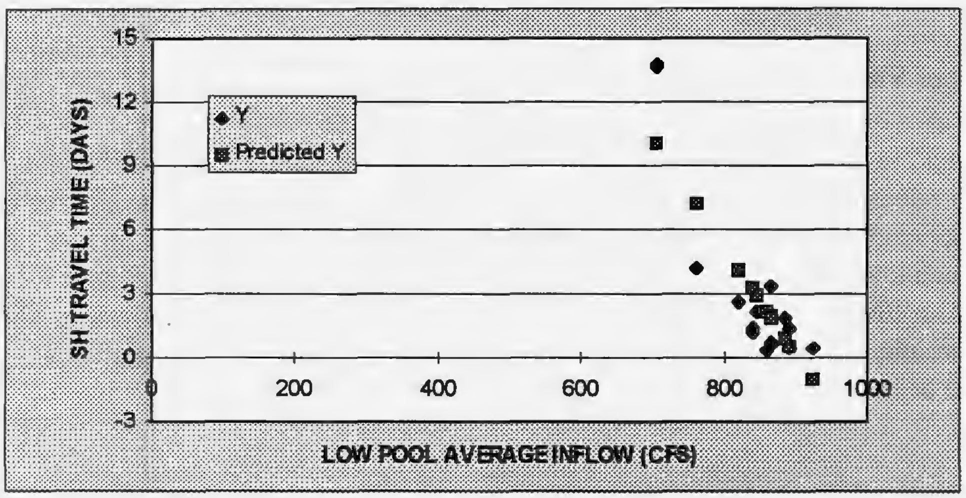
The selected model is in bold.

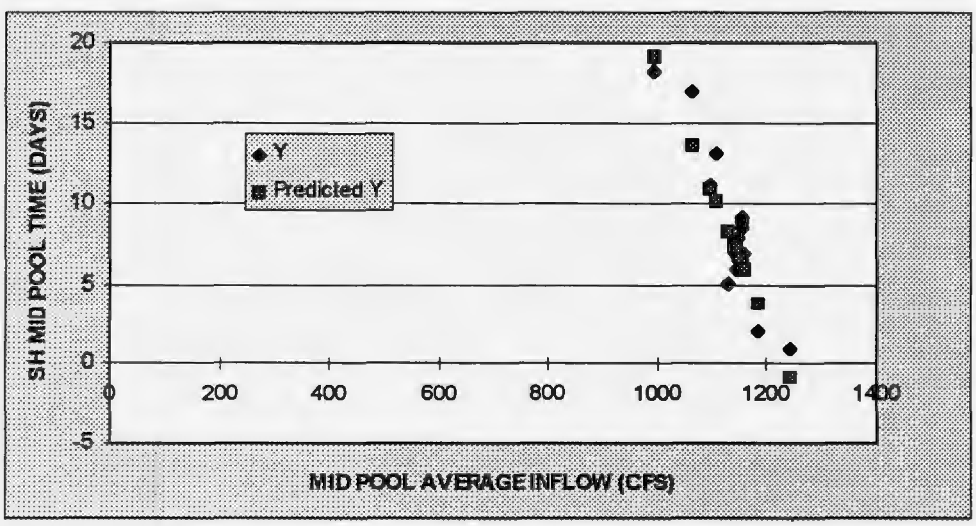
When release group was used, the stepwise procedure selected the variable release group (RG) first, followed by average inflow (IF), and then ATPase level (ATP). The best subsets regression analysis yielded the same model. The best models containing 1, 2, 3, or 4 variables are listed with respective values for R^2 in Table 8. Smolt travel time was found to be inversely related to inflow, ATPase level, forklength, and fish weight. Coho travel times, when species was used as a predictor variable, were determined to be longer than the travel times for steelhead. There are several 3-variable and one 4-variable model that are nearly equal in their ability to explain smolt travel time variation. In all of the best models, mid pool release group had positive coefficients, meaning the fish had longer travel times than low pool. The coefficients for average inflow (IF) and ATPase level (ATP) in the models suggest that greater inflows and higher ATPase levels are associated with shorter travel times. Observed vs. predicted travel times for steelhead smolts is shown in Figure 5, using the best two-variable model with average inflow,

TABLE 8. SUMMARY OF FORWARD STEPWISE MODEL SELECTION FOR TRAVEL TIMES WITH RELEASE GROUP (RG) AS A POTENTIAL PREDICTOR.

1 Variable Models.	**R^2**	**3 Variable Models.**	**R^2**
Release Group (RG)	0.21	**RG, IF, ATPase**	**0.84**
Refill Rate	0.20	RG, IF, Fork length	0.84
		RG, IF, WT	0.84
		RG, IF, Species	0.84
2 Variable Models.		**4 Variable Model.**	
RG, Inflow (IF)	0.82	RG, IF, K-Factor, ATP	0.84
RG, 1/IF	0.79		
RG, Water Part. T. Time	0.59		

The selected model is in bold.





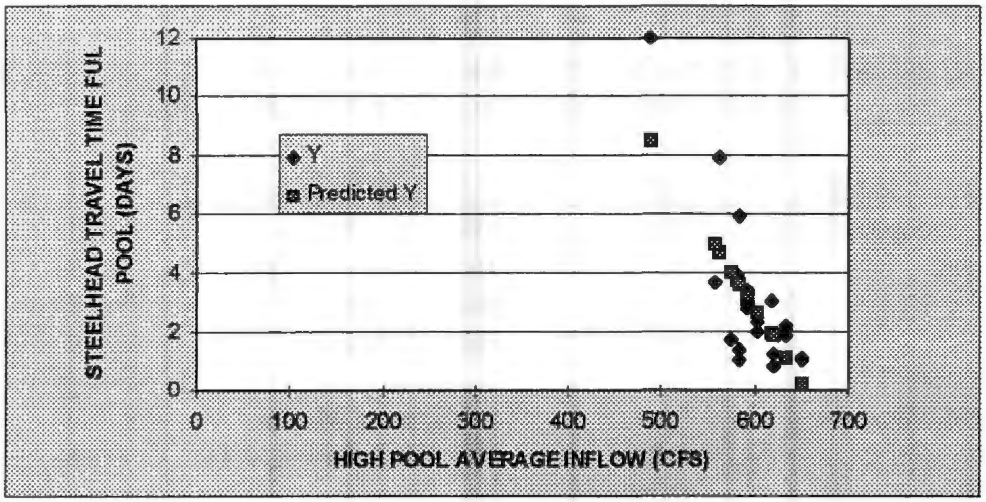


FIGURE 5. FOR THREE POOL LEVELS, COMPARISON OF OBSERVED STEELHEAD TRAVEL TIME VS. PREDICTED TRAVEL TIMES FROM THE BEST TWO VARIABLE REGRESSION MODEL, INFLOW, R^2=0.82 -- WITH RELEASE GROUP AS A CATEGORY.

Analysis of Variance of Reservoir and Biological Variables

Comparing the mean values of reservoir variables by pool period for the coho and steelhead releases (low, mid, and high pool) shows that water volume and surface area were significantly larger by pool period. Water volume at high pool was up to 8 times greater than low pool. Inflow was insignificantly higher at mid-pool, high pool was lowest. Outflow was equal for mid and low pool, but was significantly lower at high pool. Inflow turbidity and refill rate was highest at mid-pool. There was no significant difference between inflow turbidity and refill rate for low and high pool.

TABLE 9. COMPARISON OF FLOW/RESERVOIR MEAN VARIABLES BY ANOVA AND TUKEY'S MULTIPLE COMPARISON.

Physical Variable	Significance	Pool Level		
	P-value	Low	Mid	High
Water Volume (ac-ft)	<.01	3228	15970	24030
		Low	Mid	High
Surface Area (acres)	<.01	171	511	722
		High	Low	Mid
Inflow (cfs)	<.05	455.6	697.5	853
		High	Low	Mid
Outflow (cfs)	<.01	405.7	**633.3**	**511**
		High	Low	Mid
Inflow Turbidity (NTU)	<.01	**1.02**	**1.04**	1.32
		High	Low	Mid
Refill Rate (acres/day)	<.01	**4 .9**	**7.5**	18.4
		High	Low	Mid
Refill Rate (acre-ft/day)	<.01	**180.7**	**246.6**	716.6

Note: Values not in bold are not significantly different from each other.

Chinook High Pool Conditions

Fall chinook were released later (June 14 and 22) than the coho and steelhead high pool release groups (May 22-24). As a result, chinook may have experienced different reservoir conditions at high pool than the steelhead and coho who had been released earlier. All nine physical parameters discussed above were examined for differences between the early high pool conditions (May 22 to June 11) and late high pool conditions (June 14 to July 11) with a simple one-way ANOVA after rank transformation (Table 10). At late high pool, the only physical variables that were greater than the early pool were: temperature, surface area, and water volume. Primary flow variables, inflow and outflow, were significantly lower at late high pool, inflow by 40%.

TABLE 10. RESULTS OF STATISTICAL TESTS OF PHYSICAL RESERVOIR PARAMETERS COMPARING EARLY AND LATE HIGH POOL CONDITIONS.

Parameter	Significance	Early high pool mean (n=20)	Late high pool mean (n=31)
Inflow (cfs)	YES (p<0.001)	500.25	295.25
Refill (acre-ft/day)	YES (p<0.001)	180.7	-9.387
Temperature (°C)	YES (p<0.001)	10.66	12.64
Surface Area (acres)	YES (p<0.001)	721.79	767.23
Content (acre-feet)	YES (p<0.001)	24033.85	25791.19
Discharge (cfs)	YES (p<0.001)	405.7	301.6
Refill (acre/day)	YES (p<0.001)	4.91	-0.27
Inflow Turbidity (NTU)	YES (p<0.001)	1.09	0.83
Outflow Turbidity (NTU)	Uninterpretable	-	-

Comparison of Travel Times to Reservoir Variable ANOVA

Pool Size. By pool condition, GLM analysis showed inflow as the best single variable for explaining faster travel times. At early high pool, a period of lowest inflow, outflow, and highest pool volume and area, steelhead smolt travel times were the lowest for all three release groups. This suggests even under the most severe conditions of reservoir size that steelhead will successfully migrate through the reservoir. Coho smolts performed almost as well as steelhead. Their travel times were significantly longer at high pool than low pool (3 days), but given that inflow and outflow conditions were similar but pool size was 8-fold greater, the performance of these smolts should be considered satisfactory. At late high pool, chinook smolts had even more severe conditions of lower inflow and outflow and even greater pool size but their travel times were not significantly different than coho travel time at early high pool. Thus, pool size, under low refill rates, appears to be a minor factor in explaining differences in smolt travel times.

Refill Rate and Mid Pool. The GLM showed two outcomes: 1) for all tagged fish the physical variable best explaining differences in travel time was refill rate (although it was a weak predictor), and 2) for tagged fish within a pool period (release group) average inflow was the best predictor, or explanatory variable. The results of the ANOVA confirm and contradict these results. Mid-pool had the highest inflow and highest refill rate but the longest travel times for coho and steelhead. Refill rates at low and early high pool were not different. Steelhead travel times were considered equivalent for both conditions (slightly lower at high pool) but coho had longer travel times at high pool. Early high pool had a higher refill rate than late high pool while chinook travel times were not significantly different from coho. Travel rates (travel time/travel length) compared to refill rate for all three species are presented in Figure 6.

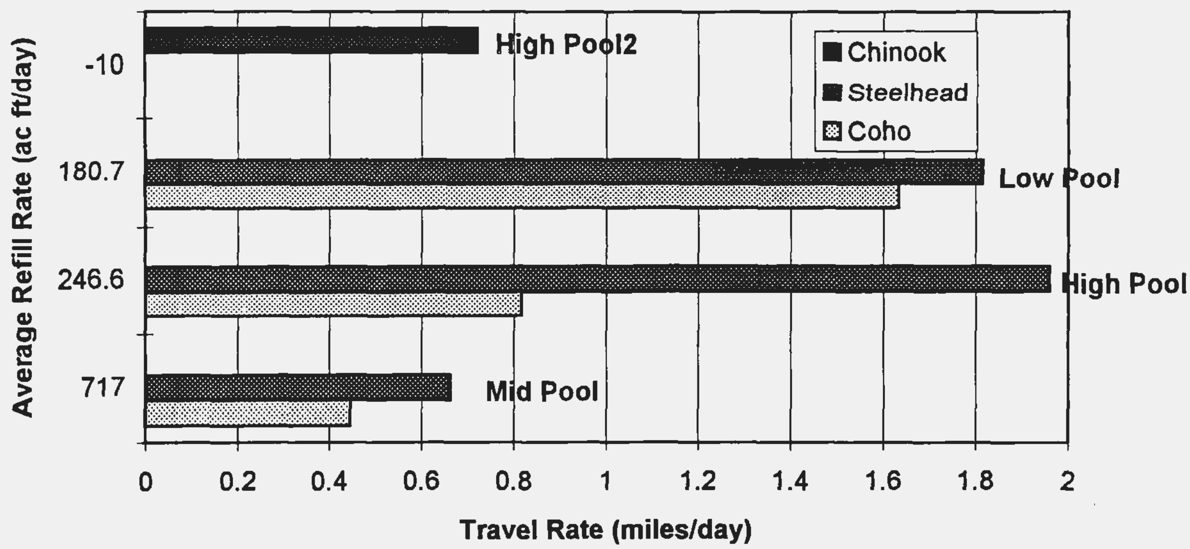


FIGURE 6. COMPARISON OF AVERAGE REFILL RATE (20 DAY AVERAGE/POOL LEVEL) VS. TRAVEL RATE OF RADIO-TAGGED COHO AND CHINOOK SALMON AND STEELHEAD SMOLTS (REFILL RATE WAS PART OF 3-VARIABLE REGRESSION MODEL R^2=0.47 FOR COHO/STEELHEAD).

2B-3.5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The travel time analysis in this paper differs from previous travel time analysis (Smith et al. 1993) in four ways: 1) estimates of the travel time and environmental variables are unique to each fish, rather than to an entire release group; 2) smolt travel included riverine and reservoir conditions; 3) more than 30 variables were considered as potential predictors of smolt travel times, rather than a select few, and 4) no estimates or inferences regarding mortality rates were determined.

The best reservoir variable in explaining travel times in this study, once release group is taken into account, was average inflow. As inflow increased, travel times decreased. Higher flow volumes were also found to decrease yearling chinook and steelhead travel times in the Willamette, Snake, and Columbia Rivers (Raymond 1979; Smith et al. 1993; Schreck et al. 1994). Sims and Ossiander (1981) reported that increased flow volumes increase the survival of yearling chinook and steelhead; other authors, however, failed to confirm their finding.

In 1995, during the travel time study, inflow to HHD was much lower than normal with flow exceedance ranging from 80% for low pool, 75% for mid pool, and 90% at high pool. This suggests that the observed travel times in this study are within the slowest range that would be expected. If travel times decrease with increasing flow, then smolts should move more quickly through the reservoir in most other years and could experience higher survival rates. Preliminary results from the adult return rate study (coded-wire tagging of coho), seem to support this conclusion for coho (Section 2E). Inflow to the reservoir was found to be the variable explaining almost all (97%) of the variation in coho with outflow as the second most important factor (explaining 89% of the variation).

Even with the results from this study, there are still concerns by the Corps that the dam detection system may not have been operated properly for the first few days of mid pool and thus early movement to the dam by tagged fish could have gone undetected. The distribution of tag detections shows one of two conclusions: 1) refill rate or high Green River flows increased the travel time of smolts for 1 or more days following release; or 2) the dam receiver was not operating properly for 1 or more days following line-splitter installation. Appendix Figures A-1 and A-2 show frequency histograms of coho and steelhead travel times. Mid pool travel times show a clear shift in the distribution of dam detections by 5-6 days for greater than 90% of detections. Either fish were "delayed" by high refill and/or high inflow, or there was a problem in detection of signals at the dam. The Corps has accepted the travel times for mid pool as accurate and the USFWS conclusion that refill rate delays reservoir travel, but we still consider further monitoring and evaluation during the AWSP as the definitive means to define reservoir travel and ultimately reservoir survival of smolts.

Conversely to the flow relationship with larger smolts, Chapman et al (1994) and Hillman et al (1997) found no relationship between rate of migration speed and flow volume for sub-yearling (summer/fall chinook) through the impounded (reservoir) mid-Columbia Reach. They theorized that sub-yearling chinook may temporarily hold and feed during downstream migration independent of flow volume. Other authors consider subyearling chinook migration as distinct from coho, steelhead, and yearling chinook emigration (Williams et al. 1996). These smaller, younger fish may spend considerable time rearing on their downstream migration, in a pattern resembling the movement of nutrients through stream, a cyclical or spiraling movement. Thus, the directed ocean movement of larger juveniles such as coho, steelhead, and yearling chinook, might be expected to benefit from the assist of flowing water but the migration pattern of subyearling chinook may not be predetermined to follow this pattern.

The best predictors of coho and steelhead travel time, when release groups were not taken into account, were measures of refill rate. The regression models suggest that as refill rate increases, smolt travel time decreases. These somewhat opposite responses, could be better described or modeled if more diverse outflow data was available during the study. In 1995, outflow from HHD was near the 75% exceedance range, or much lower than normal. Outflow was not managed to follow normal variable inflow patterns (to provide for smolt outmigration) but was held constant to protect spawning steelhead in the lower river. This constant outflow resulted in the "capture" of the only minor freshet (1300 cfs) that occurred during 1995. This freshet capture coincided with the release of the mid pool tagged fish. Mid pool travel times were the slowest for any release. By incorporating the results from the analysis showing inflow is the most important variable explaining travel times and adult survival, this suggests that outflow releases that follow inflow pattern will decrease smolt travel times and theoretically should increase survival through the project.

In comparison to total project travel time at other water control projects (dam + reservoir), the overall observed travel times through Howard Hanson Reservoir are not exceptional: coho 6.2 days, steelhead 4.2 days, chinook 6.8 (Table 11). Three years of outmigrant trapping at Wynoochee Reservoir, a shorter length but greater volume reservoir, showed a range of total project travel times of 18-44 days for coho, 11.4-20.6 days for steelhead, and over 30 days for chinook (Dunn 1978). Migrant juvenile coho salmon and steelhead appeared to have no problems passing through the reservoir and reaching the forebay. Coho juveniles reached the dam in 3 to 5 days. The poor passage design, and low outlet flow at the outlet resulted in the large increase in total project travel time. Forebay to dam passage extended the migration period by 7 to 27 days for coho and 6 to 18 days for steelhead. The author felt the extended migration time increased the adult survival of the reservoir released fish relative to smolts released below the dam.

Other studies confirm work at Wynoochee, that the reservoir is not the primary component in total project travel time at many small water control projects, but that the dam outlet is the main factor (HHD Fish Passage Technical Committee). Work on the Elwha River with coho juveniles supports this conclusion (Wunderlich and Dilley 1985). Coho released at Lake Mills took from 16 to 30 days (peak daily outmigration) to exit the project, being delayed to mid-May. Prior to mid-May there was no surface exit (spillway), spilling began in-mid May. The authors believe that the early release groups had extended holding periods, or experienced delay at the dam, because of the lack of a surface exit. Section 2D and Wunderlich and Dilley (1993) provide discussion that the primary factor determining migration success through small water control project appears to be sufficient attraction flow through a near-surface fish passage outlet.

At low pool with good outflow volume, most smolts migrate through Howard Hanson Reservoir (1.5 mile pool) and sound through the radial gates (shallow exit) in about 3 days. Seiler and Neuhauser (1985) released 4 test groups of coho yearlings (group no. 5, 6, 8, and 9) in -- mid-reservoir (0.5 miles upstream, no. 5 and 9), forebay (500 ft upstream, no. 6), and at the North Fork bridge (2.5 miles upstream, no. 8): 95% of fish recaptured were caught within 3 days. However, during refill and at high pool (deep exit), between 8-95% of coho smolts may be delayed at the dam and can become entrapped by the deeper outlet and lower outflow (Dilley and Wunderlich 1992 and 1993; Section 2E. Coho Adult Returns). We had one datalogger below the dam during the travel time study that may provide some agreement with these results: only 6 of 62 coho (9.7%) and 6 of 73 steelhead smolts (8.2%) reaching the dam were detected below the dam (passing through). We consider these below-dam detections as potentially under-representing actual outmigration, as the tags could have impaired the ability of smolts to sound to the deepwater outlet.

Comparing reservoir travel times at HHD to travel times through larger reservoirs shows some interesting results. In 1996, a pilot study to study smolt travel time was initiated at two water control projects on the Cowlitz River, Mayfield (6.7 miles long) and Mossyrock (21 miles, under this study). Radio-tagged steelhead and coho smolts were released at both projects (Harza 1997). Travel times of steelhead smolts were slightly longer (average of 5.0 and 5.1 days, for Mayfield and Mossyrock, respectively) than the average travel time through Howard Hanson Reservoir, although one travel rate was faster. Coho salmon had near identical travel rate (0.82 miles/day for Mayfield, the largest detection group) to Howard Hanson average rate (0.74/miles/day). Detection rates for steelhead (48-89%) at the Cowlitz project were within the range of Howard Hanson but coho detection rates were much lower (6-29%). The travel rates and detection rates from our study suggest that Howard Hanson Reservoir is similar to other reservoirs and does not present any unique challenges to passage of juvenile anadromous salmonids.

The concept of a time window of opportunity or a normal emigration period when environmental conditions are best for smolts to enter the ocean was first discussed by (Walters et al. 1978). Many other authors have since utilized this term in discussion of actual seasonal periods of emigration and as to the time width of the time window. Holtby et al. (1989) provides a discussion and comparison of time windows. This window of opportunity is characterized by three dimensions: 1) the time it is open, or width; 2) the extent of temporal (time) shifts in the window; and 3) prediction of temporal shifts from environmental conditions in streams. For a salmon species and particular life stage, each window type has a characteristic pattern of emigration. The width or time the window is open cannot be deduced by the emigration pattern alone, but might be inferred from observations of the timing and magnitude of mortality during emigration.

In this initial report, most discussion on time windows will focus on coho salmon, additional discussion on chinook and steelhead will be provided in the next draft.

The timing of emigration may synchronize fish movement to advantageous conditions for rearing in the ocean environment. Holtby et al. (1989) felt that differences in chum and coho emigration timing indicated differences in their time window. Coho may have a fairly narrow or wide time window. Existing studies are contradictory in defining this window. Peak survival has been found to occur within a 2-3 week period for wild and hatchery released fish (Bilton et al 1982; Thedinga and Koski 1984; Matthews and Ishida 1989). Migration occurring before this period or after this period tended to be lower.

This period of peak survival varies by geographic locality. Studies from Oregon and Alaska have found peak survival occurred for later releases in June while studies in British Columbia suggest higher survival in mid to late May (Bilton et al 1982; Matthews and Ishida 1989). One author speculated that even for wild coho smolts, that later release may increase the overall survival to adults (Irving and Ward 1989). Later outmigrant coho, whether from hatchery delayed release or normal outmigrants leaving later in the summer, appear to have differences in ocean migration patterns (Matthews and Ishida 1989). Typically these later migrants have a more compressed geographic range. In Puget Sound, late release coho tend to remain in Puget Sound rather than migrating to the ocean (Matthews and Buckley 1976). Initial CWT returns of coho released at HHD had one above-dam release group with a distinct migration pattern from below-dam releases (Aitkin 1996).

Freshwater migration delay, but itself, does not present problems for coho smolts. Zaugg (1982) showed that when hatchery coho were held well beyond their normal release date in May, until June or July, they initially lost measures of smolt readiness, but quickly regained readiness during outmigration. The author stated that this could lead to better survival. Lake Washington coho, chinook and steelhead runs are an example of a freshwater lake system operated as a water control project where smolts should be expected to experience exceptionally long periods of freshwater migration. The storage volume and length of this lake/reservoir system is miles longer than any other similar system (non-Columbia River) that smolts of these stocks must migrate through (Section 2B-2). All of the Lake Washington stocks have had dramatic declines in the last 15 years. The conventional thinking of the resource agencies who manage these stocks is that migration delay through these lakes is not affecting the survival of any one stock. In fact, for coho, chinook and sockeye, the prevailing wisdom (from initial monitoring at the dam outlet) is that <u>injury and delay at the project outlet</u> from a lack of juvenile passage facilities is a (or the) factor contributing to stock declines. Coho and sockeye have rebounded dramatically in the last two years from improvements made at the dam outlet (coho in Lake Washington discussed in Section 2E).

This study required that the coho and steelhead smolts be held past their peak migration period. Coho and steelhead were released at high pool at the end of May. These smolts were still considered smolt-ready based on measures of smoltification (ATPase). Even with this later release, these smolts showed no signs of impaired migratory ability. In fact, mean travel times and detection rates for steelhead were the lowest and highest, respectively, of all three release groups. Coho detection rates were also highest during this release, while travel times were significantly lower than mid-pool, the period which is the normal peak in migration timing.

2B-3.5.1 Summary:

- By itself, pool size does not explain differences in mean smolt travel time; mid-pool travel times were significantly greater than low and high pool.
- There were differences in travel time by species with increasing pool size; coho travel time was significantly greater than steelhead at mid and high pool. Coho and chinook travel times were not significantly different at high pool.
- A General Linear Model (GLM) suggests travel time was inversely related to inflow, when release group was used a predictor.
- A GLM without release group showed a weak direct relationship between travel time and refill rate.
- In comparing reservoir/flow variables, mid pool had significantly higher values for refill rate, inflow, and inflow turbidity.

- Other studies show that increased migration time through water control project is primarily a function of poor dam passage facilities. Travel time through Howard Hanson Reservoir may be a minor component of existing project travel times.
- A time window of opportunity exists for successful outmigration of salmon and steelhead smolts. This window is not clearly defined for the stocks for determining changes in adult survival.
- For coho, and steelhead, there is no existing information that suggests the average reservoir travel times under existing conditions will result in significant impacts to survival. However, existing total project travel time, with dam delay or entrapment from poor passage outlet, is significantly reducing project survival of coho salmon (Section 2E)

2B-3.5.2 Existing Travel Times vs Anticipated Travel Times Under ASWP

There are three potential means that the existing and/or AWSP could increase travel time that could lead to delaying smolts beyond their normal emigration period: 1) migration through the reservoir, 2) delay in finding the dam outlet, and 3) actual entrapment by lack of a suitable dam outlet. Reservoir travel time appears to be a minor component of actual travel times through the existing project. The delay in finding the dam outlet and/or actual entrapment in the reservoir because of a lack of surface exit are the major components of project passage travel, dam and reservoir.

There is one measure of the change in reservoir performance for outmigrating juveniles, increase in reservoir travel time. The third objective of this report was to develop a predictive model for assessing impacts of the AWSP. We developed such a model for prediction of travel times under the enlarged ASWP. This measure is based on an empirical relationship between reservoir refill rate and travel rate of coho, steelhead, and chinook salmon smolts. The effect of 1996 Baseline refill and the AWSP were modeled for 32 years, utilizing semi-months with percent of outmigrants, refill rate, size of pool (volume and length), and travel rate to predict travel times by species. The objective of the AWSP is to have no net loss of juvenile salmonids migrating through Howard Hanson Reservoir. Results and discussion of the modeling outputs are presented in Section 2B-5.

Beyond the actual change in travel times, the results of the predictive travel time model are open to interpretation -- there is no accepted travel rate and the implications of increased travel rate for application to small reservoirs. The Corps spent 2 years in coordination with resource agencies (HHD Technical Workgroup) to develop a level of acceptable and unacceptable travel time. In 1995 and 1996, the Corps presented a request -- that if the Workgroup did not define acceptable and unacceptable travel times -- the Corps would provide definitions for the AWSP impact analysis. The Corps has provided definitions. Final definitions included that acceptable travel times would be within the "biological window" or window of opportunity of outmigrating fish.

The time window of opportunity for coho could be narrow or conversely quite broad. This species of salmon can re-smoltify if held through early summer, however adult survival resulting from prolonged migration are uncertain. Steelhead that are held beyond the end of June, or that experience a cumulative exposure to higher temperatures, can residualize. Chinook salmon have a variety of life history types, early emigration as fry, rearing for 2-3 months in-river, and rearing for up to 1 year. The Green River stock has expressed all three types and the survival of any one type during outmigration could be distinct. Type 1 and 2 could find exceptional rearing habitat in the reservoir, Type 3 could be adversely impacted if held for any length of time. Chinook juveniles, as the smallest outmigrants, also face the risk of increased mortality from predation. Most theories of predation suggest that predators have increased opportunity to find prey if the exposure period (time prey is vulnerable) is increased.

Travel times observed in this study show all tagged fish can be expected to emigrate within their window. However, even within the accepted limits of travel times inside the biological window, the Corps has refined this definition to include maximum travel rates that could impact smolt survival. Travel rates of greater than 10 days are considered significant for coho and steelhead as these stocks have a more defined biological window while 20 days was selected for chinook which can spend a considerable period rearing prior to migrating.

To maximize smolt survival by decreasing travel time through Howard Hanson Reservoir during operation of the AWSP, a series of operation and management measures are suggested: 1) limit reservoir refill rate, 2) monitor juvenile outmigration, and 3) release periodic freshets. A maximum refill rate (rate the reservoir is filled or the difference of inflow-outflow) is proposed for each phase of the AWSP. A fill rate limit was already implemented under the AWSP hydrologic modeling (Section 9). The modeled fill rates vary by phase: Phase I had maximum rates in March of 400 cfs per day, in April of 300 cfs per day, and in May of 200 cfs per day; Phase II had maximum rates only in late April at 300 cfs per day, and in May of 200 cfs per day. These rates are lower than Baseline rates observed in 1995 and 1996, approximately 400 cfs per day in late April and most of May. Monitoring during the first years of the AWSP project operation are essential to identify the range of fill rates affecting smolt travel times and ultimately survival. This monitoring should provide the needed information to adapt the AWSP to maximize smolt survival through the project.

Development of a maximum fill rate will be dependent not only on monitoring and evaluation of outmigrants through the AWSP, but also will include monitoring and evaluation of downstream areas for potential impacts to side-channel areas, steelhead spawning and incubation, and ocean migration of lower river juveniles. In essence, adaptive management is required to "optimize" the interacting priorities of maximizing smolt survival with protection of lower watershed resources. In concept, the maximum fill rate limit, which essentially mimics natural inflow patterns, should be the preferred reservoir fill and outflow release program. To date, this refill and release strategy has not been fully discussed or completely accepted by all participating resource agencies. As such, alternatives to the this refill and release strategy can be altered based on sound, defensible data from site-specific monitoring or from information collected from appropriate parallel watersheds.

Dilley and Wunderlich (1992 and 1993) present firm results that increased outflow will increase the number of smolts that can safely exit the project. As such, periodic freshets should be considered as an important management tool to improve survival of smolts migrating through the AWSP. This measure will require careful integration of information gained from monitoring of smolts monitoring through the reservoir as well as from monitoring of downstream areas to minimize salmonid fry stranding and impacts to steelhead spawning. These freshets were modeled under the AWSP hydrologic modeling exercise (Section 9) and incorporated the best available information on juvenile salmonid behavior downstream as well has side-channel/mainstem channel dynamics.

2B-3.5.3 Conclusions and Recommendations:

- This study will be repeated either in the short-term using radio-transmitters, or more likely longer-term, after the AWSP is approved and completed (2003), with passive integrated transponders (PIT), larger release groups (n=500-1,000), and with sampling of tagged fish at dam outfall. Monitoring is discussed in *Section 10, Proposed Adaptive Management Monitoring and Evaluation Program*.
- Monitoring and evaluation of tagged fish during operation of the AWSP is essential to maximize smolt survival through the project. Evaluation results will be used to refine to refill and fish passage facility operations.
- An operation model could be developed such as the CRISP (Columbia River Salmon Passage) model for managing the reservoir. Using these study results to develop initial model parameters, a low-constant refill rate that matches inflow would be a initial guideline.
- All AWSP project modeling has incorporated some aspect of limiting the fill rate during the main outmigration period (late-April through May, *Section 9. Modeling Parameters for Baseline, Phase I, and Phase II*). Fill rate limitation results in a more natural outflow regime. These modeling results were used in the assessing impacts of the AWSP on reservoir survival.
- A surface collector/fish passage facility is being designed and will be completed by 2003, with capacity to safely screen 400-1250 cfs, and up to a maximum of 1600 cfs (95% of flow in a median or average May). This passage facility is a one-of-kind facility, and should maximize survival at the dam and vastly improve collection of smolts holding in the lower reservoir.
- If agency cooperators concur, a predator abundance and removal program is proposed. This is a preventive measure to insure successful outmigration of chinook outmigrants (the smallest outmigrants). In combination with PIT-tag and hydroacoustic monitoring and evaluation, monitoring of predators would continue during Phase I and II. If there is an increase in overall abundance in response to outmigrant presence a selective predator removal program can be initiated.

- Additional mitigation/restoration features being planned include: 1) leaving all inundated/standing trees around the reservoir for cover; 2) placing floating debris islands throughout the reservoir; 3) creating additional rearing capacity above and below the reservoir. The selected mitigation and restoration plan is discussed in *Section 8. Restoration and Mitigation Plan Summary*.

TABLE 10. COMPARISON OF RESERVOIR AND TOTAL PROJECT TRAVEL TIME AND TRAVEL RATES FOR COHO SALMON, STEELHEAD, FALL AND SPRING CHINOOK SALMON AT 6 WATER CONTROL PROJECTS IN OREGON AND WASHINGTON: TOTAL PROJECT=DAM AND RESERVOIR TRAVEL.

Dam or Reservoir	Capture or Tracking Method	Year of Study	Total Project Travel Time (days)	Reservoir Travel Time Median/Avg. Days	Reservoir Length	Project Travel Rate (miles/day)	Reservoir Travel Rate (miles/day)	NOTES
COHO SMOLTS								
Wynoochee	Scoop Trap Below Dam	1973	43.7		3.3	0.08		April 2 Release
	Scoop Trap		18.3		4.4	0.15		June 4 Release
	None	1974	20.77		4.4	0.21		May Release
	Scoop and Lake Trap	1975	28.7	4	3.3	0.11	0.8	Late April Release
Howard Hanson Low P.	Scoop Trap Below Dam	1984	3		1.5	1.33		95% of fish at trap in 3 days
Howard Hanson Average	Radio Tracking	1995		6.2	3.6		0.6	61% of 110 detected
Howard Hanson Full Pool	Radio Tracking	1995		6	4.4		0.8	74% and 87% of 38
Mayfield	Radio Tracking	1996		8.1	6.7		0.8	29% 7 of 24
Riffe	Radio Tracking	1996		6.1	22.4		3.7	6% 1 of 17
STEELHEAD SMOLTS								
Wynoochee	Scoop Trap Below Dam	1973	20.6		3.3	0.16		Late April Release
	Scoop Trap Below Dam	1975	11.4		4.4	0.39		Early May Release
Foster	Turbine Net	1969	12		5.9			
Howard Hanson Average	Radio Tracking	1995		4.2	4.4		1.2	72% of 106 detected
Howard Hanson Full Pool	Radio Tracking	1995		2.5	4.4		2.0	88% of 34 detected
Mayfield	Radio Tracking	1996		5	6.7		1.3	89% of 18
Riffe	Radio Tracking	1996		5.1	21		4.1	48% of 29

FALL CHINOOK FRY OR SMOLTS								
Wynoochee	Scoop Trap Below Dam	1973	30.9 (fry)		3.3	0.11		Early May Release
Howard Hanson	Radio Tracking	1995		6.8 (smolt)	4.4		0.7	39% 7 of 18 detected, June
SPRING CHINOOK								
Wynoochee	Scoop Trap Below Dam	1973	32.9		0.5 (forebay)	0.02		Released in Forebay
Foster	Turbine Net	1969	9		5.9	0.66		
Elwha/Lake Mills	Sample Station in Eicher	1985			2.8			
Mayfield	Radio Tracking	1996		2.1	6.7		3.19	1 of 1 detected

2B-3.6 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Aitkin, J.K. 1996. Progress report on the Howard Hanson Project Adult Return Rate Study for CWT coho and chinook salmon, 1994 and 1995. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Bilton, H.T., D.F. Alderdice, and J.T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39:426-447.

Chrisp, E.Y., and T.C. Bjornn. 1978. Parr-smolt transformation and seaward migration of wild and hatchery steelhead trout in Idaho. Final Report. Project F-49-12. Idaho Cooperative Fishery Research Unit, Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dunn, C.A. 1978. Evaluation of downstream fish passage through multi-level outlet pipes at Wynoochee Dam. Washington State Department of Fisheries, Progress Report No. 45.

Harza. 1997. Cowlitz Hydroelectric project: 1996 juvenile salmonid radio-tagging study. Harza Northwest Technical Report, Bellevue, Washington.

Holtby, L.B., T.E. McMahon, and J.C. Scrivener. 1989. Stream temperatures and inter-annual variability in the emigration timing of coho salmon (*Oncorhynchus kisutch*) smolts and fry and chum salmon (*O. keta*) fry from Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:1396-1405.

Irvine, J.R., and B.R. Ward. 1989. Patterns of timing and size of wild coho salmon (*Oncorhynchus kisutch*) smolts migrating from the Keogh River Watershed on Northern Vancouver Island. Canadian Journal of Fisheries and Aquatic Sciences 46:1086-1094.

Lee, D.C. 1991. A stochastic, compartmental model of the migration of juvenile anadromous salmonids in the Columbia River Basin. Ecological Modeling 54:227-245.

Keppel, Geoffrey. 1991. Design and analysis, 3rd edition. Prentice Hall, Englewood Cliffs, NJ.

Matthew, S.B., and R. Buckley. 1976. Marine mortality of Puget Sound coho salmon (*Oncorhynchus kisutch*). Journal of the Fisheries Resource Board of Canada 33:1677-1684.

Matthews, S.B., and Y. Ishida. 1989. Survival, ocean growth, and ocean distribution of differentially timed releases of hatchery coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46:1216-1226.

Moser, M., A. Olson, and T. Quinn. 1991. Riverine and estuarine migratory behavior of coho salmon (*Oncorhynchus kisutch*) smolts. Canadian Journal of Fisheries and Aquatic Sciences 48:1670-1678.

Newman, K. 1995. A generalized linear model analysis of adult salmonid returns to the Snake River system. North American Journal of Fisheries Management, in review.

Raymond, H.L. 1979. Effects of dam and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966-1975. Transactions of the American Fisheries Society 108:505-529.

Schreck, C.B., J.C. Snelling, R.E. Ewing, C.S. Bradford, L.E. Davis, and C.H. Slater. 1994. Migratory characteristics of juvenile spring chinook salmon in the Willamette River. Completion Report, Bonneville Power Administration.

Seiler, D., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia.

Smith, S.G., J.R. Skalski, and A. Giorgi. 1993. Statistical evaluation of the travel time estimation based on data from freeze-branded chinook salmon on the Snake River, 1982-1990. Bonneville Power Administration, Portland, Oregon.

Thedinga, J.F., and K.V. Koski. 1984. A stream ecosystem in an old-growth forest in southeastern Alaska. Part IV: the production of coho salmon smolt and adults from Porcupine Creek, P. 99-114 *in* W.R. Meehan, T.R. Merrill Jr., and T.R. Hanley (ed.) Proceedings of a symposium, Fish and wildlife relationships in old-growth forest. Am. Inst. Fish. Res. Biol., Juneau, AK.

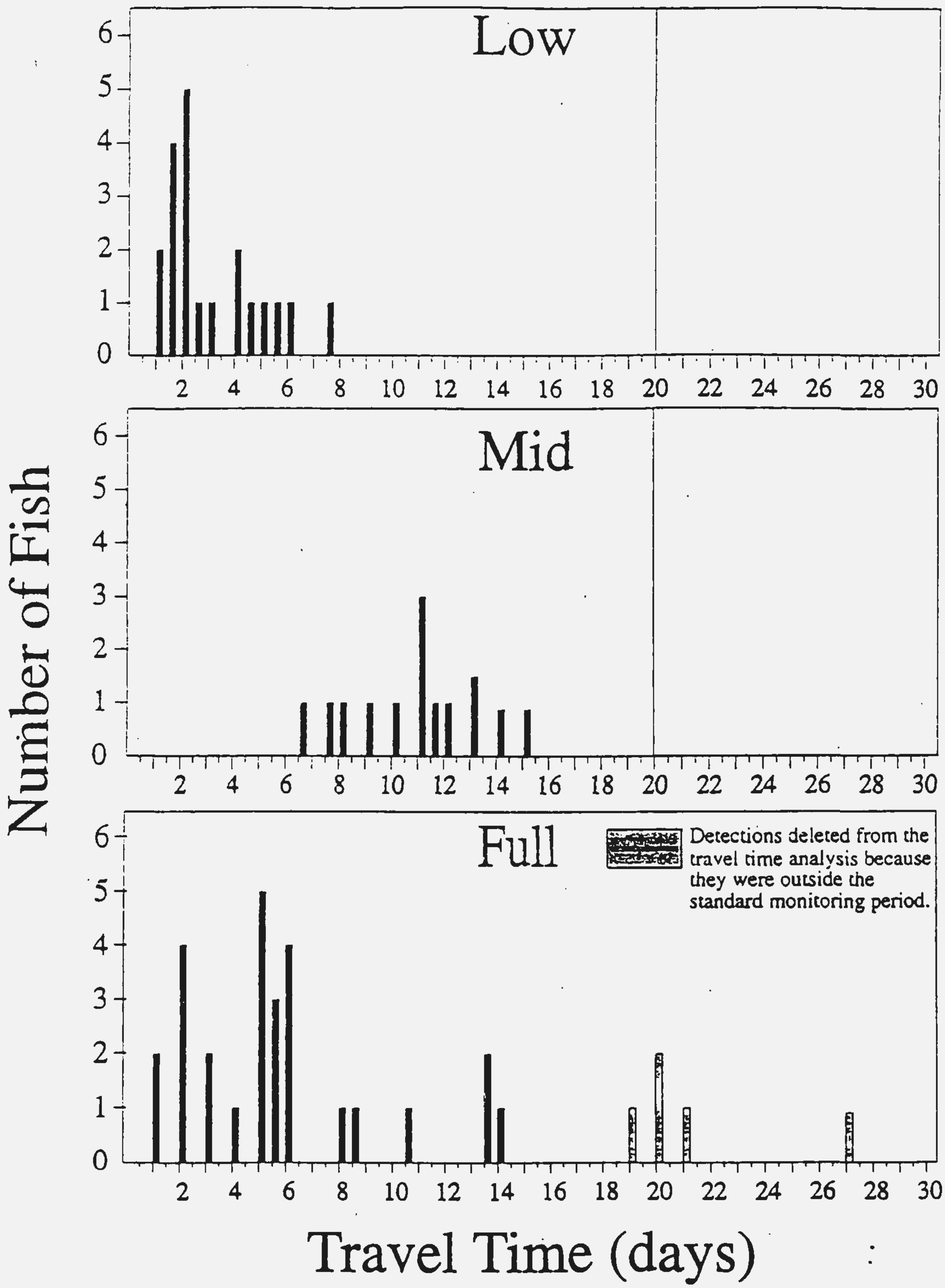
Walters, C.J., R. Hilborn, R.M. Peterman, and M.J. Staley 1978. Model for examining early ocean limitation of Pacific salmon production. Journal of the Fisheries Resource Board of Canada 35:1303-1315.

Wunderlich, R. and S. Dilley. 1985. An assessment of juvenile coho passage at the Elwha River Dams. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Zar, J.H. 1984. Biostatistical analysis, second edition. Prentice-Hall, Englewood Cliffs, New Jersey.

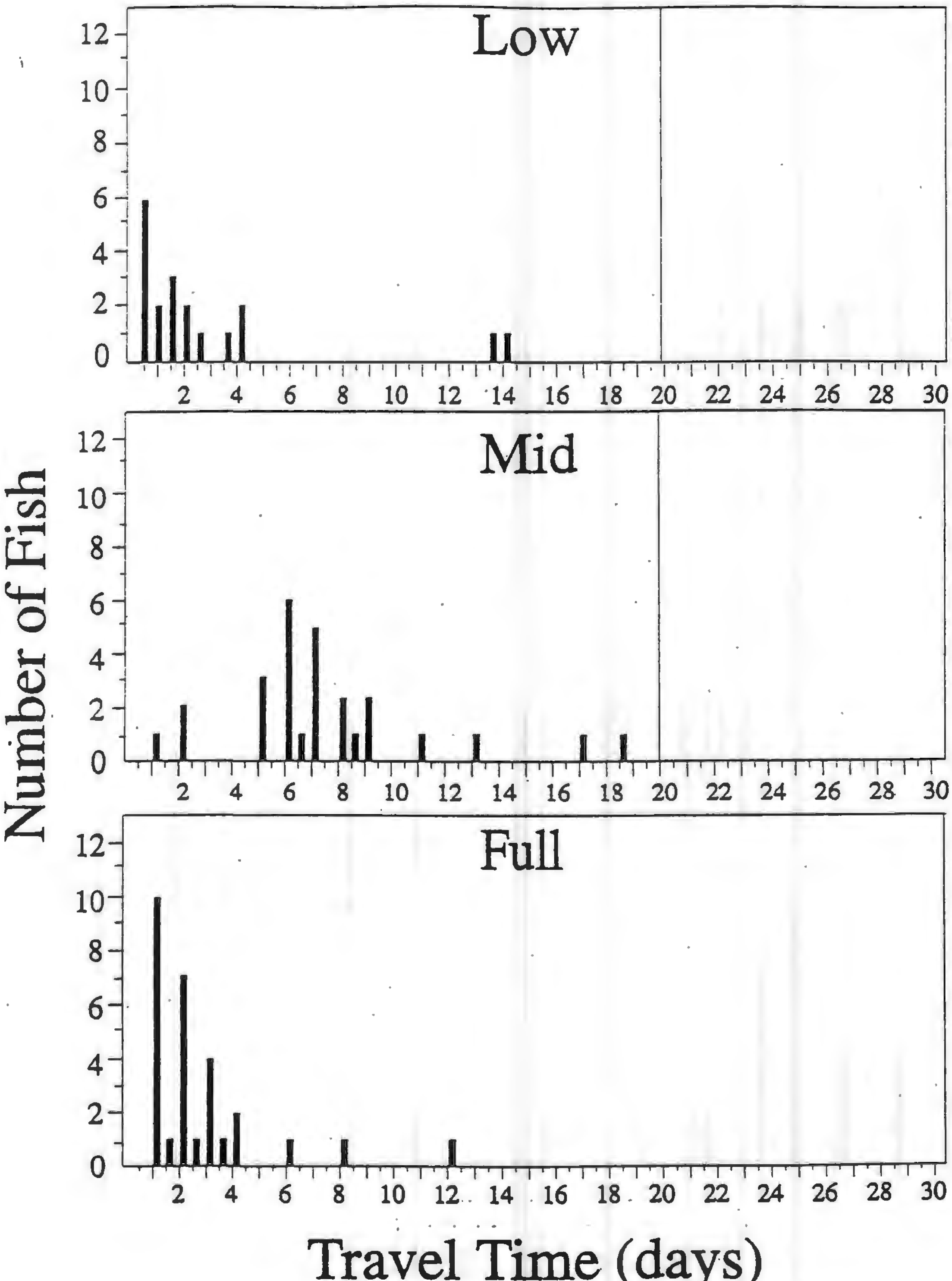
Zaugg, W.S. 1982. Some changes in smoltification and seawater adaptability of salmonids resulting from environmental and other factors. Aquaculture 28:143-151.

APPENDIX FIGURE A-1 FREQUENCY HISTOGRAM OF COHO TRAVEL TIMES TO THE DAM.



Frequency histogram of coho salmon travel time to site W at low, mid and full pools. No monitoring occured during the shaded time periods. Travel times are measured in 1/2 day increments.

APPENDIX FIGURE A-2 FREQUENCY HISTOGRAM OF STEELHEAD TRAVEL TIMES TO THE DAM.



Frequency histogram of steelhead travel time to site W at low, mid and full pools. No monitoring occured during the shaded time periods. Travel times are measured in 1/2 day increments.

SECTION 2B-4 ANALYSIS OF SMOLT TRAVEL TIME, RESERVOIR PHYSICAL VARIABLES AND BIOLOGICAL VARIABLES

2B-4.1 INTRODUCTION

The Seattle District, U.S. Army Corps of Engineers (Corps) and the City of Tacoma have initiated feasibility studies to examine the proposed increase in reservoir storage behind Howard Hanson Dam (HHD). The proposed pool increase at HHD has raised concerns by the Muckleshoot Indian Tribe and Washington Department of Fish and Wildlife (WDFW) regarding the possible impact on juvenile salmonid migration. To address these concerns, a study utilizing radio-tagged smolts was sponsored by the Corps during the spring and early summer of 1995. This study collected data on the time smolts required to transit the reservoir at three different pool levels. Additional data was collected on the physical variables associated with the reservoir at the same three pool levels (Aitkin et al., 1996). This report describes the statistical analysis and interpretation of both fish passage data, reservoir physical variables and biological variables, and is intended to be a companion report to the U.S. Fish and Wildlife Service report authored by Aitkin, et al. (1996). Summary of analysis results is presented and discussed in *Section 2B-2 Travel time and flow relationships of coho salmon and steelhead smolts migrating through Howard Hanson Reservoir, a small impoundment on the Green River, Washington.*

2B-4.2 STATISTICAL ANALYSIS

Aitkin, et al. (1996) evaluated smolt travel times and completed a multivariate analysis comparing travel time versus various refill parameters. The study methods included the release of radio tagged coho and steelhead smolts at successively higher reservoir levels. The first group was released during low pool conditions on April 11-13 1995. Smolts experiencing mid-pool conditions were released May 2-4 and high pool releases occurred May 22-24. For this section of the HHD AWSP, travel times of smolts were analyzed by analysis of variance (ANOVA), with species forming one factor and pool level (low, medium and high) comprising another factor. Late in the travel time study, two groups of chinook were released during high pool conditions (June 14 and June 21): travel time results for the chinook release groups were not included in Aitkin et al. (1996). Poor tracking results among the chinook and the small size of the release groups made individual analysis of the two release groups problematic. Instead, for this analysis, the chinook release groups were pooled, and their travel times were compared to the travel times of coho and steelhead at high pool in a one-way ANOVA with species as the main factor.

Travel times of individual species at the three different pool levels were tested for compliance with the assumptions of ANOVA. Homogeneity of variance was tested with a Levene's Test, while normalcy was evaluated with probability plots. When a data set failed to meet the assumptions of ANOVA, the data was rank-transformed and re-tested. If the transformation failed to eliminate heteroscedasticity, the ANOVA was conducted with a more stringent significance level (I=0.01 rather than I=0.05). Violation of ANOVA's assumptions leads to a loss of confidence in the Type I error rate of the test (Keppel, 1991, pp. 107). Type I error rate is the probability of rejecting a null hypothesis that is actually true and is set by the investigator. The reduction in the significance level protects against committing an error while preserving the parametric test's ability to the make inferences about populations.

Each of the physical parameters was analyzed using a one-way ANOVA with the three different pool levels serving as discrete levels. Each of the variables was tested for compliance with the assumptions of ANOVA in the same way as the biological data. The normalcy of each parameter's distribution was inspected visually with probability plots, and the assumption of homoscedasticity was tested using the Levene's test. If the specific parameter failed to meet the assumptions of ANOVA, the data were rank-transformed and retested. In several instances, the transformation failed to correct deviations from homoscedasticity and were tested at a reduced significance level (I=0.01). Parameters that yielded significant statistical results were further tested with Tukey's multiple range test to determine which treatment means were significantly different from each other.

2B-4.3 PHYSICAL PARAMETER RESULTS

The results of statistical tests on physical variables are summarized in Table 1. Each parameter is listed, along with the type of statistical test, the results and the relationship between treatment levels. The actual statistical test results are presented in the Appendix.

Parameter	Description:
Inflow (cfs)	The amount of water flowing into the reservoir.
Temperature (°C)	Daily average of stream temperature measured hourly.
Refill rate (acre-feet/day)	Rate at which the reservoir is filling based on surface area.
Outflow (cfs)	Discharge of water from the dam measured below the project.
Content (acre/feet)	Water volume of reservoir based on surface area and pool level.
Surface area (acre)	Surface area based on pool elevation.
Refill rate (acre/day)	The rate that the reservoir is filling based on content.
Inflow Turbidity (NTU)	Instantaneous turbidity of the Green River near the release site.
Outflow Turbidity (NTU)	Turbidity measurement of the reservoir outflow at the dam.

TABLE 1. RESULTS OF STATISTICAL TESTS OF PHYSICAL PARAMETERS MEASURED DURING THE HHD SMOLT PASSAGE STUDY. LEVELS UNDERLINED IN THE MRT COLUMN WERE TESTED WITH A TUKEY'S MULTIPLE RANGE TEST OR THE NONPARAMETRIC EQUIVALENT. LEVELS ARE LISTED IN ORDER OF INCREASING MAGNITUDE AND UNDERLINED LEVELS ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER (1=LOW POOL; 2=MID POOL; 3=HIGH POOL).

Parameter	Transformation	Significance Level (I)	Significance	MRT Results
Inflow	Not Required	0.05	YES ($p<0.0001$)	3 1 2
Refill (acre-ft./day)	Rank	0.01	YES ($p<0.0001$)	$\underline{3\;1}\;2$
Temperature	Not Required	0.05	YES ($p<0.0001$)	1 2 3
Surface Area	Rank	0.01	YES ($p<0.0001$)	1 2 3
Content	Rank	0.01	YES ($p<0.0001$)	1 2 3
Discharge	Rank	0.01	YES ($p<0.0001$)	$3\;\underline{1\;2}$
Refill (acre/day)	Rank	0.01	YES ($p<0.0001$)	$\underline{3\;1}\;2$
Inflow Turbidity	Rank	0.01	YES($p<0.0001$)	$\underline{3\;1}\;2$
Outflow Turbidity	Uninterpretable	N/A	N/A	N/A

2B-4.4 PHYSICAL VARIABLES ANALYSIS INTERPRETATION:

Inflow:

Null hypothesis (H_o): The mean inflow into the reservoir was the same at each pool level.

The null hypothesis was rejected. There is a significant difference in inflow between different pool levels in this study. The results of the Tukey Multiple Range Test indicate that the mean inflow during high pool was significantly lower (⌧ = 500.25 cfs) than the inflow at low pool (⌧ = 762.38 cfs). The inflow at mid-pool was significantly greater than both high and low pools (⌧ = 1045 cfs) (Figure 1).

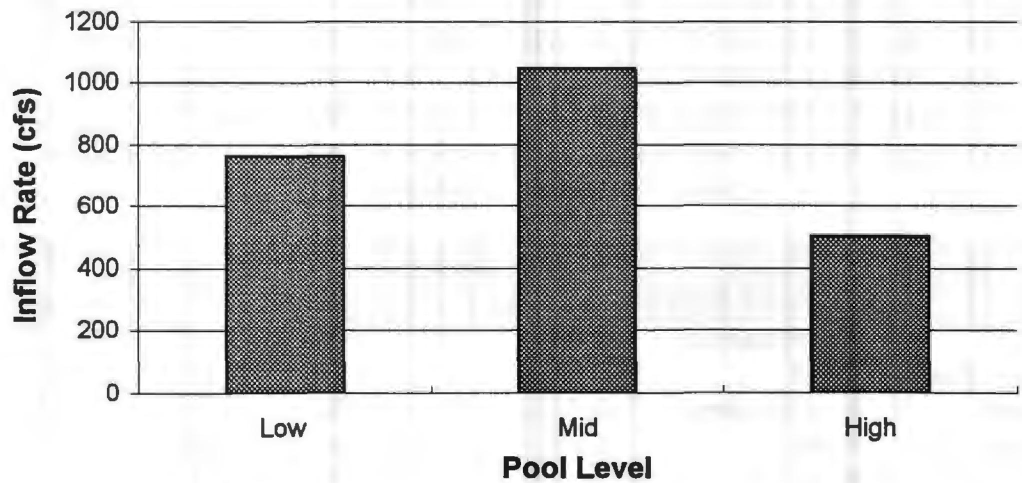


FIGURE 1. MEAN INFLOW RATES INTO THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Refill (acre-feet/day):

Null hypothesis (H_o): The mean refill rate (in acre-feet/day) was the same at each of the three pool levels.

The null hypothesis was rejected. There is a significant difference in refill rate between pool levels. The mean refill rate during high pool (⌧ = 180.7 acre-feet/day) was not significantly different than the mean refill rate during low pool (⌧ = 266.43 acre-feet/day). However, the mean refill rate at mid-pool was significantly greater than both low and high pools (⌧ = 716.6 acre-feet/day) (Figure 2).

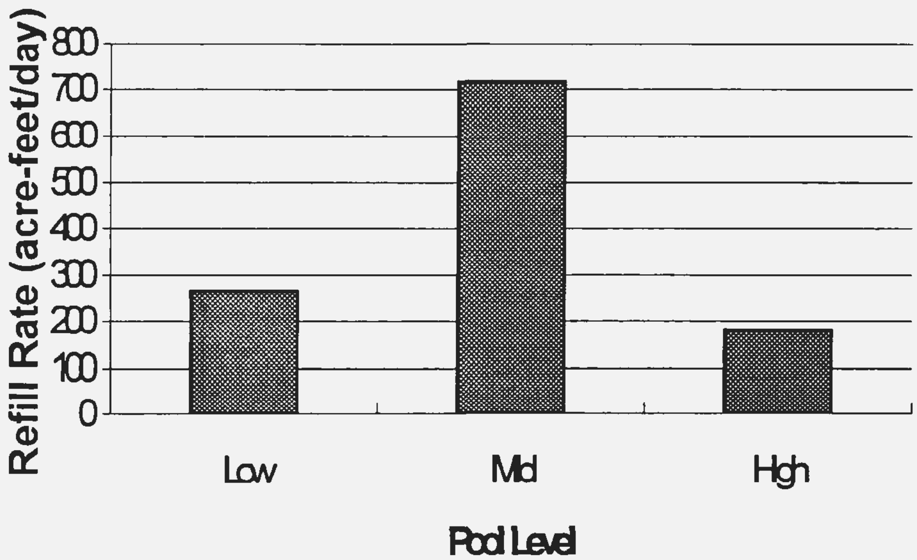


FIGURE 2. MEAN REFILL RATE IN ACRE-FEET/DAY OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SUMMER OF 1995.

Temperature:

Null hypothesis (H_o): The mean temperature was the same during each of the pool levels.

The null hypothesis was rejected. The mean temperature was significantly different in temperature between the three pool levels. The mean stream temperature during high pool was significantly greater ($\bar{x}$ = 10.66 °C) than both mid and low pool temperatures. Similarly, the mean stream temperature at mid-pool ($\bar{x}$ = 8.30°C) was significantly greater than the mean low pool temperature ($\bar{x}$ = 6.94°C) (Figure 3).

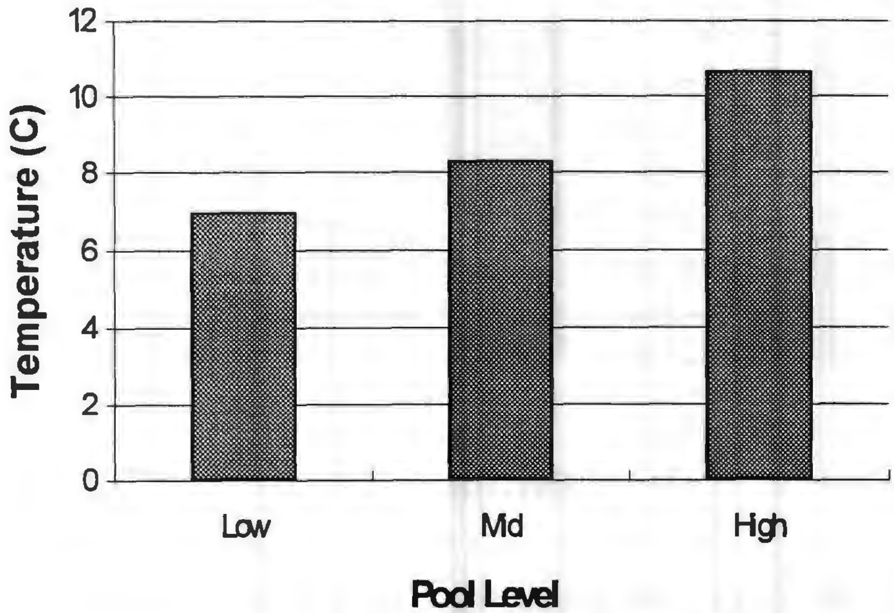


FIGURE 3. MEAN WATER TEMPERATURE FLOWING INTO THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Surface Area:

Null hypothesis (H_o): The mean surface area (acres) was the same during each of the three pool levels.

The null hypothesis was rejected. There was a significant difference in mean surface area between the three pool levels. Results of the multiple comparison test demonstrate that the mean surface area at high pool (⌧ = 721.79 acres) were significant greater than the mean surface area of both mid pool (⌧ = 511.02 acres) and low pool (⌧ = 170.91 acres). Also, the mean surface area at mid-pool was significantly greater than the mean surface area at low pool (Figure 4).

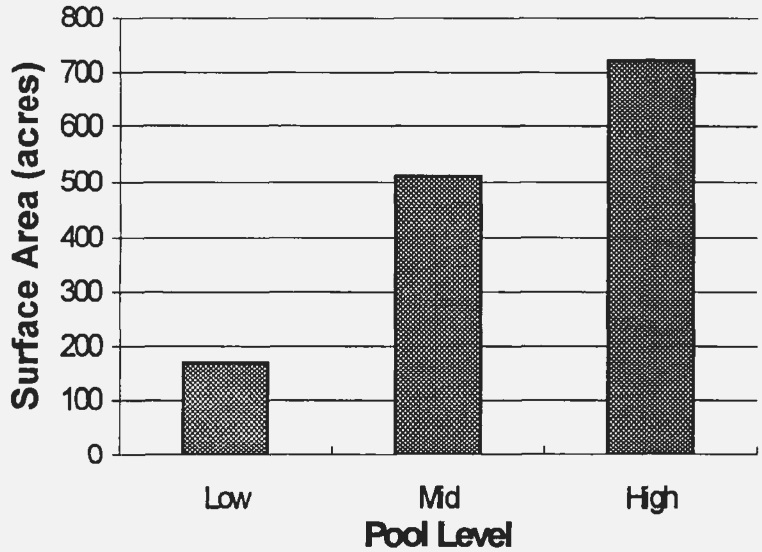


FIGURE 4. MEAN SURFACE AREA IN OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Content:

Null hypothesis (H_o): The mean content (acre-feet) was the same during each of the three pool levels.

The null hypothesis was rejected. There was a difference in the mean content of the reservoir at the three pool levels. The mean content at high pool (⌧ = 24,033.85 acre-feet) was significantly greater than both mid and high pool. Similarly, mean mid-pool content (⌧ = 15,967.30 acre-feet) was significantly greater than mean content at low pool (⌧ = 3409.95) (Figure 5).

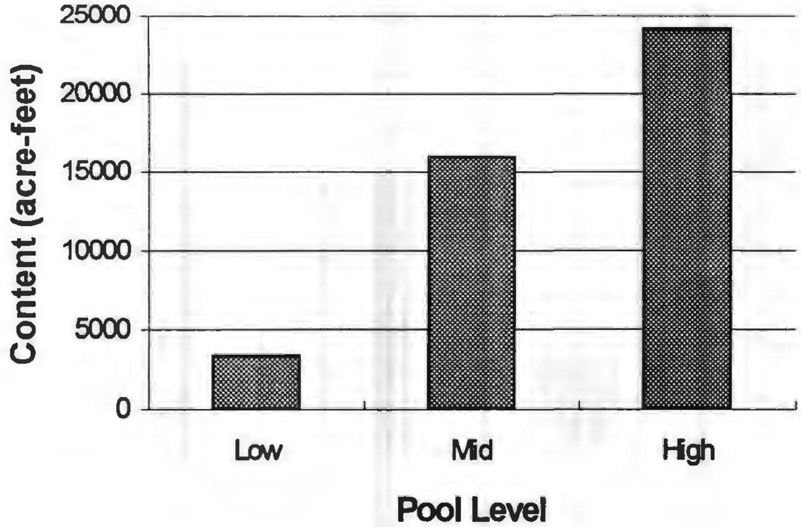


FIGURE 5. MEAN CONTENT OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Discharge:

Null hypothesis (H_o): The mean discharge rate (cfs) from the dam was the same during each of the three pool levels.

The null hypothesis was rejected. There was a difference in mean discharge rate between the three pool levels. The mean discharge rate during low (⌧ = 633.33 cfs) and mid-pool (⌧ = 511.02 cfs) were not different from each other, however, both were significantly greater than the mean discharge rate at high pool (⌧= 405.70 cfs) (Figure 6).

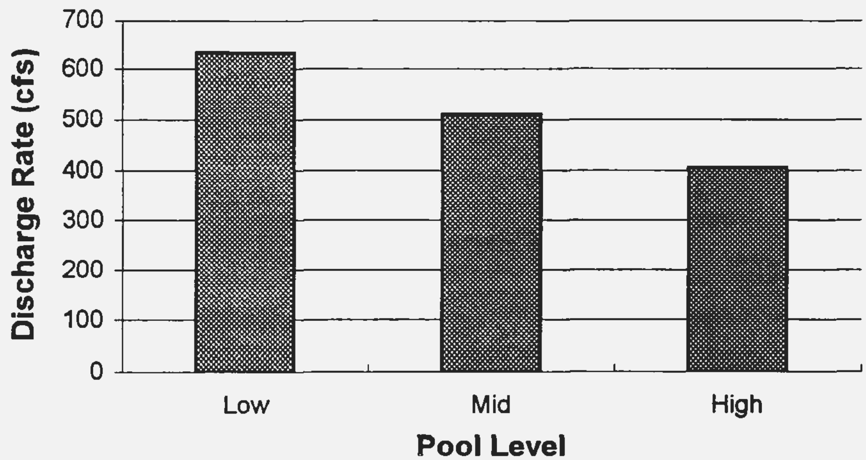


FIGURE 6. MEAN DISCHARGE RATE OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Refill (acre/day):

Null hypothesis (H_o): The mean refill rate was the same for each of the three pool levels.

The null hypothesis was rejected. The refill rate was significantly different between pool levels. The mean refill rate at mid-pool ($\bar{x}$ = 18.41 acre/day) was significantly greater than the mean refill rate at both low pool ($\bar{x}$ = 8.04 acre/day) and high pool ($\bar{x}$ = 4.91 acre/day) (Figure 7). The mean refill rate at high and low pools were not significantly different from each other.

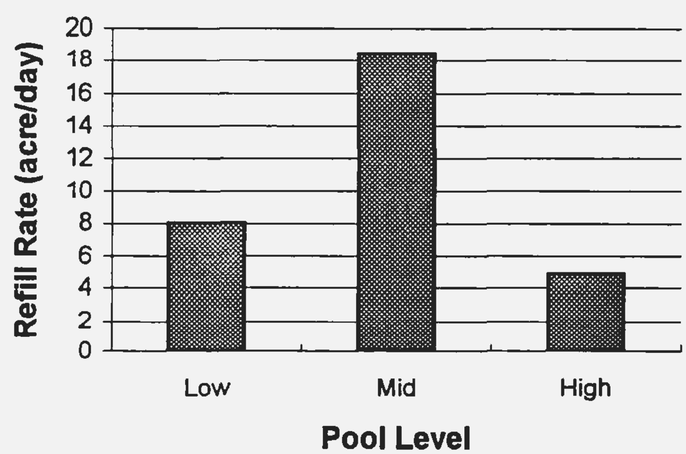


FIGURE 7. MEAN REFILL RATE IN ACRE/DAY OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Inflow Turbidity:

Null hypothesis (H_o): The mean inflow turbidity was the same for all three pool levels.

The null hypothesis was rejected. There was a significant difference in the mean inflow turbidity between pool levels. The mean inflow turbidity at mid-pool (⌧ = 1.6 NTU) was significantly greater than mean inflow turbidity for both low (⌧ = 1.15 NTU) and high pool (⌧ = 1.09 NTU) (Figure 8). The mean inflow turbidity for both high and low pools were not significantly different from each other.

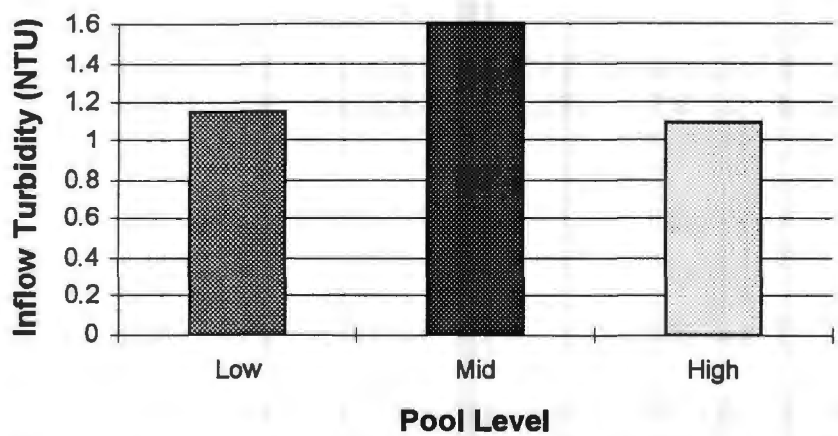


FIGURE 8. MEAN INFLOW TURBIDITY OF THE HOWARD HANSON DAM RESERVOIR DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SUMMER OF 1995.

Outflow Turbidity:

Data for outflow turbidity was uninterpretable probably due to artifacts of the sampling method. The data is discrete with large numbers of repeated values at each pool level. For example, the scatter plot of outflow turbidity at low pool results in only three data points rather that the expected 20 data points (Figure 9). This condition does not meet the assumptions of ANOVA.

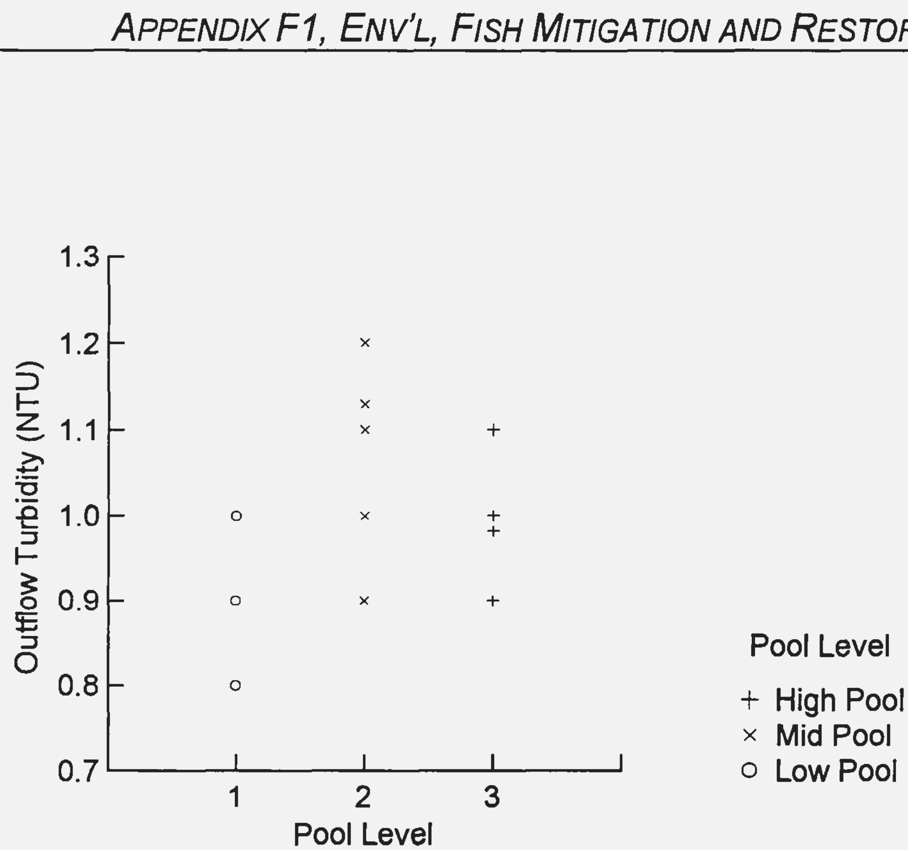


FIGURE 9. SCATTER PLOT OF OUTFLOW TURBIDITY MEASURE BELOW HOWARD HANSON DAM DURING THE SPRING AND SUMMER OF 1995 (N=60; 1=LOW POOL; 2=MID POOL; 3=HIGH POOL).

High Pool Conditions

Fall chinook were released later (June 14 and 22) than the coho and steelhead high pool release groups (May 22-24). As a result, chinook may have experienced different reservoir conditions at high pool than the steelhead and coho who had been released earlier. All nine physical parameters discussed above were examined for differences between the early high pool conditions (May 22 to June 11) and late high pool conditions (June 14 to July 11) with a simple one-way ANOVA after rank transformation (Table 2). The hypothesis being tested in each case was:

H_o: The mean value of the parameter was the same for both the early and late high pool.

TABLE 2. RESULTS OF STATISTICAL TESTS OF PHYSICAL RESERVOIR PARAMETERS COMPARING EARLY AND LATE HIGH POOL CONDITIONS.

Parameter	Significance	Early high pool mean (n=20)	Late high pool mean (n=31)
Inflow (cfs)	YES ($p<0.001$)	500.25	295.25
Refill (acre-ft/day)	YES ($p<0.001$)	180.7	-9.387
Temperature (°C)	YES ($p<0.001$)	10.66	12.64
Surface Area (acres)	YES ($p<0.001$)	721.79	767.23
Content (acre-feet)	YES ($p<0.001$)	24033.85	25791.19
Discharge (cfs)	YES ($p<0.001$)	405.7	301.6
Refill (acre/day)	YES ($p<0.001$)	4.91	-0.27
Inflow Turbidity (NTU)	YES ($p<0.001$)	1.09	0.83
Outflow Turbidity (NTU)	Uninterpretable	-	-

Biological Data Analysis

Biological data on the fish used in the study was collected and analyzed to detect differences between release groups. The parameter measures were: forklength (mm), weight (g), K factor (g/l^3 x 1000,000), and Na / K ATPase activity.

Statistical results are summarized in Table 3. The complete ANOVA tables and plots of the data are presented in the reference section.

TABLE 3. RESULTS FOR BIOLOGICAL PARAMETERS MEASURED FOR SALMONIDS RELEASED AT DIFFERENT POOL LEVELS. THE MRT COLUMN PRESENTS RESULTS OF THE TUKEY'S MULTIPLE RANGE TEST OR THE NON-PARAMETRIC EQUIVALENT. POOL LEVELS (1=LOW; 2=MID; 3=HIGH) ARE LISTED IN ORDER OF INCREASING MAGNITUDE. POOL LEVELS CONNECTED BY A LINE ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER.

Coho Salmon: Parameter	Transformation	Significance Level (I)	Significance	MRT
Forklength	Not Required	0.05	p = 0.001	3 2 1
Weight	Rank	0.01	p = 0.001	1 3 2
K - Factor	Rank	0.01	p <0.001	1 3 2
Na/K ATPase Activity	Rank	0.01	p < 0.001	3 2 1
Winter Steelhead:				
Parameter	**Transformation**		**Significance**	**MRT**
Forklength	Not Required	0.05	p = 0.045	1 3 2
Weight	Not Required	0.05	p = 0.014	1 3 2
K-Factor	Not Required	0.05	p = 0.209	N/A
Na/K ATPase Activity	Not Required	0.05	p = 0.047	Inconclusive

Biological Data Interpretation

Fork Length:

Null hypothesis (H_o): The mean forklength of coho salmon was the same for all three release groups.

The null hypothesis was rejected. Mean forklength was significant different between coho salmon released at different pool levels. The Tukey's multiple comparison test demonstrated that the mean forklength of coho released at low pool (⌧ = 140.05 mm) was significant greater than the mean forklength of coho released during high pool conditions (⌧=.134.57 mm) (Figure 10). The relationship of mean forklength of coho released during mid pool (⌧ = 142.13) is ambiguous because of overlap in the multiple range test. This ambiguity is caused by differences in the relative power of the two statistical tests. The ANOVA has detected a difference, but the Tukey's test is not powerful enough to clearly discern where the difference exists.

Null hypothesis (H_o): The mean forklength of winter steelhead is the same for all three release groups.

The null hypothesis was rejected. There was a significant difference in mean forklength of winter steelhead between release groups. Mean forklength of steelhead released at mid-pool (⌧ = 200.26 mm) was significantly greater than mean fork length of those released at low pool (⌧ = 193.58 mm) (Figure 10). The relationship of mean forklengths of steelhead released at high pool (⌧ = 196.5) is ambiguous due to overlap in the multiple range test.

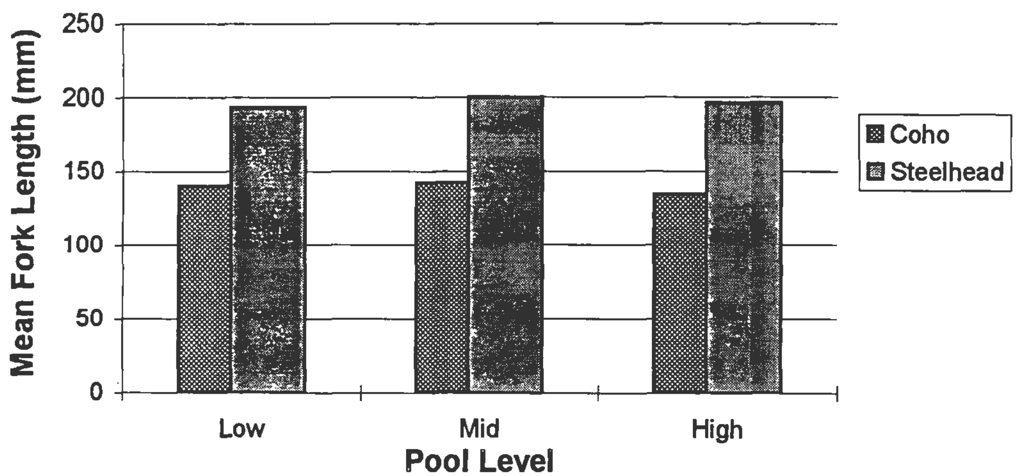


FIGURE 10. MEAN FORK LENGTHS OF COHO AND STEELHEAD RELEASED AT DIFFERENT POOL LEVELS DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SUMMER OF 1995.

Null hypothesis (H_o): The mean forklength of smolts was the same for all three species.

The null hypothesis was rejected. The mean forklength of smolts was not the same for all three species. When averaged across all release groups, the mean forklength of winter steelhead (⌧ = 195.97 mm) was significantly greater that the mean forklength of coho (⌧ = 138.36 mm) (Figure 11). Among high pool release groups, mean forklength of steelhead (⌧ = 195.29 mm) was significantly greater than both the mean forklength of coho (⌧ = 134.95 mm) and chinook (⌧ = 110.06 mm) (Figure 11). The mean forklength of coho was also significantly greater than the mean forklength of chinook.

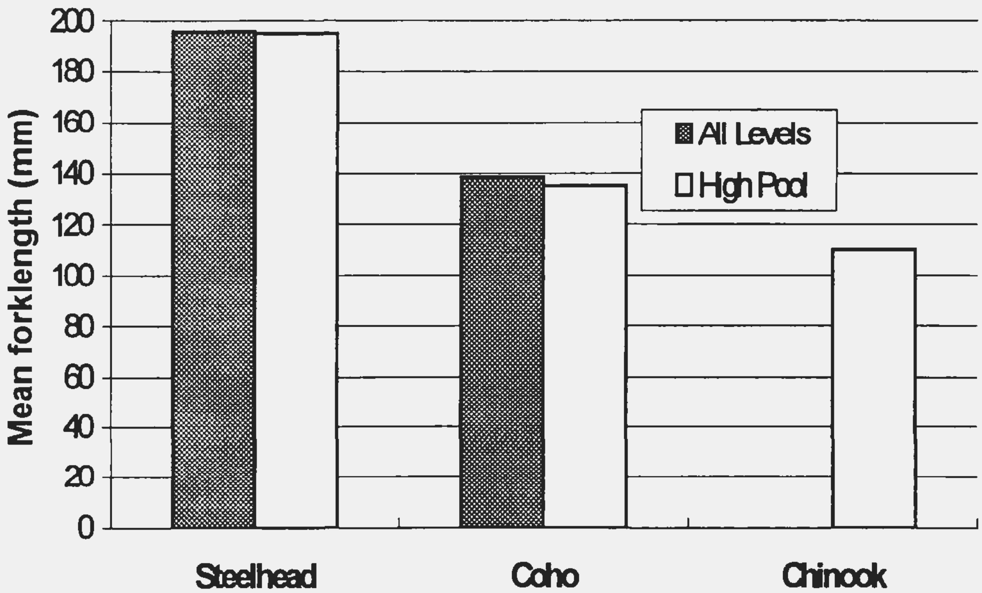


FIGURE 11. MEAN FORKLENGTHS OF SMOLTS RELEASED INTO THE HHD RESERVOIR DURING THE SPRING AND SUMMER OF 1995.

Weight:

Null hypothesis (H_o): The mean weight of coho salmon was the same for all three release groups.

The null hypothesis was rejected. The weight of coho was significantly different between release groups. Results of the multiple comparison test indicate that the mean weight of coho released at mid pool (⌧ = 33.09 g) was significantly greater than the mean weight of coho released both at high pool (⌧ = 26.84 g) and low pool (⌧= 26.98 g) (Figure 12). The mean weight of coho released at high and low pools was not significantly different from each other.

Null hypothesis (H_o): The mean weight of winter steelhead was the same for all three release groups.

The null hypothesis was rejected. The mean weight of steelhead was significantly different between release groups. The Tukey's Multiple Range test demonstrated that the mean weight of steelhead released at mid pool (⌧ = 83.0 g) was significantly greater than the mean weight of steelhead released at low pool (⌧= 74.74 g) (Figure 12). The relationship of mean steelhead weight released at high pool (⌧= 78.56 g) was ambiguous because of overlap in the multiple range test.

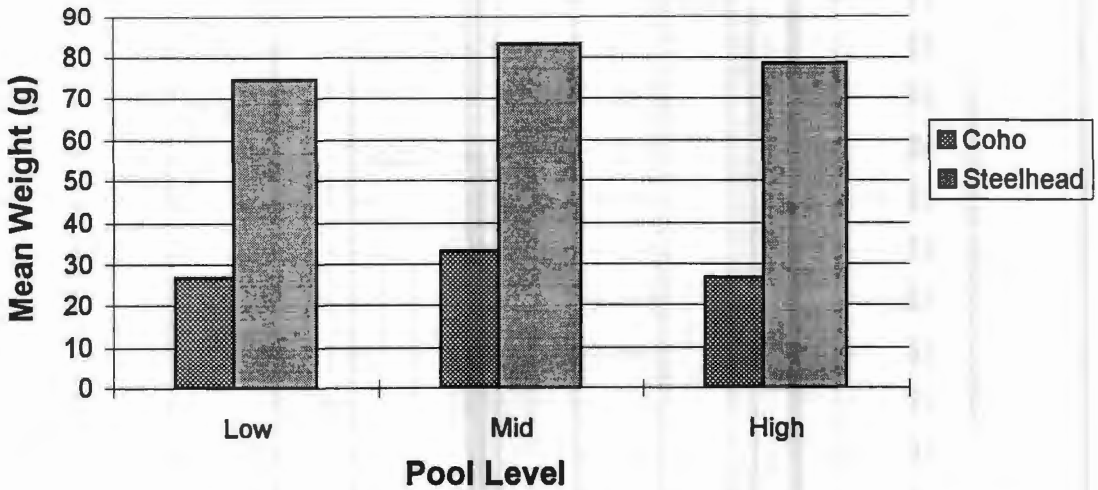


FIGURE 12. MEAN WEIGHTS OF COHO AND STEELHEAD RELEASED AT DIFFERENT POOL LEVELS DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Null hypothesis (H_o): The mean weight of smolts was the same for all three species.

The null hypothesis was rejected. The mean weight of smolts was not the same for all three species. When averaged across all release groups, the mean weight of winter steelhead ($\bar{x}$ = 77.14 g) was significantly greater that the mean weight of coho ($\bar{x}$ = 28.52 g) (Figure 13). Among high pool release groups, mean weight of steelhead ($\bar{x}$ = 77.40 g) was significantly greater than both the mean weight of coho ($\bar{x}$ = 26.92 g) and chinook ($\bar{x}$ = 16.17 g) (Figure 13). The mean weight of coho was also significantly greater than the mean weight of chinook.

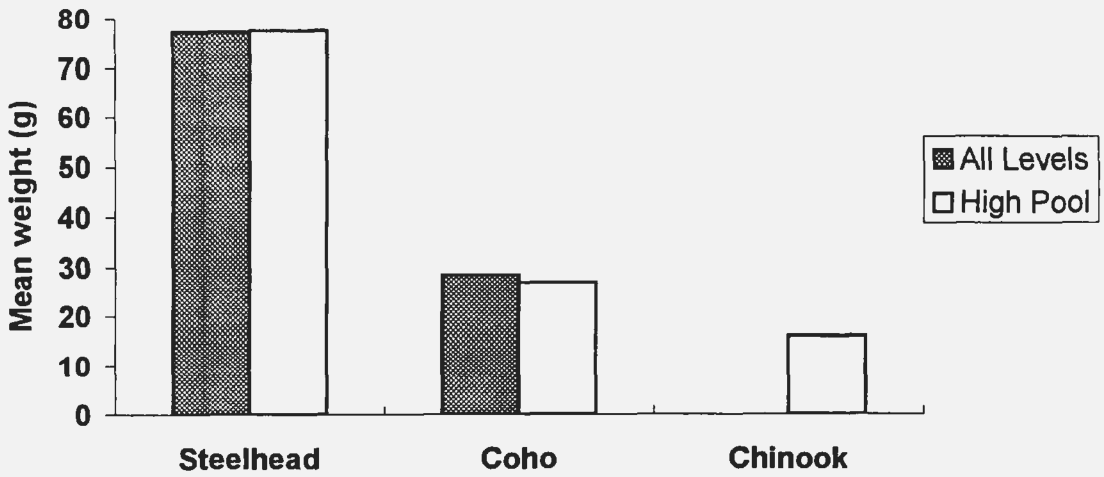


FIGURE 13. MEAN WEIGHTS OF SMOLTS RELEASED INTO HHD RESERVOIR DURING THE SPRING AND SIMMER OF 1995.

K-Factor:

Null hypothesis(H_o): The mean condition factor (K-factor) of coho was the same for all three release groups.

The null hypothesis was rejected. The mean condition factor was significantly different between release groups. The mean K-factor for coho released during mid pool (⌧ = 1.14) was significantly greater than the mean K-factor for both low and high pool release groups. Mean K-factor for coho released at high pool (⌧ = 1.09) was significantly greater than the mean condition factor for coho released at low pool (⌧ = 0.98) (Figure 14).

Null hypothesis (H_o): The mean condition factor (K-factor) for winter steelhead was the same for all three release groups.

The null hypothesis was not rejected. There was no significant difference in K-factor between release groups.

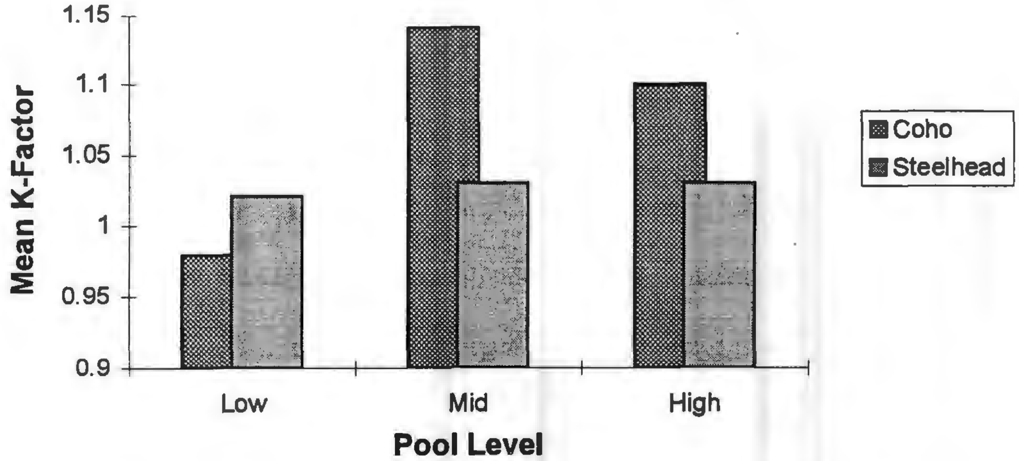


FIGURE 14. MEAN K-FACTORS [(G/L^3) X 100,000] OF COHO AND STEELHEAD RELEASED AT DIFFERENT POOL LEVELS DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

Na/K ATPase Activity:

Null hypothesis (H_o): The mean ATPase activity of coho was the same for all three release groups.

The null hypothesis was rejected. The mean ATPase activity was significantly different between release groups. The mean ATPase activity for coho released during high pool (⌧ = 9.10) was significantly less than the mean ATPase activity for both low and mid pool release groups. Mean ATPase activity for coho released at mid pool (⌧ = 14.17) was not significantly different than the mean ATPase activity for coho released at low pool (⌧ = 14.62) (Figure 15).

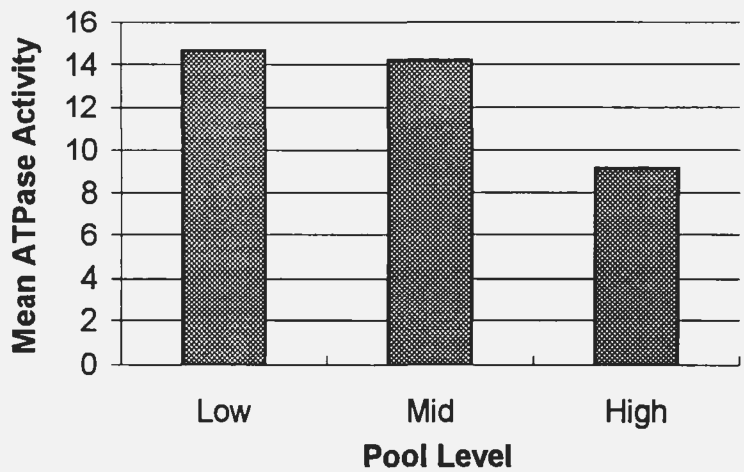


FIGURE 15. MEAN ATPASE ACTIVITY FOR COHO SMOLTS RELEASED AT DIFFERENT POOL LEVELS DURING THE SPRING OF 1995.

Null hypothesis (H_o): The mean ATPase activity of steelhead was the same for all three release groups.

The null hypothesis was rejected. The mean ATPase activity was significantly different between release groups. However, the multiple range test was unable to discern which groups were significantly different from each other (Figure 16).

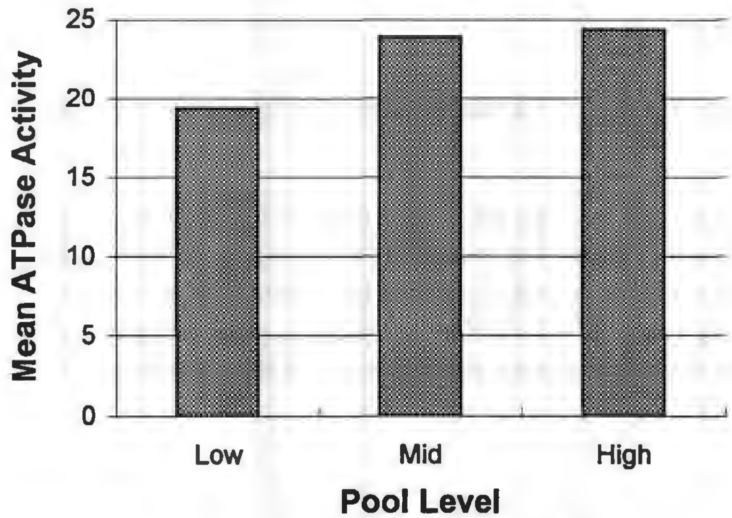


FIGURE 16. MEAN ATPASE ACTIVITY FOR STEELHEAD SMOLTS RELEASED AT DIFFERENT POOL LEVELS DURING THE SPRING OF 1995.

Null hypothesis (H_o): The mean ATPase activity was the same for all three species released during high pool conditions.

The null hypothesis was rejected, the mean ATPase activity was significantly different between species released at high pool. The mean ATPase activity for coho released during high pool (⌧ = 9.10) was significantly less than the mean ATPase activity for both chinook and steelhead. Mean ATPase activity for chinook released at high pool (⌧ = 22.84) was not significantly different than the mean ATPase activity for steelhead released at high pool (⌧ = 24.34) (Figure 17).

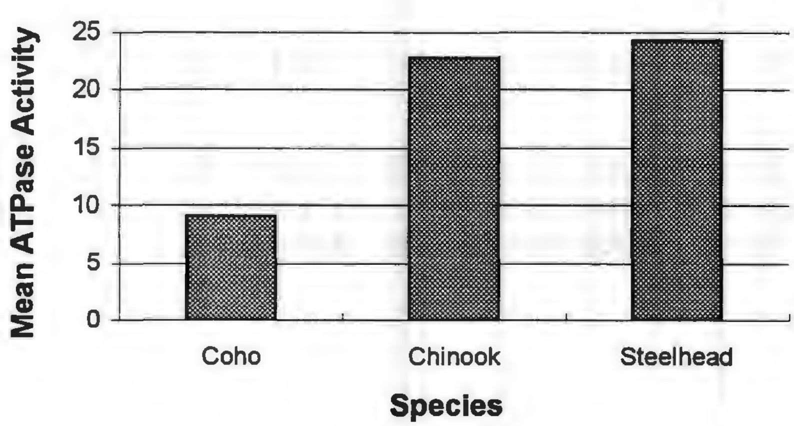


FIGURE 17. MEAN ATPASE ACTIVITY FOR DIFFERENT SPECIES OF SMOLTS RELEASED AT DURING HIGH POOL CONDITIONS IN THE SPRING AND SUMMER OF 1995.

Reservoir Transit Time:

Null hypothesis (H_o): The mean reservoir transit time is the same for all three salmonids species at high pool.

The null hypothesis was rejected. There was a significant difference in mean rank transformed transit time between species at high pool (I=0.05). The mean reservoir transit time of coho (⌧ = 6.0 days) and fall chinook (⌧ = 6.8 days) were not significantly different from each other, but were significantly longer than winter steelhead (⌧ = 2.7 days) (Figure 18). Winter steelhead transited the reservoir significantly faster than coho or chinook.

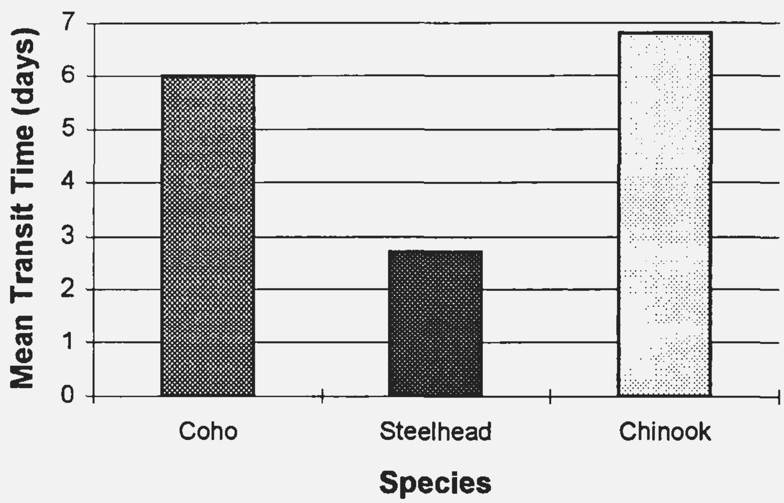


FIGURE 18. MEAN TRANSIT TIMES FOR DIFFERENT SPECIES OF RADIO-TAGGED SMOLTS RELEASED INTO THE HOWARD HANSON DAM RESERVOIR AT HIGH POOL.

NULL HYPOTHESES FOR THE 2X2 FACTORIAL TESTING TRAVEL TIME BY SPECIES AND POOL LEVEL:

Factor = Species; H_o = The mean reservoir transit time was the same for coho and steelhead.

Factor = Pool Level; H_o = The mean reservoir transit time for salmonids was the same for each pool level.

Interaction of Species & Pool Level; H_o = There was a significant interaction between Pool Level and Species on mean transit time.

The null hypothesis for the main factor Species was significant. There was a significant difference in mean travel time between species. The mean travel time for coho measured during this study was 6.2 days which was significantly slower than winter steelhead with a mean transit time of 4.4 days (Figure 19).

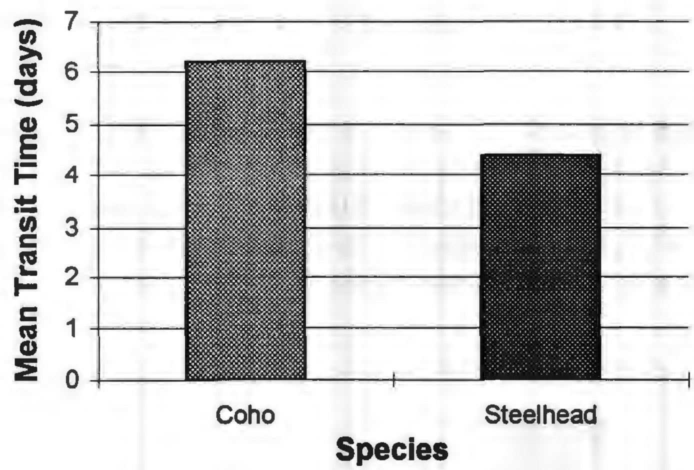


FIGURE 19. MEAN TRANSIT TIME OF RADIO TAGGED COHO AND STEELHEAD RELEASED AT DIFFERENT POOL LEVELS DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

The null hypothesis for the main factor Pool Level was also rejected, the mean transit time of salmonids used in this study was not the same at each pool level. The mean travel time of salmonids was significantly slower at mid pool (⌧ = 8.6 days) than mean transit time at both mid and high pool levels. Mean transit times at high pool (⌧ = 4.3 days) were significantly higher at than at low pool (⌧ = 2.9 days) (Figure 20). The interaction between Species and Pool Level was not significant.

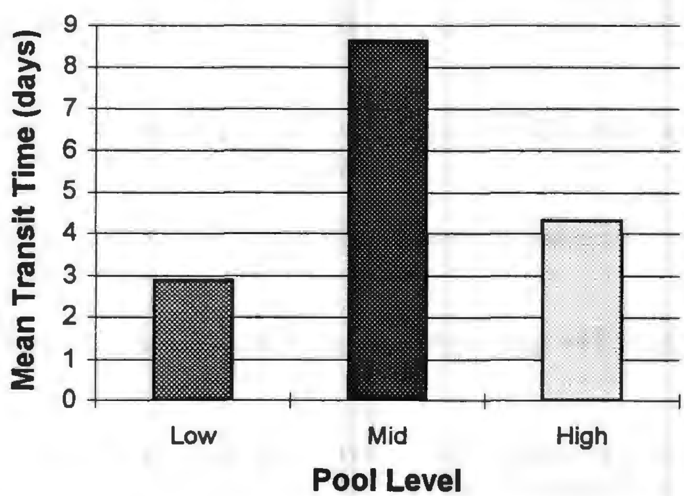


FIGURE 20. MEAN TRANSIT TIMES OF RADIO TAGGED SMOLTS RELEASED AT DIFFERENT POOL LEVELS DURING THE SMOLT TRANSIT STUDY CONDUCTED DURING THE SPRING OF 1995.

2B-4.5 LITERATURE CITED

Aitkin, J.K., C.K. Cook-Tabor and R.C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Keppel, Geoffrey. 1991. Design and analysis, 3rd edition. Prentice Hall, Englewood Cliffs, NJ.

2B-4.6 REFERENCE ANOVA TABLES -- AVAILABLE UPON REQUEST

SUBSECTION 2B-5 ASSESSMENT OF THE ECOSYSTEM RESTORATION AND AWSP ON RESERVOIR OUTMIGRATION SUCCESS OF COHO, STEELHEAD, AND CHINOOK SMOLTS

2B-5.1 INTRODUCTION

Two aspects of the AWSP may affect the survival of salmon and steelhead juveniles migrating through the reservoir: the larger pool size and the rate at which the pool is filled (refill rate). These two features can increase the travel time it takes juveniles to migrate through the reservoir. Increased travel times can result in two general negative outcomes: 1) if smolts are "delayed" beyond the normal outmigration period, "biological window," this can result in residualism, smolts stay in the reservoir and don't migrate to the ocean; and 2) increased travel times can provide more opportunities (increased exposure of prey to predators) for predation by opportunistic birds, mammals or large fish.

Aitkin et al. (1996) provided evidence that increased refill rates will increase the travel times, or travel rates, of smolts migrating through the reservoir. During periods where refill rates approached a storage rate of 400 cfs per day (800 ac-ft storage), observed travel times were from 180 to 270% greater than under lower refill rates (50-200 cfs storage) and with a longer pool. This study parallels results from travel time studies on the Snake River which have shown an increase in reservoir travel time with increased refill rate, outflow/inflow (Smith et al. 1993).

The analysis in this sub-section completes *Section 2B. Reservoir Outmigration of Juvenile Salmonids.* Here we will provide a measured impact analysis, utilizing a Baseline performance measure, travel time. Changes in smolt travel time will be assessed using 32 years of varying modeled flows and refill conditions. A summary of the AWSP and definitions used in the impact analysis were provided in the introduction to Section 2B. Modeling characteristics for Baseline, Phase I, and Phase II are discussed in Section 9.

Baseline travel times were developed as an interagency study and were discussed in the previous subsection, 2B-4. Travel time is the only measure available to assess potential impacts on juveniles migrating through the enlarged pool of the AWSP. This measure is not a value of reservoir survival but is only a potential indicator. As discussed in subsection 2B-4, travel rate has been correlated with outmigrant survival on the Columbia River, but the only available data to show such a relationship for small reservoirs is one year of study at HHD. In fact, reservoir travel time appears to be a minor component of project travel time in reservoirs with juvenile outmigrants (Section 2B-4). Inadequate dam passage with associated delays at the dam or entrapment in reservoir appears to be the major component of juvenile survival through water control projects (*Section 2D Outmigration of Juvenile Salmonids through Howard Hanson Dam*). Nevertheless, none of our agency counterparts developed a better measure or potential predictor of outmigrant success through Howard Hanson Reservoir, and there is uncertainty in our understanding of reservoir survival, so we will use travel time as a measure of change with interpolation of that change to assess reservoir survival.

The goal of this analysis is to assess impacts of the AWSP on the reservoir outmigrant success of juvenile coho, steelhead, and chinook. Specific objectives of this analysis are:

- Develop a model to predict reservoir travel times of all juvenile outmigrants under Baseline, Phase I, and Phase II conditions.
- Interpolate predicted travel times in assessing reservoir survival under Baseline, Phase I, and Phase II.
- Discuss potential means to avoid increased travel times or ways to compensate for potential declines in smolts migrating through the AWSP reservoir pool.

2B-5.2 MODEL DEVELOPMENT

Overview. A predictive travel time model was developed using 5 input variables:

1. Proportion of the outmigrant population, by species, migrating through the reservoir at half-month intervals.
2. Half-month modeled refill rates (ac-ft/day) for Baseline, Phase I, and Phase II, utilizing daily Howard Hanson inflow values for 32 years, 1962-1995.
3. Reservoir travel rate (miles/day) of each species, created as an index of travel rate vs refill rate. Observed travel rates from HHD studies were basis.
4. Half-month modeled reservoir volume (ac-ft) for Baseline, Phase I, and Phase II, utilizing daily Howard Hanson inflow values for 32 years, 1962-1995.
5. Transform reservoir volume into reservoir length, used with reservoir travel rate.

These values were then used to develop half-month travel times for each reservoir condition, Baseline, Phase 1, and Phase 2, for each species, steelhead, coho, and chinook. These travel times were then compiled into two statistics: 1) a yearly proportional travel time for the three reservoir conditions; and 2) percent of outmigrants exceeding various travel times, 5-30 days).

Development of Input Variables

Variable 1: Juvenile Outmigration. The proportion of the outmigrants is simply a statement of periodicity, or seasonal migration times of each species. A variety of references were reviewed to develop an summary of outmigrant periodicity for the Green River Basin: discussed with references in Section V.A Green River Juvenile Salmon and Steelhead Outmigrant Timing. Figure 1 shows the proportion of outmigrants in half-month increments. For comparison, Table 1 presents the only available data on outmigrant timing through and into the Howard Hanson Project.

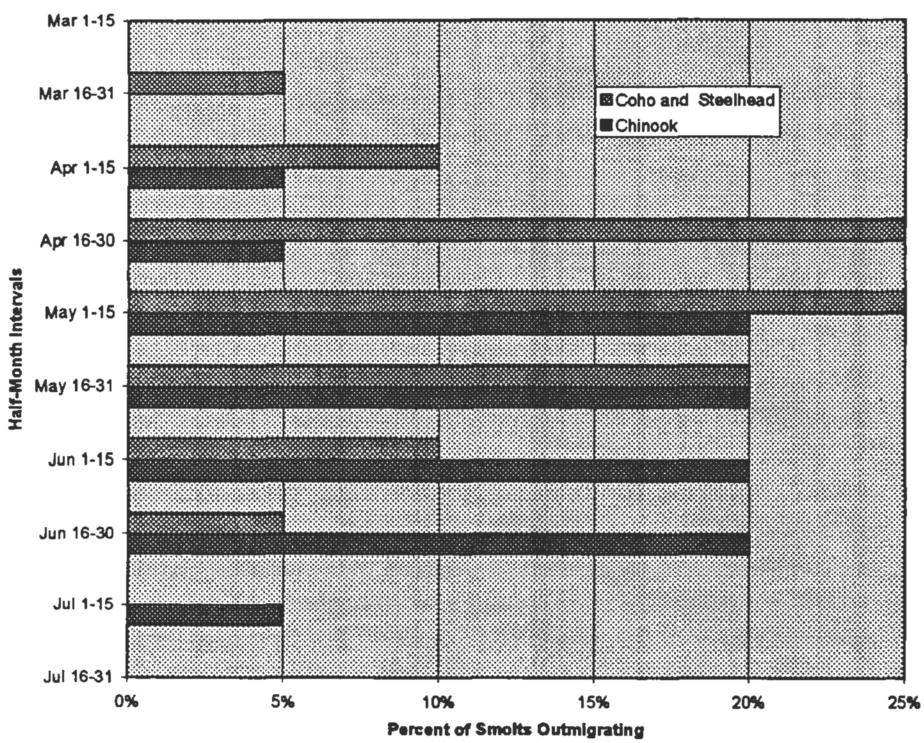


FIGURE 1. OUTMIGRATION PERIOD FOR COHO SALMON, STEELHEAD, AND CHINOOK SALMON SMOLTS ON THE GREEN RIVER (COMPILED FROM VARIOUS REFERENCES: SEE SECTION V.A. GREEN RIVER JUVENILE SALMON AND STEELHEAD OUTMIGRANT TIMING).

TABLE 1. SEASONAL PERIODICITY OF UPPER GREEN RIVER SALMON AND SMOLT OUTMIGRANTS THROUGH (AT LOWEST POOL) AND INTO THE HOWARD HANSON PROJECT (SEILER AND NEUHAUSER 1985; DILLEY AND WUNDERLICH 1992, 1993): GREY AREA=NO SAMPLES.

SUMMARY OF SEILER SCOOP TRAP BELOW HHD IN 1984 (POOL AT 1070 FT UNTIL JUNE 2).

Weekly Percentages 1984	Coho	Steelhead	**Half-Month Percentages**	Coho	Steelhead
7-Apr	0.6%	5.8%	15-Apr	1.1%	9.2%
14-Apr	0.4%	3.5%	30-Apr	7.2%	36.8%
21-Apr	2.2%	7.5%	15-May	40.3%	39.1%
28-Apr	2.9%	22.4%	31-May	44.2%	13.8%
5-May	11.2%	23.0%	15-Jun	7.2%	1.2%
12-May	23.4%	16.1%			
19-May	17.6%	10.9%			
26-May	21.3%	8.1%			
2-Jun	17.3%	2.3%			
9-Jun	3.2%	0.0%			

SUMMARY OF DILLEY FYKE TRAP ABOVE HHD IN 1991 AND 1992 ON GREEN RIVER.

	1991 Half-Month Percentages		**1992 Half-Month Percentages**	
	Coho	Chinook	Coho	Chinook
28-Feb			9.1%	31.5%
15-Mar			5.7%	1.0%
31-Mar			5.7%	50.0%
15-Apr			2.3%	68.0%
30-Apr	4.4%	2.5%	20.5%	3.8%
15-May	13.2%	0.6%	56.8%	6.7%
31-May	36.6%	2.1%	0.0%	0.3%
15-Jun	41.4%	37.7%	0.0%	0.0%
30-Jun	4.4%	49.8%	0.0%	0.0%
15-Jul	0.0%	7.4%		

Table 1, while being site specific, only provides one to three years of data that is not directly comparable. The 1984 scoop trap data does not report coho and steelhead outmigration after early June, these smolts were entrapped in the reservoir as refill started. This data set is also suspect for steelhead as the trap efficiency was very low during periods of lower outflow. The 1991 and 1992 fyke trap data are also incomplete. the trap was only operated for selected periods of time and the trap itself is not an efficient means to capture migrating smolts. Lastly, steelhead data are not provided from either. The data in this table was used to develop the overall proportions presented in Figure 1.
Variable 2: Refill Rate. Half month modeled refill rates were developed as part of an interdisciplinary team of hydrologists, modelers, and biologists. A full discussion of the data base, 1962-1995, assumptions used, and modeling characteristics is presented in Section 9. A brief discussion of refill rates is discussed here.

Baseline refill rates are based on 1996 actual refill conditions which included -- a maximum refill rate of 400 ac ft per day March 15-April 15 and 800 ac ft per day April 15-May 31, not exceeding a pool elevation of 1100 ft (6300 ac ft total volume) before April 15, following the 98% refill rule curve, filling to 1147 ft elevation for two weeks for debris clearing, evacuate the debris volume over a 10 day period. Phase I and II refill conditions are compilation of existing refill rules and agreements and projected needs based on existing fisheries information. Phase I maximum refill rates are: 200 ac ft/day February 15-February 28, 800 ac ft/day from March 1-March 30, 600 ac ft/day from April 1 to 30, and 400 ac ft/day from May 1 to May 30. Phase II maximum refill rates are: 1500 ac ft/day for February 15-April 15, 600 ac ft/day for April 16-April 30, and 400 ac ft/day for May 1-May 31. All 3 reservoir conditions had specified minimum baseflows, refill and low-flow periods, and included a number of priorities for use of water stored in the reservoir and for priorities of use for outflow releases. Modeled daily refill rates in half-month increments are presented in Appendix Tables A-1 (Baseline), A-2 (Phase I), and A-3 (Phase II). Daily values for any particular year are available upon request.

Variable 3: Travel Rate. Travel rate is the number of miles per day a smolt travels through Howard Hanson Reservoir, or the observed travel time divided by the reservoir length. Four different travel rates were considered for incorporation into the model. All travel rates assume a direct proportional relationship of travel time/rate to reservoir refill rate (Aitkin et al. 1996). Lower refill rates have faster travel rates. Higher refill rates have lower travel rates. Travel rates are specific to each species observed migrating through the Howard Hanson Reservoir (Figure 2). The four methods considered for calculation of travel rate were:

Rate 1. Using actual travel times for mid and high pool divided by the reservoir length of 3.1 pool (mid) and 4.2 (full) mile pool. Chinook travel rate at higher refill rates was assumed to equal coho travel time at mid pool.
Rate 2. Using travel times for the reservoir travel time to the dam minus the travel time to mid-reservoir. This creates a measure of reservoir travel time eliminating the travel times through the upper river. Chinook for Rate 2 equals the median value of actual travel

time at high pool (0.9 miles/day) and the lowest rate is 0.0 miles/day which is the endpoint of extrapolated coho travel time to refill rates greater than 1,000 ac ft/day.

Rate 3. Using actual travel times for low/mid/high Pools over 4.9 miles, which incorporates travel time over both reservoir and river length. Chinook for Rate 3 equals the average value of actual travel time at high pool (0.7 miles/day) and uses the mid pool coho travel rate (0.4 miles per day) for higher refill rates.

Rate 4. An attempt was made to model travel times using the GLM Model for the selected years combined with actual travel rates when refill rate is low or negative.

Rate 3 was selected as the input to the travel time model. Rate 1 was rejected as travel rates were higher than observed values. Rate 2 was rejected because of the uncertainty in detection rate and observed travel times for the mid-reservoir. Rate 4 was rejected as this model underestimates travel times vs observed travel times. The slope of the travel rate (Rate 3) for each species is presented in Figure 3. Index equations were developed to predict travel rate vs refill rate based on the slope of the travel rate line: steelhead -- y=2.14 -0.002x; coho -- y=1.34-0.001x; and chinook y=0.9-0.0008x. Maximum travel rates were found at low to negative refill rates. The absolute maximum travel rate was drawn at -200 ac ft refill rate. This would be a situation where the reservoir is being drafted say to produce a freshet. A zero refill rate occurs when the reservoir is full thereby creating a run-of-the-river situation. The minimum travel rate occurs for refill rates greater than 900 ac-ft per day. This refill rate is outside the bounds of observed travel time/refill rate relationship. A base travel rate was established for each species for refill rates greater than 900 ac ft: 0.3 miles/day for steelhead, 0.3 miles per day for coho, and 0.1 miles per day for steelhead. If refill rates exceed 900 ac ft for 1 two week period, travel times may exceed 20 days.

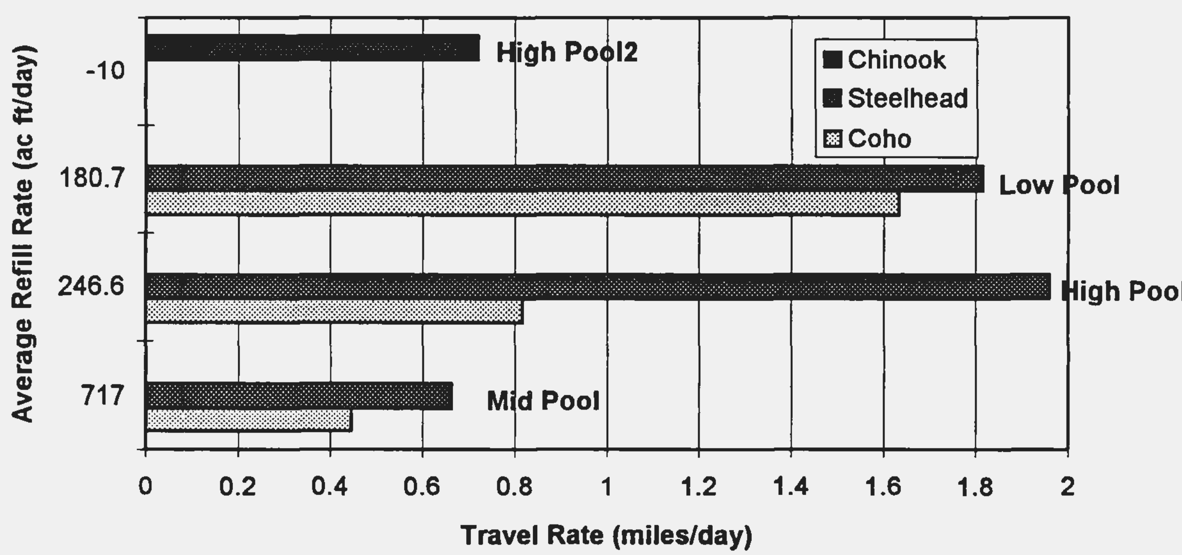


FIGURE 2. COMPARISON OF AVERAGE REFILL RATE (20 DAY AVERAGE/POOL LEVEL) VS. TRAVEL RATE OF RADIO-TAGGED COHO AND CHINOOK SALMON AND STEELHEAD SMOLTS.

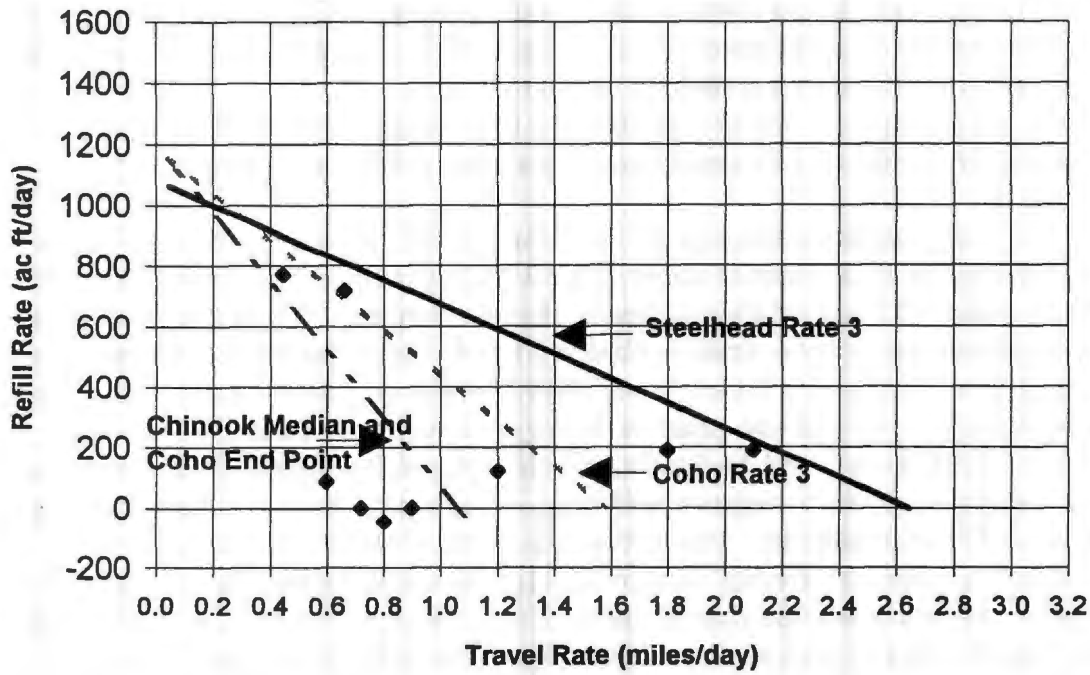


FIGURE 3. TRAVEL RATES (RATE 3) FOR STEELHEAD, COHO AND CHINOOK SALMON USED IN PREDICTING TRAVEL TIMES UNDER BASELINE, PHASE 1, AND PHASE 2.

Variable 4: Reservoir Volume. Half-month modeled total storage volumes (ac-ft) were developed in the same manner as refill rates. A full discussion is presented in Section 9. A brief discussion of storage volumes is discussed here. Total storage is defined as the total amount of reservoir storage. Active storage is total storage minus 1200 ac ft of "dead storage" from operation of the turbidity pool. Thus, active storage is the total storage minus 1200 ac ft. Baseline storage volume is based on 1996 actual refill conditions and have two volumes: 1) normal year, 25,400 ac ft with 5,000 ac-ft temporary storage for debris removal; and 2) drought year, 30,400 ac ft. Original Phase I storage volume is based on negotiated amounts from the Agency Resolution Process. Two volumes are used; 1) normal year, 45,400 ac ft; and 2) drought year, 50,400 ac-ft: this has since been modified following Fall 1997 negotiations, Phase I now includes annual storage of Section 1135 5,000 ac ft every year for a 50,400 ac ft total storage volume. The negotiated change in the Phase I is not reflected in this modeling effort and will not be revised for the final. Phase II total storage volume, 62,400 ac ft, is based on total AWSP project needs, M&I and flow augmentation. Modeled daily active storage volumes in half-month increments are presented in Appendix Tables A-4 (Baseline), A-5 (Phase I), and A-6 (Phase II). Total storage volume was used in the model, so these modeled volumes were adjusted by 1200 ac ft to produce total storage.

<u>Variable 5: Reservoir Length.</u> The last input variable to the travel time model is reservoir length. The reservoir length is multiplied against the predicted travel rate (from variable 1, 2, 3 and 4) to create the travel time (days) for a particular half-month period. Reservoir length varies markedly depending on the amount of water stored in the reservoir (Table 2.) For example, at low pool, the reservoir is only 1.5 miles in length, while the AWSP Phase II full pool is 5.7 miles in length, 4.2 additional miles. The increase in full pool length from Baseline, to Phase I and II is between 1.1-1.4 miles. As storage volume was modeled for the 32 years of record, a regression relationship was developed between reservoir volume (total volume in ac-ft) and reservoir length (miles). The regression model was a multiplicative model (curvilinear) and provides for a fairly good fit of predicted lengths to actual measured lengths (R^2=0.99) (Figure 4). The regression equation used to convert reservoir volume to reservoir length took the form y=aX*b, where the slope is the exponent of b and the intercept equals the natural log of a. The actual equation was: y=0.139*X^0.3385, with X equal to the storage volume.

TABLE 2. SUMMARY OF MAJOR RESERVOIR VARIABLES -- POOL ELEVATION, RESERVOIR LENGTH AND TOTAL STORAGE VOLUME

Pool El ft	Res Length miles	Total Volume ac ft	Description
1070	1.5	1200	Low Pool (Turbidity Pool)
1080	1.8	2400	
1090	2.5	4100	
1100	2.8	6300	
1110	3.1	9300	
1120	3.4	13100	
1130	3.9	18100	
1140	4.3	24600	
1141	4.3	25400	Current Conservation Pool
1147	4.6	30400	Drought Year Pool, Section 1135
1150	4.7	33000	
1160	5.1	42800	
1162	5.1	45400	
1167	5.4	50400	Phase 1 Pool
1170	5.5	53900	
1177	5.7	62400	Phase II Conservation Pool

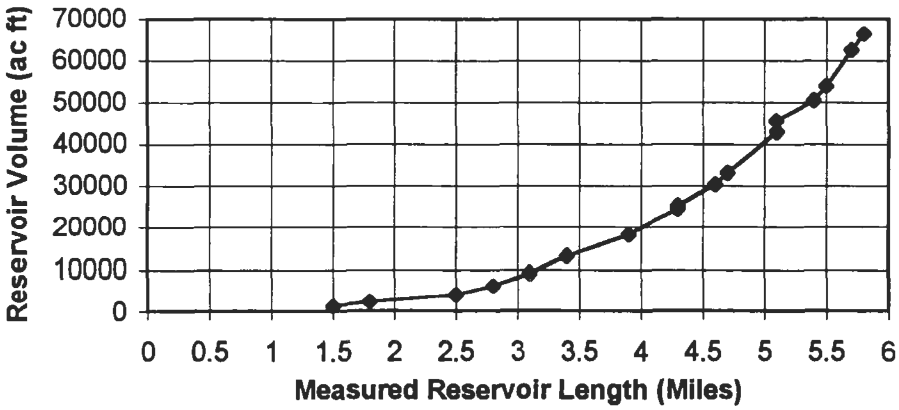


FIGURE 4. COMPARISON OF MODELED RESERVOIR VOLUME (TOTAL VOLUME) TO MEASURED RESERVOIR LENGTH.

2B-5.3 BASELINE TRAVEL TIMES VS ANTICIPATED TRAVEL TIMES UNDER ASWP

There is one measure of the change in reservoir performance for outmigrating juveniles, increase in reservoir travel time. This measure is based on an empirical relationship between reservoir refill rate and travel rate of coho, steelhead, and chinook salmon smolts. The effect of 1996 Baseline refill and the AWSP were modeled for 32 years, utilizing semi-months with percent of outmigrants, refill rate, size of pool (volume and length), and travel rate to predict travel times by species. Appendix B provides model outputs for one sample year, 1990, for each of the three species, Table B-1 steelhead, Table B-2 coho, and Table B-3 chinook.

Beyond the actual change in travel times, the results of this model are open to interpretation -- there is no accepted travel rate and the implications of increased travel rate for application to small reservoirs. The Corps spent 2 years in coordination with resource agencies (HHD Technical Workgroup) to develop a level of acceptable and unacceptable travel time. In 1995 and 1996, the Corps presented a request -- that if the Workgroup did not define acceptable and unacceptable travel times, -- the Corps would provide definitions for the AWSP impact analysis. The Corps has provided definitions. Final definitions included that acceptable travel times would be within the "biological window" of outmigrating fish. However, even within the accepted limits of travel times inside the biological window, the Corps has refined this definition to include maximum travel rates that could impact smolt survival. Travel rates of greater than 10 days are considered significant for coho and steelhead as these stocks have a more defined biological window while 20 days was selected for chinook which can spend a considerable period rearing prior to migrating.

Model traveled times for this analysis are presented as 1) maximum travel time, and 2) proportional travel time. Maximum travel times are considered periods when travel rates exceed 10 or 20 days for any given half-month period. Proportional travel time is the sum of travel times per half-month period for a given year. In other words, summing all half-month travel times against the percent of smolts migrating at that times produces the proportional travel time. The percent of time maximum travel rates are exceeded under Baseline, Phase I and Phase II are presented in Tables 3-5 for steelhead, coho, and chinook. The proportional travel times are presented in Tables 6-8 for steelhead, coho, and chinook.

For coho and steelhead, if the time required to traverse the reservoir was greater than 10 days, this was considered an adverse impact requiring additional monitoring and potential mitigation. For chinook, if the time required to traverse the reservoir was greater than 20 days, this was considered an adverse impact requiring additional monitoring and potential mitigation. The discussion below covers the percent of time each species exceeded a maximum travel rate, 10 or 20 days. Also, a comparison of proportional travel times is presented.

Under Baseline, there were no periods of time when travel times exceeded 10 days for coho and steelhead. Under Phase I, there was a slight but negligible increase in the percent of time (1.0%<), for 32 years, coho and steelhead exceeded 10 days. For chinook, there was an overall decline in travel rate from Baseline to Phase 1 for periods exceeding 10 days but less than 20 days (-7.2%) and a slight increase for periods greater than 20 days (0.2%).

From Baseline to Phase 1, performance of smolts is expected to equal or improve based on the modeled travel time results. In comparison to total project travel time at other water control projects (dam + reservoir), the overall expected travel times (proportional) through HHD under Phase I are not exceptional: coho 4.5 days, steelhead 3.7 days, chinook 6.7. Three years of outmigrant trapping at Wynoochee Reservoir, a shorter length but greater volume reservoir, showed a range of total project travel times of 18-44 days for coho, 11.4-20.6 days for steelhead, and over 30 days for chinook (Dunn 1978). Phase I has the potential for major improvements (even with greater reservoir volume and length) over Baseline -- 1) a reduced refill rate during the major outmigration period; 2) greater outflow in May, with 2 artificial freshets; and 3) unaccounted improvements in attraction to the dam from the selected fish passage facility.

Unlike Phase I, there is an obvious change from Baseline to Phase II for all species. For coho, maximum travel times increase by 3.9% for 10-20 days, and by 6.0% for 20-30 days. This equals a total increase in maximum travel rate (percent of travel exceeding 10 days) of 9.9% over Baseline. For steelhead, the total increase was 2.3 % for periods of 10-15 days, and 7% for 15-20 days, a total maximum travel rate increase of 9.3% over Baseline. For chinook, there was a decline in maximum travel time from Baseline to Phase II for periods between 10-20 days (9.8%). There was an increase in travel rate for periods greater than 20 days (4.7%). In addition, Phase II proportional (overall) travel times are greater than Phase I, coho 5.8 vs. 4.5 days, steelhead 4.8 vs. 3.7 days, chinook 8.6 vs. 6.7 days.

For chinook, even with the decrease in travel rate for 10-20 days and low increase for over 20 days, we have the greatest uncertainty in predicting potential survival for this stock: we only have travel rates for a small release group of smolts that were undersized for the radio-tags used. This stock is also the latest outmigrant at the smallest size migrating through the largest pool at lowest inflow and outflow. So, although percent change is less for chinook than steelhead or coho, greater precautions are recommended to increase certainty for successful reservoir migration. Based on assumptions and definitions applied above, monitoring and mitigation management measures are required under Phase II for coho and steelhead requiring greater than 10 days of travel and for chinook greater than 20 days.

TABLE 3. EFFECT OF PROJECT ALTERNATIVES ON MAXIMUM TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Steelhead

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Percent Exceeding Maximum Travel Times >10 Days Baseline	>10 Days Phase 1	10-15 Days Phase 2	15-20 Days Phase 2
1964	Average	Average	0%	0%	5%	10%
1965	Average	Average	0%	0%	0%	0%
1966	Average	Average	0%	0%	5%	10%
1967	Average	Average	0%	5%	5%	0%
1968	Dry	Average	0%	0%	5%	10%
1969	Wet	Average	0%	5%	5%	10%
1970	Average	Average	0%	0%	5%	10%
1971	Average	Average	0%	0%	5%	10%
1972	Wet	Average	0%	0%	0%	5%
1973	Dry	Average	0%	0%	0%	0%
1974	Wet	Average	0%	0%	0%	5%
1975	Wet	Average	0%	0%	0%	0%
1976	Average	Average	0%	5%	5%	10%
1977	Dry	Dry	0%	0%	0%	10%
1978	Average	Dry	0%	5%	0%	0%
1979	Average	Average	0%	0%	0%	15%
1980	Average	Average	0%	0%	5%	10%
1981	Dry	Dry	0%	0%	0%	10%
1982	Average	Average	0%	0%	0%	0%
1983	Average	Average	0%	0%	0%	15%
1984	Average	Average	0%	0%	0%	5%
1985	Average	Average	0%	10%	0%	10%
1986	Dry	Average	0%	0%	0%	5%
1987	Average	Dry	0%	0%	0%	10%
1988	Average	Average	0%	0%	0%	5%
1989	Average	Dry	0%	0%	5%	10%
1990	Wet	Average	0%	0%	0%	5%
1991	Dry	Average	0%	0%	0%	10%
1992	Dry	Dry	0%	0%	0%	0%
1993	Average	Average	0%	0%	0%	5%
1994	Average	Average	0%	0%	0%	15%
1995	Average	Average	0%	0%	25%	5%
Avg.			0.0%	0.9%	2.3%	7%

TABLE 4. EFFECT OF PROJECT ALTERNATIVES ON MAXIMUM TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Coho

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Percent Exceeding Maximum Travel Times >10 Days Baseline	>10 Days Phase 1	10-20 Days Phase 2	20-30 Days Phase 2
1964	Average	Average	0%	0%	5%	15%
1965	Average	Average	0%	0%	0%	0%
1966	Average	Average	0%	0%	0%	15%
1967	Average	Average	0%	0%	5%	0%
1968	Dry	Average	0%	0%	0%	15%
1969	Wet	Average	0%	5%	5%	10%
1970	Average	Average	0%	0%	5%	10%
1971	Average	Average	0%	0%	5%	10%
1972	Wet	Average	0%	0%	10%	5%
1973	Dry	Average	0%	0%	0%	0%
1974	Wet	Average	0%	0%	0%	5%
1975	Wet	Average	0%	0%	0%	0%
1976	Average	Average	0%	5%	5%	10%
1977	Dry	Dry	0%	0%	0%	10%
1978	Average	Dry	0%	5%	0%	0%
1979	Average	Average	0%	0%	10%	5%
1980	Average	Average	0%	0%	5%	10%
1981	Dry	Dry	0%	0%	10%	0%
1982	Average	Average	0%	0%	0%	0%
1983	Average	Average	0%	0%	0%	0%
1984	Average	Average	0%	0%	0%	5%
1985	Average	Average	0%	0%	0%	10%
1986	Dry	Average	0%	0%	0%	5%
1987	Average	Dry	0%	0%	0%	15%
1988	Average	Average	0%	0%	0%	5%
1989	Average	Dry	0%	0%	0%	15%
1990	Wet	Average	0%	0%	10%	5%
1991	Dry	Average	0%	0%	0%	10%
1992	Dry	Dry	0%	0%	0%	0%
1993	Average	Average	0%	0%	10%	5%
1994	Average	Average	0%	0%	10%	5%
1995	Average	Average	0%	0%	30%	0%
Avg.			0.0%	0.5%	3.9%	6%

TABLE 5. EFFECT OF PROJECT ALTERNATIVES ON MAXIMUM TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Chinook

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Percent Change 10-20 Days Base-Ph 1	Percent Change 10-20 Days Base - Ph2/1	Percent Change > 20 Days Base-Ph 1	Percent Change > 20 Days Base - Ph2
1964	Average	Average	-10%	-20%	0%	5%
1965	Average	Average	-10%	10%	0%	0%
1966	Average	Average	-10%	-20%	0%	5%
1967	Average	Average	-15%	-10%	0%	20%
1968	Dry	Average	5%	-5%	0%	5%
1969	Wet	Average	-15%	-20%	0%	5%
1970	Average	Average	-10%	-20%	0%	5%
1971	Average	Average	-10%	-20%	0%	5%
1972	Wet	Average	-15%	-20%	0%	0%
1973	Dry	Average	0%	0%	0%	5%
1974	Wet	Average	10%	5%	0%	0%
1975	Wet	Average	-20%	5%	0%	0%
1976	Average	Average	-10%	-20%	0%	5%
1977	Dry	Dry	5%	0%	0%	5%
1978	Average	Dry	5%	0%	0%	0%
1979	Average	Average	-10%	-20%	0%	5%
1980	Average	Average	-10%	-20%	0%	5%
1981	Dry	Dry	0%	5%	0%	20%
1982	Average	Average	-10%	0%	0%	0%
1983	Average	Average	-15%	5%	0%	0%
1984	Average	Average	-15%	-15%	0%	0%
1985	Average	Average	-15%	-20%	5%	5%
1986	Dry	Average	5%	0%	0%	0%
1987	Average	Dry	-10%	-20%	0%	5%
1988	Average	Average	-10%	-15%	0%	0%
1989	Average	Dry	-10%	-20%	0%	5%
1990	Wet	Average	-10%	-20%	0%	5%
1991	Dry	Average	5%	-5%	0%	5%
1992	Dry	Dry	0%	0%	0%	0%
1993	Average	Average	-10%	-20%	0%	5%
1994	Average	Average	5%	0%	0%	5%
1995	Average	Average	-20%	-15%	0%	20%
Avg.			-7.2%	-9.8%	0.2%	4.7%

TABLE 6. EFFECT OF PROJECT ALTERNATIVES ON PROPORTIONAL TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Steelhead

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Proportional Travel Time (days) Baseline	Phase 1	Phase 2	Change In Travel (days) Base-Ph 1	Base - Ph2/1
1964	Average	Average	4.0	3.5	5.0	-0.5	1.0
1965	Average	Average	3.7	3.5	4.7	-0.2	1.1
1966	Average	Average	3.7	3.4	5.0	-0.3	1.3
1967	Average	Average	3.1	3.5	5.7	0.4	2.6
1968	Dry	Average	3.5	4.5	4.9	1.0	1.4
1969	Wet	Average	4.0	3.7	4.7	-0.3	0.7
1970	Average	Average	3.8	3.5	4.9	-0.4	1.1
1971	Average	Average	4.0	3.5	4.9	-0.5	0.9
1972	Wet	Average	4.0	3.5	4.3	-0.6	0.2
1973	Dry	Average	3.5	4.3	3.9	0.8	0.4
1974	Wet	Average	4.0	3.5	3.8	-0.5	-0.2
1975	Wet	Average	4.0	3.4	5.2	-0.6	1.3
1976	Average	Average	4.0	3.8	4.8	-0.3	0.8
1977	Dry	Dry	3.5	4.8	5.8	1.3	2.3
1978	Average	Dry	3.1	4.4	5.1	1.3	2.0
1979	Average	Average	4.0	3.5	5.1	-0.5	1.1
1980	Average	Average	3.3	3.5	4.8	0.2	1.5
1981	Dry	Dry	3.6	4.7	6.8	1.1	3.2
1982	Average	Average	3.8	3.5	4.4	-0.4	0.6
1983	Average	Average	3.5	3.3	5.8	-0.2	-0.2
1984	Average	Average	3.9	3.4	4.0	-0.5	0.1
1985	Average	Average	3.5	4.6	4.3	1.0	0.8
1986	Dry	Average	3.5	3.5	3.8	0.0	0.3
1987	Average	Dry	3.6	3.7	4.6	0.1	0.9
1988	Average	Average	4.0	3.7	3.8	-0.3	-0.2
1989	Average	Dry	3.6	3.8	4.9	0.2	1.3
1990	Wet	Average	4.0	3.6	4.5	-0.4	0.5
1991	Dry	Average	3.5	3.7	4.4	0.2	0.9
1992	Dry	Dry	3.6	3.5	3.5	0.0	-0.1
1993	Average	Average	4.0	3.9	4.2	-0.1	0.2
1994	Average	Average	2.7	3.4	5.0	0.7	2.3
1995	Average	Average	3.5	2.7	5.6	-0.2	2.3
Avg.			3.7	3.7	4.8	0.1	1.0

TABLE 7. EFFECT OF PROJECT ALTERNATIVES ON PROPORTIONAL TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Coho

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Proportional Travel Time (days) Baseline	Phase 1	Phase 2	Change In Base-Ph 1	Travel (days) Base - Ph2/1
1964	Average	Average	4.7	4.5	6.6	-0.2	1.9
1965	Average	Average	4.5	4.6	6.0	0.1	1.5
1966	Average	Average	4.5	4.5	6.6	-0.1	2.1
1967	Average	Average	4.0	4.4	6.3	0.4	2.3
1968	Dry	Average	4.4	5.3	6.5	0.8	2.1
1969	Wet	Average	4.7	4.5	6.5	-0.2	1.8
1970	Average	Average	4.6	3.5	6.5	-0.1	1.9
1971	Average	Average	4.7	4.5	6.6	-0.2	1.9
1972	Wet	Average	4.7	4.5	4.8	-0.2	0.2
1973	Dry	Average	4.4	5.3	5.0	0.8	0.5
1974	Wet	Average	4.7	4.5	4.5	-0.2	-0.1
1975	Wet	Average	4.6	4.6	6.3	0.0	1.7
1976	Average	Average	4.7	4.5	6.4	-0.2	1.7
1977	Dry	Dry	4.4	5.7	7.4	1.3	3.0
1978	Average	Dry	4.0	5.2	5.8	1.2	1.7
1979	Average	Average	4.7	4.5	5.4	-0.2	0.8
1980	Average	Average	4.3	4.5	6.4	0.2	2.1
1981	Dry	Dry	4.5	5.7	6.9	1.2	2.4
1982	Average	Average	4.5	4.5	5.6	0.0	1.1
1983	Average	Average	4.1	4.4	5.4	0.2	1.3
1984	Average	Average	4.6	4.4	4.7	-0.1	0.2
1985	Average	Average	4.4	5.1	6.4	0.7	2.0
1986	Dry	Average	4.4	4.6	4.5	0.1	0.1
1987	Average	Dry	4.5	4.9	6.5	0.4	2.0
1988	Average	Average	4.7	4.8	4.5	0.1	-0.1
1989	Average	Dry	4.5	4.9	6.5	0.4	2.0
1990	Wet	Average	4.7	4.6	4.9	0.0	0.2
1991	Dry	Average	4.4	4.7	6.5	0.3	2.0
1992	Dry	Dry	4.5	4.6	4.6	0.2	0.1
1993	Average	Average	4.7	5.0	4.8	0.3	0.1
1994	Average	Average	3.8	4.4	5.6	0.6	1.8
1995	Average	Average	4.1	3.8	5.9	-0.3	1.8
Avg.			4.5	4.7	5.8	0.2	1.4

TABLE 8. EFFECT OF PROJECT ALTERNATIVES ON TRAVEL TIME OF JUVENILE SALMONIDS MIGRATING THROUGH HOWARD HANSON RESERVOIR USING MODELED HALF-MONTHLY REFILL RATES AND TOTAL STORAGE VOLUME (YEARS 1964-1995).

Chinook

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Proportional Travel Time (days) Baseline	Phase 1	Phase 2	Change In Travel (days) Base-Ph 1	Base - Ph2
1964	Average	Average	7.2	6.2	8.8	-1.0	1.7
1965	Average	Average	6.8	6.3	8.8	-0.5	2.0
1966	Average	Average	6.8	6.2	9.1	-0.6	2.2
1967	Average	Average	6.4	6.2	9.6	-0.2	3.1
1968	Dry	Average	5.6	6.6	8.8	1.0	3.2
1969	Wet	Average	7.2	6.2	8.8	-1.0	1.6
1970	Average	Average	7.1	6.2	8.8	-0.9	1.7
1971	Average	Average	7.2	6.2	8.9	-1.0	1.7
1972	Wet	Average	7.2	6.2	7.2	-1.0	0.0
1973	Dry	Average	5.7	6.2	7.3	1.3	1.6
1974	Wet	Average	7.2	6.2	6.8	-1.0	-0.4
1975	Wet	Average	7.2	6.6	9.8	-0.6	2.5
1976	Average	Average	7.2	6.2	8.7	-1.0	1.5
1977	Dry	Dry	5.8	7.4	9.1	1.6	3.3
1978	Average	Dry	6.6	7.4	9.4	0.8	2.8
1979	Average	Average	7.2	6.2	8.8	-1.0	1.6
1980	Average	Average	6.3	6.2	8.8	-0.1	2.5
1981	Dry	Dry	6.0	8.1	13.9	2.1	7.9
1982	Average	Average	7.2	6.2	8.4	-1.0	1.2
1983	Average	Average	7.1	6.3	8.2	-0.8	1.2
1984	Average	Average	7.2	6.2	7.1	-1.0	-0.1
1985	Average	Average	6.7	7.4	8.8	0.7	2.1
1986	Dry	Average	5.6	6.2	6.7	0.6	1.1
1987	Average	Dry	6.9	6.8	8.6	0.0	0.0
1988	Average	Average	7.4	6.5	6.9	-0.8	-0.5
1989	Average	Dry	6.8	6.8	8.8	0.0	2.0
1990	Wet	Average	7.2	6.4	7.4	-0.8	0.2
1991	Dry	Average	5.6	6.3	8.8	0.7	3.2
1992	Dry	Dry	5.8	6.3	6.1	0.5	0.3
1993	Average	Average	7.4	6.9	7.2	-0.5	-0.2
1994	Average	Average	5.6	6.2	11.3	0.6	5.7
1995	Average	Average	7.1	5.6	9.5	-1.4	2.4
Avg.			6.7	6.5	8.6	-0.2	1.9

2B-5.4 MITIGATION SUMMARY DESCRIPTION:

The first two objectives of this report was to develop and apply a reservoir travel time model and assess potential changes in travel times between Baseline and the phased AWSP. The third objective was to develop a mitigation plan that will avoid potential increases in travel time and mitigate for situations where avoidance is not possible. The discussion that follows provides the basis for the mitigation plan to avoid, minimize and compensate for potential impacts to smolts migrating through the enlarged AWSP reservoir pool.

The objective of the AWSP is to have no net loss of juvenile salmonids migrating through Howard Hanson Reservoir and maximize survival of outmigrants through the dam. Dam passage survival has been maximized by the expansion of the preferred fish passage facility to handle a normal capacity of 400-1250 cfs (within criteria), and up to 1600 cfs (outside criteria). This fish passage facility capacity expansion will also mitigate for many aspects related to the uncertainty of survival of smolts migrating through the enlarged AWSP reservoir (discussed below).

Impacts from increased travel time are unquantified beyond the percent change in maximum travel rates. There is no formula, empirical relationship, or accepted concept that can equate an increase in travel time to a measured decrease in survival. However, there is a general understanding that delaying fish beyond a period of time can decrease the chance that they will successfully migrate to the ocean. In Howard Hanson Reservoir, this delay can lead to increased residualism and predation risk for coho, steelhead, and chinook. The greatest predation risk occurs for chinook, as they migrate later and are the smallest smolt. For smolts that do outmigrate, the delays we have estimated should not result in lowered ocean survival as estimated times for all stocks will fall within their "biological window" of opportunity to reach the ocean. Avoidance of impacts and mitigation is required for all stocks under Phase II for increased travel times, and potential for decreased survival, and will be compensated for by: 1) expansion of the fish passage facility outflow volume; 2) minimizing refill rate during main outmigration periods; 3) use of periodic artificial freshets; 4) a long-term monitoring program, 15 years; 5) potential removal of predatory fish; and 6) habitat improvements above and below the reservoir, restoration and mitigation projects. Mitigation projects are:

<u>Expansion of the Fish Passage Facility.</u> After the initial selection of fish passage facility alternative 4, the FPTC felt there was enough concern about passing smolts through the reservoir and collection at the dam that they requested maximizing the outflow capacity of facility. Following this, the fish passage facility was increased in size from a maximum 550 cfs outflow volume at surface withdrawal (5-20 ft) to 1250 cfs (within screening criteria) to 1600 cfs (outside criteria): the original design was constrained by the size of the existing bypass pipe and head of the reservoir. *Final Outflow Volumes must be*

Verified. The new screened outflow (within criteria) represents a 225% increase in total flow volume over the existing bypass pipe and the original facility design. The FPTC recommended the maximum expansion of the facility to provide for capacity to pass surface flows to assist in reservoir outmigration of smolts.

Outmigrant Monitoring and Evaluation. For coho, steelhead, and chinook, 15 years of outmigrant monitoring is required (discussed in Section 2G.), cost is shared by mitigation and restoration. A sampling station, hydroacoustic monitoring, and pit-tag release and evaluation are proposed. First year construction costs are estimated at $750,000 and are included in the cost of the fish passage facility. Annual monitoring and evaluation costs are estimated at $_____. (*to be completed*).

Predator Monitoring, Evaluation, and Selective Removal. Beginning in 1998, PED Phase, 2 years of Baseline monitoring of predator abundance is proposed. This is a preventive measure to insure successful outmigration of chinook outmigrants (the smallest outmigrants). In combination with PIT-tag and hydroacoustic monitoring and evaluation, monitoring of predators would continue during Phase I and II. If there is an increase in overall abundance in response to outmigrant presence a selective predator removal program can be initiated. The predator removal program must be coordinated through the City of Tacoma, and cooperating resource agencies. Annual Baseline and Phase I and Phase II monitoring costs are estimated at $30,000.

Maximum Refill Rate. A maximum refill rate (rate the reservoir is filled or the difference of inflow-outflow) is proposed for each phase of the AWSP. A fill rate limit was already implemented under the AWSP hydrologic modeling (Section 9). The fill rates varied by phase: Phase I had maximum rates in March of 400 cfs per day, in April of 300 cfs per day, and in May of 200 cfs per day; Phase II had maximum rates only in late April at 300 cfs per day, and in May of 200 cfs per day. Even with the maximum fill rates, there are less protected times when smolts outmigrate, especially any early migrants in March or early April in Phase II. Our empirical data has only looked at travel times when fill was up to 400 cfs per day. We are uncertain if additional travel times well beyond the 11 days observed for coho salmon could occur. Monitoring during the first years of the AWSP project operation are essential to identify the range of fill rates affecting smolt travel times and ultimately survival. This monitoring should provide the needed information to adapt the AWSP to maximize smolt survival through the project.

Development of a maximum fill rate will be dependent not only on monitoring and evaluation of outmigrants through the AWSP, but also will include monitoring and evaluation of downstream areas for potential impacts to side-channel areas, steelhead spawning and incubation, and ocean migration of lower river juveniles. In essence, adaptive management is required to "optimize" the interacting priorities of maximizing smolt survival with protection of lower watershed resources. In concept, the maximum fill rate limit, which essentially mimics natural inflow patterns, should be the preferred reservoir fill and outflow release program. To date, this refill and release strategy has not been fully discussed or completely accepted by all participating resource agencies. As such, alternatives to the this refill and release strategy can be altered based on sound, defensible data from site-specific monitoring or from information collected from appropriate parallel watersheds.

Artificial Freshets. Another project operation or management tool for mitigation of potential reservoir mortality is the use of increased outflows or artificial freshets. In the past few years under existing operation, the Corps has "captured" natural freshets to guarantee the 98% reliability of filling the pool. This capture was necessary as the existing pool has a limited storage capacity, it cannot be raised above 1141 ft (until the Section 1135 project is approved) with the river has almost dewatered during some drought years. The capture of freshets results in a flat or constant outflow rate with an associated high refill rate that is presumed to have a very negative effect on outmigration success.

Outmigration study results (Dilley and Wunderlich 1992 and 1993) are unequivacable that increased outflow will increase the number of smolts that can safely exit the project. As such, periodic freshets should be considered as an important management tool to improve survival of smolts migrating through the AWSP. This measure will require careful integration of information gained from monitoring of smolts monitoring through the reservoir as well as from monitoring of downstream areas to minimize salmonid fry stranding and impacts to steelhead spawning. These freshets were modeled under the AWSP hydrologic modeling exercise (Section 9) and incorporated the best available information on juvenile salmonid behavior downstream as well has side-channel/mainstem channel dynamics.

These freshets are necessary to decrease the travel-time of outmigrating smolts through HHD reservoir and for smolts transiting the lower river to the estuary and to maintain connections between floodplain and mainstem habitats. Phase I targets are for Auburn are: 1) normal years -- two 2500 cfs, 38 hour freshets, and 2) dry years -- two 1250 cfs, 38 hour freshets. Phase II targets are for: 1) normal years -- four 2500 cfs freshets, and 2) dry years -- four 1250 cfs freshets, with modeled average frequency for 32 years of 2.91/year.

Habitat Improvement. Additional habitat improvement and increased production capacity is planned as part restoration and mitigation measures for original and AWSP riparian and tributary inundation: all habitat projects selected are planned as improvements for anadromous salmonid rearing and spawning habitat. These projects are discussed in Section 8. Fish Mitigation and Restoration Plan.

2B-5.5 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dunn, C.A. 1978. Evaluation of downstream fish passage through multi-level outlet pipes at Wynoochee Dam. Washington State Department of Fisheries, Progress Report No. 45.

Smith, S.G., J.R. Skalski, and A. Giorgi. 1993. Statistical evaluation of the travel time estimation based on data from freeze-branded chinook salmon on the Snake River, 1982-1990. Bonneville Power Administration, Portland, Oregon.

APPENDIX A TRAVEL TIME VARIABLE INPUTS: MODELED ACTIVE VOLUMES AND REFILL RATES FOR BASELINE, PHASE I, AND PHASE II (SOURCE CH2MHILL 1997).

APPENDIX TABLE A-1. BASELINE HALF-MONTHLY REFILL RATE FOR 32 YEARS (1964-1995)

Half Monthly Average Fill Rate in Acre Feet

Baseline Acre Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15																
Jan 16-31		1,978														
Feb 1-15		-2,110														
Feb 16-28																
Mar 1-15	26	26	26	1	5		26	26	26	6	26	26	4			26
Mar 16-31	294	279	294	318	314	319	294	294	294	-6	294	294	315	319	319	294
Apr 1-15		16			164					504				164	-196	
Apr 16-30	595	595	595	287	795	595	537	595	595	795	595	570	595	795	478	585
May 1-15	833	789	793	746	429	833	826	833	833	426	833	833	833	409	731	833
May 16-31	167	209	204	397	205	167	228	167	167	207	167	191	167	224	395	177
June 1-15				151						-13				-5	172	-21
June 16-30	-333	-333	-333	-333	-333	-333	-333	-333	-333	-320	-333	-333	-333	-78		-312
July 1-15		-24		-40			-64			-15				-28	-82	-107
July 16-31		-160	-8	-86	-77		-97			-164		-39	-39	-87	-84	-95
Aug 1-15	-160	-193	-157	-239	-128	-167	-234	-160	-160	-213	-160	-199	-119	-173	-155	-197
Aug 16-31	-156	-180	-255	-256	-109	-234	-268	-197	-156	-220	-166	-80	-156	-110	-156	-188
Sept 1-15	-233	-186	-230	-171	-233	-256	-78	-190	-233	-218	-228	-233	-233	-233	-233	-133
Sept 16-30	-167	-188	-237	-237	-167	-54	-116	-194	-167	-139	-277	-247	-251	-167	-167	-253
Oct 1-15	-220	-89	-158	28	-220	-220	-65	-199	-220	-42	-200	-140	-139	-220	-220	-202
Oct 16-31	-163	-72	-54	-90	-163	-163	-163	-156	-167	-78	-183	-163	-159	-163	-163	69
Nov 1-15	-213	-213	-213	-213	-213	-213	-213	-213	-209	-213	-97	-213	-213	-213	-213	-220
Nov 16-30	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-210
Dec 1-15	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-230	-230	-63
Dec 16-31																

Acre Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15																
Jan 16-31																
Feb 1-15																
Feb 16-28																
Mar 1-15	26		26	26	26		26	26	26	26	26	26	26	26	26	26
Mar 16-31	294		294	294	294	319	294	294	294	294	294	294	-25	294	294	294
Apr 1-15		504		-10			164					164	494			
Apr 16-30	595	795	489	210	504	564	795	595	595	595	595	795	805	595	510	200
May 1-15	712	436	833	833	833	769	429	789	833	763	826	426	409	833	497	833
May 16-31	171	198	267	359	253	257	205	81	167	233	174	207	224	167	377	359
June 1-15	102			175			-19	39					-21		197	170
June 16-30	-318		-333	-317	-333	-333	-315	-69	-146	-46	-225	-333	-178	-93	-333	-312
July 1-15		-82				-65	-36	-7	-57	-49	-57		28	-57	-19	-100
July 16-31	-109	-79	-80			-143	-62	-95	-177	-151	-72	-81	-104	-61	-182	-203
Aug 1-15	-192	-160	-148	-160	-160	-170	-201	-173	-244	-220	-222	-203	-133	-221	-253	-210
Aug 16-31	-163	-156	-258	-156	-156	-259	-286	-242	-237	-198	-99	-279	-229	-218	-205	-142
Sept 1-15	-79	-233	-51	-233	-233	-121	-249	-267	-241	-286	-246	-260	-115	-287	-126	-263
Sept 16-30	-167	-167	-184	-167	-204	-160	131	-255	-22	-296	-266	-234	-120	-253	-196	-123
Oct 1-15	-257	-220	-203	-243	-183	-131	-238	-292	-130	-233	-81	-180	-220	-210	-181	117
Oct 16-31	-222	-163	-163	-141	-163	-41	-145	-150	-160	-77	-163	-121	-163	-96	63	-163
Nov 1-15	-112	-213	-213	-213	-213	-213	-213	-83	-213	84	-213	56	-213	-152	-213	-213
Nov 16-30	-217	-217	-217	-217	-217	-217	-217	-41	-217	-217	-217	-217	-217	-209	-217	1,591
Dec 1-15	-63	-230	-63	-63	-63	-63	-63	-141	-63	-230	-63	-63	-230	-63	-63	-1,871

APPENDIX TABLE A-2. PHASE 1 HALF-MONTHLY REFILL RATE FOR 32 YEARS (1964-1995)

Half Monthly Average Fill Rate in Acre Feet

Phase1

Acre Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15																
Jan 16-31		1,978														
Feb 1-15	13	-2,097	13	13	13	3	13	13	13	5	13	13	13	13	13	13
Feb 16-28	199	199	199	199	199	41	199	199	199	188	199	199	199	199	199	199
Mar 1-15	814	814	814	744	724	126	814	814	814	654	814	814	543	627	264	814
Mar 16-31	800	702	800	866	600	1,584	800	800	800	392	800	638	1,055	655	1,156	800
Apr 1-15	600	678	600	600	595	600	600	600	600	369	600	408	600	595	456	600
Apr 16-30	493	519	481	423	799	479	493	493	481	796	493	455	493	799	572	493
May 1-15			12	70	2	14			12	302		402		374	568	
May 16-31										225						
June 1-15																
June 16-30																-30
July 1-15	-163	-187	-163	-203	-163	-163	-226	-163	-163	-178	-163	-163	-163	-245	-243	-239
July 16-31	-163	-323	-170	-249	-240	-163	-259	-163	-163	-327	-163	-202	-201	-266	-243	-257
Aug 1-15	-323	-356	-320	-402	-291	-329	-397	-323	-323	-375	-323	-362	-281	-335	-323	-360
Aug 16-31	-319	-343	-418	-418	-271	-397	-431	-359	-319	-382	-328	-243	-319	-283	-319	-350
Sept 1-15	-396	-349	-392	-334	-396	-419	-241	-353	-396	-381	-391	-396	-396	-396	-396	-296
Sept 16-30	-329	-351	-400	-399	-329	-216	-279	-356	-329	-302	-439	-409	-414	-329	-329	-416
Oct 1-15	-383	-251	-321	-134	-383	-383	-228	-362	-383	-205	-363	-302	-301	-383	-383	-365
Oct 16-31	-325	-235	-217	-253	-325	-325	-325	-319	-330	-240	-345	-325	-322	-325	-325	-93
Nov 1-15	-213	-213	-213	-213	-213	-213	-213	-213	-209	-213	-97	-213	-213	-213	-213	-220
Nov 16-30	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-217	-210
Dec 1-15	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-63	-230	-230	-63
Dec 16-31																

Acre Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15																
Jan 16-31																
Feb 1-15	13	13	13	13	13	13	13	13	13	13	13	13	13	13	5	13
Feb 16-28	199	199	199	199	199	154	187	199	199	199	199	199	199	141	199	199
Mar 1-15	814	437	814	814	814	448	794	814	794	814	794	794	732	557	822	814
Mar 16-31	800	120	793	800	800	847	794	756	755	800	794	704	502	794	800	752
Apr 1-15	600	578	607	574	600	955	595	646	595	600	595	595	198	595	600	651
Apr 16-30	493	799	493	338	434	493	536	493	566	493	525	621	685	595	435	369
May 1-15		425		181	59			333	100	333	105		293	308	58	124
May 16-31		397		-20				-208	82		3		-9	99	-104	-120
June 1-15		305		22				159					28	43	111	47
June 16-30								-103		-37			-30			-4
July 1-15	-163	-245	-163	-163	-163	-227	-199	-170	-220	-208	-220	-163	30	-220	-181	-185
July 16-31	-271	-242	-243	-163	-163	-306	-225	-257	-340	-298	-234	-243	-104	-224	-345	-347
Aug 1-15	-354	-323	-311	-323	-323	-332	-364	-336	-407	-382	-385	-365	-171	-384	-415	-373
Aug 16-31	-325	-319	-420	-319	-319	-421	-449	-405	-400	-360	-262	-441	-391	-381	-368	-304
Sept 1-15	-241	-396	-214	-396	-396	-284	-411	-430	-404	-449	-408	-422	-278	-449	-289	-438
Sept 16-30	-329	-329	-346	-329	-366	-323	-32	-418	-185	-458	-429	-397	-282	-416	-358	-285
Oct 1-15	-420	-383	-366	-405	-345	-294	-401	-455	-293	-436	-244	-343	-383	-373	-344	-46
Oct 16-31	-385	-325	-325	-304	-325	-204	-308	-313	-323	-265	-325	-284	-325	-258	-100	-325
Nov 1-15	-112	-213	-213	-213	-213	-213	-213	-83	-213	121	-213	56	-213	-152	-213	-213
Nov 16-30	-217	-217	-217	-217	-217	-217	-217	-41	-217	-217	-217	-217	-217	-209	-217	1,591
Dec 1-15	-63	-230	-63	-63	-63	-63	-63	-141	-63	-230	-63	-63	-230	-63	-63	-1,871
Dec 16-31																

APPENDIX TABLE A-3. PHASE 2 HALF-MONTHLY REFILL RATE FOR 32 YEARS (1964-1995)

Half Monthly Average Fill Rate in Acre Feet

Phase2Alt1

Acre Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15																
Jan 16-31		1,978														
Feb 1-15	24	-2,087		24	4		24	24	24		24	24	24			24
Feb 16-28	357	357	135	357	380		357	357	357	29	357	357	357		110	357
Mar 1-15	1,065	1,493	778	621	956	16	759	764	1,500	504	1,169	1,240	343	440	64	1,500
Mar 16-31	1,279	486	1,481	1,030	1,210	1,619	1,010	1,086	1,288	192	1,799	504	1,006	831	956	1,082
Apr 1-15	1,318	492	1,528	566	1,421	2,177	1,757	1,637	791	328	641	222	2,175	2,013	257	1,005
Apr 16-30	-72	523	-63	524	79	82	25	91	5	759	18	570	120	741	550	76
May 1-15	72	699	141	763		78	128	96	77	415		764	36		770	12
May 16-31		19		163						323		387			397	
June 1-15										8					258	-26
June 16-30		-1		-1			-3			241					3	-152
July 1-15	-182	-228	-182	-237	-182	-182	-274	-182	-182	11	-182	-182	-182	-283	-4	-109
July 16-31	-182	-342	-190	-269	-259	-182	-313	-182	-182	-35	-182	-221	-221	-346	-26	-235
Aug 1-15	-182	-375	-311	-421	-311	-288	-416	-232	-184	-114	-188	-381	-272	-454	-190	-311
Aug 16-31	-505	-363	-437	-450	-308	-416	-506	-458	-504	-186	-499	-279	-382	-149	-222	-306
Sept 1-15	-505	-473	-498	-499	-505	-571	-360	-505	-505	-400	-509	-505	-505	-339	-505	-428
Sept 16-30	-505	-384	-518	-518	-505	-429	-298	-505	-505	-331	-578	-553	-570	-503	-505	-506
Oct 1-15	-505	-551	-536	-432	-505	-505	-388	-579	-505	-449	-578	-540	-511	-540	-505	-736
Oct 16-31	-505	-365	-411	-259	-505	-505	-505	-437	-514	-377	-457	-428	-445	-472	-505	-361
Nov 1-15	-323	-323	-323	-323	-323	-323	-323	-323	-313	-304	-226	-323	-318	-323	-323	-251
Nov 16-30	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-323	-352
Dec 1-15	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164	-130
Dec 16-31	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110
Acre Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15																
Jan 16-31																
Feb 1-15	12	24	24	24	24			24	24		24	24	24			24
Feb 16-28	371	357	357	357	323	385	385	155	346	64	357	357	357		333	357
Mar 1-15	1,397	296	1,500	1,494	843	248	1,475	1,675	1,430	805	1,500	1,113	727	837	1,394	1,020
Mar 16-31	893	26	704	756	1,992	648	1,523	733	1,575	1,497	1,310	530	377	2,202	1,163	1,000
Apr 1-15	1,377	861	436	716	705	2,807	612	1,313	647	1,622	849	2,068	190	798	1,055	614
Apr 16-30	-19	799	414	143	-85	-107	35	136	-82	-67	-65		685	96	-85	189
May 1-15	40	425	646	587	188	107		16	82	67	65		331		179	799
May 16-31	-84	397						-132					-56		-367	-39
June 1-15	77	915		-68				98					-169		-48	-74
June 16-30				39				-151	-4	-37			-103		281	-57
July 1-15	-178	-182	-186	-153	-182	-286	-247	-145	-183	-371	-182	-182	50	-182	-94	-132
July 16-31	-291	-182	-259	-182	-182	-376	-244	-277	-298	-408	-206	-263	-104	-182	-237	-354
Aug 1-15	-374	-265	-331	-194	-221	-352	-383	-356	-365	-501	-404	-385	-133	-182	-335	-392
Aug 16-31	-345	-428	-440	-495	-469	-484	-468	-424	-417	-479	-281	-461	-229	-505	-387	-324
Sept 1-15	-361	-511	-341	-505	-505	-403	-548	-509	-516	-522	-498	-547	-178	-528	-371	-517
Sept 16-30	-505	-500	-505	-505	-518	-342	-170	-444	-279	-475	-607	-573	103	-621	-476	-471
Oct 1-15	-623	-505	-509	-600	-560	-598	-523	-780	-505	-553	-402	-722	-360	-609	-721	-147
Oct 16-31	-702	-505	-502	-553	-443	-239	-489	-587	-505	-294	-505	-621	-501	-505	-303	-505
Nov 1-15	4	-323	-323	-177	-323	-323	-323	-91	-323	242	-323	197	-323	-248	-323	-323
Nov 16-30	-323	-323	-323	-323	-323	-323	-323	-41	-323	-323	-323	-152	-323	-170	-323	1,506
Dec 1-15	-164	-164	-164	-164	-164	-164	-164	-29	-164	-164	-164	-164	-164	-150	-164	-1,993
Dec 16-31	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110	-110

APPENDIX TABLE A-4. BASELINE ACTIVE VOLUME (TOTAL VOLUME - 1200 AC FT DEAD STORAGE) STORED HALF-MONTHLY FOR 32 YEARS (1964-1995)

Baseline	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Average Half-Monthly Values																
Jan 1-15																
Jan 16-31		5,867										423				
Feb 1-15		1,985														
Feb 16-28																
Mar 1-15	26	26	26	1	5		26	26	26	6	26	26	4			26
Mar 16-31	3,503	3,396	3,302	3,356	2,197	3,376	3,503	3,502	3,503	111	3,503	3,493	3,384	1,622	2,319	3,503
Apr 1-15	5,100	5,100	5,100	5,100	5,560	5,100	5,100	5,100	5,100	3,775	5,100	5,035	5,100	5,560	4,278	5,097
Apr 16-30	9,861	9,861	9,861	7,253	13,793	9,861	9,356	9,861	9,861	13,793	9,861	9,517	9,861	13,793	5,373	9,766
May 1-15	20,553	20,222	20,172	14,701	23,196	20,553	19,680	20,553	20,553	23,169	20,553	20,176	20,553	23,107	15,040	20,405
May 16-31	28,716	28,423	28,457	23,967	28,264	28,716	28,264	28,716	28,716	28,389	28,716	28,557	28,716	28,191	23,663	28,657
June 1-15	29,200	29,200	29,200	29,101	29,200	29,200	29,200	29,200	29,200	29,187	29,200	29,200	29,200	29,195	28,623	29,179
June 16-30	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	26,388	28,406	29,200	26,388
July 1-15	24,200	24,149	24,200	24,063	24,200	24,200	23,964	24,200	24,200	24,176	24,200	24,200	24,196	27,733	28,527	23,451
July 16-31	24,200	22,496	24,191	22,782	23,829	24,200	22,386	24,200	24,200	22,726	24,200	24,049	24,065	26,978	27,264	22,152
Aug 1-15	22,920	19,654	22,902	20,347	21,718	22,906	20,048	22,920	22,920	19,674	22,920	22,118	22,605	24,911	25,419	19,409
Aug 16-31	20,472	16,867	19,676	16,512	20,299	19,811	15,799	20,298	20,471	16,152	20,453	20,152	20,470	22,364	22,972	16,603
Sept 1-15	17,433	13,543	15,786	13,034	17,433	15,901	13,319	17,397	17,433	12,985	17,357	17,433	17,433	19,933	19,933	14,359
Sept 16-30	14,467	11,527	12,395	10,161	14,467	13,813	11,921	14,020	14,446	10,273	13,372	13,760	14,161	16,960	16,967	10,988
Oct 1-15	11,540	8,780	9,364	7,945	11,540	11,540	10,136	11,116	11,540	8,595	9,948	11,075	11,370	14,040	14,040	7,500
Oct 16-31	8,619	8,472	8,028	8,372	8,619	8,619	8,619	8,593	8,603	7,979	6,977	8,619	8,337	11,119	11,119	6,462
Nov 1-15	5,693	5,689	5,693	5,693	5,693	5,693	5,693	5,693	5,693	5,693	4,919	5,693	5,693	8,193	8,193	5,683
Nov 16-30	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	4,967	4,967	2,323
Dec 1-15	443	443	443	443	443	443	443	443	443	443	443	8,669	443	9,056	1,610	443
Dec 16-31																
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15		8,244														
Jan 16-31																
Feb 1-15																
Feb 16-28	2,773	2,698	2,525	2,562	1,141	2,586	2,773	2,771	2,773	144	2,773	2,760	2,600	480	1,284	2,773
Mar 1-15	5,100	5,050	5,100	5,100	5,120	5,100	5,100	5,100	5,100	1,975	5,100	5,035	5,100	5,075	4,879	5,097
Mar 16-31	8,001	8,001	8,001	6,371	11,118	8,001	7,686	8,001	8,001	11,118	8,001	7,750	8,001	11,118	4,110	7,940
Apr 1-15	18,137	17,938	17,844	12,601	21,826	18,137	17,275	18,137	18,137	21,807	18,137	17,760	18,137	21,790	12,890	17,989
Apr 16-30	27,946	27,501	27,582	22,455	27,466	27,946	27,283	27,946	27,946	27,592	27,946	27,701	27,946	27,335	22,197	27,854
May 1-15	29,200	29,200	29,200	28,340	29,200	29,200	29,200	29,200	29,200	29,200	29,200	29,200	29,200	29,200	27,777	29,200
May 16-31	27,442	27,442	27,442	27,442	27,442	27,442	27,442	27,442	27,442	27,430	27,442	27,442	27,442	28,670	29,200	27,423
June 1-15	24,263	24,261	24,263	24,213	24,263	24,263	24,179	24,263	24,263	24,261	24,263	24,263	24,263	27,826	28,758	23,809
June 16-30	24,200	23,036	24,200	23,095	24,063	24,200	22,715	24,200	24,200	23,281	24,200	24,164	24,170	27,264	27,557	22,471
July 1-15	23,496	20,423	23,480	21,284	22,352	23,496	20,927	23,496	23,496	20,524	23,496	22,852	23,063	25,564	26,008	20,219
July 16-31	21,098	17,577	20,651	17,502	20,629	20,719	16,897	21,054	21,098	17,049	21,098	20,513	21,098	22,831	23,598	17,330
Aug 1-15	18,336	14,439	16,731	13,735	18,336	16,927	13,636	18,162	18,335	13,823	18,247	18,336	18,334	20,836	20,836	14,875
Aug 16-31	15,075	12,036	13,211	10,962	15,075	14,051	12,332	14,742	15,056	10,793	14,375	14,632	15,006	17,568	17,575	11,886
Sept 1-15	12,189	9,112	9,861	8,005	12,189	12,189	10,343	11,717	12,189	8,784	10,534	11,497	11,790	14,689	14,689	8,129
Sept 16-30	9,199	8,686	8,211	8,564	9,199	9,199	9,199	9,127	9,197	8,193	7,626	9,193	8,895	11,699	11,699	6,183
Oct 1-15	6,526	6,522	6,526	6,526	6,526	6,526	6,526	6,526	6,512	6,509	5,286	6,526	6,526	9,026	9,026	6,479
Oct 16-31	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,220	3,224	3,224	5,724	5,724	3,080
Nov 1-15	664	664	664	664	664	664	664	664	664	664	664	8,889	664	9,743	2,297	664
Nov 16-30	13	13	13	13	13	13	13	13	13	13	13	13	13	46	46	13
Dec 1-15	1,573	2,169	1,558	1,360	1,809	1,562	1,535	1,574	1,574	1,512	1,574	1,575	1,563	1,766	1,073	1,567
Dec 16-31	16,082	14,895	15,585	14,123	16,110	15,903	14,895	16,013	16,080	14,893	15,757	16,410	16,006	18,447	17,346	14,625

APPENDIX TABLE A-5. PHASE 1 ACTIVE VOLUME (TOTAL VOLUME - 1200 AC FT DEAD STORAGE) STORED HALF-MONTHLY FOR 32 YEARS (1964-1995)

Phase 1 Total Dam Average Half-Monthly Values	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15																
Jan 16-31		5,867										423				
Feb 1-15	13	1,999	13	13	13	3	13	13	13	5	13	13	13	13	13	13
Feb 16-28	1,596	1,596	1,596	1,596	1,596	404	1,596	1,596	1,596	1,352	1,596	1,596	1,596	1,596	1,596	1,596
Mar 1-15	9,410	9,410	7,732	9,206	8,951	1,443	9,150	9,257	9,410	7,653	9,394	9,410	7,036	7,821	4,840	9,410
Mar 16-31	21,810	21,479	21,622	21,413	18,460	14,214	21,810	21,521	21,810	16,314	21,810	21,169	20,085	17,043	13,422	21,806
Apr 1-15	32,610	31,948	32,610	32,610	28,016	32,610	32,610	32,610	32,610	21,078	32,610	28,294	32,610	27,435	30,526	32,592
Apr 16-30	41,379	41,060	41,367	41,099	38,471	41,365	41,379	41,379	41,366	30,417	41,379	35,912	41,379	37,889	36,669	41,379
May 1-15	44,105	44,154	43,799	43,227	44,200	44,065	44,062	44,135	44,059	37,896	44,200	41,281	44,200	46,748	44,495	44,200
May 16-31	44,200	43,872	43,471	44,200	44,200	44,200	43,938	44,115	44,200	43,291	44,200	44,200	43,858	49,200	48,686	43,773
June 1-15	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	49,200	49,200	44,171
June 16-30	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	49,200	49,200	44,064
July 1-15	42,899	42,848	42,899	42,762	42,899	42,899	42,663	42,899	42,899	42,875	42,899	42,899	42,895	47,226	47,254	42,146
July 16-31	40,379	38,675	40,370	38,961	40,008	40,379	38,565	40,379	40,379	38,905	40,379	40,228	40,244	43,354	43,484	38,331
Aug 1-15	36,579	33,313	36,560	34,005	35,377	36,565	33,706	36,579	36,579	33,332	36,579	35,776	36,264	38,729	39,078	33,067
Aug 16-31	31,610	28,005	30,814	27,651	31,437	30,949	26,937	31,436	31,609	27,290	31,591	31,290	31,608	33,602	34,110	27,742
Sept 1-15	26,051	22,161	24,404	21,652	26,051	24,518	21,937	26,015	26,051	21,603	25,975	26,051	26,051	28,551	28,551	22,977
Sept 16-30	20,646	17,706	18,573	16,340	20,646	19,992	18,100	20,199	20,625	16,452	19,551	19,939	20,340	23,139	23,146	17,166
Oct 1-15	15,280	12,520	13,103	11,684	15,280	15,280	13,876	14,856	15,280	12,335	13,688	14,815	15,109	17,780	17,780	11,239
Oct 16-31	9,838	9,692	9,247	9,592	9,838	9,838	9,838	9,812	9,823	9,198	8,196	9,838	9,556	12,338	12,338	7,681
Nov 1-15	5,693	5,689	5,693	5,693	5,693	5,693	5,693	5,693	5,693	5,693	4,919	5,693	5,693	8,193	8,193	5,683
Nov 16-30	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	2,467	4,967	4,967	2,323
Dec 1-15	443	443	443	443	443	443	443	443	443	443	443	8,669	443	9,056	1,610	443
Dec 16-31																
Jan 1-15	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 16-31		8,244														
Feb 1-15	1,135	1,135	1,135	1,135	1,135	296	1,135	1,135	1,135	945	1,135	1,135	1,135	1,135	1,135	1,135
Feb 16-28	8,596	8,596	6,917	8,463	8,227	1,317	8,335	8,443	8,596	6,999	8,580	8,596	6,493	7,194	4,576	8,596
Mar 1-15	19,810	19,730	19,578	19,240	16,980	9,811	19,810	19,455	19,810	15,407	19,810	19,640	17,373	15,304	10,124	19,810
Mar 16-31	30,130	29,313	30,130	30,130	25,556	29,857	30,130	30,130	30,130	19,750	30,130	26,751	30,130	24,975	27,979	30,108
Apr 1-15	39,482	39,065	39,482	39,285	35,760	39,482	39,482	39,482	39,482	27,714	39,482	33,963	39,482	35,179	34,850	39,482
Apr 16-30	44,105	44,151	43,787	43,157	44,030	44,051	44,062	44,135	44,046	36,911	44,200	40,228	44,200	45,497	42,755	44,200
May 1-15	44,200	43,850	43,422	44,200	44,200	44,200	43,921	44,110	44,200	42,432	44,200	44,200	43,836	49,165	48,587	43,745
May 16-31	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	49,200	49,200	44,182
June 1-15	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	44,200	49,200	49,200	44,143
June 16-30	43,354	43,353	43,354	43,305	43,354	43,354	43,271	43,354	43,354	43,353	43,354	43,354	43,354	47,913	47,935	42,811
July 1-15	40,948	39,784	40,948	39,843	40,811	40,948	39,463	40,948	40,948	40,029	40,948	40,912	40,918	44,274	44,335	39,219
July 16-31	37,805	34,732	37,789	35,593	36,660	37,805	35,236	37,805	37,805	34,833	37,805	37,161	37,372	40,033	40,336	34,528
Aug 1-15	32,887	29,365	32,439	29,291	32,418	32,508	28,685	32,842	32,887	28,837	32,887	32,302	32,887	34,759	35,387	29,119
Aug 16-31	27,604	23,707	25,999	23,003	27,604	26,195	22,904	27,430	27,603	23,092	27,515	27,604	27,602	30,104	30,104	24,143
Sept 1-15	21,823	18,784	19,959	17,710	21,823	20,799	19,080	21,490	21,803	17,541	21,123	21,380	21,754	24,316	24,323	18,634
Sept 16-30	16,417	13,339	14,088	12,233	16,417	16,417	14,571	15,945	16,417	13,011	14,762	15,724	16,018	18,917	18,917	12,356
Oct 1-15	10,988	10,474	9,999	10,353	10,988	10,988	10,988	10,916	10,986	9,982	9,415	10,981	10,684	13,488	13,488	7,971
Oct 16-31	6,591	6,587	6,591	6,591	6,591	6,591	6,591	6,591	6,577	6,574	5,351	6,591	6,591	9,091	9,091	6,544
Nov 1-15	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,224	3,220	3,224	3,224	5,724	5,724	3,080
Nov 16-30	664	664	664	664	664	664	664	664	664	664	664	8,889	664	9,743	2,297	664
Dec 1-15	13	13	13	13	13	13	13	13	13	13	13	13	13	46	46	13
Dec 16-31	8,368	8,871	8,223	8,300	7,498	7,078	8,348	8,334	8,367	6,061	8,367	7,599	8,053	7,213	6,850	8,367

APPENDIX TABLE A-6. PHASE 2 ACTIVE VOLUME (TOTAL VOLUME - 1200 AC FT DEAD STORAGE) STORED HALF-MONTHLY FOR 32 YEARS (1964-1995)

Phase2Alt1	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Average Half-Monthly Values																
Jan 1-15																
Jan 16-31		5,867										423				
Feb 1-15	24	2,009		24	4		24	24	24		24	24	24			24
Feb 16-28	2,857	2,857	458	2,857	2,720		2,857	2,857	2,857	48	2,857	2,857	2,857		369	2,857
Mar 1-15	13,663	16,631	5,328	10,788	14,650	175	10,508	10,807	17,000	4,179	13,907	16,194	7,647	3,518	1,887	16,599
Mar 16-31	35,129	34,282	22,048	22,503	24,903	10,588	25,782	23,104	39,837	10,233	39,926	28,933	18,199	11,355	7,377	39,312
Apr 1-15	56,608	39,310	57,450	35,497	50,550	45,118	46,309	48,080	59,200	13,228	59,402	33,154	41,615	36,617	21,389	54,435
Apr 16-30	61,128	47,252	61,020	43,407	61,161	60,877	60,851	60,752	61,078	21,991	61,200	39,408	60,933	56,309	25,736	61,132
May 1-15	61,182	56,625	61,071	52,965	61,200	61,176	61,107	61,158	61,177	30,764	61,200	49,977	61,200	61,200	36,011	61,200
May 16-31	61,200	60,807	60,519	60,696	61,200	61,167	61,000	61,091	61,179	36,697	61,026	58,370	60,881	61,084	44,738	60,838
June 1-15	61,200	61,200	61,200	61,200	61,200	61,200	61,200	61,200	61,200	38,830	61,200	61,200	61,200	61,200	50,358	61,093
June 16-30	61,200	61,196	61,200	61,196	61,200	61,200	61,171	61,200	61,200	40,754	61,200	61,200	61,200	61,200	51,631	59,752
July 1-15	59,743	59,486	59,743	59,486	59,743	59,743	59,224	59,743	59,743	42,522	59,743	59,743	59,739	59,026	51,604	58,046
July 16-31	56,920	54,876	56,911	55,259	56,549	56,920	54,285	56,920	56,920	42,488	56,920	56,770	56,785	54,173	51,479	55,042
Aug 1-15	54,098	49,212	53,145	50,001	51,616	53,502	48,931	53,911	54,095	41,173	54,087	52,015	52,623	47,928	49,892	50,694
Aug 16-31	48,528	43,601	47,170	43,326	47,473	47,797	41,581	48,452	48,528	39,007	48,528	47,333	48,243	41,751	46,601	45,921
Sept 1-15	40,681	36,424	39,360	35,288	40,693	39,847	34,315	40,652	40,572	34,258	40,543	40,686	40,670	40,094	40,638	40,264
Sept 16-30	33,116	31,116	32,251	28,265	33,116	32,659	30,047	33,014	33,115	28,782	32,355	32,727	32,910	32,998	33,116	33,115
Oct 1-15	25,536	23,174	24,225	20,304	25,536	25,536	24,123	24,763	25,536	22,372	23,771	24,383	24,969	25,302	25,536	23,642
Oct 16-31	17,704	17,331	17,144	16,286	17,704	17,668	17,704	17,429	17,631	16,022	15,730	17,538	16,307	17,108	17,704	14,704
Nov 1-15	11,324	11,322	11,328	11,328	11,328	11,313	11,328	11,328	11,328	11,328	10,745	11,328	11,328	11,328	11,328	11,212
Nov 16-30	6,481	6,481	6,481	6,481	6,481	6,481	6,481	6,481	6,479	6,481	6,481	6,481	6,481	6,481	6,481	6,095
Dec 1-15	2,829	2,829	2,829	2,829	2,829	2,829	2,829	2,829	2,829	2,829	2,829	11,247	2,829	10,223	2,829	2,804
Dec 16-31	826	826	826	826	826	826	826	826	826	826	826	826	826	826	826	826
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15		8,244														
Jan 16-31	2,031	2,031	263	2,031	1,901		2,031	2,031	2,031	15	2,031	2,031	2,031		210	2,031
Feb 1-15	12,598	15,138	4,550	10,167	13,694	158	9,749	10,043	15,500	3,674	12,738	14,954	7,304	3,078	1,823	15,099
Feb 16-28	32,408	33,042	18,726	19,667	21,549	6,398	23,394	20,318	36,500	9,824	35,844	27,783	15,531	8,906	4,578	36,480
Mar 1-15	51,070	37,940	49,391	33,122	44,072	35,650	38,662	40,696	55,655	12,106	56,125	32,396	32,843	28,476	19,640	50,352
Mar 16-31	61,200	45,255	61,090	41,602	60,540	59,951	60,659	60,116	61,081	19,438	61,183	37,438	60,121	53,526	24,097	61,066
Apr 1-15	61,111	54,631	60,930	50,729	61,200	61,098	60,979	61,062	61,100	29,445	61,200	47,651	61,164	61,149	33,744	61,188
Apr 16-30	61,200	60,641	60,474	59,978	61,200	61,165	60,986	61,083	61,177	35,503	61,015	56,985	60,859	61,076	43,266	60,814
May 1-15	61,200	61,200	61,200	61,200	61,200	61,200	61,200	61,200	61,200	38,743	61,200	61,072	61,200	61,200	49,190	61,177
May 16-31	61,200	61,199	61,200	61,200	61,200	61,200	61,182	61,200	61,200	39,982	61,200	61,200	61,200	61,200	51,599	60,243
June 1-15	60,253	60,111	60,253	60,128	60,253	60,253	59,971	60,253	60,253	42,461	60,253	60,253	60,253	59,811	51,618	58,362
June 16-30	57,558	56,053	57,558	56,210	57,421	57,558	55,374	57,558	57,558	42,584	57,558	57,522	57,528	55,368	51,556	55,844
July 1-15	54,826	50,709	54,340	51,667	52,978	54,577	50,539	54,787	54,826	41,627	54,826	53,478	53,727	49,701	50,600	51,926
July 16-31	50,428	45,040	48,873	45,062	48,536	49,434	43,593	50,213	50,425	39,670	50,418	48,428	49,679	42,698	47,443	47,140
Aug 1-15	42,702	38,431	41,357	37,292	42,715	42,071	35,797	42,674	42,593	35,819	42,568	42,708	42,692	41,074	42,587	41,902
Aug 16-31	34,884	32,317	34,034	30,050	34,884	34,204	31,095	34,789	34,884	29,956	34,420	34,640	34,851	34,772	34,884	34,884
Sept 1-15	27,052	24,864	25,835	21,727	27,052	27,052	25,280	26,504	27,052	23,754	25,454	26,032	26,499	26,916	27,052	25,812
Sept 16-30	19,472	18,585	18,582	17,052	19,472	19,439	19,472	18,954	19,417	17,370	17,345	19,035	17,959	18,768	19,472	16,073
Oct 1-15	12,690	12,688	12,694	12,694	12,694	12,674	12,694	12,694	12,672	12,485	11,708	12,694	12,534	12,665	12,694	12,130
Oct 16-31	7,612	7,612	7,612	7,612	7,612	7,612	7,612	7,612	7,611	7,612	7,602	7,612	7,612	7,612	7,612	7,338
Nov 1-15	3,354	3,354	3,354	3,354	3,354	3,354	3,354	3,354	3,354	3,354	3,354	11,772	3,354	10,748	3,354	3,228
Nov 16-30	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220	1,220
Dec 1-15	13,233	11,603	11,456	9,054	12,047	9,184	11,459	11,404	14,048	4,024	13,842	9,510	10,301	8,495	4,569	13,615
Dec 16-31	37,660	36,032	37,213	35,359	37,418	37,491	36,010	37,562	37,647	27,196	37,324	36,989	37,387	36,995	32,548	36,578

APPENDIX B EXAMPLE OF MODELED RESERVOIR TRAVEL TIME -- 1990: COMPARISON OF MODELED FLOWS FOR BASELINE, PHASE 1 AND PHASE 2 FOR 1990.

APPENDIX TABLE B-1. EXAMPLE OF MODELED RESERVOIR TRAVEL TIME FOR STEELHEAD -- 1990 MODELED YEAR USING HALF MONTH REFILL RATES AND ACTIVE STORAGE: COMPARISON OF MODELED FLOWS FOR BASELINE, PHASE 1 AND PHASE 2 FOR 1990.

STEELHEAD, RESERVOIR SMOLT OUTMIGRATION

Baseline

Period	Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Baseline Time by Percent Migration
Feb 1-15	0%		2.1	1200.0	1.5	0.7	0.0
Feb 15-28	0%		2.1	1200.0	1.5	0.7	0.0
Mar 1-15	0%	26	2.1	1226.5	1.5	0.7	0.0
Mar 16-31	5%	294	1.6	4703.1	2.4	1.6	0.1
Apr 1-15	10%		2.1	6300.0	2.7	1.3	0.1
Apr 16-30	25%	595	0.9	11061.0	3.2	3.4	0.9
May 1-15	25%	826	0.5	21746.1	4.1	8.4	2.1
May 16-31	20%	174	1.8	29802.0	4.5	2.5	0.5
Jun 1-15	10%		2.1	30400.0	4.6	2.1	0.2
Jun 16-30	5%	-225	2.6	27923.0	4.4	1.7	0.1
Jul 1-15	0%	-57	2.3	26590.4	4.4	1.9	0.0
Jul 16-31	0%	-72	2.3	25620.9	4.3	1.9	0.0
			Proportional Average Travel Time				**4.0**

Phase 1

Period	Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Phase 1 Time by Percent Migration
Feb 1-15	0%	13	2.1	1213.3	1.5	0.7	0.0
Feb 15-28	0%	199	1.7	2795.8	2.0	1.2	0.0
Mar 1-15	0%	794	0.6	10340.7	3.2	5.7	0.0
Mar 16-31	5%	794	0.6	22640.1	4.1	7.5	0.4
Apr 1-15	10%	595	0.9	33352.4	4.7	5.0	0.5
Apr 16-30	25%	525	1.1	42179.6	5.1	4.7	1.2
May 1-15	25%	105	1.9	45999.1	5.3	2.7	0.7
May 16-31	20%	3	2.1	45986.2	5.3	2.5	0.5
Jun 1-15	10%		2.1	47020.0	5.3	2.5	0.2
Jun 16-30	5%		2.1	47020.0	5.3	2.5	0.1
Jul 1-15	0%	-220	2.6	45289.5	5.2	2.0	0.0
Jul 16-31	0%	-234	2.6	41799.8	5.1	2.0	0.0
			Proportional Average Travel Time				**3.6**

Phase 2

Period	Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Phase 2 Time by Percent Migration
Feb 1-15	0%	23.8	2.1	1223.8	1.5	0.7	0.0
Feb 15-28	0%	357.1	1.4	4057.1	2.3	1.6	0.0
Mar 1-15	0%	1500.0	0.3	18200.0	3.8	12.8	0.0
Mar 16-31	5%	1310.3	0.3	41016.2	5.1	16.9	0.8
Apr 1-15	10%	849.0	0.4	60287.6	5.8	13.1	1.3
Apr 16-30	25%	-64.7	2.3	62335.3	5.8	2.6	0.6
May 1-15	25%	64.7	2.0	62389.6	5.8	2.9	0.7
May 16-31	20%	0.0	2.1	61717.6	5.8	2.7	0.5
Jun 1-15	10%	0.0	2.1	62400.0	5.8	2.7	0.3
Jun 16-30	5%	0.0	2.1	62400.0	5.8	2.7	0.1
Jul 1-15	0%	-182.1	2.5	60943.1	5.8	2.3	0.0
Jul 16-31	0%	-206.2	2.6	58069.9	5.7	2.2	0.0
			Proportional Average Travel Time				**4.5**

Note I established a base travel time of 0.3 miles/day for refill rate>900 ac ft/day

APPENDIX TABLE B-2. EXAMPLE OF MODELED RESERVOIR TRAVEL TIME FOR COHO SALMON -- 1990 MODELED YEAR USING HALF MONTH REFILL RATES AND ACTIVE STORAGE: COMPARISON OF MODELED FLOWS FOR BASELINE, PHASE 1 AND PHASE 2 FOR 1990.

COHO, RESERVOIR SMOLT OUTMIGRATION

Period	Baseline Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Baseline Time by Percent Migration
Feb 1-15	0%	0.0		1200.0			
Feb 15-28	0%	0.0	1.3	1200.0	1.5	1.1	0.0
Mar 1-15	0%	26.5	1.3	1226.5	1.5	1.2	0.0
Mar 16-31	5%	294.0	1.0	4703.1	2.4	2.3	0.1
Apr 1-15	10%	0.0	1.3	6300.0	2.7	2.0	0.2
Apr 16-30	25%	595.1	0.7	11061.0	3.2	4.4	1.1
May 1-15	25%	825.8	0.5	21746.1	4.1	7.9	2.0
May 16-31	20%	174.1	1.2	29802.0	4.5	3.9	0.8
Jun 1-15	10%	0.0	1.3	30400.0	4.6	3.4	0.3
Jun 16-30	5%	-225.3	1.6	27923.0	4.4	2.8	0.1
Jul 1-15	0%	-57.3	1.4	26590.4	4.4	3.1	0.0
Jul 16-31	0%	-71.6	1.4	25620.9	4.3	3.1	0.0
			Proportional Average Travel Time				4.7

Phase 1 Period	Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	(days)	Phase 1 Travel Time
Feb 1-15	0%	13.3	1.3	1213.3	1.5	1.2	0.0
Feb 15-28	0%	199.5	1.1	2795.8	2.0	1.8	0.0
Mar 1-15	0%	793.5	0.5	10340.7	3.2	5.8	0.0
Mar 16-31	5%	793.5	0.5	22640.1	4.1	7.6	0.4
Apr 1-15	10%	595.1	0.7	33352.4	4.7	6.3	0.6
Apr 16-30	25%	525.3	0.8	42179.6	5.1	6.3	1.6
May 1-15	25%	105.0	1.2	45999.1	5.3	4.3	1.1
May 16-31	20%	2.9	1.3	45986.2	5.3	3.9	0.8
Jun 1-15	10%	0.0	1.3	47020.0	5.3	4.0	0.4
Jun 16-30	5%	0.0	1.3	47020.0	5.3	4.0	0.2
Jul 1-15	0%	-219.9	1.6	45289.5	5.2	3.4	0.0
Jul 16-31	0%	-234.2	1.6	41799.8	5.1	3.2	0.0
			Proportional Average Travel Time				4.6

Phase 2 Period	Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Phase 2 Time by Percent Migration
Feb 1-15	0%	23.8	1.3	1223.8	1.5	1.2	0.0
Feb 15-28	0%	357.1	1.0	4057.1	2.3	2.4	0.0
Mar 1-15	0%	1500.0	0.2	18200.0	3.8	19.2	0.0
Mar 16-31	5%	1310.3	0.2	41016.2	5.1	25.3	0.0
Apr 1-15	10%	849.0	0.5	60287.6	5.8	11.7	1.2
Apr 16-30	25%	-64.7	1.4	62335.3	5.8	4.2	1.0
May 1-15	25%	64.7	1.3	62389.6	5.8	4.6	1.1
May 16-31	20%	0.0	1.3	61717.6	5.8	4.3	0.9
Jun 1-15	10%	0.0	1.3	62400.0	5.8	4.4	0.4
Jun 16-30	5%	0.0	1.3	62400.0	5.8	4.4	0.2
Jul 1-15	0%	-182.1	1.5	60943.1	5.8	3.8	0.0
Jul 16-31	0%	-206.2	1.5	58069.9	5.7	3.7	0.0
			Proportional Average Travel Time				4.9

Note I established a base travel time of 0.2 miles/day for selected refill rates>1100 ac ft/day

APPENDIX TABLE B-3. EXAMPLE OF MODELED RESERVOIR TRAVEL TIME FOR CHINOOK SALMON -- 1990 MODELED YEAR USING HALF MONTH REFILL RATES AND ACTIVE STORAGE: COMPARISON OF MODELED FLOWS FOR BASELINE, PHASE 1 AND PHASE 2 FOR 1990.

CHINOOK, RESERVOIR SMOLT OUTMIGRATION

Period	Baseline Percent of Migration	Refill Rate (ac ft/day)	Travel Rate (miles/day)	Reservoir Volume	Reservoir Length	Travel Time (days)	Baseline Time by Percent Migration
Feb 1-15	0%	0.0	0.9	1200.0	1.5	1.7	0.0
Feb 15-28	0%	0.0	0.9	1200.0	1.5	1.7	0.0
Mar 1-15	0%	26.5	0.9	1226.5	1.5	1.8	0.0
Mar 16-31	0%	294.0	0.7	4703.1	2.4	3.7	0.0
Apr 1-15	5%	0.0	0.9	6300.0	2.7	3.0	0.1
Apr 16-30	5%	595.1	0.4	11061.0	3.2	7.7	0.4
May 1-15	20%	825.8	0.2	21746.1	4.1	17.1	3.4
May 16-31	20%	174.1	0.8	29802.0	4.5	6.0	1.2
Jun 1-15	20%	0.0	0.9	30400.0	4.6	5.1	1.0
Jun 16-30	20%	-225.3	1.1	27923.0	4.4	4.1	0.8
Jul 1-15	5%	-57.3	0.9	26590.4	4.4	4.6	0.2
Jul 16-31	5%	-71.6	1.0	25620.9	4.3	4.5	0.2
			Proportional Average Travel Time				**7.2**

Period	**Phase 1 Percent of Migration**	**Refill Rate (ac ft/day)**	**Travel Rate (miles/day)**	**Reservoir Volume**	**Reservoir Length**	**Travel Time (days)**	**Phase 1 Time by Percent Migration**
Feb 1-15	0%	13.3	0.9	1213.3	1.5	1.7	0.0
Feb 15-28	0%	199.5	0.7	2795.8	2.0	2.8	0.0
Mar 1-15	0%	793.5	0.3	10340.7	3.2	12.0	0.0
Mar 16-31	0%	793.5	0.3	22640.1	4.1	15.6	0.0
Apr 1-15	5%	595.1	0.4	33352.4	4.7	11.1	0.6
Apr 16-30	5%	525.3	0.5	42179.6	5.1	10.7	0.5
May 1-15	20%	105.0	0.8	45999.1	5.3	6.5	1.3
May 16-31	20%	2.9	0.9	45986.2	5.3	5.9	1.2
Jun 1-15	20%	0.0	0.9	47020.0	5.3	5.9	1.2
Jun 16-30	20%	0.0	0.9	47020.0	5.3	5.9	1.2
Jul 1-15	5%	-219.9	1.1	45289.5	5.2	4.9	0.2
Jul 16-31	5%	-234.2	1.1	41799.8	5.1	4.7	0.2
			Proportional Average Travel Time				**6.4**

Period	**Phase 2 Percent of Migration**	**Refill Rate (ac ft/day)**	**Travel Rate (miles/day)**	**Reservoir Volume**	**Reservoir Length**	**Travel Time (days)**	**Phase 2 Time by Percent Migration**
Feb 1-15	0%	23.8	0.9	1223.8	1.5	1.8	0.0
Feb 15-28	0%	357.1	0.6	4057.1	2.3	3.8	0.0
Mar 1-15	0%	1500.0	0.1	18200.0	3.8	38.5	0.0
Mar 16-31	0%	1310.3	0.1	41016.2	5.1	50.6	0.0
Apr 1-15	5%	849.0	0.2	60287.6	5.8	26.1	1.3
Apr 16-30	5%	-64.7	1.0	62335.3	5.8	6.1	0.3
May 1-15	20%	64.7	0.8	62389.6	5.8	6.9	1.4
May 16-31	20%	0.0	0.9	61717.6	5.8	6.5	1.3
Jun 1-15	20%	0.0	0.9	62400.0	5.8	6.5	1.3
Jun 16-30	20%	0.0	0.9	62400.0	5.8	6.5	1.3
Jul 1-15	5%	-182.1	1.0	60943.1	5.8	5.5	0.3
Jul 16-31	5%	-206.2	1.1	58069.9	5.7	5.3	0.3
			Proportional Average Travel Time				**7.4**

Note I established a base travel time of 0.1 miles/day for selected refill rates>1100 ac ft/day

SECTION 2C. ASSESSMENT OF RESERVOIR PASSAGE SUCCESS USING THE DELPHI PROCESS

2C.1 INTRODUCTION

Information on the HHD AWS Project is being provided for the purpose of soliciting assistance from a panel of fisheries scientists in predicting the likely outcome of raising the storage pool behind Howard Hanson Dam and constructing a juvenile/kelt downstream passage facility at the dam on the outmigration success of juvenile coho and fall chinook salmon and steelhead trout through the Howard Hanson Reservoir.

The Delphi Technique is a method for systematically developing consensus among experts. The technique is used as a forecasting tool, based on the premise that opinions of panelists are justifiable sources of information for decision making where absolute information is lacking, and that a consensus of experts provides more authority on a question than the opinion of a single expert. Primary characteristics of Delphi are anonymity of the experts, controlled feedback, and an estimator of group opinion. Anonymity is important because it helps to eliminate bias. In any group interaction, an individual may be influenced either by what another says or simply the manner in which the individual says it.

The Delphi process is iterative. At each iteration, there is an assessment of group judgment and controlled feedback to all participants in succeeding rounds. This presents the panelists with an opportunity to revise their opinion based on new information as the experiment progresses. The basic elements of the Delphi consist of a group of experts willing to participate, a monitor or monitoring committee that selects panelists, designs appropriate inquiries, evaluates responses, summarizes results, and serves as the primary source of information for clarifying questions that arise.

To date, the Corps and Tacoma have received responses to the first round of questions submitted to the Delphi panel. Included in this section (Paragraph 2C.2) is the main text of the package sent to the Delphi panel. Enclosures are not included in this section. A second round of questions based on the first round responses is being prepared and will be sent to the Delphi Panel during public review of the HHD AWS Project Draft Feasibility Report and EIS. If panelist responses are returned promptly, the first and second round results may be included in the Final FR/EIS. Otherwise a separate report will be prepared and distributed at the appropriate time.

NOTE TO READERS: *This Delphi Submittal occurred prior to recent negotiations and project modifications that have changed Phase II storage volume to 32,000 ac-ft, with the Section 1135 5,000 ac-ft storage becoming an existing project feature with yearly storage beginning in Phase I.*

2C.2 FIRST ROUND QUESTIONS SUBMITTED TO THE DELPHI FISHERIES PANEL

HOWARD HANSON DAM ADDITIONAL WATER STORAGE PROJECT

Reservoir Smolt Migration Travel Time
Delphi Exercise

<u>Outline</u>

A. Introduction
B. Background
   1. Delphi Technique
   2. Existing Howard Hanson Dam Project
   3. Proposed Howard Hanson Dam Additional Water Storage Project
C. Feasibility Studies
D. Reservoir Travel Time Delphi Exercise

A. Introduction

This information on the Howard Hanson Dam Additional Water Storage Project (HHD AWS) is being provided for the purpose of soliciting assistance from a panel of fisheries scientists in predicting the likely outcome of raising the storage pool behind Howard Hanson Dam and constructing a juvenile/kelt downstream passage facility at the dam on the outmigration success of juvenile coho and fall chinook salmon and steelhead trout through the Howard Hanson Reservoir.

In 1995 the U.S. Army Corps of Engineers (Corps), Tacoma Public Utilities Water Division (Tacoma), U.S. Fish and Wildlife Service, Washington State Department of Fish and Wildlife and the Muckleshoot Indian Tribe participated in a study to determine the travel time of coho (Oncorhynchus kisutch) and steelhead (Oncorhynchus mykiss) smolts through the Howard Hanson Reservoir. The purpose of this investigation was to develop baseline information about smolt migration travel time through the existing reservoir project and, if possible, predict smolt passage success through the proposed additional storage project. The results of the study are contained in the U.S. Fish & Wildlife Service (USFWS) report, *Travel Time of Coho Salmon and Steelhead Smolts Emigrating Through Howard Hanson Reservoir, King County, Washington, April 1996* (Enclosure 1). Fall chinook salmon (Oncorhynchus tshawytscha) smolts were included in the reservoir migration study to help assess migration routes and behavior, but were not used in determining travel time estimates.

Although the reservoir migration study provided baseline information about reservoir travel through the Howard Hanson Reservoir for coho and steelhead smolts, and some indication of chinook behavior, it did not provide conclusive evidence about smolt migration through the reservoir under the proposed additional storage conditions. The Corps and Tacoma have therefore invited several fisheries scientists with expertise in fields such as salmonid behavior, physiology, and reservoir migration to review the travel time study results, and the Howard Hanson Dam Additional Water Storage Project description and objectives, and provide their best assessment of smolt passage success through the Howard Hanson Reservoir under the proposed additional storage conditions. The information gained from this Delphi exercise will be used in conjunction with other pertinent information to assess the impact of the proposed project on Green River salmonid populations.

B. Background

1. Delphi Technique

The Delphi Technique is a method for systematically developing consensus among experts. The technique is used as a forecasting tool, based on the premises that opinions of panelists are justifiable sources of information for decision making where absolute information is lacking, and that a consensus of experts provides more authority on a question than the opinion of a single expert. Primary characteristics of

Delphi are anonymity of the experts, controlled feedback, and an estimator of group opinion. Anonymity is important because it helps to eliminate bias. In any group interaction, an individual may be influenced either by what another says or simply the manner in which the individual says it.

The Delphi process is iterative. At each iteration, there is an assessment of group judgment and controlled feedback to all participants in succeeding rounds. This presents the panelists with an opportunity to revise their opinion based on new information as the experiment progresses. The basic elements of the Delphi consist of a group of experts willing to participate, a monitor or monitoring committee that selects panelists, designs appropriate inquiries, evaluates responses, summarizes results, and serves as the primary source of information for clarifying questions that arise.

2. Existing Howard Hanson Dam Project

Howard Hanson Reservoir was created with the construction of the Howard Hanson Dam, an earth and rockfill structure located in a narrow gorge at river mile (RM) 64.5 on the Green River in King County, Washington. It was authorized for standard project flood protection to the urbanized lower Green River basin, and for summer flow augmentation for fisheries enhancement by Section 204 of the Flood Control Act of 1950 (Public Law 516, 81st Congress) in accordance with House Document No. 271, 81st Congress, 1st Session. Water storage began in December 1961.

About 3.5 miles downstream of the Howard Hanson Dam at RM 61, the City of Tacoma operates a 17 foot high concrete water supply diversion dam. The Tacoma dam diverts up to 72 mgd or 113 cfs of surface water based on historic water claims dating from 1906 and 1908. River water enters the diversion intake and travels a distance of 26 miles through a concrete and steel gravity pipeline to the McMillin Reservoir, located 8 miles northeast of Tacoma, and from there to the Tacoma Water service area. A second pipeline, the Second Supply Project pipeline, is proposed to be constructed from the existing diversion dam (dam height to be raised by about 6.5 feet) to Tacoma, pending receipt of a Section 404 permit from the Corps of Engineers.

Howard Hanson Dam controls runoff from approximately 220 square miles within the Green River Watershed. During winter months when the flood threat is greatest, Howard Hanson Reservoir is kept at minimum pool size (elevation 1,070 ft; 100 surface acres; 1,600 ac-ft) (Figure 1) affording approximately 106,000 ac-ft of flood storage (at elevation 1,206 ft). The reservoir is kept empty from November through the end of March to provide full flood capacity through the end of March. At elevation 1070 ft, the pool extends approximately 1.3 miles (thalweg measure) eastward from the dam along the main river channel and 0.25 miles (thalweg measure) northerly up the main tributary of the North Fork of the Green River. Normal river flows pass through the project outlet tunnel in the dam's left abutment. When river flows approach 12,000 cfs at Auburn, discharge from the dam is reduced and water is impounded in the reservoir. As river flows return to normal following a storm event, impounded water is released at a rate which ensures safe discharge within channel capacity in the downstream area and minimizes damage to levees from sloughing during evacuation of storage.

Conservation storage refill operations normally begin by April with the full pool reached in early June. At full pool (elevation 1,141 feet; 732 surface acres; 25,400 ac-ft), the reservoir extends approximately 4.1 miles (thalweg measure) eastward from the dam along the main river channel and 1.2 miles northerly up the main tributary of the North Fork of the Green River (Figure 1). During the summer and fall months, the conservation pool provides up to 25,400 ac-ft of storage for downstream low flow augmentation. Summer storage assures sufficient dam discharge to provide the required 110 cfs instream flow below the City of Tacoma's Water Diversion Dam at 98% reliability, and up to 113 cfs for municipal and industrial uses.

Project discharges up to 500 cfs following spring refill and during summer draw-down are generally passed through the 48" bypass outlet located at invert elevation 1,069 ft. During winter and spring refill, flows are generally regulated through the gate-controlled tunnel located at invert elevation 1,035 feet. To date, the flood spillway located on the left abutment has not been used.

Anadromous fish stocks were present in the upper Green River watershed until the City of Tacoma constructed its water supply diversion dam across the Green River in 1911 at river mile 61. Since then, adult salmon have been excluded from the upper watershed. Adult steelhead were also excluded until 1992, when the Washington Department of Wildlife began transporting adult wild winter steelhead into the upper watershed from a fish trap constructed at the diversion dam by Trout Unlimited and Tacoma Public Utilities.

Juvenile plants of hatchery winter steelhead have been made in the upper Green River watershed since 1982. Juvenile plants of hatchery coho have been made since 1983, and of hatchery fall chinook since 1987.

3. Proposed Howard Hanson Dam Additional Water Storage Project

The Howard Hanson Dam Additional Water Storage Project is a proposal by the City of Tacoma and Corps of Engineers to store up to an additional 37,000 ac-ft of water behind Howard Hanson Dam to be used for municipal and industrial purposes, to supplement instream flows in the Green River, and to provide ecosystem restoration to selected aquatic system functions and structures. Project implementation is proposed to take place in two phases as described in "U.S. Army Corps of Engineers and Tacoma Public Utilities Proposal for the Howard Hanson Dam Additional Water Storage Project" (February 9, 1996) (Enclosure 2).

Phase I of the proposal would involve construction of a downstream fish passage facility at Howard Hanson Dam for juveniles and kelts (Enclosures 3, 4), storage of up to 20,000 ac-ft of water (elevation 1167 ft; 1084 surface acres; 50,400 ac-ft) (Figure 2) currently available to Tacoma under its second diversion water right, construction of fish and wildlife habitat restoration projects both upstream and downstream of the reservoir, and implementation of an adaptive management plan for the operation of the additional project storage.

Phase II would involve ongoing monitoring and adaptive management of the additional storage and downstream fish passage facility, and decisions by state and federal resource agencies, the Muckleshoot Indian Tribe, Tacoma and Corps of Engineers on future diversion and storage of additional (new) water up to the total proposed project storage of 37,000 ac-ft (elevation 1177 ft; 1246 surface acres; 62,400 ac-ft) (Figure 2). Second Diversion water right water would not be stored under Phase II. Additional water storage would be allocated between instream and municipal and industrial uses.

C. Feasibility Studies

On August 23, 1990, the City of Tacoma and Corps of Engineers entered into an agreement to study the feasibility of storing water for municipal and industrial uses and low-flow augmentation behind Howard Hanson Dam. The objective of the Howard Hanson Dam Additional Water Storage Project Feasibility Study is to investigate and recommend implementable solutions to providing additional water in the Howard Hanson Reservoir. In June 1994 Corps policy was modified to include ecosystem restoration as an objective for Corps projects. In October 1994 the Howard Hanson Dam Additional Water Storage Project was expanded to include ecosystem restoration as a study objective.

Feasibility Study efforts include investigations to identify baseline fisheries conditions for the purpose of predicting future fisheries conditions with an elevated pool. A number of fisheries investigations have been completed or are in progress. In 1991 and 1992 the USFWS conducted studies on juvenile anadromous fish passage with funding from the Corps and Tacoma in accordance with the Fish and Wildlife Coordination Act of 1958. These studies identified juvenile anadromous fish passage in relation to reservoir elevations and project outflows that are useful for assessing project impacts, designing mitigation facilities, and establishing baseline passage conditions. The results of the 1991 and 1992 studies are included in the reports *Juvenile Anadromous Fish Passage at Howard Hanson Dam, Green River, Washington, 1991* (Enclosure 5) and *Juvenile Anadromous Fish Passage at Howard Hanson Dam, Green River, Washington, 1992* (Enclosure 6). Study results were that April reservoir refill delayed or entrapped most outmigrating smolts until drawdown in the fall. Entrapped chinook, for example, increased in size from 46 mm in February to 180 mm by late November. Ninety-seven percent of the decline in passage of coho smolts was attributed to the decrease in outflow and increase in pool height during refill. The radial flood gates caused minimal or no injury to outmigrating juveniles, while the 48 inch bypass used during low flow caused the greatest injury. Chinook smolts had the highest injury and mortality rates. Up to 14% of chinook were killed and 37% injured during outmigration through the bypass in June and July.

Two fisheries studies were conducted by the USFWS in 1993. These were the Horizontal/Vertical Distribution of Juvenile Fish and Adult Return Rate studies.
The purpose of the Horizontal/Vertical Distribution of Juvenile Fish study was to provide information on the movement and vertical distribution of outmigrating juvenile salmon and steelhead in the downstream end of the reservoir. This information is to aid in the design of a future downstream fish passage facility. The study involved using mobile hydroacoustics and gillnets to establish horizontal and vertical distribution of juvenile outmigrants in the lower portion of the reservoir within the likely influence of the existing project outlet flow net. It was conducted from March through June 1993. Results of the study are contained in the report *Horizontal and Vertical Distribution of Juvenile Salmonids in Howard Hanson Reservoir, February 1994* (Enclosure 7). The study concluded that juvenile fish are generally surface oriented, are found in the upper 50 feet of the water column, and orient towards the shoreline.

The Adult Return Rate study is a multiple year study initiated in March 1993 with the recovery of adult fish to continue through the year 2000. The purpose of the Adult Return Rate study is to determine existing (baseline) adult return rates of chinook and coho salmon and steelhead fry and smolts that have been outplanted in the watershed above the Howard Hanson project. The rates for the baseline condition will be used for future comparison with post project adult return rates to verify success of restoration and mitigation measures. The study involves marking juvenile salmon and steelhead with coded wire tags or by adipose or ventral fin clipping and releasing them at predetermined locations upstream of the reservoir in tributaries to and in the North Fork and mainstem Green River, and downstream of the project. The marked fish are to be recovered from among the adult fish captured in the tribal and sport fisheries, and in the Trout Unlimited adult fish trap located at the Tacoma Headworks. Coded-wire tags will be read, and fin-clipped fish will be inspected by the appropriate organizations. Products from this study include annual progress reports by August of each year and a final report in the year 2001. The results from the first two years of adult returns, coho planted in 1993 and 1994, indicate no significant difference in survival between coho smolts planted upstream and downstream of the reservoir in April when reservoir elevation was relatively low (elevation 1,110 - 1122 ft), and a significant difference in survival between coho smolts planted upstream and downstream of the reservoir in May at full or nearly full conservation pool (elevation 1132 - 1141 ft.) (Enclosure 8).

Water particle travel time through Howard Hanson Reservoir was examined by the Corps for five pool levels at inflows ranging from 200-6,000 cfs. Results of these investigations are presented in Enclosure 9.

<u>Reservoir Migration Travel Time Study</u>
A study to document baseline travel time of outmigrating coho salmon and steelhead smolts through the existing project reservoir was conducted in the spring and summer of

1995. The information from this study will be used to predict whether a larger pool is likely to increase smolt travel time resulting in an unacceptable outmigration delay of juvenile fish traveling through the larger reservoir. The results of this study are contained in the report *Travel Time of Coho Salmon and Steelhead Smolts Emigrating through Howard Hanson Reservoir, King County, Washington, April 1996* (Enclosure 1). Chinook salmon smolts were included in the reservoir migration study to help assess migration routes and behavior, but were not used in determining travel time estimates. A series of Microsoft PowerPoint® slides summarizing the travel time study is included as Enclosure 10.

Results from this study showed that pool size by itself did not explain differences in mean smolt travel time for steelhead and coho; however, coho travel times were influenced by pool size more than steelhead travel times. A general linear model showed that travel time was inversely related to inflow and directly proportional to refill rate.

D. Reservoir Travel Time Delphi Exercise

Six panelists have agreed to participate in this exercise. Panelists were chosen for their recognized expertise in either salmonid behavior, salmonid physiology, or smolt passage through reservoirs. Background information on existing and proposed reservoir conditions, and results from various recently conducted and ongoing fisheries feasibility studies have been included to assist the panelists.

This exercise will consist of a series of questions designed to elicit responses from panelists about how steelhead, coho and chinook smolts are likely to respond to changes in the Howard Hanson Reservoir Project being proposed by Tacoma and the Corps. Three to four rounds of questions are anticipated. If panelists respond within 10 days of receipt of the questions, we anticipate the exercise to last about eight to twelve weeks.

Questions to Delphi Panelists

Where questions pertain to more than one species, please provide a separate response for each species.

Given the existence of the proposed outmigrant bypass facility and the following possible refill strategies:

			Refill Storage Capacity (ac-ft)	
Begin Refill Between	End Refill	Duration (days)	Phase I	Phase II
Feb 16 - 28	June 1	95 - 103	50,400	62,400
Mar 1 - 15	June 1	78 - 92	50,400	62,400
Mar 16 - 31	June 1	63-77	50,400	62,400
April 1 - 15	June 1	48-61	50,400	62,400

1. If reservoir refill began between February 16-28,

   a. What effect would increased water storage to pool elevation 1167 ft, in combination with the proposed surface outlet, have on the travel time through the reservoir of outmigrating steelhead, coho and chinook smolts released upstream of Howard Hanson Reservoir?

   b. What effect would increased water storage to pool elevation 1167 ft, in combination with the proposed surface outlet, have on the survival through the reservoir of outmigrating steelhead, coho and chinook smolts released upstream of Howard Hanson Reservoir?

   c. What effect would additional water storage to elevation 1177 ft, in combination with the proposed surface outlet, have on the travel time through the reservoir of outmigrating steelhead, coho and chinook smolts released upstream of Howard Hanson Reservoir?

   d. What effect would additional water storage to elevation 1177 ft, in combination with the proposed surface outlet, have on the survival through the reservoir of outmigrating steelhead, coho and chinook smolts released upstream of Howard Hanson Reservoir?

2. How would your response to questions 1a, b, c, and d change if the start of refill were delayed as late as April 1-15?

3. Would you expect there to be a difference in smolt passage and survival between hatchery fish planted in the upper watershed and the progeny of wild adults that spawned in the upper watershed? If so, please describe the difference/s you would expect.

4. How could the Additional Storage Project be operated to maximize smolt passage and survival through the project? (An example of an operational change to improve smolt passage and survival would be to control reservoir outflow to closely track inflow. An example of a structural change would be to provide cover along the reservoir shoreline.)

5. What approach would you recommend be used to gain a better understanding of how to manage the Howard Hanson Additional Storage Project to maximize outmigrant salmonid survival through the reservoir?

6. Please prioritize the following watershed and reservoir features in order of greatest to least contribution to outmigration success of salmonid populations (freely insert any other features you feel are important that are not included in this list):

   Primary productivity of reservoir tributaries
   Frequency and magnitude of major flooding in reservoir tributaries
   Severity of annual summer low flow conditions in reservoir tributaries
   Presence of upstream or downstream fish hatcheries

Habitat quality of reservoir tributaries
Total stream miles above reservoir accessible to anadromous fish
Reservoir volume during smolt outmigration
Reservoir surface area during smolt outmigration
Depth of outflow
Reservoir shape factor[1]
Number of major reservoir tributaries
Annual range of reservoir pool level fluctuation
Presence of warmwater or coolwater predator fish species
Presence of cold water predator fish species
Constant reservoir release schedule
Reservoir release schedule that mimics inflow
Primary productivity of reservoir
Distance of reservoir from saltwater
Ratio of inflow to reservoir volume during smolt outmigration period

[1] An index of the irregularity of lake shape. A dimensionless ratio of the length of the shoreline to the circumference of a circle having an area equal to that of the lake. The value is always greater than 1.0.

If you refer to, or rely on, specific reports or data when forming your opinion, please provide a citation and/or copy of the report with your response. We will distribute copies of the reference to other participants prior to the next Delphi round.

SECTION 2D OUTMIGRATION OF JUVENILE SALMONIDS THROUGH HOWARD HANSON DAM

2D.1 PROJECT PURPOSE AND SCOPE

From the outset of the Additional Water Storage Project (AWSP), reconnecting the Headwaters watershed, RM 64.5 to RM 88, has been the priority project for restoration. The reconnection entails providing downstream and upstream fish passage at two anadromous barriers: downstream fish passage through Howard Hanson Dam (HHD, RM 64.5) and upstream fish passage at the Tacoma Diversion Dam (RM 61). Upstream, or adult fish passage, will be provided at the Diversion Dam by the City of Tacoma with a fish ladder and trap and haul program. Downstream fish passage, for juvenile salmonids and adult steelhead, is the major design and construction aspect of the AWSP. To accomplish this technically complex and challenging project, the Corps and the City of Tacoma formed the Fish Passage Technical Committee in 1989, this committee produced an initial report that become the planning document for fish passage improvement at HHD.

In their 1990 report, the FPTC provided a recommended list of studies necessary to evaluate each of the proposed AWSP fish passage options and to verify the aspects of the biological and physical assumptions presented in their report. Three of the recommended studies specific to dam passage through Howard Hanson Dam were:

- Evaluation of attraction by juvenile fish by species to the existing outlet(s) at selected pool evaluations.
- Evaluate attraction flow (required to pass fish) at selected pool elevations.
- Study depth (vertical) and lateral (horizontal) distribution of juvenile fish near the outlet as functions of reservoir temperature, pool elevation and outflow.

These recommended studies were completed by the U.S. Fish and Wildlife Service (USFWS) in 1991, 1992, and 1993 and resulted in three technical reports:

Dilley, S. and R. Wunderlich. 1992. *Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991*. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1993. *Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992*. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. *Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir*. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

The results from these studies, in addition to earlier work by the Washington Department of Fisheries (WDF), Seiler and Neuhauser (1985), provided the basis for conceptualization and development of the preferred fish passage facility -- a combination modular incline screen (MIS) and fish lock (discussed in Hydraulics and Hydrology Appendix and Section 8).

This section will review the major findings of the four reports, one WDF and three USFWS, and discuss results in the context of other water control projects and the AWSP. Objectives for this section are:

1. review previous HHD juvenile outmigrant monitoring study results,
2. compare these results to studies from other river systems, and
3. discuss existing survival against proposed AWSP flow and dam passage improvements.

2D.2 INTRODUCTION

Existing Dam Features and Operation. Originally Authorized as Eagle Gorge Dam and Reservoir by the Flood Control Act of 1950. Construction of the dam was completed in 1962 at river mile 64.5 on the Green River. Primary authorized use of the project is flood control. Three secondary authorized uses: low flow augmentation for fish resources of the Green River, irrigation, and water supply. The project was not built with adequate downstream fish passage facilities. At high pool, smolts must sound between 72 to 106-112 ft to exit the project.

Under current operation, refill of HHD begins each spring at or around April 15, pool elevation 1070 ft, and is progressively filled to high pool, elevation 1141 ft, by the end of May or early June. As the pool fills the reservoir increases in size from about 1.5 miles length at low pool to 4.3 miles at high pool (Figure 1). For a two-week period in most years the pool is filled an additional 6 feet to 1147 ft to provide a cushion to clear debris around the reservoir. The AWSP would increase pool size from Baseline length 4.3 miles, 1141 ft elevation, to 5.3 miles in Phase I, 1162 ft elevation, and to 5.7 miles in Phase II, 1177 ft elevation. The measured and modeled changes in reservoir physical variables are discussed in subsection 2B-1.

Howard Hanson Dam is an earth and rockfill structure with a base width of 960 ft and a height of 235 ft. Top elevation is 1,230 ft and the crest length is 450 ft. Flow is discharged from the reservoir through a 19 ft wide concrete-lined horseshoe tunnel 900 ft in length located near the south abutment of the dam. Two 10-ft by 12-ft high tainter gates (invert elevation 1035 ft) in the intake tower discharge flow through the tunnels (maximum discharge is 6,500 cfs/tunnel) in normal flow periods (fall, winter, and spring). Low flows (summer and early fall) are passed through a 48 in bypass pipe which runs under the outlet tunnel and discharges into the stilling basin. The bypass entrance is an 8 ft square opening (elevation 1069 ft) with the 48 in bypass pipe (maximum discharge is 560 cfs) exiting through the floor of the bypass entrance. Flow through the bypass pipe is controlled via a valve located on the downstream end (elevation 1024 ft). Howard Hanson Reservoir has a maximum storage capacity of 106,000 ac ft (1206 ft elevation for flood control) and normally operates during spring through fall between low pool (1070 ft, 1200 ac ft, 1.5 miles long) and full pool (1141 ft, 25,400 ac ft, 4.1 miles long). During drought years and for a short period in May each year the pool is raised to 1147 ft elevation (30,400 ac ft). Yearly fill to this elevation is for debris clearing and is only maintained for two weeks.

History of Anadromous Fish. In 1911, over 220 mi^2 of the Headwaters Green River was blocked to anadromous fish passage (salmon and steelhead) with the construction of the diversion dam at river mile (RM) 61 to supply public water to the City of Tacoma. A second anadromous fish barrier, HHD, was constructed at RM 64.5 in 1962 for water storage and flood control. The initial construction did not include upstream or downstream passage facilities for juvenile or adult salmon and steelhead. Historical adult returns (run-size or preharvest) to the upper water are estimated to include: 9,000-27,000 coho, 1,500-5,000 steelhead, and 100-400 spring chinook.

The first outplanting of juvenile anadromous salmonids above HHD occurred in 1982 with release of steelhead fingerlings, coho salmon in 1983, and chinook salmon in 1987. Since this time, all of these species have been planted and will continue to be planted. The three stocks planted are mostly lower Green River hatchery stock. Spring chinook was the original chinook race using the Headwaters, it appear to have been extirpated from the Green River basin. In 1992, the first adult steelhead were released above Howard Hanson Reservoir since 1911. In the near future, improved adult collection of Headwaters Green River stock and improved quality of outplanted juveniles will occur with completion of the Tacoma/Muckleshoot Indian Tribe fish ladder and Fish Restoration Facility (hatchery).

The outmigration of juvenile salmonids was first studied by the Washington Department of Fisheries in 1984 (Seiler and Neuhauser 1984). Coho daily passage appeared to be associated with increases in project outflow volume. Passage stopped and an unknown number of steelhead and coho smolts were trapped within the reservoir when refill began, outflow volume decreased, and discharge was transferred to the bypass outlet, at increased outlet depth.

AWSP baseline studies at the HHD were begun in 1990 by the USFWS and have continued through 1996. Studies specific to identifying reservoir or dam features that affect the safe passage of juvenile outmigrants began in 1991 and have included: monitoring and evaluation of juvenile passage at the dam, and flow or outlet features affecting daily passage, in 1991 and 1992 (Dilley and Wunderlich 1992 and 1993); monitoring of the distribution of juveniles rearing or entrapped in the lower reservoir in

1993 (Dilley 1994); estimation of juvenile travel time through the reservoir in 1995, and evaluation of factors affecting travel time (Aitkin et al. 1996). The majority of these studies were identified and recommended by the FPTC in 1990 for use in development of the AWSP preferred fish passage facility.

2D.3 METHODS

Each study, WDF and USFWS, will be discussed separately for methods used to count, capture, and evaluate juvenile outmigration.

Seiler and Neuhauser (1985). In 1984, WDF monitored downstream migrants passing through HHD and Reservoir with a floating scoop trap.

The scoop trap dimensions were 6 by 6 ft opening and length of incline was 16 ft. It could screen 200 cfs at velocities of 6-7 fps. The trap was located 200 yd below the dam discharge tunnel in the tailout of the stilling basin. The trap was fished continuously from March 30 to June 16 except for April 15 and May 13 when flows were too high. Captured steelhead and coho smolts were counted and inspected for fin clips (test fish) and injuries. A random sample of naturally-reared coho and steelhead smolts were measured for length. Eight groups of marked coho and steelhead were released into the tailrace to serve as control groups. Thirteen test groups were released at 5 locations upstream of the dam: the North Fork Green at RM 2.5, mid-reservoir, directly into the intake tower, and into the gatewells and bypass pipe with a hose.

Dilley and Wunderlich (1992 and 1993). During 1991 and 1992, the USFWS monitored downstream migrants passing through the HHD project with a combination of hydroacoustic equipment at the inlet to the bypass and radial gates and trapping above and below the reservoir and dam.

Hydroacoustic monitoring of the inlets occurred for 220 days in 1991, April 16-November 22 and 285 days in 1992, February 18-November 30. A scoop trap was fished below the dam during the same period to determine species composition of outmigrants: hydroacoustic echos only give an estimate of signal strength, they do not discriminate between size of fish or species. Trap counts apportioned hydroacoustic estimates by age class and species. Captured fish were examined for physical injuries and size (length). Fyke traps were fished on the North Fork and mainstem Green River. Fyke catch was used to assess movement trends into the reservoir (periodicity) and compared to estimated dam passage. Daily estimated fish passage was compared to exit depth, exit outflow, and outflow temperature. Simple regression was used to identify relationships between dam passage conditions and daily passage by species and life-stage.

Dilley (1994). In 1993, the USFWS hydroacoustically monitored the vertical (water column depth) and horizontal (distance from shoreline) distribution of juvenile salmonids at the intake and in the lower reservoir of HHD during the spring migration period (April 5 through July 29). A combination of gill nets and hydroacoustics was used to collect specific information on individual species, year class, and day and night horizontal and vertical distribution.

Bi-weekly, day and night mobile hydroacoustic surveys used a dual-beam system on a six-transect course of the lower mile of the reservoir. Each transect was divided into four sections, left shore, left middle, right middle and right shore (looking downstream) to provide horizontal distribution information across the reservoir. Within month comparisons for horizontal and vertical distributions were made using fish densities at depth, location, transect and by day or night. Analysis of variance was used to test horizontal distributions for significant differences by month, transect, and location relative to shore. Vertical gill nets were used to collect species-specific vertical distribution and to provide year-class information. Day and night net sets were done bimonthly using 3 monofilament vertical nets.

2D.4 RESULTS

The primary conclusion of the three years of dam passage outmigrant studies at HHD (1984, 1991, and 1992) was that spring refill, especially early spring refill, substantially delays and/or entraps migratory juvenile salmonids, resulting in major late-fall emigrations of fish with low migratory readiness. The 1993 study focused on horizontal (shoreline or center channel) and vertical (water depth) position of delayed/entrapped smolts and rearing juveniles in the lower reservoir. This delay and entrapment is the result of three factors: 1) reduced exit outflow; 2) increased outlet depth; and 3) poor attraction through the bypass pipe. Since 1991, delay and entrapment have increased. From 1984-1991 refill was delayed until after the peak of coho and steelhead emigration (late May), since 1992 refill has begun in early to mid-April, well before the peak for all stocks, including chinook.

2D.4.1 Periodicity

Timing Under Normal Outmigration. The 1984 scoop trap data and 1991-1992 fyke trap data provide the best site-specific information on timing of outmigration (Seiler and Neuhauser 1985; Wunderlich and Dilley 1992 and 1993). However, this data is still limited, 3 years for coho, 2 years for chinook, and partial counts in one year for steelhead and actual timing is dependent on when hatchery-reared fish were planted (Table 1). Timing from scoop trap data and hydroacoustic expansion in 1991, and especially in 1992 is biased, reflecting the later outmigrant timing from earlier refill and is presented later. The Corps, Tacoma, and R2 Resources Consultants have completed a comprehensive review of all existing Green River outmigration data (Figure 1, discussion in Section 5). We would consider this data more reliable, but we present the site-specific data for comparison.

The site-specific data includes one year of below dam trapping, 1984. This trapping was completed during the majority of the outmigration period (April through early June) at the lowest pool HHD is operated at, 1062-1080 ft, until the first week of June when refill began. Trapping below the dam in 1991 and 1992 had protracted periods where refill was occurring or had occurred during the main outmigration period (April and May) which would have delayed or entrapped outmigrants. Only 1984 below dam information is presented. Coho smolts were captured throughout the trapping period, as were steelhead. Steelhead capture totals were much lower, the authors felt the trap was inefficient at capture of steelhead at the velocities encountered. Fyke trap data was also used, from 1991 and 1992. Only coho smolts and chinook subyearlings were captured. Again, this data is somewhat suspect for actual percentages as this trap type is meant for species presence not actual counts. Table 1 lists information by week or half-month total. Figure 1 shows half-month percentages for all three stocks from comprehensive literature reviews for an average year. Monthly totals from all HHD and comprehensive sources are listed in Table 2.

TABLE 1. SEASONAL PERIODICITY OF HEADWATERS GREEN RIVER SALMON AND SMOLT OUTMIGRANTS THROUGH (AT LOWEST POOL) AND INTO THE HOWARD HANSON PROJECT (SEILER AND NEUHAUSER 1984; DILLEY AND WUNDERLICH 1992, 1993): GRAY AREA=NO SAMPLES.

Summary of Seiler Scoop Trap below HHD in 1984 (pool at 1070 ft until June 2).

Weekly Percentages

1984	Coho	Steelhead
7-Apr	0.6%	5.8%
14-Apr	0.4%	3.5%
21-Apr	2.2%	7.5%
28-Apr	2.9%	22.4%
5-May	11.2%	23.0%
12-May	23.4%	16.1%
19-May	17.6%	10.9%
26-May	21.3%	8.1%
2-Jun	17.3%	2.3%
9-Jun	3.2%	0.0%

Half-Month Percentages

	Coho	Steelhead
15-Apr	1.1%	9.2%
30-Apr	7.2%	36.8%
15-May	40.3%	39.1%
31-May	44.2%	13.8%
15-Jun	7.2%	1.2%

Summary of Fyke Trap above HHD, into the reservoir, 1991 and 1992 Green River

	1991 Half-Month Percentages		1992 Half-Month Percentages	
	Coho	**Chinook**	**Coho**	**Chinook**
28-Feb			9.1%	31.5%
15-Mar			5.7%	1.0%
31-Mar			5.7%	50.0%
15-Apr			2.3%	6.8%
30-Apr	4.4%	2.5%	20.5%	3.8%
15-May	13.2%	0.6%	56.8%	6.7%
31-May	36.6%	2.1%	0.0%	0.3%
15-Jun	41.4%	37.7%	0.0%	0.0%
30-Jun	4.4%	49.8%	0.0%	0.0%
15-Jul	0.0%	7.4%		

TABLE 2. MONTHLY COMPARISON OF NORMAL JUVENILE OUTMIGRATION TIMING FOR THREE YEARS OF OUTMIGRANT STUDIES AT HHD AND A COMPILATION OF ALL GREEN RIVER SOURCES FOR AN AVERAGE YEAR.

	Year	February	March	April	May	June	July	Notes
Steelhead	1984			48%	53%	1%		9% before 4/15
	Figure 1		5%	35%	45%	15%		Section V
Coho	1984			6%	74%	20%		WDF
	1991			4%	50%	46%		USFWS
	1992	9%	11%	23%	57%			USFWS
	Figure 1		5%	35%	45%	15%		Section V
Chinook	1991			3%	3%	88%	7%	USFWS
	1992	32%	50%	7%	4%	7%		USFWS
	Figure 1			10%	40%	40%	5%	Section V

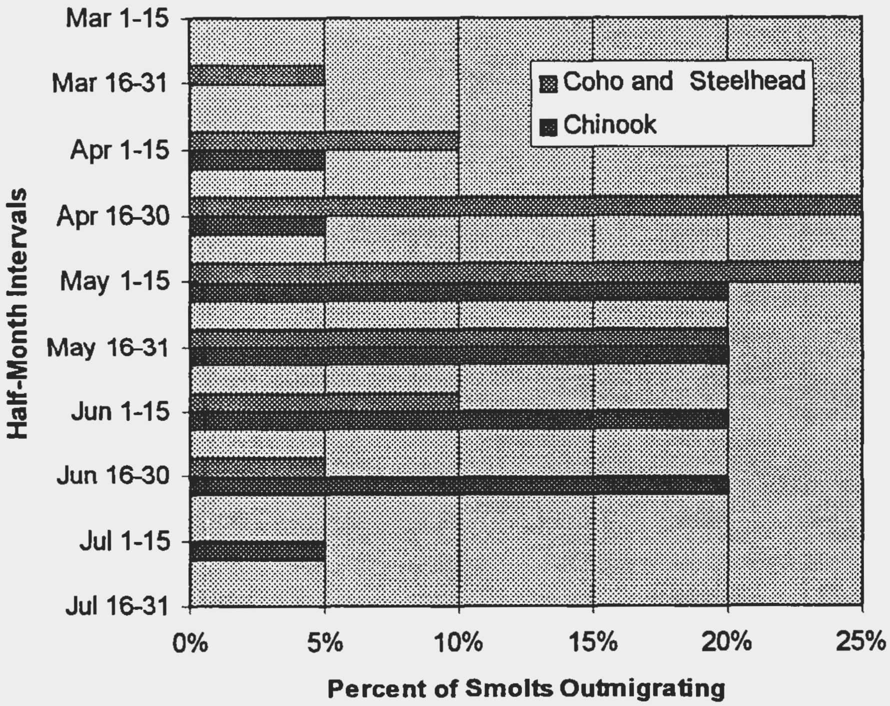


FIGURE 1. OVERALL PERIODICITY OF GREEN RIVER MIGRATORY JUVENILE STEELHEAD, COHO AND CHINOOK SALMON: REPORTED AS PERCENT OF SMOLTS OUTMIGRATING PER HALF-MONTH FOR AN AVERAGE YEAR (SEE SECTION 5 FOR LITERATURE REFERENCES).

Timing with Delay or Entrapment. Estimated daily dam passage of coho yearlings in 1991 (total n=5900) suggests that few fish were entrapped in the reservoir but many still experienced some delay. Comparing monthly percentages of 1991 to 1984 and 1991 to Green River average shows that June of 1991 had a much higher percentage of outmigrants: 46% vs. 15% and 20%, respectively (Table 2). The monthly percent for June 1984 is also underestimated, some smolts were entrapped when refill occurred in early June. In 1991, all trapped smolts presumably emigrated prior to June 30 (Dilley and Wunderlich 1992), a general date used to estimate the end of the coho emigration period in most Washington rivers. The fyke trap catches suggest otherwise, peak movement into the reservoir occurred in late May, while the lowest dam passage occurred at this time. In 1992, 42% of all yearlings (total n=7500) emigrated after June 30, suggesting these fish were delayed and entrapped in the reservoir for an extended period (Appendix Figure A-1). In that year, a large pulse of fish (24% of all migrants) exited through the dam at the end of July. Even at final drawdown in November of 1992 a number of coho yearlings (10%) were still exiting the dam.

Chinook subyearlings appear to experience greater delay and entrapment than coho. As described in Section V, chinook emigration in the Green River is typically complete by July 15, with 95% complete by June 30 (Figure 1). In 1991, only 16% of chinook (total n=21,700) emigrated prior to June 30. In 1992, a similar trend occurred, 25% of chinook emigrated by June 15, 35% between June 15 and June 30. A large number of chinook were entrapped in the reservoir until final drawdown in November, a two-year average of 33% exited that month (Appendix Figure A-2).

2D.4.2 Growth Rate

The scoop trap data from 1984 provides the best data for coho yearling growth rates, fork length, with little influence from entrapment within the reservoir (Seiler and Neuhauser 1985). This study also provides limited data on steelhead size, but not on a periodic basis. Overall, 506 coho were measured for length over 11 weeks in the spring outmigration period (Table 3). Average lengths increased from 91.5 mm in early April to 102.2 mm in early May and 134.5 mm in mid-June. The fish caught in June may have experienced from 2-3 weeks of accelerated growth from rearing in the reservoir, the 120-134 mm size is 20-30% larger than similar sized wild smolts in nearby river systems. A single gill net set was taken from the upper reservoir in mid-September to sample for entrapped smolts. Out of 28 fish captured, 18 were coho (rest were trout) which had an average length of 152 mm. There were 42 steelhead sampled in from April to June, there average length was 155 mm, 77-216 mm range.

TABLE 3. WEEKLY MEAN FORK LENGTH, RANGE, STANDARD DEVIATION, AND NUMBER OF COHO SMOLTS SAMPLED, AND CORRESPONDING SEASONAL DATA FOR STEELHEAD SMOLTS FOR 1984 (SEILER AND NEUHAUSER 1985).

	Mean Length (mm)	Standard Deviation	Minimum and Maximum	Total
April 2-8	91.5	8.8	81-101	4
April 9-15	97.9	8.8	82-18	21
April 16-22	99.1	8.2	80-121	57
April 23-29	101.6	10.6	67-128	91
April 30-May 6	102.2	7.9	87-125	60
May 7-13	103	8.8	75-121	57
May 14-20	103.7	8.6	78-120	57
May 21-27	107.5	9.2	90-140	54
May 28-June 3	120.1	16.9	95-152	53
June 4-10	124.2	13.4	100-156	48
June 11-17	134.5	18.1	111-155	4
September 19[a]	152	N/A	134-210	18

a. Gillnet sample in the upper reservoir to check for entrapment of coho yearlings, 18 caught; underyearlings were caught in the lower reservoir (80-110 mm).

USFWS sampled forklength of fish on a regular basis in 1991 and 1992 (Wunderlich and Dilley 1992 and 1993). The measurements were for juvenile outmigrants (subyearling and yearling) trapped below the dam (Appendix Table A-1). Except for early outmigrants in February and March, length measurements were of fish that had experienced some period of time rearing in the reservoir. Yearling measurements, coho and chinook, beginning in May and June should be considered entrapped fish unable to exit. Subyearling chinook measured in February and March represent hatchery planted fingerlings displaced from the planting site or fish volitionally emigrating downstream in search of better rearing habitat. Beginning in April, subyearling coho represent downstream migrants of the same type as the early subyearling chinook. Subyearling chinook captured in April through July represent potential smolts. After late July, all subyearling chinook can be considered entrapped smolts.

Coho yearlings captured from February to mid-May averaged 103 mm in 1991 and 102 mm in 1992 which was consistent with length in spring 1984 (105 mm) (Seiler and Neuhauser 1985). Yearlings that were delayed or reared (late May to early June migrants) in the reservoir in 1984 averaged 127 mm which is consistent with the 1991 average of 122 mm. Yearlings entrapped in the reservoir in 1984 averaged 154 mm in September and in 1992, those emigrating in November averaged 164 mm in length. This represents a 50-60% increase in total length for yearlings entrapped through the summer.

Coho subyearlings captured from February to May averaged 55 and 48 mm in 1991 and 1992, respectively. Subyearlings who emigrated in November during the fall drawdown averaged 121 and 116 mm in the same years, respectively. This represents a 110-150% increase in total length for juveniles who reared in the reservoir throughout the entire rear.

Chinook subyearlings captured from February to early May averaged 55 and 59 mm in 1991 and 1992, respectively. Subyearlings who emigrated between mid May and the end of July averaged 113 and 117 mm in the same years, respectively. Those juveniles emigrating during August through November, averaged 182 and 166 mm in length. The smolts who emigrated between mid May and July experienced some period of delay with a large increase in size. The smolts emigrating after July were significantly delayed or entrapped until the pool outlet reached a depth they could exit at. The size of these entrapped subyearlings compares to a mean size of 190 mm for yearling chinook reared in the upper Elwha River reservoir (Wunderlich and Dilley 1990), and far exceeds that of stream-reared yearling chinook in the Skykomish basin (110 mm; Seiler et al. 1984).

2D.4.3 Smolt Readiness

In 1991 and 1992, the USFWS took limited measurements of gill ATPase, an enzyme measure of how ready juvenile salmonids are to migrate to the ocean (smolt-readiness). Measurements were taken at various locales above and below the dam. These measurements were used to correlate fish movement through the dam and reservoir with fish physiological condition (smolt readiness). Dilley and Wunderlich (1992) provided an index to compare measured ATPase against normal periods of rearing, onset of smoltification, and smoltification (Table 6 in Dilley and Wunderlich).

Study findings were: 1) coho yearlings and chinook subyearlings held in the reservoir beyond their normal outmigration window lost smolt readiness; and 2) chinook subyearlings captured in the reservoir forebay were found to be smolt ready from mid May to early September while coho yearlings were smolt ready between April and late June. As discussed above, the typical outmigration period for coho yearlings is from April to late June and from late April to July for chinook subyearlings. The ATPase results correspond with what is normally expected, however the chinook smolt readiness period appears to extend beyond the normal migration period. Dilley and Wunderlich (1992 and 1993) felt that pulses of yearling coho and subyearling chinook emigrating during summer, after refill, were delayed/entrapped smolts driven to emigrate against poor passage conditions by their advanced physiological condition. Coho subyearlings that reared in the reservoir through late summer and early fall were not smolt ready and were not expected to be smolt ready at that time.

2D.4.4 Diel Behavior

Juvenile behavior in the lower reservoir is strongly related to day/night differences. Above the forebay, Dilley (1994) found daytime abundance was low throughout the spring outmigration in 1993, in contrast, nighttime abundance was double daytime and increased throughout the study. Behavioral differences may explain the abundance differences. During the day, fish were actively feeding at the intake outlet, often in large schools, while at night they appear to disperse throughout the reservoir. Vertical distribution did not vary between day and night, 80-96% of all juveniles were found in the upper 50 ft of the water column. In 1984, almost all passage through the dam occurred at night, with 90% of all fish caught at night (Seiler and Neuhauser 1985).

2D.4.5 Lower Reservoir Horizontal and Vertical Distribution:

Horizontal. Dilley (1994) found most rearing fish were more shoreline oriented than in the main channel, both day and night. During the day, most observations from April through June occurred along the left shoreline, the side nearest the intake tower. By July, the greatest concentration of fish was along the right shore. At night, there was a more dispersed distribution between the left and right shores. Analysis of variance showed a strong preference for shoreline areas.

Vertical. There was a heavy weighting of fish density for shallower water depths throughout the 4 months of study. The percent of fish observed in the upper 50 ft during the day was: 97% in April, 80% in May, 96% in June, and 96% in July. At night, a similar depth trend for percent of fish observed in the upper 50 ft: 96% in April, 94% in May, 90% in June, and 80% in July. July had the most even density distribution through all depth strata for any month. The July distribution may reflect addition of chinook juveniles. Gill net samples showed that coho smolts were generally distributed higher in the water column than chinook yearlings which were more evenly distributed. Temperature and dissolved oxygen profiles showed no related vertical barriers to fish movement.

No resident rainbow or cutthroat trout were recorded in the lower reservoir. The largest fish caught was a 12 in mountain whitefish. In 1989, WDFW surveyed the upper reservoir and found large numbers of rearing fish, including coho, chinook, and cutthroat and rainbow trout (Cropp, Undated).

2D.4.6 Analysis of Dam Passage Conditions and Daily Passage:

Table 4 lists all periods for regression analysis, including gate operation. Coho yearling, subyearling and chinook subyearling daily passage is discussed in relation to dam passage conditions. Scoop trap capture was inefficient for steelhead so daily passage numbers are unavailable for comparison. All regression analyses were performed by the USFWS including review of WDF data from 1984 (Dilley and Wunderlich 1992 and 1993).

Coho Yearling. In 1984, coho smolt passage was associated with outflow volume (r^2=0.39), the higher the daily outflow the more fish passed through the dam (Figure 2). The researchers felt the radial gates were not an impediment to outmigration at low pool (outlet depth 30-35 ft) but that the bypass gates were a barrier to fish, delaying and ultimately entrapping smolts in the reservoir. The pool was kept at lower elevation (1062-1080 ft) until refill began in early June. With switch over to the bypass pipe on June 6, all outmigration ceased within several days (Figures 3 and 4). A good number of coho smolts were probably still present in the lower reservoir and were trapped by refill. During one gill net sample in the upper reservoir in September, 18 coho smolts were caught (152 mm mean length, 135-210 mm range) vs. only 8 rainbow and 2 cutthroat. On the same date 3 coho 0+ were caught in the lower reservoir (93 mm mean, 80-110 mm range) (Seiler and Neuhauser 1985). The pattern of smolts trapped and found in the upper reservoir follows results from the 1995 radio-tracking study. Smolts that reached the dam but could not exit turned around and went back upstream to the upper reservoir near tributary confluences. This is known as the "ping-pong" effect.

Significant reductions in yearling passage occurred during both test and actual refills in 1991. These reductions were very strongly associated with both outflow and exit depth (r^2=0.95 and 0.97)(Figures 5 and 6). Lack of comparable association in 1992 may be due to the early refill, which occurred well before the expected peak in coho smolt emigration in mid May. In effect, poor exit conditions in 1992 associated with early refill probably stopped most emigration just as it started, and resulted in several pulses of trapped yearlings exiting during the late summer and fall which were not seen in 1991. Although no correlation was identified in 1992, a switch to combined radial/bypass release on May 1-2 resulted in over 46% of all coho smolts emigrating in a two day period (for smolts outmigrating in their biological window). This bypass to radial gate switch was accompanied by a 170% increase in outflow from 300 cfs to 500 cfs for the first two days (Figure 7 and 8). The flow eventually reached 650 cfs, a 215% increase, but all smolts captured passed in the first 2 days (Dilley and Wunderlich 1992 and 1993).

Coho Subyearling. Fyke trap catches in 1991 and 1992 indicated that subyearlings began downstream movement into the reservoir from April through mid-June. Coho subyearlings normally do not emigrate to the ocean until the following spring and these juveniles were probably seeking suitable rearing habitat after being planted further upstream. Below the dam, in 1991, no statistically significant relationships were found between daily coho subyearling passage and reservoir elevation or outflow until the final drawdown in early November. A large pulse of coho occurred beginning on November 6, the date the radial gate opened. Over 1/3 of all subyearling coho emigrating in 1991 passed the dam after that date. During November 6-22, coho passage was significantly related to increased outflow through the radial age (r^2=0.27) (Dilley and Wunderlich 1992).

In 1992, virtually all emigration through the dam occurred during the fall. At fall drawdown (early and late drawdown periods combined) increased outflow was significantly related to increased dam passage (r^2=0.37). Increased exit depth was significantly related to reduced subyearling passage during refill (r^2=0.22), but during no other study period (Dilley and Wunderlich 1993),

Chinook Yearling. In 1991, chinook yearlings were not observed emigrating during periods when only the bypass gate was used and they were not detected in passage during the test refill, actual refill or drawdown, so a direct measure of their response to these conditions is not available. In 1992, chinook yearlings were mainly observed during periods when only the bypass gate was in operation. There was no significant relationship between yearling passage and operational variables tested in 1991 or 1992 (Dilley and Wunderlich 1992 and 1993).

Chinook Sub-yearling. Chinook subyearlings were the only juveniles passing through the dam through much of the summer with passage occurring at exit depths of up to 70 ft over the bypass pipe. In 1991, the bulk of subyearling movement occurred during periods of high flows, when the radial gates were in operation (Figure 9). Daily passage of subyearling chinook was significantly related only to reservoir outflow. This relationship held during high summer pool (June 21 to July 8, r^2=0.53), total drawdown (July 9 to November 22; r^2=0.34), and final drawdown (November 6 to 22, r^2=0.19). Virtually no subyearling passage was detected during refill.

In 1992, daily passage was significantly related to exit conditions during refill, as passage declined as outflow declined (April 1 to May 1, r^2=0.19). During late drawdown, when outflow shifted to the radial gate (September 26 to November 30), more chinook passed when outflow increase (r^2=0.13). A specific test in late June, 1992, when a large number of chinook emigrated, showed no relation to any dam exit condition. This "spike" in emigration may be related to increased ATPase and/or to the tendency for deeper forebay distribution later in the season (Dilley and Wunderlich 1993, Dilley 1994).

TABLE 4. SUMMARY OF CORRELATIONS BETWEEN OUTFLOW/DEPTH AND JUVENILE FISH PASSAGE AT HOWARD HANSON DAM IN 1984, 1991 AND 1992 (BY PERIOD). DATES OF 1991 AND 1992 PERIODS ARE LISTED BELOW. EXCEPT AS NOTED, INCREASED FISH PASSAGE WAS RELATED TO INCREASED EXIT OUTFLOW. WHERE NO VALUE IS SHOWN, NO RELATION WAS DETECTED; GRAY AREA SHOWS NO TEST CONDUCTED IN 1992 (DILLEY AND WUNDERLICH 1993).

Passage of	Year	Pre-refill	Test Refill	Refill	High Pool	Total Drawdown	Final Drawdown
Coho Yearling	1984			0.39[a]			
Chinook	1991				0.53	0.34	0.19
Subyearling	1992			0.19			0.13
Coho	1991		0.95	0.97[b]			
Yearling	1992						
Coho	1991						0.27
Subyearling	1992			0.22[c]		0.37	

a. Reduced coho yearling passage related to exit outflow (Seiler and Neuhauser 1985).
b. Reduced coho yearling passage was related to both reduced exit outflow and increased exit depth.
c. Reduced coho subyearling passage was related to increased exit depth (outflow was not related).

Periods for Regression Analysis:

Pre-refill: 1991 -- April 16 to May 7, reservoir elevation declined and remained stable, radial gate only. 1992 -- February 18 to March 31, all outflow through radial gate, chinook released above project.

Test Refill: 1991 Only, May 8 to May 17, partial fill and drawdown from 1076 to 1120 ft, radial gate only.

Refill: 1991 -- May 20 to June 21, reservoir increased from 1075 to 1145 ft, shift to bypass gate May 29th. 1992 -- April 1 to May 1, radial gate until April 8, bypass gate thereafter.

High Pool: 1991 -- June 22 to July 8, reservoir elevation remained steady, radial and bypass gates used. 1992 -- May 2 to June 3, reservoir elevation was steady, radial and bypass through May 13, bypass only after.

Total Drawdown: 1991 -- July 9 to November 22, reservoir fell from high to winter low pool, bypass until Nov. 5. 1992 -- June 4 to September 25, bypass used,.

Final Drawdown: 1992 -- September 26 to November 30, bypass and radial to September 28, radial only thereafter.

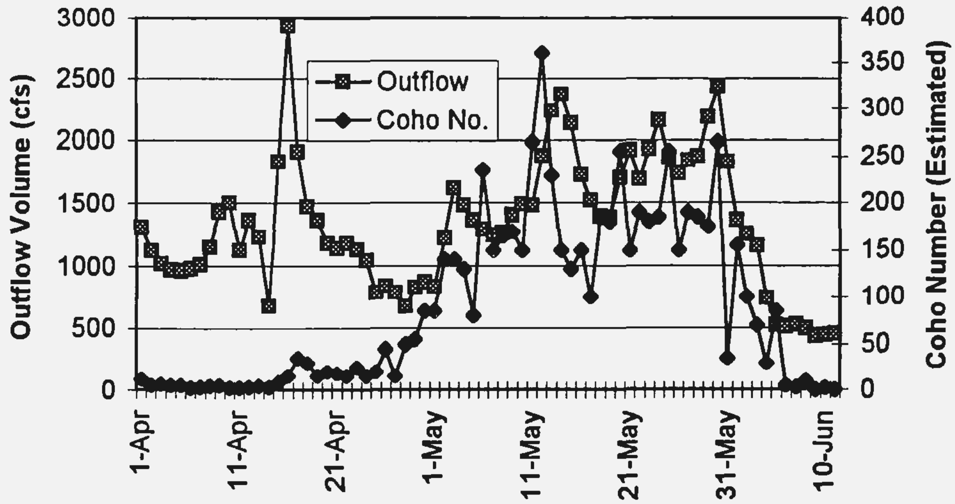


FIGURE 2. COMPARISON OF 1984 OUTFLOW VOLUME VS. COHO OUTMIGRATION (SEILER AND NEUHAUSER 1985; DILLEY AND WUNDERLICH 1993; R^2=0.39).

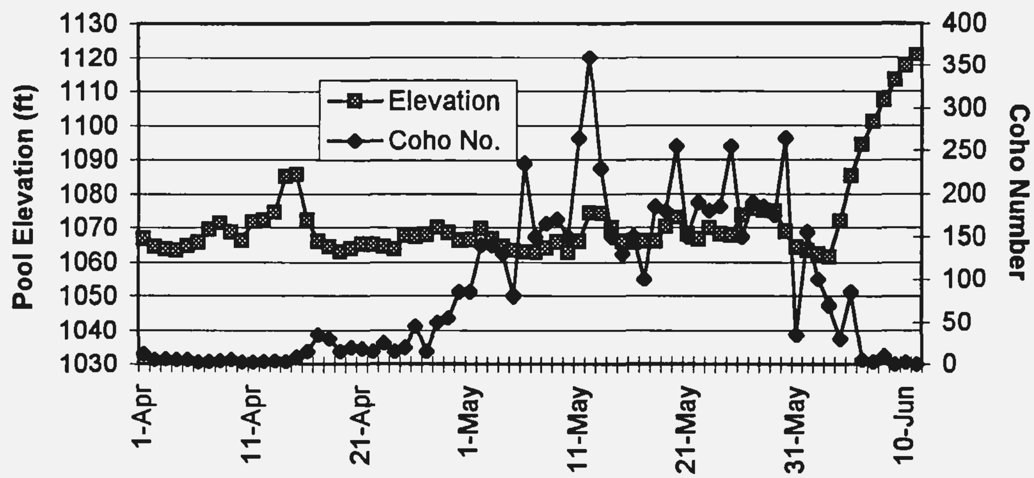


FIGURE 3. COMPARISON OF 1984 POOL ELEVATION VS. COHO OUTMIGRATION (SEILER AND NEUHAUSER 1985).

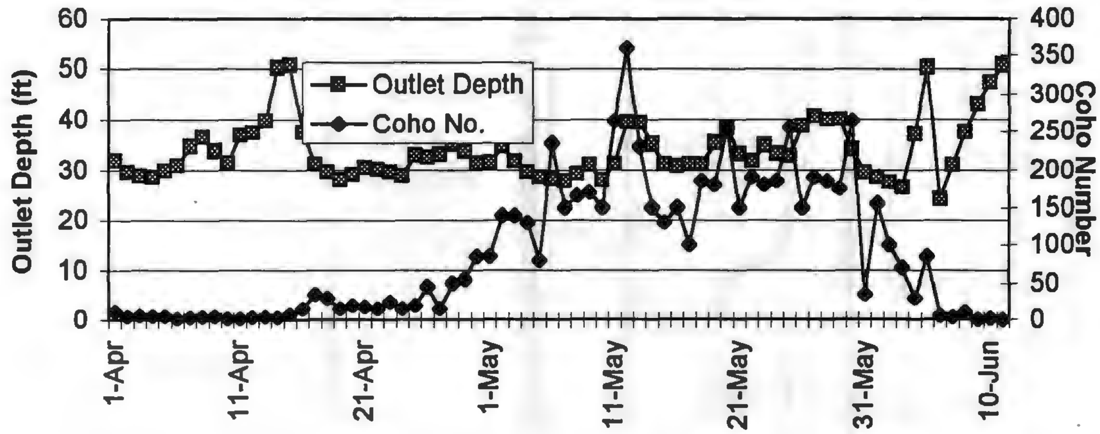


FIGURE 4. COMPARISON OF 1984 OUTLET DEPTH VS. COHO OUTMIGRATION (SEILER AND NEUHAUSER 1985). SWITCH TO THE BYPASS PIPE OCCURRED ON JUNE 6.

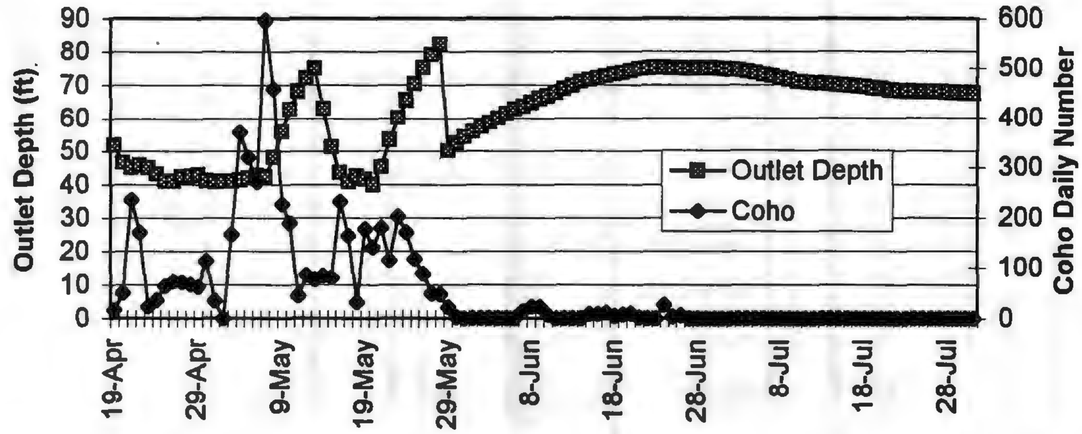


FIGURE 5. DAILY PASSAGE OF COHO YEARLINGS IN 1991 COMPARED TO OUTLET DEPTH OF THE RADIAL GATES AT HOWARD HANSON DAM (R^2=0.97 FOR OUTFLOW AND OUTLET DEPTH DURING REFILL).

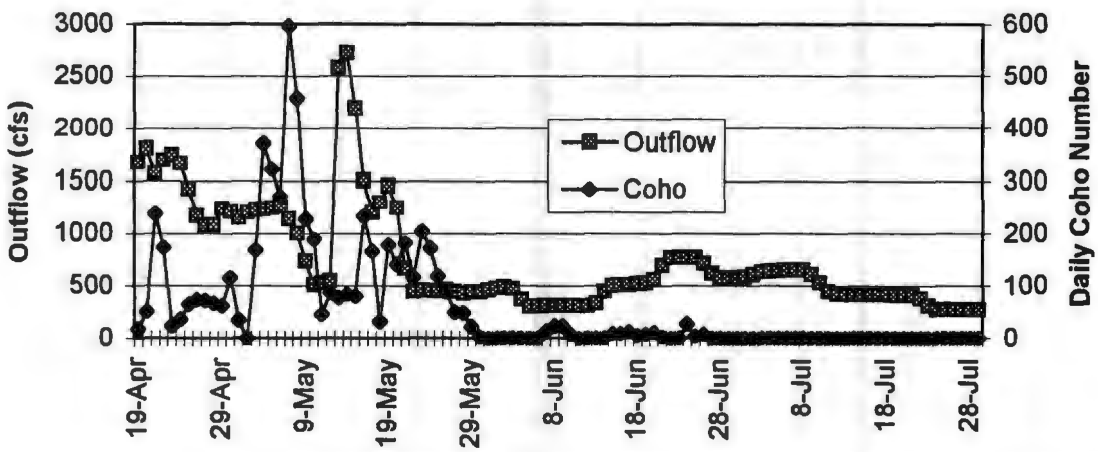


FIGURE 6. DAILY PASSAGE OF COHO YEARLINGS IN 1991 COMPARED TO OUTFLOW VOLUME THROUGH THE RADIAL GATES AT HOWARD HANSON DAM (R^2=0.95 DURING TEST REFILL, MAY 8-17).

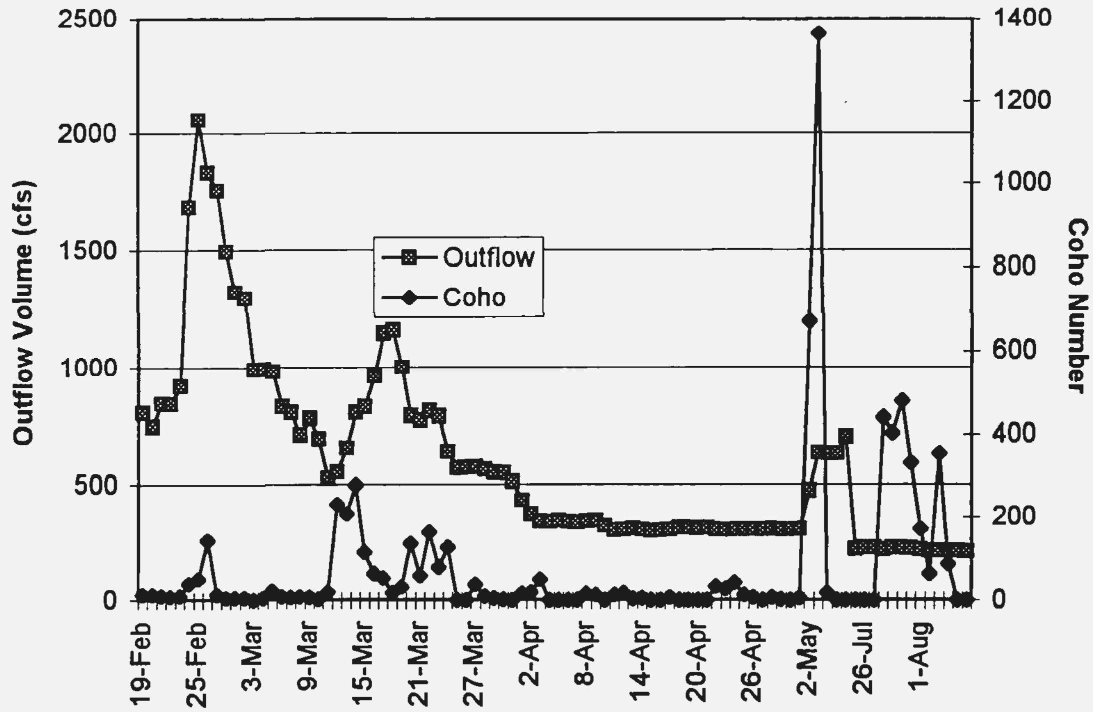


FIGURE 7. DAILY PASSAGE OF COHO YEARLINGS IN 1992 COMPARED TO OUTFLOW VOLUME AT HOWARD HANSON DAM THROUGH THE RADIAL (THROUGH APRIL 8), BYPASS (AFTER APRIL 8), AND RADIAL AND BYPASS (MAY 2-13), AND BYPASS GATE ONLY AFTERWARDS (DATES FROM MAY 5 TO JULY 24 REMOVED, 40 COHO WERE PASSED).

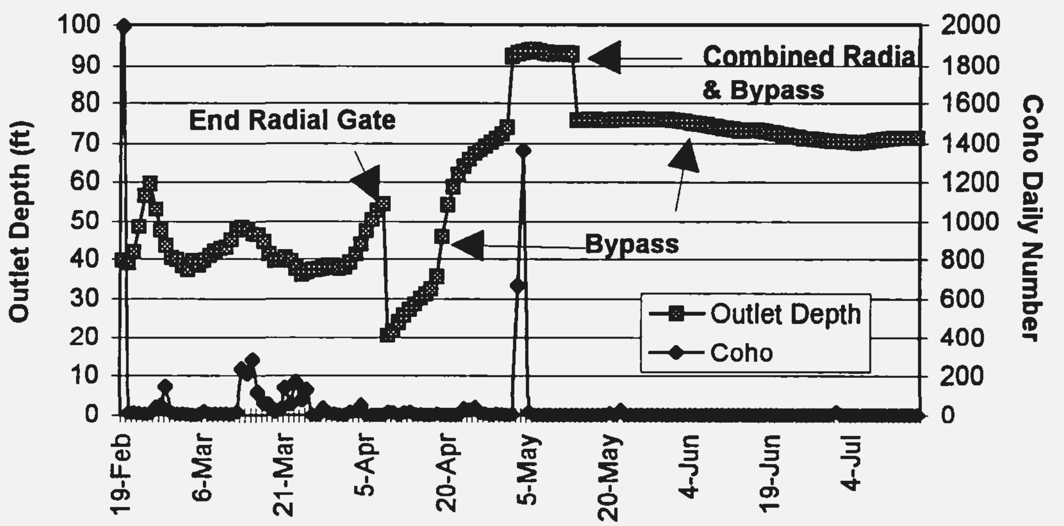
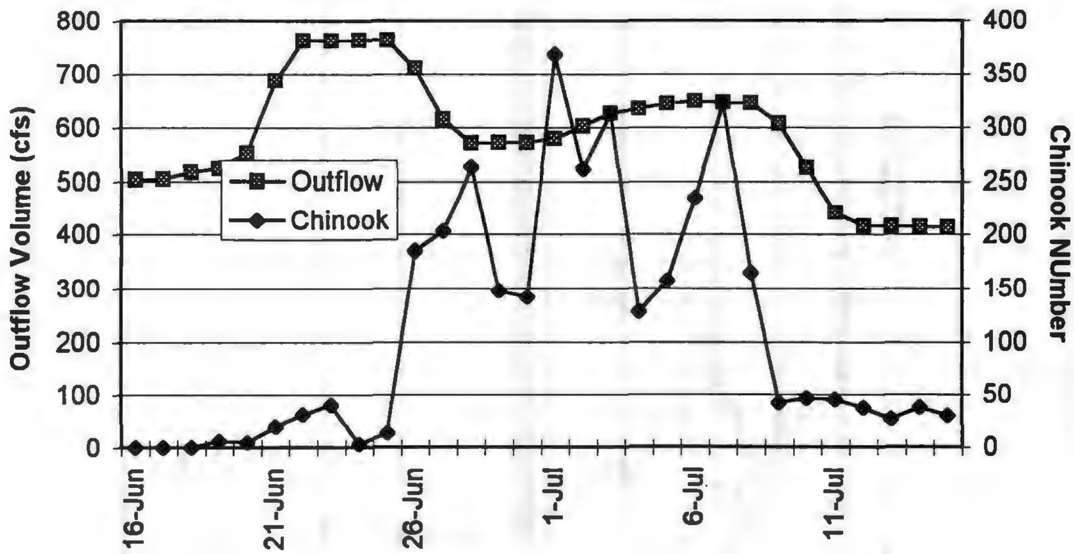
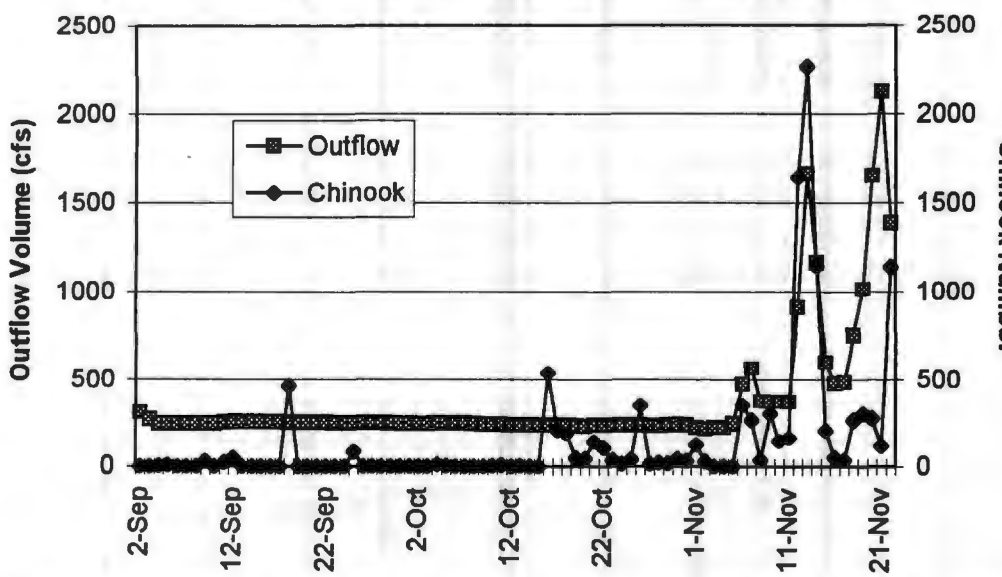


FIGURE 8. DAILY PASSAGE OF COHO YEARLINGS IN 1992 COMPARED TO OUTLET DEPTH THROUGH THE VARIOUS GATE SETTINGS AT HOWARD HANSON DAM: MAY 2-13 COMBINED BYPASS AND RADIAL GATE OPERATION.





FIGURES 9. DAILY PASSAGE OF CHINOOK SUBYEARLINGS IN 1991 COMPARED TO OUTFLOW VOLUME AT HOWARD HANSON DAM: BYPASS AND RADIAL GATE USED DURING HIGH POOL (JUNE 22-JULY 8, R^2=0.53) AND BYPASS GATE (UNTIL NOV. 5) DURING DRAWDOWN (JULY 9-NOV 22 R^2=0.34) AT HOWARD HANSON DAM.

2D.4.7 Injury and Mortality

There has been a change in refill operations since 1991, from 1984-1991 refill was delayed to allow for emigration of juveniles, primarily through the radial gates. Since 1992, refill is much earlier, beginning in late March to mid April and bypass pipe use has begun much earlier, often throughout the entire juvenile emigration period.

Overall, from three years of outmigrant studies, through the existing outlets there is little or no injury for fish using the radial gates but up to 90% mortality for smolts using the bypass pipe. In 1984, using test and control releases of fish into the radial and bypass gates, WDF did not observe injury and mortality of captured coho and steelhead smolts going through the radial gates. There was injury and mortality of smolts introduced into the bypass pipe: of 347 coho smolts examined, 9 were dead or severely injured (0.9%) and of 29 steelhead smolts examined, 10 were dead (35%) (Seiler and Neuhauser 1985).

The USFWS found much higher injury and mortality rates for juveniles captured after passing through the bypass pipe, which was used almost exclusively in 1992: the bypass pipe has been used through much of the outmigration season in 3 of the past 5 years. In 1992, over 33% of all chinook subyearlings and 14% of chinook yearlings captured were dead following passage through the pipe. The USFWS researchers considered this mortality rate much lower than the actual rate as many dead fish were sighted in the tailrace but never captured and counted. Higher head (high pool elevation) and warmer water temperatures may exacerbate conditions. During one three-day period in September of 1992, almost 90% of all captured chinook that passed through the bypass were found dead (Dilley and Wunderlich 1992 and 1993).

Injury rates for chinook subyearlings in 1992 were 19% partially descaled, 9% with multiple injuries, and 8% descaled. Up to 20% of chinook yearlings were partially descaled and 17% were descaled. Coho yearling mortality and injuries were high during bypass operation, May 14-September 25, 25% of yearlings were dead, 25% descaled, and 8% were descaled and bruised. The overall number of coho yearlings passing at this time was 40% of outmigrants so overall mortality was reduced. Coho subyearling mortality was the lowest of all life stages, 5%, but they also had the highest rate of partial descaling, 32%. Estimates of indirect mortality from injuries were not studied.

The Corps with cooperation from the FPTC also estimated Baseline survival for chinook smolts passing through the bypass pipe using a series of hydraulic equations. The estimated survival rate was 46% assuming a constant outflow of 400 cfs, and at full pool, 1140 ft elevation.

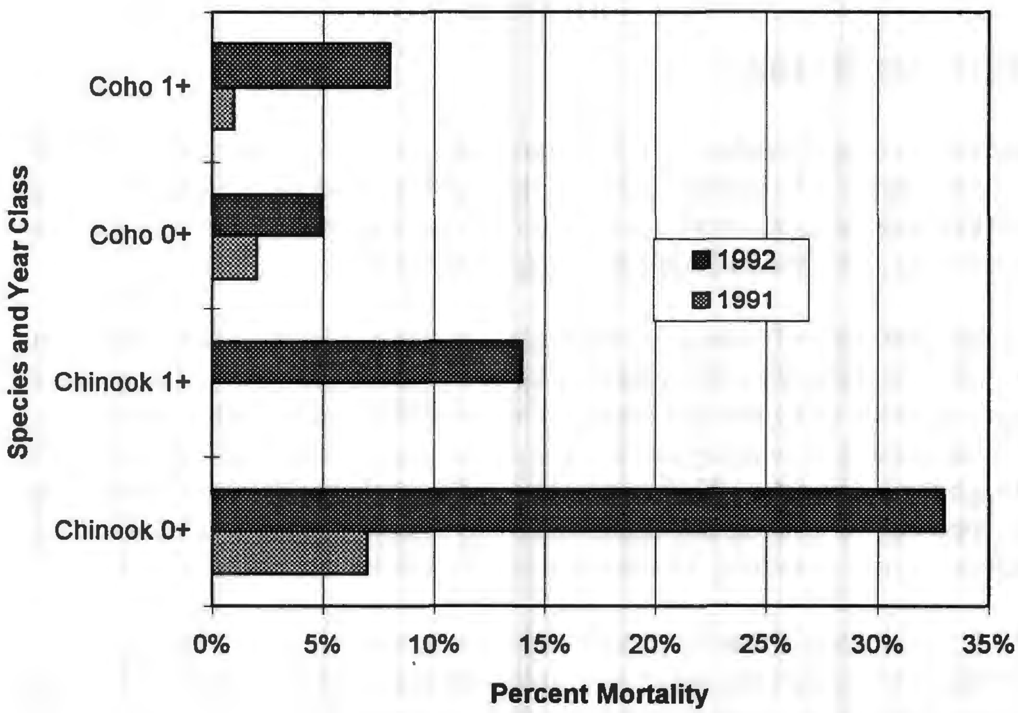


FIGURE 10. OBSERVED MORTALITY RATES OF JUVENILE OUTMIGRANTS THROUGH HOWARD HANSON DAM IN 1991 AND 1992 (DILLEY AND WUNDERLICH 1993). TOTAL OBSERVATIONS FOR MORTALITY: 1991 N=59,000; 1992 N=218,000; BYPASS GATES IN OPERATION BEGINNING EARLY APRIL OF 1992, IN EARLY JULY OF 1991.

2D.4.8 Fry to Smolt Survival

Coho Yearling. There was a 0.73% fry to smolt survival of the 1990-brood year fry observed in 1992. This was almost twice that observed in 1991 (0.44%) for the 1989 brood fry planted in 1990. The increase observed in 1992, like a similar increase for chinook yearlings, may be due to a milder winter and spring. In 1984, estimated total outmigration was 34,868 with fry (3,099,080 planted) to smolt survival of 1.13% (Dilley and Wunderlich 1992 and 1993; Seiler and Neuhauser 1985). This was the highest fry to smolt survival observed during the 3 years of monitoring and it came during the only year monitored when refill began late, in early June. It should be noted for 1992, over 42% of the smolts passed the project after June 30, well beyond their normal "biological window." Thus, these outmigrants are not necessarily successful outmigrant smolts, so the 1992 fry to smolt survival estimate may be high. Seiler and Neuhauser (1985) felt a very extensive mark and recapture program would be the only means to estimate total entrapment or residualism.

Overall Headwaters coho fry-to-smolt survival appears to be low compared to other systems. Other researchers have reported fry-to-smolt values for western Washington of

1.3-30.1% (Johnson and Cooper 1991; Smith et al. 1985). To date, HHD baseline studies suggest the lower Headwaters survival rate is related to 1) poor passage conditions at the dam with delay or entrapment (average 70% reduction in coho smolt survival during 1993 and 1994, Section 2E. Adult Return); and 2) outplanting of hatchery raised lower Green River stock (see subyearling chinook below).

Chinook Yearling. There is no estimate of fry to yearling survival as this life-history type is not expected from fall chinook hatchery releases: still, we will present fry to smolt percents. This life-history type (stream type chinook) may be limited to the highest elevation areas of the Green River and may not be expressed elsewhere in the Green River. The 1,645 estimated yearlings emigrating from the dam in 1992 represent 0.085% of the 1990-brood chinook fry (1,939,530) released into the Headwaters in 1991. Passage of 760 yearlings in 1992 represents 0.045% of the 1989-brood chinook fry (1,702,889) released into the Headwaters in 1990 (Dilley and Wunderlich 1992 and 1993).

Subyearling Chinook. The 14.5% subyearling survival from fingerling release to emigration through the dam observed in 1992 was substantially higher than the 1.1% observed in 1991. Both environmental and physical factors may have played a role in this increased survival. The 1992 spring weather was milder than 1991. Planting of fry was considerably different between years, size and release number. In 1992, fry were planted from February 21 to March 7 at an average 482 per pound and 100,000 fish released per site. In 1992, fry were planted February 18 to April 2, three size groups were used (483, 267, and 177/lb), and the fish per release site declined to 26,000 (Dilley and Wunderlich 1992 and 1993).

Steelhead Yearlings. In 1984, steelhead numbers were estimated at 1933 with confidence intervals of 1332 and 3528 based on 91772 fingerling plants which is equal to a 2.1% fry to smolt survival (Seiler and Neuhauser 1985). The 1984 numbers may have underestimated total outmigration for 4 reasons: 1) the trap was not operated on the highest flow days when peak outmigrant numbers might be expected; 2) the trap efficiency may have been low for steelhead smolts; 3) a number of smolts may not have emigrated even at the low pool (we don't know the exit depth preference for steelhead); and 4) at least a portion of the run become entrapped after refill (with switch to the bypass pipe) began in early June. Less than 300 steelhead smolts were captured in the two years of monitoring in 1991 (32) and 1992 (259). The USFWS attributes the low steelhead capture rate in 1991 and 1992 to four factors: 1) the 1984 trap was operated continuously, in 1992 the trap was operated twice per week, 2) stream velocities were lower than 1984, scoop trap capture efficiency improves with higher velocities; 3) fewer steelhead fry were released in 1990 vs. 1982; and 4) early refill may have resulted in delay or total entrapment of smolts (Dilley and Wunderlich 1992 and 1993).

2D.5 DISCUSSION: COMPARISON OF HOWARD HANSON DAM STUDIES TO OTHER SYSTEMS

The outmigration of coho, steelhead, and chinook juveniles through small to medium sized water control projects has been occurring for decades. However, prolonged studies of outmigrants has not occurred. Typically, projects are monitored and evaluated in one of three ways :

- If fish passage facilities have been built (required by mitigation) studies will occur to evaluate the effectiveness of the facilities for the first few years of operation. If facilities are deemed acceptable, monitoring ceases and upper watershed planting of fingerlings, or release of adult salmon continues. Examples of these projects include: in Washington -- Wynoochee Dam, Wynoochee River; upper Baker Dam, Baker River; Mud Mountain Dam, White River; in Oregon -- Green Peter Dam, Middle Santiam River; Foster Dam, South Santiam River; North Fork Dam, Clackamas River;
- If passage facilities have not been built, studies may occur decades following construction only after state or tribal agencies have established a need for studies either through interagency coordination, litigation or legislative action. These studies are conducted to determine the existing level of survival through the project and what type of improvements, if any, can be made to reach an acceptable project survival rate. Examples of these projects include: in Washington -- Glines Canyon Dam, Elwha River; Howard Hanson Dam, Green River; Lake Washington Ship Canal; Condit Dam, White Salmon River; in Oregon -- Umatilla River; Blue River. In this case, Howard Hanson Dam is considered a Corps restoration project.
- If fish passage facilities have been built, but have not proven effective, follow-on studies may occur years to decades after initial monitoring. These studies are conducted to determine what has changed since initial monitoring, physical or biological change, and what improvements, if any, can be made to return to an acceptable level of project survival. Examples of these projects include: In Washington -- Mayfield Dam, Tilton and Cowlitz River; Mossyrock Dam, Cowlitz River; Wynoochee Dam, Wynoochee River; in Oregon -- Green Peter Dam, Middle Santiam River; Foster Dam, South Santiam River; Falls Creek Dam, Middle Fork Willamette River; Round Butte and Pelton Dams, Deschutes River.

The results of monitoring from these projects has shown a clear trend in dam passage needs for migrating coho, steelhead and chinook smolts at all projects. All of these stocks need a near-surface exit (5-20 ft in depth) and a continuous source of surface flow. Without such a passage facility or exit, juveniles become entrapped in the reservoir for prolonged periods and either become entrapped and residualize or try to find a less acceptable exit (deepwater). If they residualize, these smolts can die if food is not available or they can be eaten by reservoir predators. Alternatively, after residualizing, they can become predators themselves eating non-smoltified fish, fry, or even smaller smolt-sized fish (subyearling chinook). Smaller juvenile, non-migratory fish, can become entrapped as well, these juveniles can experience tremendous growth during residence in the reservoir. Increased growth of juvenile salmonids has almost universally been shown to lead to increased adult survival, however survival of these juveniles to smolt size is specific to a particular reservoir as predators can off-set the advantages of increased reservoir growth. Lastly, many smolts do not residualize and can continue to seek an exit. These smolts often experience injury and mortality when exiting through deepwater outlets that were not designed for smolt passage.

In Oregon, at various Willamette Valley projects, juvenile anadromous salmonids at five dams preferred surface exits of about 15 ft depth; Green Peter, Foster, Cottage Grove, North Fork Clackamas, and Fall Creek dams (Korn et al. 1967; Korn and Smith 1971; Wagner and Ingram 1973; Smith 1990). At these same projects, outmigrants used shoreline areas as they moved out. The Oregon Department of Fish and Wildlife believes that reservoirs with long shorelines appear to be less effective in passing fish than those with short shorelines (Smith 1990). The one reservoir where this is particularly been noted is Green Peter Reservoir, which has a 48 mile long shoreline perimeter, which is up to 40 miles longer than the other studied reservoirs: Cottage Grove 7.6 miles; North Fork 8; Foster 19.7; and Fall Creek 22.4. In comparison, Howard Hanson Reservoir shoreline perimeter is 12 miles under Baseline, 15 miles Phase I, and 17 miles in length for Phase II.

Over a series of years, the USFWS studied outmigration at one Elwha River dam, Glines Canyon (Dilley and Wunderlich 1987; Wunderlich and Dilley 1988; Wunderlich et al. 1989; Dilley and Wunderlich 1990). In a situation unlike existing passage at HHD, Glines canyon has a surface exit (20 ft deep spill gate) and deep water exit (turbine exit at 75 ft). During a 15 month study period, almost 90% of all yearling and subyearling chinook selected the surface exit even though most flow went through the deep exit (Dilley and Wunderlich 1990). Over three years of spring monitoring, 90-98% of coho and steelhead smolts selected the surface exit under similar conditions (Dilley and Wunderlich 1987; Wunderlich and Dilley 1988; Wunderlich et al. 1989). Coho and steelhead passage rates were strongly related to the volume of surface exit outflow unlike subyearling chinook passage. However, even with less of a relationship to surface spill, interruption of spill during the summer -- the peak of Elwha chinook subyearling emigration, stopped all chinook passage (Dilley and Wunderlich 1990).

At other western Washington water control projects, coho smolts selected or preferred surface exits (over deeper water exits) at five other projects: 1) upper Baker Dam; 2) Mayfield Dam; 3) Merwin Dam; 4) Wynoochee Dam; and 5) Lake Washington Ship Canal (Gary Sprague, WDFW, pers. comm., Stober 1986; Hamilton et al. 1970; Dunn 1978; F. Goetz, unpublished data). Similar observations have been noted for chinook at Mayfield (Stober 1986) and steelhead at Wynoochee (Dunn 1986).

2D.5.1 Summary of HHD Baseline Studies

Three existing features of reservoir refill and dam outlet structure affect juvenile salmon and steelhead survival through HHD: 1) outflow volume; 2) outlet depth; and 3) bypass gate operation. Outflow volume, outlet depth, and bypass gate operation are all linked together. If each one is addressed singly, additional mortality effects to salmon and steelhead smolts or downstream effects are unaddressed or new ones may occur. Past operation under existing structural limitations of the dam and reservoir have made this very clear.

For example, outflow volume has two aspects for smolt passage, operational and physical structure. The total amount of water passed through the dam can be increased but it must be timed properly for use by fish or for water supply to develop its full value. This is an operational feature but it must be linked to physical structure of the outlets, or shallow outlet depth, to safely pass smolts. In the past, HHD has been managed to pass higher outflow volume during the peak smolt outmigration period (timing) by delaying refill to late May or early June and thereby keeping outlet depth shallow (years 1984-1991). This refill regime may have worked to pass more smolts through HHD, but it still trapped an unknown number of fish even at the lowest pool elevations (35 ft exit depth) and more importantly it resulted in not storing enough water to maintain lower river flows through early fall. As discussed in Section I, delay of refill in 1987 dewatered over 50% of all steelhead redds and eggs in the lower river and later resulted in physical entrapment of adult chinook salmon. The impact to the Green River steelhead run will be felt for years.

Changes in refill operations since 1991, resulting in earlier refill, have given priority to downstream resources, in particular steelhead spawning and egg incubation. Instead of delaying refill until late May, refill has typically begun in early to mid April, before the peak of outmigration from the Headwaters. This change in refill operation has resulted in decreased survival of smolts in following years. In particular, during low runoff years, earlier refill and low outflow appear to entrap a large portion of all outmigrating juveniles. In 1992, at least 42% of all coho smolts emigrated after their normal emigration season, an additional unknown number may have residualized or died before emigrating during fall drawdown. Of those smolts who do emigrate after entrapment, a large number are killed or injured if they exit through the low-flow bypass pipe.

As discussed in the next section, Section 2E., initial adult returns of coho salmon adults have confirmed the low survival through the existing HHD project and the need for adequate outflow and outlet depth from the project. Two years of coho smolt releases above and below the dam have shown that adult returns from above-dam-releases average about 30% of below-dam-releases. The difference in above and below adult returns, or the potential project survival (adult survival from above-dam-release/adult survival from below-dam) is used to illustrate the potential impacts that the dam has on smolt survival (Figure 11). The two year average of adult returns from above dam releases shows existing project survival is approximately 30%, with a high of 53% in an average run-off year 1993, and a low of 13% in a low run-off year 1994. The third and final year of coho releases was in 1995, another low-flow year, and we expect overall survival to decline even further. Flow into and out of the project appears to explain almost all the differences in above and below dam coho salmon adult returns. The 30-day average inflow into the project explained 97% of the variation in two years of above-dam-release adult returns.

The 30 day average outflow explained 89% of the variation. In combination, outflow volume and outlet depth appear to explain 100% of the variation.

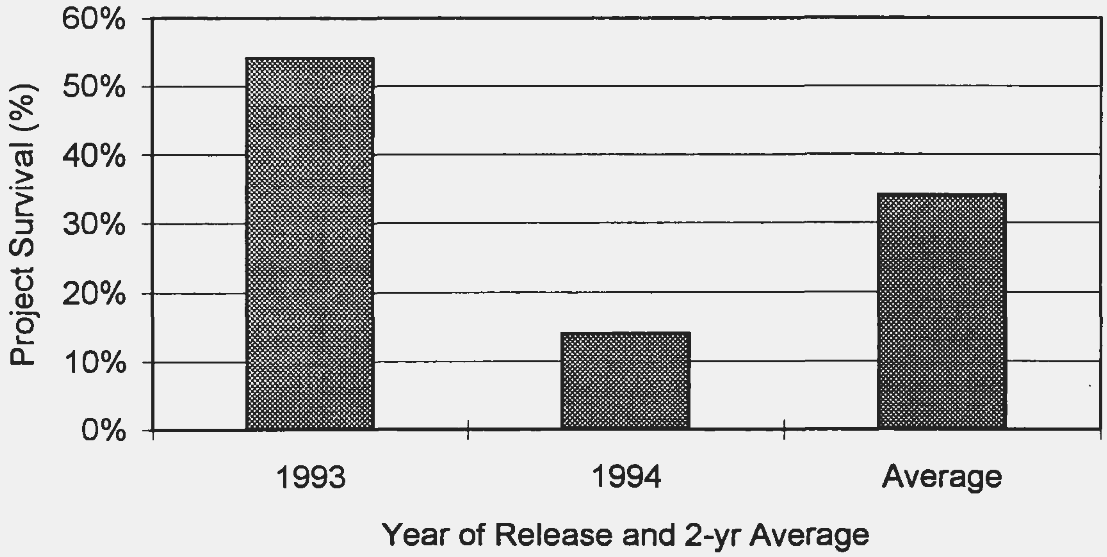


FIGURE 11. MEASURE OF PROJECT SURVIVAL FOR COHO SALMON SMOLTS RELEASED ABOVE THE DAM IN 1993 AND 1994. PROJECT SURVIVAL IS DESCRIBED AS THE DIFFERENCE BETWEEN ABOVE-DAM/BELOW-DAM ADULT RETURNS.

SUMMARY AND CONCLUSIONS

- The Fish Passage Technical Committee recommended a suite of studies to determine what factors explained successful or unsuccessful passage through the existing HHD project. These studies were completed by the U.S. Fish and Wildlife Service and results are presented in this section. Results were used by the FPTC to develop the preferred AWSP fish passage facility.
- Delay and or entrapment of subyearling coho in the reservoir can result in exceptional growth rates. From 20-30,000 subyearlings passed the dam during fall drawdown: at an equivalent size to yearling. The reservoir growth potential is also outstanding for juvenile chinook. However, most chinook are entrapped in the reservoir well past their window of opportunity so most large juveniles are not ocean-ready when they finally leave the project.
- Emigration of ocean-ready coho and chinook salmon through HHD is significantly related to outflow. Outlet depth is an additional factor required for successful emigration. The combination of outflow and outlet depth explains 97% of the decline in daily passage of coho salmon juveniles through HHD.
- Horizontal and vertical studies show juveniles are shoreline oriented and that between 80-96% of all smolts are found in the upper 50 ft of the water column. The shallowest

depth of the existing outlet is 35-40 ft at low pool, with refill the depth can vary from 50-112 ft.

- Under existing HHD refill operation, large numbers of ocean-ready outmigrants are delayed beyond their normal emigration period or trapped with earlier refill. This delay-entrapment can result in reduced survival rates of adult returns; adult coho returns from Headwaters coho smolt plants averaged 70% lower than coho planted below the dam (Figure 11).
- The major component of delay and/or entrapment is poor dam passage conditions, low outflow and deep exit depth, not from reservoir size or refill rate. Reservoir travel probably represents a small increment of project travel time (time required to pass the reservoir and dam, Section 2B-3) and so far, refill rate is not related to adult returns (Section 2E).
- The existing bypass pipe, while at lower depths than the radial gate, has poor attraction and kills and injures large numbers of outmigrants.
- Direct morality rates in 1992, a period of extended bypass use ranged from 5-33% for all species. The bypass pipe is used every year throughout the low-flow period and has been used throughout much of the juvenile emigration period in the spring since 1992. Indirect or latent mortality from injuries would reduce survival even lower. Estimated bypass survival, reviewed by FPTC, is 46%.
- Studies of other small impoundments have confirmed that coho, steelhead, and chinook require adequate outflow volume and a shallow, near-surface, low-mortality exit for successful dam passage.

2D.5.2 Additional Water Storage Project Flow and Dam Passage Improvements

There are three goals for aquatic resources under the AWSP:

- Restore salmon and steelhead to the Headwaters watershed (Upper Green River) with improved fish passage and selected habitat improvements.
- Restore selected aquatic habitat features of the lower watershed through flow and sediment augmentation.
- No net loss of habitat or fish during ASWP spring refill: avoid and minimize impacts or compensate.

From the beginning of the AWSP, reconnection of the Headwaters watershed to the lower river has been <u>the</u> priority for restoration. The major focus for engineering design and Baseline study has been to provide for successful fish passage through Howard Hanson Dam and ultimately restoration of the salmon and steelhead runs to the Headwaters. If successful passage can be provided, the Headwaters watershed represents the best restoration opportunity for salmon and steelhead in the Green River basin. The Headwaters represents almost 45% of the area and stream miles found within the basin (Section 2A). Historical run size to the Headwaters was from 10-30,000 coho and spring chinook salmon and steelhead (Grette and Salo 1986), the successful additional of fall chinook salmon could add another 25-33% more salmon to these historical run totals.

To provide for successful passage through HHD, the AWSP directly addresses the reservoir/dam factors that appear to be influencing coho, steelhead, and chinook smolt or juvenile outmigrant survival -- near-surface outflow and safe passage conditions. The only means to adequately provide near-surface outflow through the dam at the correct time is to provide for smolt passage through a new fish passage facility. Under existing operations, the Corps has tried delaying refill to provide for adequate outflow and exit depths with huge impacts to lower watershed fish.

a. AWSP Dam Passage Improvements

Near-surface outflow is no longer a consideration of factors affecting smolt survival. The objective of the AWSP for successful passage is 95% or greater survival through the dam. To meet this project objective, the preferred fish passage facility covers all pool elevations (1070-1185 ft) and will "fish" from 5-20 ft deep, well within the optimum range of depths that all juvenile salmonids naturally use. This is a major improvement over existing depths, which range from 35 ft (1070 ft elevation, at low pool) to 112 ft (1147 ft, drought year full pool). There is an interaction between outflow and outlet depth under current conditions. Under higher outflow, smolts will still sound (dive) to exit the deep radial gates. Under low outflow, smolts show limited use or will not use the shallower bypass outlet. The preferred fish passage facility (modular incline screen and fish lock), while eliminating water depth as an impediment to smolt passage, has also maximized surface outflow volume. The facility will draw up to 1250 cfs when meeting all biological screening criteria. This large surface volume withdrawal cannot be compared to the existing facility, and may have additional benefits in improving smolt survival that cannot be accounted for.

Up to 15 years of downstream outmigrant monitoring is also proposed using a combination of passive integrated transponders and hydroacoustics. A sampling station is planned near the bypass outfall. Full discussion of facility design is presented in the Hydraulics and Hydrology Appendix, and Incremental Analysis of the 9 alternatives is presented in *Section 8 Fish Mitigation and Restoration Plan.*

Below is a brief discussion of the entrance to the fish bypass system, the modular incline screen, and listing of biological criteria used in design of the screen and bypass system.

The AWSP preferred fish passage facility design is a high velocity screen (Modular Incline Screen MIS) and juvenile fish bypass system, consisting of the MIS, bell mouth intake horn, single lock/wetwell, and bypass flume, to improve downstream fish passage at Howard Hanson Dam. The AWSP Fish Passage Technical Committee (FPTC -- which developed the current design of the new fish passage system) believe current outlet moralities (injury, mortality, and entrapment) will be dramatically reduced through the installation of the MIS and fish-lock. Eicher screens (the originator of the MIS) have been installed at Elwha Dam in Washington and the Puntledge project on Vancouver Island in British Columbia, with reported survival rates of 91% to greater than 98%. Attaining this level of survival is considered essential to successfully restore existing native Headwaters Green River fish stocks.

Review of Existing Survival Rates During the spring outmigration period (approximately April 15 to June 30) downstream migrant chinook (underyearling and yearling), coho salmon and steelhead smolts experience direct morality rates of approximately 1-35% from impact through the existing radial and bypass gates, and greater than 40-60% entrapment rate from refill, when passing through Howard Hanson Dam and Reservoir using the existing outlet facilities (Dilley and Wunderlich 1992, 1993). Two years of adult returns from coded-wire tagging of coho smolts shows an average survival rate of 32.9%, with a range of 5-92%. Estimated project survival (1-entrapment, and mortality at dam) if the existing bypass gate is used throughout the migration period (and refill begins as early as in recent years) is 3% to 27% for coho salmon, 1% to 18% for steelhead, and 3% to 18% for chinook salmon (see Section 8, Incremental Analysis of the Fish Passage Facility, and Appendix A).

Dam survival through the bypass pipe is estimated at 46% (FPTC review). The new bypass facility and MIS Screen are expected to improve dam passage survival rate by an estimated 50% to 95%. The objective for the restoration project is to attain a 95% dam passage survival rate. Entrapment in the reservoir is expected to be removed or greatly minimized as a project impact with the near-surface outlet. Estimated total project survival (dam + reservoir survival) is estimated at between 85-90% for coho and steelhead and between 60-65% for chinook. To reach this estimated total project survival rate, the MIS Screen and fish bypass system were designed to meet 39 distinct criteria for the bypass, screen and hydraulics, from maximum screen velocity to minimum water depth in the bypass (Table 5). FPTC members, including staff from the Washington Department of Fisheries and the National Marine Fisheries Service, provided criteria for hydraulic conditions to be met throughout the bypass and screen system. These criteria were based on the environmental requirements of the juvenile salmon and steelhead which are to be passed through the system.

Biological Criteria

Hydraulic features of the proposed design was required to meet a number of criteria for flow characteristics, residence time limits, attraction, predation limitations, and screening velocities. A summary list of these criteria is provided below. Biological criteria are separated into two general categories; bypass and screening criteria, referring to the individual components of fish passage facilities. In addition, general guidance was provided in "Fisheries Handbook" by Milo Bell, for the Portland District of the Corps of Engineers (NPP), and by "Fish Passage Through Turbines", also by Milo Bell, for NPP.

TABLE 5. BIOLOGICAL HYDRAULIC DESIGN CRITERIA FOR THE HOWARD HANSON DAM FISH BYPASS SYSTEM AND SCREEN SYSTEM.

Bypass Criteria

1. No pumping of fish
2. No free-fall within shaft
3. Constant bypass flow (within a narrow range)
4. Maximum plunge impact velocity = 35 fps, deceleration control required
5. Maximum open channel flow velocity = 30 fps (higher rates need verification) (in smooth channel, 10 fps in hydraulically rough channel)
6. Discharge into tailrace will be designed to not induce adult jumping injuries (not a concern here, since no adults are expected to return to the dam)
7. May be full pipe or open-channel flow
8. No negative pressure
9. Pipe radius of curvature > 3 diameters
10. No constrictions that may cause rapid pressure change, direct impact or injury to fish, or may cause collection of debris
11. Smooth wall and joints required for all conduits and channels
12. Maximum velocity = 25 fps for full pipe flow (higher rates need verification)
13. Maximum bypass entrance velocity equal to or greater than the maximum resultant velocity vector of flow approaching screens
14. Gradual transition of flow into the bypass entrance necessary to minimize delay by outmigrants (further refined to maximum linear velocity increase of 0.1 fps/ft, or a linear acceleration a = 0.005+(point velocity/10))
15. Bypass system to be designed to minimize debris accumulation; therefore, minimum pipe diameter = 24 inches
16. Access necessary to check locations of potential debris accumulations
17. No closure valves (i.e., butterfly or gate type) within the bypass system (further refined to state that no partially open valve operation)
18. Minimum 9-inch depth for open channel flow

Screen Criteria (Subsequently redefined for high velocity MIS and Eicher Screen systems)

1. Apply Washington Department of Fisheries, National Marine Fisheries and Washington Department of Wildlife screen criteria
2. Maximum 0.4 fps approach velocity for fry (depends on temperature and size of fish)
3. Minimum 1:1 approach angle
4. Maximum screen opening: 1/8" for fry
5. Entire screen visible and accessible for monitoring, observation and maintenance
6. 100% exclusion screening
7. Uniform screen approach velocity distribution
8. Screen entire required flow (instream flow + Tacoma diversion - bypass flow)
9. Controlled acceleration approaching collection intakes and bypass entrance

10. Velocities approaching collection entrances and bypasses adequate to trap fish being collected
11. Primary debris control should be with a forebay log boom
12. Fish to be collected in the vicinity of their predominant distribution at any specific time or condition
13. Fish to be attracted or guided to bypass
14. Automatic cleaning of screen
15. No straining of flow (ie., using a wolf trap to completely separate fish from flow)

Hydraulic Criteria

Hydraulic features of the proposed fish passage facilities were also required to meet the following hydraulic design criteria and guidance.

1. EM 1110-2-1602, "Hydraulic Design of Reservoir Outlet Works"
2. EM 1110-2-1601, "Hydraulic Design of Flood Control Channels"
3. EM 1110-2-1603, "Hydraulic Design of Spillways"
4. USBR Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators"
5. "Hydraulic Design Criteria", published by the Waterways Experiment Station
6. WES Publication "Prototype Evaluation of Sluiceway Aeration System, Libby Dam, Kootenai River, Montana, " Technical Report HL-84-2 dated March 1984

MIS screen flow capacity is 410 cfs to 1250 cfs for velocities from 2.56 fps to 7.8 fps, respectively. Maximum capacity at 10 fps is 1600 cfs. The FPTC has proposed to limit operation to less than 7.8 fps until prototype operation proves that higher velocities will not result in unacceptable injury rates of fish. Screen area when in the screening position is about 410 square ft, resulting in a normal velocity (beyond the near-screen orifice effects) of from 1 fps at 410 cfs to about 3.0 fps at 1250 cfs, to about 3.9 fps at 1600 cfs. Head loss through the screen was assumed to be about the same as that measured at the Puntledge Eicher screen (Ref #8 and #9) and Elwha Eicher screen (Ref. #10) installations.

Existing Studies of High Velocity Screens To date, several studies have been performed on the survival of juvenile salmonids passed through high velocity incline screens such as the Eicher and a similar design, modular incline screen (MIS) (Taft et al. 1993; Winchell et al. 1993; and Smith 1993). These studies have consistently shown that for the design range of flows (400-1250 cfs) and velocities (<8 fps) that the HHD MIS will screen, survival rates for outmigrant salmonids should exceed 95% (Table 6 and Table 7). A physical model of the screen and bypass system is planned for PED Phase, years 1998-2000, for physical and biological evaluation to verify that the HHD design will meet screen and bypass criteria.

TABLE 6. NET PASSAGE SURVIVAL FOR JUVENILE ANADROMOUS SALMONIDS DURING TWO YEARS OF TESTS FOR THE ELWHA EICHER SCREEN (ADAPTED FROM WINCHELL ET AL. 1993).

Species and Size Class	Average. Length in & (mm)	Average Diversion Efficiency	Net Passage Survival
steelhead smolts	6.9 (174)	99.6%	99.4%
steelhead fry	2.0 (52)	92.0%	97.1%
coho smolt 1990	5.3 (135)	99.5%	99.4%
1991	5.7 (145)	98.7%	98.7%
coho juvenile	4.0 (102)	99.4%	99.2%
coho fry all data	1.7 (44)	96.1%	91.6%
tests<7 fps		98.0%	**95.9%**
chinook smolts	3.9 (99)	99.7%	98.8%
chinook juveniles	2.9 (73)	99.9%	99.9%

TABLE 7. NET PASSAGE SURVIVAL FOR JUVENILE SALMONID SPECIES TESTED DURING THE MIS BIOLOGICAL EVALUATION, 1992-93 (TAFT ET AL. 1993).

Species and size class	Avg. Length mm & (in)	NET PASSAGE SURVIVAL 2 fps[1]	4 fps	6 fps	8 fps	10 fps	Combined Survival
rainbow trout fry	1.9 (48)	92.6	100	100	95.2	91.9	96.8
rainbow juveniles	2.6 (66)	100	99.2	100	98.9	89.9	97.4
coho fry	1.9 (49)	100	100	100	99	99.3	99.6
chinook fry	2.1 (53)	100	100	99.3	98	93.8	97.2

1. fps=velocity in feet per second.

b. Outflow Volume

Outflow volume under the AWSP will be equal to or greater than existing project outflow during the peak juvenile outmigration period (late April-mid July) in almost all periods and years (Table 8). An objective of operation of the AWSP is to mimic natural hydrology, especially during the main smolt outmigration period (Section 8). In an average water year, approximately 80% of coho and steelhead, and 65% of chinook salmon smolts would be expected to emigrate between mid April and mid June: an additional 25% of chinook emigrate from mid June to mid July (Figure 1). As modeled for this Feasibility Study, during late-April, May, and early June, refill rates will be lower under the AWSP than Baseline with resulting greater outflow volume and in most cases more natural patterns in dam flow releases. Percentage improvements in flow are greater under Phase II than under Phase I. This partially represents the re-allocation of water stored earlier in the refill period for release during the smolt outmigration period through addition of higher baseflows, and more freshets. In Phase II, because of the flow augmentation storage, outflow volumes are also higher throughout the summer beginning about July 1. The only period of time when outflow volumes are consistently lower under the AWSP than Baseline is during late June, June 15-30.

TABLE 8. PERCENTAGE INCREASE IN HALF-MONTH MODELED FLOW VOLUME FROM BASELINE TO PHASE I (B-PH I), AND FROM BASELINE TO PHASE II (B-PH II) FOR 5 PERCENT EXCEEDANCE FLOWS -10%, 25%, 50%, 75%, AND 90%. FLOW VOLUMES IN APPENDIX TABLE A-2.

	10%		25%		50%		75%		90%	
Half-Month	B-Ph I	B-Ph II	B-Ph I	B-Ph II	B-Ph I	B-Ph II	B-Ph I	B-Ph II	B-Ph I	B-Ph II
4/16-4/30	5%	20%	5%	24%	5%	26%	-2%	18%	-14%	-8%
5/01-5/15	17%	16%	33%	26%	28%	24%	33%	22%	14%	5%
5/16- 5/31	6%	9%	17%	14%	10%	4%	9%	6%	-6%	2%
6/01- 6/15	0%	0%	-1%	-1%	-1%	-2%	1%	-7%	11%	20%
6/16-6/30	-12%	-12%	-15%	-16%	-20%	-26%	-24%	-23%	-17%	-10%
07/01-715	10%	11%	15%	14%	22%	20%	27%	31%	28%	18%

Freshets, both natural and artificial, are planned under both Phase I and Phase II at regular intervals in April and May. The total number of freshets during spring refill, minimum volume defined as 1,800 cfs (equivalent to 2,500 cfs defined freshet at Auburn), increases from Baseline to Phase I and Phase II. The average number of freshets per month also increases from Baseline to Phase I and Phase II (Table 9, Appendix Table A-3 lists events for all years). The monthly total of freshets does decrease in March under the AWSP: refill limits are not applied during this month, and no artificial freshets are released. The greatest monthly increase in total and average freshets occurs in May, the peak month for juvenile outmigration.

TABLE 9. NUMBER OF FLOW EVENTS FROM HOWARD HANSON DAM GREATER THAN OR EQUAL TO 1,800 CFS. ONE FLOW EVENT DEFINED AS SINGLE CONTINUOUS FLOW EXCEEDING SPECIFIED VALUE WITHOUT REGARD TO DURATION.

	February	March	April	May	June	Total
Total No. of Events						
Baseline	36	30	42	36	15	159
Phase I	37	19	37	73	13	179
Phase II	37	22	54	57	13	183
Average No. of Events						
Baseline	1.1	0.9	1.3	1.1	0.5	5
Phase I	1.1	0.6	1.2	2.3	0.4	5.6
Phase II	1.1	0.7	1.7	1.8	0.4	5.7

There is some uncertainty with use of these freshets (Section 8). The fish passage facility cannot pass all outflow volume during freshets and some water must pass through the radial gate outlets. The potential exists that some juveniles may hold during the freshets or may sound to the radial gate outlets. We expect this to be a minor problem, monitoring at Elwha Dams has shown 90-98% of all smolts exited through near-surface outlets even when deep water spill occurred: the same pattern exits for the Wells-Hydro Combine on the Columbia River. If juveniles sound, the radial gates at HHD have been shown to have very low mortality rates and are considered "safe" for juvenile passage.

2D.6 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Cropp, T. Undated. Howard Hanson Reservoir fish population study, July-August, 1989. Washington Department of Wildlife.

Dilley, S. and R. Wunderlich. 1987. Steelhead smolt exit selection at Glines Canyon Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Diley, S. and R. Wunderlich. 1990. Juvenile chinook passage at Glines Canyon Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dunn, C.A. 1978. Evaluation of downstream fish passage through multi-level outlet pipes at Wynoochee Dam. Washington State Department of Fisheries, Progress Report No. 45.

Fish Passage Technical Committee. 1990. Howard A. Hanson Dam Fish Passage Alternatives for the Proposed New Operating Rule Curve. Interagency Technical Report presented to the Seattle District, Corps of Engineers. January 1990.

Grette, G, and E. Salo. 1986. The status of anadromous fishes of the Green River/Duwamish River system. Evans Hamilton, Inc. Report to the Seattle District, U.S. Army Corps of Engineers.

Johnson, T., and R. Cooper. 1991. Snow Creek anadromous fish research; July 1, 1990 -- June 30, 1991. Annual Performance Report #92-5. Washington Department of Wildlife.

Korn, L., L. Hreha, R. Montagne, W. Mularkey, and E. Wagner. 1967. The effect of small impoundments on the behavior of juvenile anadromous salmonids. Fish Commission of Oregon, Research Division. 127 pp.

Korn, L. and E. Smith. 1971. Rearing juvenile salmon in Columbia River basin storage reservoirs. Pages 287-297 *in:* Reservoir fisheries and Limnology. American Fisheries Society Special Publication Number 8, Washington, DC

Seiler, D., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia.

Smith, E. 1990. "Green Peter" type fish collectors. Memorandum to D. Buchanon dated October 18, 1990. Oregon Department of Fish and Wildlife.

Smith, E., B. Miller, J. Rodgers, and M. Buckman. 1985. Outplanting anadromous salmonids -- a literature survey. Report to Bonneville Power Administration. Oregon Department of Fish and Wildlife.

Smith, H.A. 1993. Development of a fish passage solution at the Puntledge Hydro intake facility. Pages 197-204 in K. Bates, editor. Fish Passage Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.

Stober, Q. 1986. Reintroduction of anadromous fish runs to the Tilton and upper Cowlitz Rivers. Fisheries Research Institute, University of Washington.

Taft, E.P., S.V. Amaral, F.C. Winchell, C.W. Sullivan. 1993. Biological evaluation of a new modular fish diversion screen. Pages 177-188 in K. Bates, editor. Fish Passage Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.

Wagner, E. and P. Ingram. 1973. Evaluation of fish facilities and passage at Foster and Green Peter Dams on the South Santiam River drainage in Oregon. Management and Research Division, Fish Commission of Oregon. Report to Portland District, U.S. Army Corps of Engineers.

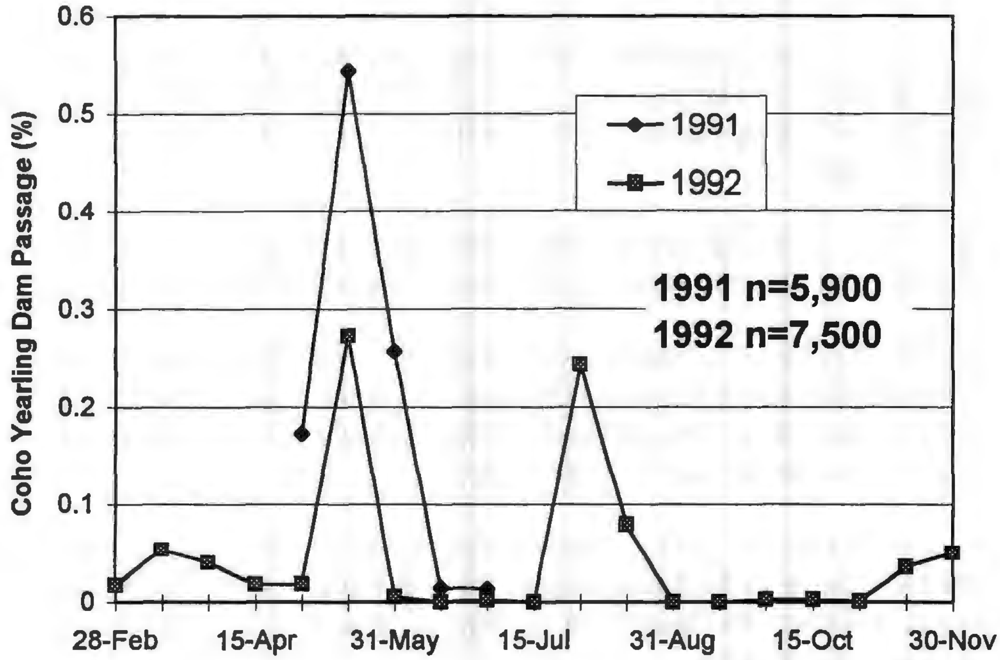
Winchell, F., N. Taft, and T. Cook. EPRI's evaluation of the Elwha Dam Eicher Screen and subsequent design changes and hydraulic tests. Pages 189-196 in K. Bates, editor. Fish Passage Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.

Wunderlich, R. and S. Dilley. 1988. Evaluation of juvenile chinook and juvenile steelhead passage at Glines Canyon Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

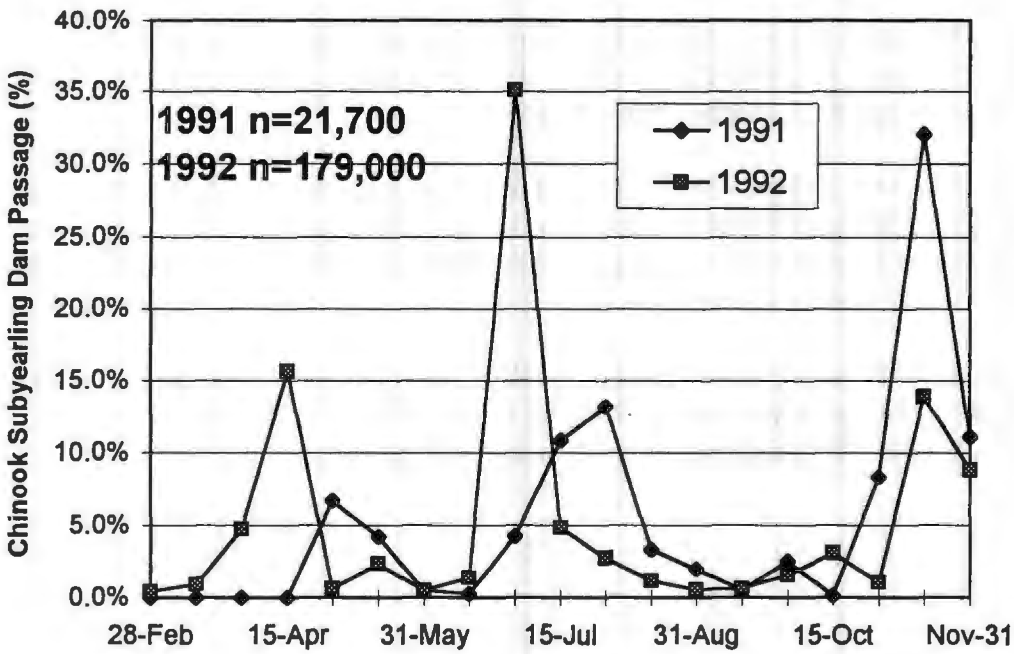
Wunderlich, R. and S. Dilley. 1990. Chinook and coho emigration in the Elwha River, Washington. Pages 268-279 in T. Hassler, ed. 1990 Northeast Pacific Chinook and Coho Salmon Workshop Proceedings. Humboldt and California-Nevada Chapters of the American Fisheries Society.

Wunderlich, R., S. Dilley, and E. Knudsen. 1989. Timing, exit selection, and survival of steelhead and coho salmon smolts at Glines Canyon Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

APPENDIX FIGURE A-1. HALF-MONTH COHO YEARLING PASSAGE RATE (PERCENT) THROUGH HHD IN 1991 AND 1992.



APPENDIX FIGURE A-2. HALF-MONTH CHINOOK SUB-YEARLING PASSAGE RATE (PERCENT) THROUGH HHD IN 1991 AND 1992.



APPENDIX TABLE A-1. BIWEEKLY MEAN (AVERAGE) FORKLENGTHS OF SUBYEARLING AND YEARLING COHO AND CHINOOK CAUGHT IN THE SCOOP TRAP IN 1991 AND 1992.

1991	Coho (0+a) Mean Length		Coho (1+a) Mean Length		Chinook (0+) Mean Length		Chinook (1+) Mean Length	
Date	(mm)	No.	(mm)	No.	(mm)	No.	(mm)	No.
7-Apr			100	17	56	23		
21-Apr	49	169	96	18	57	39	105	10
5-May	59	138	107	58	51	2		
19-May	56	35	108	136	75	4	103	2
2-Jun			124	6	107	2		
16-Jun			119	8	117	21		
30-Jun					113	155		
14-Jul					129	98		
28-Jul					137	25		
11-Aug					170	21		
25-Aug					176	4		
8-Sep					180	49		
22-Sep					180	25		
6-Oct					181	13		
20-Oct					184	11		
3-Nov	121	154			194	140		
17-Nov	121	134			191	101		

a. 0+=subyearling; 1+=yearling.

1992	Coho (0+[a]) Mean Length		Coho (1+[a]) Mean Length		Chinook (0+) Mean Length		Chinook (1+) Mean Length	
Date	(mm)	No.	(mm)	No.	(mm)	No.	(mm)	No.
18-Feb			94	15	46	69		
1-Mar			97	4	48	38		
15-Mar			99	10	60	78		
29-Mar			99	12	61	244		
12-Apr	48	7	107	2	66	35	130	2
26-Apr					74	12		
10-May			117	3	93	101	160	3
24-May					102	137	143	2
7-Jun					114	307	150	20
21-Jun	96	1	137	3	128	402	163	17
5-Jul					130	52	163	2
19-Jul			137	7	138	20	166	1
2-Aug			137	3	137	10		
16-Aug	100	1			150	2		
30-Aug								
13-Sep	122	9	145	1	163	32		
27-Sep	116	36			168	60		
11-Oct	112	19			172	19		
25-Oct	113	27	155	1	175	113		
8-Nov	113	106	165	11	179	180		
22-Nov	119	115	163	14	181	63		

a. 0+=subyearling; 1+=yearling.

APPENDIX TABLE A-2. PERCENT EXCEEDANCE FLOW BY HALF-MONTH PERIOD, HOWARD HANSON DAM OUTFLOW, 1964-1995 (SOURCE: CH2MHILL 1997).

Exceedance	10% Exceedance			25% Exceedance			50% Exceedance			75% Exceedance			90%		
CFS	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II
01/01 to 01/15	2596	2596	2596	1561	1561	1561	808	808	808	537	537	537	430	430	430
01/16 to 01/31	4090	4090	4090	2172	2172	2172	1043	1043	1043	675	675	675	484	484	484
02/01 to 02/15	2545	2545	2545	1591	1574	1553	976	976	972	630	629	626	440	437	440
02/16 to 02/28	3441	3340	3192	1647	1546	1387	1065	964	885	697	597	621	529	428	495
03/01 to 03/15	2058	1591	1121	1324	920	601	970	552	491	716	398	483	605	390	476
03/16 to 03/31	1808	1472	951	1225	936	596	854	582	491	671	399	482	568	390	472
04/01 to 04/15	2533	2228	2076	1768	1457	942	1274	989	523	833	552	477	625	416	464
04/16 to 04/30	1846	1941	2211	1407	1482	1749	965	1009	1220	690	673	816	560	479	515
05/01 to 05/15	2242	2627	2608	1484	1970	1876	966	1238	1200	719	957	878	559	636	587
05/16 to 05/31	2189	2325	2377	1527	1789	1747	1037	1136	1082	675	733	717	518	486	527
06/01 to 06/15	1992	1992	1992	1325	1317	1314	812	807	793	530	535	495	358	398	428
06/16 to 06/30	1540	1350	1350	1029	871	865	695	555	517	515	393	399	391	325	350
07/01 to 07/15	849	931	941	546	628	625	368	450	442	295	376	386	260	334	307
07/16 to 07/31	547	629	630	343	425	428	298	380	383	260	340	347	231	308	307
08/01 to 08/15	403	485	417	318	400	396	285	367	366	266	348	342	245	323	309
08/16 to 08/31	379	461	511	307	389	423	282	364	380	256	338	352	242	324	309
09/01 to 09/15	470	552	676	364	446	509	286	368	410	256	338	366	237	320	342
09/16 to 09/30	629	711	792	353	435	516	281	363	429	251	333	377	225	307	347
10/01 to 10/15	663	745	787	426	508	564	297	379	493	246	330	464	215	298	439
10/16 to 10/31	1233	1315	1372	667	749	760	367	449	538	278	359	480	210	296	435
11/01 to 11/15	2611	2611	2646	1445	1444	1492	783	783	827	446	446	496	318	318	371
11/16 to 11/30	2861	2861	2915	1569	1569	1623	1023	1023	1072	667	667	719	433	433	464
12/01 to 12/15	3745	3745	3790	1952	1952	1997	1228	1228	1264	757	757	777	542	542	580

APPENDIX TABLE A-3. NUMBER OF FLOW EVENTS FROM HOWARD HANSON DAM GREATER THAN OR EQUAL TO 1,800 CFS. ONE FLOW EVENT IS DEFINED AS THE SINGLE CONTINUOUS FLOW EXCEEDING SPECIFIED VALUE WITHOUT REGARD TO DURATION.

	BASELINE						PHASE I						PHASE II					
Year	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
1964	1	2	3	2	2	10	1	1	2	3	2	9	0	1	3	2	2	8
1965	3	0	2	0	0	5	3	0	2	2	0	7	4	1	2	1	0	8
1966	0	1	1	1	0	3	0	1	1	3	0	5	0	0	3	2	0	5
1967	4	0	0	2	1	7	4	0	0	5	0	9	4	0	0	3	0	7
1968	2	1	0	0	1	4	2	1	0	0	1	4	2	0	0	0	1	3
1969	0	1	4	2	1	8	0	1	4	3	1	9	0	0	3	2	1	6
1970	1	0	1	3	1	6	1	0	1	4	1	7	1	0	2	4	1	8
1971	2	0	0	3	2	7	2	0	0	3	1	6	2	0	3	3	1	9
1972	2	1	3	2	2	10	2	1	3	3	2	11	2	3	3	2	2	12
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	1	2	3	3	1	10	1	1	2	3	1	8	1	1	2	4	1	9
1975	1	1	0	3	1	6	1	1	0	3	1	6	1	1	0	3	1	6
1976	0	0	2	2	0	4	0	0	2	2	0	4	0	0	2	2	0	4
1977	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0
1979	1	1	2	0	0	4	1	1	1	2	0	5	1	2	2	2	0	7
1980	2	2	3	0	0	7	2	0	3	1	0	6	2	1	2	1	0	6
1981	1	0	2	0	0	3	1	0	2	0	0	3	1	0	2	0	0	3
1982	2	1	0	3	0	6	2	1	0	4	0	7	2	2	1	4	0	9
1983	0	2	0	0	0	2	0	1	0	2	0	3	0	1	2	1	0	4
1984	1	2	1	3	0	7	1	1	0	4	0	6	1	1	2	3	0	7
1985	0	0	2	2	1	5	0	0	3	3	1	7	0	0	2	2	1	5
1986	1	2	0	1	0	4	1	1	0	1	0	3	1	0	0	1	0	2
1987	1	3	2	0	0	6	1	2	2	2	0	7	1	3	2	2	0	8
1988	1	2	1	2	0	6	1	1	2	4	0	8	1	1	2	3	0	7
1989	1	0	2	0	0	3	1	0	2	2	0	5	1	0	2	2	0	5
1990	3	3	3	0	2	11	3	1	1	3	2	10	3	1	3	2	2	11
1991	2	0	1	1	0	4	3	0	1	1	0	5	3	0	1	1	0	5
1992	1	0	1	0	0	2	1	0	1	0	0	2	1	0	1	0	0	2
1993	0	2	2	1	0	5	0	2	1	5	0	8	0	1	3	3	0	7
1994	0	1	0	0	0	1	0	1	0	1	0	2	0	2	3	1	0	6
1995	2	0	0	0	0	2	2	0	0	2	0	4	2	0	1	1	0	4
Total	**36**	**30**	**42**	**36**	**15**	**159**	**37**	**19**	**37**	**73**	**13**	**179**	**37**	**22**	**54**	**57**	**13**	**183**
Average	**1.1**	**0.9**	**1.3**	**1.1**	**0.5**	**5.0**	**1.1**	**0.6**	**1.2**	**2.3**	**0.4**	**5.6**	**1.1**	**0.7**	**1.7**	**1.8**	**0.4**	**5.7**

SECTION 2E ADULT RETURN RATE: PRELIMINARY INFORMATION ON BASELINE SURVIVAL

2E.1 PROJECT PURPOSE AND SCOPE OF STUDY

Coded-wire tagging (CWT), otolith marking, and fin clipping of coho salmon smolts, steelhead fry and smolts, and chinook salmon fingerlings was a multiple year study requested in 1991 by Washington Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service (USFWS), and the Muckleshoot Indian Tribe (MIT). This study was designed to provide pre-project or Baseline condition adult survival or adult return rates. It was not contained in the original Additional Water Storage Project (AWSP) study plan and was added through a SACCAR.

The first adult return report prepared by the USFWS, with preliminary results from coho adult returns, is by Kevin Aitkin and is entitled:

Aitkin, J.K. 1996. *Progress report on the Howard Hanson Project Adult Return Rate Study for CWT Coho and Chinook Salmon, 1994 and 1995* . U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Most of the text of Aitkin (1996) will be presented as part of this report. Additional data from the tagging and recoveries is attached to the original report as Appendices.

The objectives of this report is to:

1. document adult returns of 1993 and 1994 coho yearling releases,
2. analyze reservoir variables potentially affecting coho salmon above-dam release smolt to adult survival, and
3. compare coho salmon adult survival rates of Headwaters Green River returns with other Puget Sound coho returns, wild and hatchery.

NOTE: Portions of this report will be updated for the Final FR/EIS to reflect additional coho salmon coded-wire-tag returns from 1997.

2E.2 INTRODUCTION

In 1911, over 220 mi^2 of the Headwaters Green River was blocked to anadromous fish passage (salmon and steelhead) with the construction of a diversion dam at river mile (RM) 61 to supply public water to the City of Tacoma. A second anadromous fish barrier, HHD, was constructed at RM 64.5 in 1962 for water storage and flood control. The initial construction did not include upstream or downstream passage facilities for juvenile or adult salmon and steelhead.

The first outplanting of juvenile anadromous salmonids above HHD occurred in 1982 with release of steelhead fingerlings, coho salmon in 1983, and chinook salmon in 1987. Since this time, all species have been planted and will continue to be planted. In 1992, the first adult steelhead were released above Howard Hanson Reservoir since 1911.

The outmigration of juvenile salmonids was first studied by the Washington Department of Fisheries in 1984 (Seiler and Neuhauser 1984). Coho daily passage appeared to be associated with increases in project outflow volume. Passage stopped and an unknown number of steelhead and coho smolts were trapped within the reservoir when refill began, outflow volume decreased, and discharge was transferred to the bypass outlet, at increased outlet depth.

AWSP baseline studies at the HHD were begun in 1990 and have continued through 1996. Studies specific to identifying reservoir or dam features that affect the safe passage of juvenile outmigrants began in 1991 and have included: monitoring and evaluation of juvenile passage at the dam, and flow or outlet features affecting daily passage, in 1991 and 1992 (Dilley and Wunderlich 1992 and 1993); monitoring of the distribution of juveniles rearing or entrapped in the lower reservoir in 1993 (Dilley 1994); estimation of juvenile travel time through the reservoir in 1995, and evaluation of factors affecting travel time (Aitkin et al. 1996).

In 1993, a cooperative study was undertaken to look at the adult return rates of coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) planted above (and below) HHD. Steelhead fingerlings and smolts were fin-clipped and released above and below the dam. Juvenile coho and chinook salmon were coded-wire tagged (CWT); CWT coho salmon smolts were released above and below the dam, and all CWT chinook salmon were released above the dam. Tagging of salmon and steelhead occurred from 1993-1996. As there are multiple-age classes of chinook salmon, and the last year of fingerling tagging occurred in 1996, adult returns are expected at least through the year 2001.

2E.3 METHODS

2E.3.1 Coho Salmon Coded-Wire Tagging

The methods discussion will focus on the experimental design, tag and release, and tag recoveries for CWT coho and chinook salmon smolts. A brief review of existing tagging and recovery of coho fingerling, chinook fingerling, and steelhead fry and smolt releases is discussed in 3.1 Juvenile Salmon and Steelhead Tagging and Adult Tag Collection. More detailed description of fin-clipped steelhead fry and smolts is expected in a report from WDFW in 1997.

Four groups of 20,000 coho salmon smolts were tagged with different CWT codes. The four groups formed two test/control pairs. In each test/control pair, test and control groups were released above and below the project, respectively, on or within a day of each other. The first test/control pair was released during reservoir refill and the second pair was released approximately two weeks later at a higher pool level. Approximately 80,000 CWT coho salmon smolts were released per year from 1993 to 1995. The CWT coho salmon portion of the adult return rate study was designed and implemented by Gary Sprague (WDFW). Detailed information on the tagging and releases of the CWT coho salmon is found in Appendix A of Aitkin (1996).

The tagging of juvenile coho salmon and chinook salmon with a binary-coded wire tag and their subsequent recovery and reporting follows standard CWT protocol (Johnson 1989; Nielsen 1992). The CWT is implanted into the nasal cartilage of the juvenile fish, and the fish is marked externally with an adipose fin clip. The adult fish is identified by the fin clip, sacrificed, and the tag is extracted and read.

Coho salmon used in this study were Big Soos Creek stock spawned and reared at the Soos Creek Hatchery (WDFW), transferred to Crisp Creek Rearing Pond (MIT and WDFW) in August of the following year, and CWT with full-length tags (0.25 x 1.1 mm) on-site as smolts.

Fall chinook salmon used in this study were Big Soos Creek stock spawned at the Soos Creek Hatchery (WDFW), transferred to Keta Creek hatchery (MIT) in November of that year as eyed eggs, and CWT with half-length tags (0.25 x 0.5 mm) on-site as fingerlings.

Coho control groups were released directly below HHD and coho test groups were released immediately above the reservoir in the Green River mainstem (about 4.5 miles upstream of the dam). Chinook were released throughout 56 possible planting sites in the Headwaters Green River tributaries and mainstem above the reservoir.

There are two sources for adult coho CWT returns: 1) the collection of adults returning to fish trap at the Tacoma Diversion Dam, and 2) collection of adult heads in commercial and sport fisheries by state and tribal fisheries and reported to the Pacific State Marine Fisheries Commission (PSMFC). The Tacoma Diversion Dam fish trap at RM 61 is operated by TPU and sampling of the trap is the responsibility of the MIT. In 1994, the trap was operated from September 2 to November 29. In 1995, it was operated from October 6 to November 28, but was pulled due to high water during October 25-27.

The PSMFC on-line database is the clearinghouse for all CWT recovery data on the West Coast. This is a very dynamic database. A period of at least two years from date of adult return is needed for verification of marine tag recoveries and final reporting; any data used before this time are preliminary. The observed data are expanded using a recovery estimation equation (Johnson 1989) to estimate the total marked catch. Data used here are found in Appendix B of Aitkin (1996) and were obtained on September 12, 1996 (PSMFC 1996). A second check of the database to confirm September 12 recovery data was completed on March 13, 1997.

Sufficient recovery data are presently available to conduct a very preliminary analysis of brood year (BY) 1991 and 1992 coho salmon recoveries. Expanded recovery data were used to compare the test and control survivals and distribution. Absolute survival rates were computed by dividing total expanded recoveries by the total number of tagged fish released. To compare survival rates of tests and controls, a chi-square test was used, a = 0.05. Poisson, a contribution rate testing program employing a Poisson distribution (Newman and Comstock 1991), was used to test for homogeneity of contribution patterns of test and control pairs among the fisheries. However, due to lack of expanded recovery information, the following data was deleted: the 1995 WDFW estuary sport recoveries of tag codes 05-35-36 and 37, and the 1995 WDFW ocean sport recoveries of tag codes 05-35-38, and 39.

2E.3.2 Evaluation of Coho Salmon Adult Survival Against Reservoir Conditions

In Section 2C, the Corps evaluated various physical and biological factors related to the travel time of coho, steelhead and chinook smolts traveling through the reservoir refill parameters while the USFWS conducted a multivariate analysis of physical variables to explain differences in observed travel times (Aitkin et al. 1996). The Corps analysis used analysis of variance (ANOVA) while the USFWS used multivariate regression in their work. A similar analysis, utilizing both ANOVA and linear regression, is presented in this report to evaluate adult survival of coho salmon against changing reservoir conditions.

The Corps maintains a historic daily database of all major reservoir variables. This database was queried to compile the physical variables used in the ANOVA and regression analysis. Adult survival information comes from Aitkin (1996).

None of the previous USFWS studies provided the Corps with a definitive estimate of the total project passage time required for smolts to travel through both the reservoir and the dam. In addition, these studies cannot provide an accurate estimate of the point at which smolts become trapped within the reservoir, as this point appears to be a dynamic balance between reservoir outflow and outlet gate depth and operation (radial vs bypass). Lastly, the studies cannot answer what is the ultimate survival rate for smolts who are trapped within the reservoir. These studies did provide an association of daily passage and reservoir travel times to various flow or storage variables. Most of the associated variables were used in the analysis.

Because we had no apriori knowledge of what time period to use for analysis of physical variables, an ANOVA comparison of various averages of the physical variable (7 days, 14 days, 21 days, 28 days, 30 days) was completed to ascertain if there was any point where there was a clear break in average values. A breakpoint in the reservoir or flow variables could provide an indication of when survival differences might occur. The study design for the test releases was for Group 1 to be released during refill and Group 2 to be released at full pool. This design was followed in 1993 but was not fully executed in 1994. Under this initial analysis, verification of ANOVA assumptions was not performed, homogeneity of variance and normalcy, so Type I error may occur for selected variables. Violation of ANOVA's assumptions leads to a loss of confidence in the Type I error rate of the test (Keppel, 1991, pp. 107). Type I error rate is the probability of rejecting a null hypothesis that is actually true and is set by the investigator. Verification of ANOVA assumptions will occur with final report submission.

Once the time period breakpoint, or lack of breakpoint was identified, an ANOVA was conducted of the average values for 1) within-year release group, and 2) between-year release groups. The within-year analysis involved a single factor comparison of the average values for physical variables present during Group 1 vs variables present during Group 2. The between-year analysis compared average physical variable values for 1) Group 1 in 1993 vs Group 1 in 1994; and 2) Group 2 in 1993 vs Group 2 in 1994. These two comparisons should provide an indication of differences in reservoir variables that may parallel differences in test group survival.

In addition to the ANOVA, the average value of single variables for the selected period was regressed against the test survival rates (simple regression). A second multi-variate regression (forward stepwise) was also conducted to identify combinations of variables that might explain more of the variation in test-group survival rates. Lastly, a variant of the test-group survival was used. The ratio of test/control adult survival pairs, project survival, was developed. These project survival rates were used as an indicator of the actual project survival for the test release for that pair. The variables (average daily values) used in the regression analysis were: inflow (cfs), outflow (cfs), outlet depth (ft), pool elevation (ft), refill rate1 (outflow/inflow), refill rate2 (ac-ft of storage/day), and content or storage volume (ac-ft). All regression analyses were conducted using STATGRAPHICS, Inc., statistical software.

2E.4 RESULTS

2E.4.1 Juvenile Salmon and Steelhead Tagging and Adult Tag Collection

A summary of all planned releases by species and year class in listed in Table 1. Items listed in bold indicate adult returns for those releases beginning in 1996 with data collection and preliminary reporting to occur sometime into 1997. The results from most of that data collection will not be available for this feasibility report. What is available is the preliminary data from the coho yearling releases reported in Aitkin (1996). Following are some notes on the actual release and collection of marked fish.

TABLE 1. SPECIFIC RETURN DATA FOR THE HHD ADULT RETURN RATE STUDY. BOLD ITEMS INDICATE RETURN DATA COLLECTED IN 1996 WITH PRELIMINARY REPORTING DUE SOMETIME IN 1997.

Species	Age	Brood Year	Mark Year	Number	Mark	Main Return Year	Total Run Return
Coho	**0+**	**1993**	**1994**	**1600000**	**Otolith**	**1996**	**1995-1997**
Coho	**0+**	**1994**	**1995**	**1000000**	**Otolith**	**1997**	**1996-1998**
Coho	1+	1991	1993	80,000	CWT	1994	1993-1995
Coho	**1+**	**1992**	**1994**	**80,000**	**CWT**	**1995**	**1994-1996**
Coho	**1+**	**1993**	**1995**	**80,000**	**CWT**	**1996**	**1995-1997**
Chinook	**0+**	**1993**	**1994**	**400,000**	**CWT**	**1997**	**1996-1999**
Chinook	0+	1994	1995	400,000	CWT	1998	1997-2000
Chinook	0+	1995	1996	400,000	CWT	1999	1998-2001
Steelhead	0+	1993	1993	0	-	-	-
Steelhead	**0+**	**1994**	**1994**	**53,000**	**Adipose**	**1997**	**1996-1998**
Steelhead	0+	1995	1995	55,000	Adipose	1998	1997-1999
Steelhead	1+	1992/93	1994	0	-	-	-
Steelhead	**1+**	**1993/94**	**1995**	**120,000**	**Ad/Ventral**	**1997**	**1996-1998**
Steelhead	1+	1994/95	1996	100,000	Ad/Ventral	1998	1997-1999

2E.4.2 Coho Salmon CWT Returns

Table 2 shows all release and recovery data for the 1993 and 1994 coho smolt releases. These fish come from the 1991 and 1992 BY, respectively. Table 1 shows the potential total years of return for these releases.

Coho BY 1991, 1993 Smolt Release. Appendix B (Aitkin 1996) provides 1994 recovery information. Preliminary adult return rates for test (release above dam) and control were: Release Group 1 test -- 5.5 %, control 6.1%; Release Group 2 test 1.8%, and control 7.8%. Group 1 was released during reservoir refill and Group 2 was released at full pool. Test Group 2 survival (full pool release, 1141 ft elevation) was 67% lower than Test Group 1 at mid-pool (1110 ft release). A chi-square test showed that both test groups survived at lower rates than their respective controls ($P<0.02$ for Group 1, $P<0.001$ for Group 2). Fishery contribution patters for Group 1 and Group 2 test/control pairs differed. The first pair was not significantly different, while the second pair was significantly different ($P<0.01$). This suggests a difference in contribution patters among the fisheries based on the project conditions encountered at full pool.

Because of the somewhat preliminary nature of the 1991 BY recoveries, a second check on the PSMFC database was completed on March 13, 1997. There was virtually no change in the expanded recoveries:

	Test 1	Control 1	Test 2	Control 2
September 12, 1996	1121	1241	353	1572
March 13, 1997	1118	1242	355	1575

Because of the late nature of the reporting, and the lack of major change in adult numbers, the September 12, 1996 recovery data will be used in analyses following this section.

Coho BY 1992, 1994 Smolt Release. Appendix B (Aitkin 1996) provides 1995 recovery information. Although this data is more preliminary than 1994 recoveries, a survival trend for test releases being lower than controls is developing. Adult survival rates for 1994 test and control were: Release Group 1 test 0.1%, control 0.9%; Release Group 2 test 0.03%, control 0.6%. Both test releases occurred during refill; 1122 ft Group 1, 1132 ft Group 2. A chi-square test showed that both test groups survived at lower rates than the respective controls ($P<0.001$ for both Groups). Group 2 test survival was 78% lower than Group 1 test survival. Fishery contribution patterns for the first and second test/control pairs were not significantly different. Aitkin (1996) noted that there was a smaller difference in reservoir conditions between Group 1 and Group 2 than there was in 1993: in actuality, the releases did not specifically follow the study design, as Group 2 was not released at full pool. In addition, the statistical power of the Poisson contribution test may be low due to the low CWT recoveries.

Because of the preliminary nature of the 1992 BY recoveries, a second check on the PSMFC database was completed on March 13, 1997. There was an increase in the expanded recoveries from:

	Test 1	Control 1	Test 2	Control 2
September 12, 1996	20	177	6	120
March 13, 1997	27	232	6	134
Percent Survival 9/12	0.10	0.9	0.03	0.6
Percent Survival 3/13	0.13	1.1	0.03	0.7

Because of the late nature of the reporting, the September 12, 1996 recovery data will be used in analyses following this section.

TABLE 2. THE 1994 AND 1995 RECOVERIES OF CWT COHO SALMON (BY 91, 92, 93) RELEASED ABOVE AND BELOW HOWARD HANSON DAM IN 1993 AND 1994 REPORTED AS OF JULY 29, 1997.

1993 Release Group (1991 BY)	Release Data			
	Release Group 1		Release Group 2	
	First Test	First Control	Second Test	Second Control
Date	26-Apr	26-Apr	11-May	12-May
No Released	20268	20430	20078	20307
No. with CWT and Ad Clip	20187	20307	19978	20266
Size at Release (no/lb)	21	21	19	19
	Recovery Data			
Observed Recoveries	566	617	202	746
Expanded Recoveries	1103	1196	350	1526
Survival Based on Expanded Recovery (%)	5.5%	5.9%	1.8%	7.6%
	Chi-squared Test			
Test/Control Survival	$\chi^2 = 5.7$		$\chi^2 = 792.5$	
Test Significance	$P < 0.02$		$P < 0.001$	
	Poisson Test			
Test/Control Recovery Distribution Test Significance	p = 0.152		p = 0.004	

1994 Release Group (1992 BY)	Release Data			
	Release Group 1		Release Group 2	
	First Test	First Control	Second Test	Second Control
Date	26-Apr	27-Apr	10-May	11-May
No Released	20406	20474	20344	20337
No. with CWT and Ad Clip	20284	20433	19937	20296
Size at Release (no/lb)	26	26	24.7	25.7
	Recovery Data			
Observed Recoveries	8	77	2	45
Expanded Recoveries	27	232	6	134
Survival Based on Expanded Recovery (%)	0.13%	1.14%	0.03%	0.66%
	Chi-squared Test			
Test/Control Survival	$\chi^2 = 124.6$		$\chi^2 = 101.4$	
Test Significance	$P < 0.001$		$P < 0.001$	
	Poisson Test			
Test/Control Recovery Distribution Test Significance	p = 0.152		p = 0.004	

1995 Release Group (1993 BY)	Release Data			
	Release Group 1		Release Group 2	
	First Test	First Control	Second Test	Second Control
Date	26-Apr	27-Apr	9-May	10-May
No Released	20412	20521	20178	20485

1993 Release Group (1991 BY)	Release Data			
	Release Group 1		Release Group 2	
No. with CWT and Ad Clip	20210	20318	20098	20039
Size at Release (no/lb)				
	Recovery Data			
Observed Recoveries	42	111	6	119
Expanded Recoveries	106	307	17	278
Survival Based on Expanded Recovery (%)	0.52%	1.51%	0.08%	1.39%
	Chi-squared Test			
Test/Control Survival				
Test Significance				
	Poisson Test			
Test/Control Recovery Distribution				
Test Significance				

2E.4.3 Evaluation of Coho Salmon Adult Survival Against Reservoir Conditions

Determination of Period of Analysis

The average value for five physical variables (outflow, outlet depth, refill rate1, inflow, and pool elevation) were compared (within-year) over five time periods (7, 14, 21, 28, and 30 days) to identify an appropriate period for analysis against test-group survival. These variables have been previously identified in various studies as having some influence on the outmigration of juvenile salmonids. Appendix Table 1 presents the results of the ANOVA for these five periods. A general inspection shows that for most of the variables, the differences between the average values of within-year comparison of Group 1 vs Group 2 were fairly consistent. Outflow was significantly different in 1993 and 1994 for all comparisons except for the 14-day average in 1993. Outlet depth was different for all periods in both years. Refill rate1 (ac-ft/day) was not different in 1994 during the 7, 14, and 21-day average comparisons. Inflow was significantly different (highly $P<.001$) for all comparisons. There was no difference in pool elevation for all periods of comparison.

Based on these results the 30-day average was used in all subsequent analyses. This time period allows incorporation of the possibility that the majority of smolts could take a protracted period to outmigrate through the project. Results from outmigration studies at Wynoochee Dam show the average project travel rate (reservoir and dam passage) for coho smolts is 18-43 days (Section 2B). Wynoochee has a similar reservoir length, refill pattern, and has identified problems with attraction and passage of smolts at the dam (Corps of Engineers Wynoochee Dam Section 1135 PMR). These provides some basis for selection of the longer time period for ANOVA and regression analysis.

a. Comparison of Reservoir Conditions Within-year and Between-year

After the 30-day time period for averaging flow and reservoir variables was identified, an ANOVA was conducted for these values for within-year and between-year periods (Table 3).

Within-year. In 1993, there was a significant difference between four of the five variables from Group 1 to Group 2. The early release on April 26, and following 30 days, had higher inflow, outflow, refill rate and outlet depth (radial gate) than the later release (and 30 days) on May 11. Pool elevation was not different. Test survival of coho adults declined from Group 1, 5.5%, to Group 2, 1.8% or a 67% decline. In 1994, the early release had higher inflow, deeper outlet depth, and higher refill rate. There was no difference between periods for outflow and pool elevation. Test survival of coho adults declined from Group 1, 0.1%, to Group 2, 0.03%, a 78% decline. The higher flows during the early release appear to be associated with the higher test survival of the early release.

TABLE 3. SINGLE-FACTOR ANOVA COMPARING 30-DAY AVERAGE RESERVOIR AND DAM PHYSICAL VARIABLES FOR 1) WITHIN-YEAR; AND 2) BETWEEN-YEAR COMPARISONS FOR COHO CWT RELEASE GROUPS (RG1 VS RG2 WITHIN AND BETWEEN YEARS).

			WITHIN-YEAR ANOVA OF COHO CWT					
30-Day Average	1993 RG1[a]	1993 RG2[a]	% Differ.	P-VALUE	1994 RG1	1994 RG2	% Differ.	P-VALUE
OUTFLOW	1348.2	1000.6	25.78%	0.017	550.2	388.3	29.43%	N/A
DEPTH	102.5	106.0	-3.41%	0.020	79.2	69.5	12.25%	0.000
REFILL RATE	550.4	8.0	98.55%	0.030	379.3	266.5	29.74%	0.012
INFLOW	1623.4	1004.6	38.12%	0.000	739.9	525.5	28.98%	0.000
ELEVATION=VOLUME	1137.5	1141.0	-0.31%	N/A	1131.7	1139.5	-0.69%	N/A
		WITHIN-YEAR ADULT COHO CWT RETURN						
	1993 RG1	1993 RG2	% Differ.		1994 RG1	1994 RG2	% Differ.	
ADULT RETURN TEST	5.60%	1.80%	67.86%		0.1	0.03%	99.70%	
ADULT RETURN CONTROL	6.10%	7.80%	-27.87%		1.8	0.59%	99.67%	
TEST/CONTROL %	92%	23%	74.86%		23%	5%	77.97%	
			BETWEEN-YEAR ANOVA OF COHO CWT					
30-Day Average	1993 RG1	1994 RG1	% Differ.	P-VALUE	1993 RG2	1994 RG2	% Differ.	P-VALUE
OUTFLOW	1348.2	550.2	59.19%	0.000	1000.6	388.3	61.19%	0.000
DEPTH	102.5	79.2	22.73%	0.000	106.1	69.5	34.50%	0.000
REFILL RATE	550.4	379.3	31.09%	0.446	8.0	266.5	-3231.25%	0.009
INFLOW	1623.4	1004.6	38.12%	0.000	739.9	521.5	29.52%	0.000
ELEVATION=VOLUME	1137.5	1131.7	0.51%	0.000	1141.0	1139.5	0.13%	0.047
		BETWEEN-YEAR ADULT COHO CWT RETURN						
	1993 RG1	1994 RG1	% Differ.		1993 RG2	1994 RG2	% Differ.	
ADULT RETURN TEST	5.60%	0.10%	98.21%		1.80%	0.03%	98.33%	
ADULT RETURN CONTROL	6.10%	0.87%	85.74%		7.80%	0.59%	92.44%	
TEST/CONTROL %	92%	11%	87.48%		23%	5%	77.97%	

a. RG1=Release Group 1, early release in late April during refill, RG2=Release Group 2 in May.

Between-Year. Comparing flow and reservoir values between 1993 and 1994 shows some interesting results. For the early release, four of the five values were significantly greater in 1993 than in 1994: outflow, outlet depth, inflow, and pool elevation. Refill rate was not different between the early release of 1993 and 1994. For the later release, all five variables were different, with four of the five greater in 1993 than in 1994: outflow, depth, inflow, and pool elevation. In contrast, refill rate was greater in 1994 than in 1993.

Early release test survival was 98% lower in 1994 (0.1%) than in 1993 (5.5%). Later release test survival was also 98% lower in 1994 (0.03%) than in 1993 (1.8%). This follows the same survival trend for the control releases. Early release survival of controls in 1994 (0.9%) was 86% lower than in 1993 (6.1%) while later release in 1994 (0.6%) was 92% lower than in 1993 (7.8%). The higher flows in 1993 (vs 1994) appear to be associated with the higher survival of the test and control releases.

b. Regression Analysis of Reservoir Conditions vs Coho Adult Test-Survival

The ANOVA provides an initial indicator of what reservoir and flow factors could be associated with the survival of coho smolt migrating through Howard Hanson Reservoir and Dam. A regression analysis was also performed to further evaluate the survival of adult coho released above HHD against flow and reservoir factors. In the ANOVA, 5 variables were used -- outflow, inflow, refill rate2 (ac-ft), outlet depth, and pool elevation. In the regression analysis, 7 variables were used -- outflow, inflow, outlet depth, pool elevation, refill rate1 (outflow/inflow), refill rate2 (ac-ft/day), and storage volume (ac-ft).

Two regression analyses were performed, simple regression (single factor) and multiple regression (multiple factors). The results from both analyses are presented in Tables 4 and 5.

TABLE 4. SIMPLE LINEAR REGRESSION (AND MULTIPLICATIVE) COMPARING 30-DAY AVERAGE RESERVOIR AND DAM PHYSICAL VARIABLES FOR FOUR COHO CWT RELEASE GROUP CONDITIONS AGAINST 1) TEST SURVIVAL; AND 2) TEST/CONTROL SURVIVAL; AND 3) CONTROL SURVIVAL. SIGNIFICANT RELATIONSHIPS REPORTED IN BOLD.

Simple Regression

Survival	30-Day Average Variable	Analysis	Correlation r^2	P-Value
Test	**Inflow**	Simple Linear	**0.97**	**0.02**
	Outflow	Simple Linear	**0.89**	**0.05**
		Multiplicative	**0.99**	**0.002**
	Outlet Depth	Simple Linear	0.54	0.26
		Multiplicative	**0.93**	**0.035**
	Elevation	Simple Linear	0.0028	Not Sig.
	Refill Rate (outfl./inflow)	Simple Linear	0.0017	Not Sig.
	Refill Rate(ac-ft/day)	Simple Linear	0.1	Not Sig.
	Storage Volume	Simple Linear	0.0034	Not Sig.
Project (Test/Control)	**Inflow**	Simple Linear	**0.94**	**0.03**
	Outflow	Simple Linear	**0.81**	**0.05**
	Outlet Depth	Simple Linear	0.42	Not Sig.
	Elevation	Simple Linear	0.04	Not Sig.
	Refill Rate(ac-ft/day)	Simple Linear	0.04	Not Sig.
	Storage Volume	Simple Linear	0.04	Not Sig.
Control	**Outflow**	Simple Linear	0.75	0.14
		Multiplicative	**0.94**	**0.03**

TABLE 5. FORWARD STEPWISE REGRESSION COMPARING 30-DAY AVERAGE RESERVOIR AND DAM PHYSICAL VARIABLES FOR FOUR COHO CWT RELEASE GROUP CONDITIONS AGAINST 1) TEST SURVIVAL; AND 2) TEST/CONTROL SURVIVAL. ALL MODELS TESTED FIRST AS THREE VARIABLES, MODEL SELECTS BEST 1 OR MORE VARIABLES.

Forward Stepwise Regression

Survival	30-Day Average Variable	Number of Variables in Model	Correlation r^2	P-Value
Test	Inflow	1	**0.96**	**0.02**
Best Model Selected against 2 and 3 Variable Models				
Test	Outflow	1	**0.89**	**0.05**
Without Inflow in Model, Outflow was Best Model Selected				
Project	Inflow	1	**0.94**	**0.03**
Project	Outflow/Outlet Depth	2	**1.0**	**0.016**
Without Inflow in Model, Outflow+Outlet Depth was Best Model Selected				

Under simple regression, three variables were found to be significantly correlated with the test-survival -- inflow, outflow, and outlet depth: two models were used under the simple regression, linear and multiplicative. There was a positive direct relationship between increased test-survival and increased flow, both for inflow and outflow. Inflow was the highest correlated variable under simple linear regression (r^2=0.97, P=0.02) (Figure 1). Outflow was the second highest correlated variable using linear regression (r^2=0.89, P=0.05) (Figure 2). The correlation improved using the multiplicative model (r^2=0.99, P=0.002). Outlet depth was also correlated under the multiplicative model (r^2=0.93, P=0.04) (Table 4).

Using Project survival, the ratio of test survival/control survival, the single variable explaining the greatest variation was inflow (r^2=0.94, P=.03) (Figure 3) with outflow as a second significant variable (r^2=0.84, P=0.05). A regression of control survival vs outflow was completed. There was a significant relationship using the multiplicative model (r^2=0.94, P=0.03) (Table 4).

Under multivariate regression, the single variable model selected that best describes the relationship of test-survival to flow or reservoir conditions was inflow (r^2=0.96). This variable was selected against all combinations of 2 to 3-variable models. A second regression was completed without inflow as an input variable. Without inflow, outflow was the best single variable model selected against all combinations of 2 and 3-variable models. Using Project survival, the ratio of test survival/control survival, inflow was still the best one variable model. The best 2-variable model, without inflow, was outflow and outlet depth (Table 5).

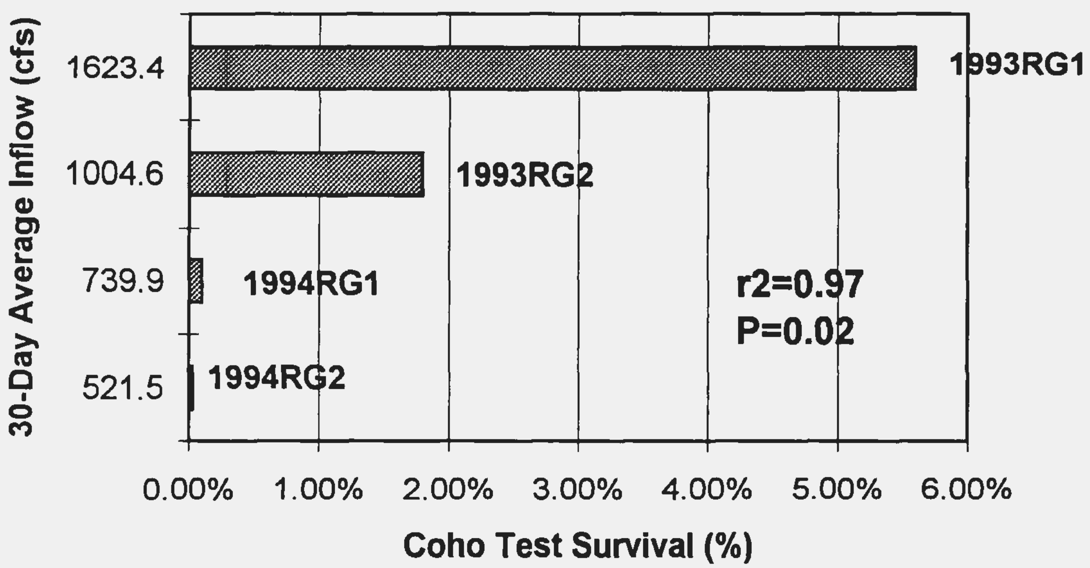


FIGURE 1. COMPARISON OF INFLOW VS. TEST SURVIVAL OF PRELIMINARY COHO ADULT CODED-WIRE TAG RETURNS (RELEASE GROUPS AS SMOLTS IN 1993 AND 1994, ADULT RETURNS IN 1994, 1995, 1996).

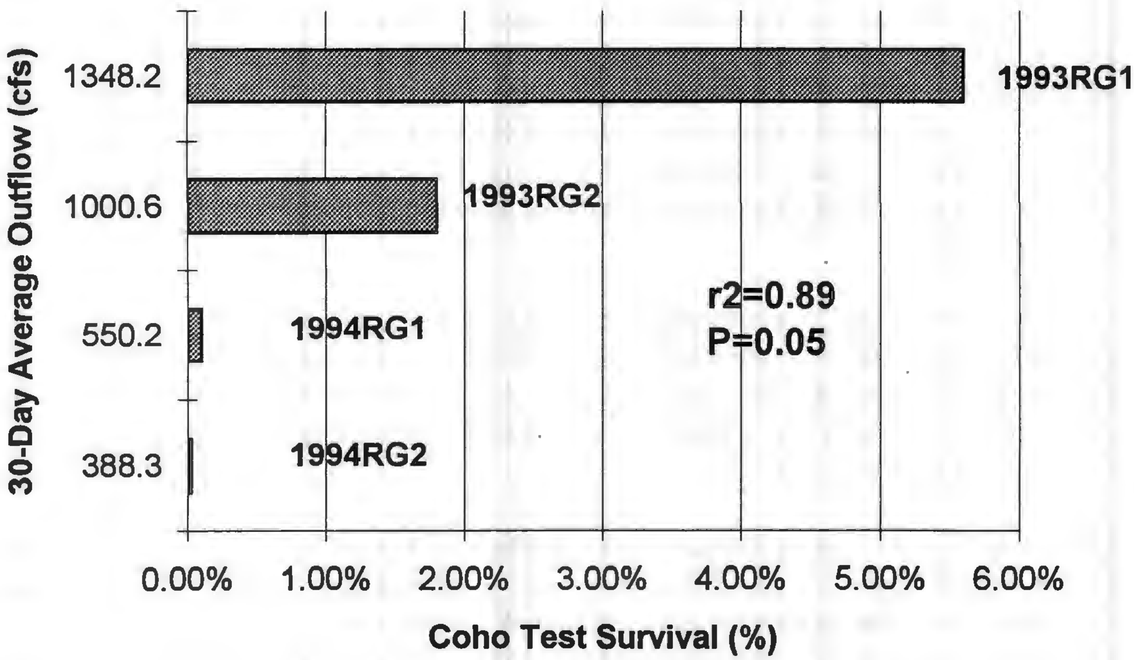


FIGURE 2. COMPARISON OF OUTFLOW VS. TEST SURVIVAL OF PRELIMINARY COHO ADULT CODED-WIRE TAG RETURNS (RELEASE GROUPS AS SMOLTS IN 1993 AND 1994, ADULT RETURNS IN 1994, 1995, 1996).

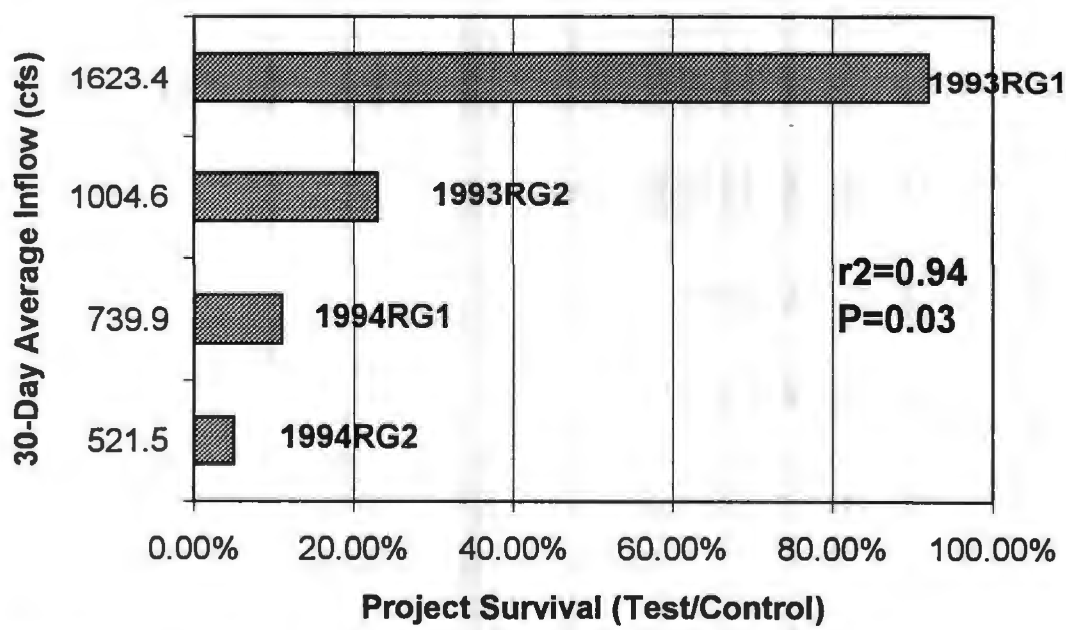


FIGURE 3. COMPARISON OF INFLOW VS. PROJECT SURVIVAL (TEST/CONTROL)OF PRELIMINARY COHO ADULT CODED-WIRE TAG RETURNS (RELEASE GROUPS AS SMOLTS IN 1993 AND 1994, ADULT RETURNS IN 1994, 1995, 1996).

2E.5 DISCUSSION OF COHO SALMON ADULT RETURN RATES

The results of the simple and multivariate model parallel the ANOVA results or are a different way of explaining the relationship of test-survival to flow and reservoir conditions. Put simply, the higher the flow volume (inflow and/or outflow), the higher the survival of coho smolts released above the reservoir and dam. Of importance is the fact that 3 of 4 releases in 1993 and 1994 were at average or dry conditions.

Of the four release groups, only the 1993 early release had flows approaching or near-exceeding normal or average conditions: at flow volumes approaching normal (30% exceedance) conditions, the survival of smolts released above the dam approached control survival (Group 1=92%, project survival - test/control). For the later 1993 release at flow volumes near median (50% exceedance) conditions, the test survival was only 23% of the control survival (Table 3). In 1994, under dry to drought runoff conditions, both control and test survival were 83-98% lower than survival was under near-normal flows in 1993: 1994 test survival was only 5-23% of the control survival (Table 3). In fact, flows at Auburn in May of 1994 were the second lowest for 35 years of operation of HHD, 1962-1995. If higher flow volume truly results in higher survival under existing conditions, then we may expect even higher survival under wet conditions.

These results compare well with the outmigration study results showing that outflow and outlet depth explain much of the variation in coho smolt outmigration (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992 and 1993). In addition, these results confirm the travel time study results showing inflow is important for fast travel time (and potential improved survival) but cast doubt that refill rate could influence potential smolt survival (Aitkin et al. 1996).

These study results also parallel conclusions from Dilley and Wunderlich (1992 and 1993) and from Dilley (1994) that many smolts are entrapped in the reservoir because of low outflow or dam exit depth. Dilley (1994) in particular supports the study results that smolts are entrapped within the reservoir. In 1993, the USFWS was conducting a horizontal and vertical study of fish density in the lower reservoir. The study period overlapped the two release group periods for the CWT study. Vertical gill net samples were collected bi-weekly from April 12 to July 29. There was a peak in coho smolt catch in June, up to 6 weeks after Group 1 release and 4 weeks after Group 2 release. The percentage of fin-clipped coho smolts was 40% and 32% of all fish caught in the late May and early June gill net samples. Travel time of some CWT smolts was very rapid. Smolts from Group 1 were found at the dam the same evening as release, April 26 (4 of 5 fish caught were fin-clipped coho).

An associated factor with lower survival in 1994 (and lower flows) could be the use of the bypass gate beginning on May 12. The operation of the bypass falls half-way into the 30-day period for Group 1, and falls one day after release of Group 2. The radial gates were in operation for both groups in 1993, and were used well into July in 1993 because of the higher flow volume. Early studies identified this limitation of the bypass gates. In 1984, Seiler and Neuhauser (1985) attributed the decline in coho outmigration to the switch to the bypass gate (with lower outflow and attraction) in early June during refill. In 1992, Dilley and Wunderlich (1993) found 40% of all coho outmigrating in 2 days when outflows increased (300-650 cfs) and both the radial and bypass gates were used in early May: prior to and after this the bypass gate was used.

The AWSP directly addresses the three reservoir/dam factors that appear to be influencing coho smolt survival: 1) outflow volume; and 2) outlet depth; and 3) bypass gate operation. Outflow volume under the AWSP will be equal to or greater than existing project outflow during the peak juvenile outmigration period (late April-June) in almost all years (Appendix Table A-2). An objective of operation of the AWSP is to mimic natural hydrology, especially during the main smolt outmigration period (Section 8). As modeled for this Feasibility Study, during late-April and May, refill rates will be lower under the AWSP with resulting greater outflow volume and more natural patterns in dam flow releases (Section 2B. Reservoir Survival).

Freshets, both natural and artificial freshets are planned under both Phase I and Phase II at regular intervals in April and May. The total number of freshets during spring refill, minimum volume defined as 1,800 cfs (equivalent to 2,500 cfs defined freshet at Auburn), increases from Baseline to Phase I and Phase II. The average number of freshets per month also increases from Baseline to Phase I and Phase II (Table 6, Appendix Table A-3 lists events for all years). The monthly total of freshets does decrease in March under the AWSP: no refill limits are applied during this month, and no artificial freshets are released. The greatest monthly increase in total and average freshets occurs in May, the peak month for juvenile outmigration.

TABLE 6. NUMBER OF FLOW EVENTS FROM HOWARD HANSON DAM GREATER THAN OR EQUAL TO 1,800 CFS. ONE FLOW EVENT DEFINED AS SINGLE CONTINUOUS FLOW EXCEEDING SPECIFIED VALUE WITHOUT REGARD TO DURATION.

	Feb	Mar	Apr	May	Jun	Total
Total No. of Events						
Baseline	36	30	42	36	15	159
Phase I	37	19	37	73	13	179
Phase II	37	22	54	57	13	183
Average No. of Events						
Baseline	1.1	0.9	1.3	1.1	0.5	5
Phase I	1.1	0.6	1.2	2.3	0.4	5.6
Phase II	1.1	0.7	1.7	1.8	0.4	5.7

Outlet depth is no longer a consideration of factors affecting smolt survival. The preferred fish passage facility will "fish" from 5-20 ft deep, well within the optimum range of depths that all juvenile salmonids naturally use. This is a major improvement over existing depths, which range from 35 ft (at low pool) to 112 ft (drought year full pool). There is an interaction between outflow and outlet depth under current conditions. Under higher outflow, smolts will still sound (dive) to exit the deep radial gates. Under low outflow, smolts show limited use or will not use the shallower bypass outlet. The preferred fish passage facility (modular incline screen and fish lock), while eliminating water depth as an impediment to smolt passage, has also maximized surface outflow volume. The facility will draw up to 960 cfs when meeting all biological screening criteria. This large surface volume withdrawal cannot be compared to the existing facility, and may have additional benefits in improving smolt survival that cannot be accounted for.

The coho salmon adult return rates of the two years of test survival averaged 32.9% of the control survival: two-year average for test survival was 1.9%; and control was 3.8%. The 1993 average was 3.7% for the test and 7.0% for the control. The 1994 average was 0.07% for the test and 0.7% for the control. Comparison of these return rates to other Puget Sound hatchery adult returns shows that the 1993 control survival rates were well within comparable hatchery return rates. Test survival rates were exceeded at one nearby hatchery and were 30-40% of the return rate of other hatcheries. In 1994, however, the control and test return rates appear to be significantly lower than other hatcheries (Table 7).

It should be expected that the control and test return rates would be lower than the volitional hatchery releases of coho yearlings, up to 25% lower. It has been documented by the WDFW and the Oregon Department of Fish and Wildlife that there is an element of mortality just from transporting fish from the hatchery to a remote release site (Seiler 1989 and ___). The WDFW compared smolt to adult survival of coho yearlings in the Chehalis River basin. Adult survival from smolts transported a distance or for a period of time was compared to adult survival for smolts allowed to outmigrate under their own volition from the hatchery. Adult returns from the trucked smolts were 25% lower than returns from the hatchery. The author termed this mortality a "transportation effect" of moving smolts (Seiler 1989).

Besides lower survival for the HHD smolt releases from the "transportation effect," these smolts are from lower Green River stock. The genetic distance of the stock can influence overall smolt to adult survival and the homing ability of returning adults.

TABLE 7. ADULT RETURN RATE (TOTAL RUN SIZE) OF 1993 AND 1994 HATCHERY RELEASED SMOLTS FROM SEVERAL PUGET SOUND WATERSHEDS.

1993 River Basin	Hatchery	No of Smolts Released	Terminal Run	Adult Return Percent (T/S)
Skykomish	Skykomish	303,000	25,190	8.3%
Lake Washington	Issaquah	563,900	1,639	0.3%
	All Hatchery Release[a]	631,900	1,698	0.3%
Green River	Soos Creek	605,100	79,103	13.1%
	All Hatchery Release[b]	1,330,100	103,089	7.8%
Headwaters	HHD Control	40,573	2,813	6.9%
Headwaters	HHD Test	40,165	1,474	3.7%
1994				
Skykomish	Skykomish	331,500	31,878	9.6%
Lake Washington	Issaquah	577,500	35,429	6.1%
	All Hatchery Release[a]	710,800	36,107	5.1%
Green River	Soos Creek	622,180	23,749	3.8%
	All Hatchery Release[b]	1,324,100	31,509	2.4%
Headwaters	HHD Control	40,729	297	0.7%
Headwaters	HHD Test	40,221	26	0.1%

a. Lake Washington hatchery release includes University of Washington and Ballard.
b. Green River hatchery release includes Muckleshoot release from Crisp Creek, Elliott Bay and others.

Issaquah Creek Hatchery in the Lake Washington Basin is a good case history showing where an existing dam and navigation canal (Corps operated) without juvenile salmonid passage may decrease coho salmon hatchery adult survival vs. nearby watersheds without dams: hatcheries such as the Green River (Soos Creek) and Skykomish River. The Ballard Locks (Locks) is located at the outlet of Lake Washington. Until 1994, the Locks (6 spillway gates, 2 navigation locks) was not operated to pass juvenile salmonids, even though 2-12 million smolts pass the facility in any given year. From 1978-1993, coho adult return rates for the Issaquah Creek Hatchery have averaged only 40-50% of the return rates for the Soos Creek and Skykomish River hatcheries (Table 7). Since 1994, the Corps has made a series of operational and structural changes at the Locks with the intention to improve smolt survival. Monitoring of the facility has shown that there is no surface outlet during dry springs and most summers, and during these periods most smolts may become entrained in the lock conduits, experiencing injury rates from 5-60%.

Since the operation and structural changes began at the Locks in 1994, there has been a large increase in adult survival with Issaquah Hatchery run returns being near equal or exceeding the two parallel hatcheries in 1995 and 1996. Prior to the changes in 1994/1995, the previous 5 years had Issaquah Creek run returns of 0.59-1.85% vs. the other hatchery returns of 4-21% (Table 7). Since the changes, Issaquah run return in 1995 was 6.1% and the return in 1996 was 9.3%. While other factors have resulted in higher returns for other watersheds in the past two years, Lake Washington and Issaquah Hatchery are unique in having a dam/navigation channel at the lake/estuary interface. The two parallel hatcheries used in this comparison (without dams downstream) are both adjacent to Lake Washington; Green River to the south, and Skykomish River to the north. The only apparent factor(s) that could explain the major change in survival for Issaquah Creek coho salmon adults returning in 1995 and 1996 is the improvements made at the Ballard Locks. This project (and case-history) is another potential project for the Corps; a request for feasibility funding of a Section 1135 project at the Ballard Locks will be submitted in 1997.

If the improvements at the Ballard Locks can increase smolt and adult survival to equal or exceed systems without water development projects, it bodes well that the AWSP could potentially restore salmon and steelhead runs above HHD. However, it should be noted that unlike HHD, Lake Washington is not a high-head dam and it has a multiple lake/reservoir system that vastly exceeds the length and storage volume of Howard Hanson Reservoir.

We have observed differences in hatchery survival between various Puget Sound hatcheries. These survival rates are not a true indicator of the potential adult returns if the natural self-sustaining runs of salmon and steelhead can be established. It is a generally accepted concept that juvenile to adult survival for hatchery-reared fish is about half the long-term survival rate for wild or natural spawned and reared fish. If natural self-sustaining runs can be established above HHD, and the above relationship holds, then adult returns to the Headwaters watershed could potentially be up to 200-250% greater than the CWT returns indicate.

For example, in Puget Sound, the 18-year average of the three hatcheries discussed above ranges from 4-10.3%, while the 16-18 year average for three wild runs is 15.2-19.2%. The average for the three hatcheries is then 7.6% while the wild-run average is 17.8%, a 234% increase in adult survival. Removing the impoverished returns from Lake Washington and comparing the remaining hatcheries (Soos Creek + Skykomish) to the three wild-runs shows a 190% increase, 9.5% and 17.8% average, respectively (Table 8).

A simple estimation of the potential adult returns for coho salmon from the Headwaters watershed can be approximated by applying the "transportation effect" and potential wild-fish survival rate increase. For example, using the 1993 and 1994 control returns and applying a 25% increase for the "effect" and a 200% increase for potential wild survival provides estimated wild potential as:

Control Release Year	Return Rate	Transportation	Wild	Wild Potential
1993	6.55%	125%	200%	16.38%
1994	0.7%	125%	200%	1.75%

The estimated wild potential adult return for the 1993 coho smolt release falls within the range of other Puget Sound wild-runs (16.38%). The 1994 release survival are still much lower than any of the presented hatchery or wild survival rates (1.75%). Additional unaccounted factors maybe influencing survival of outmigrants from the Headwaters watershed.

TABLE 8. COMPARISON OF ADULT RETURN RATES (TOTAL RUN) FOR THREE PUGET SOUND HATCHERIES AND THREE WILD RUNS (WDFW 1997).

		Hatchery Percent Return			*Wild Stock Percent Return*		
Brood Year	Adult Return Year	Skykomish	Issaquah	Soos Creek	*Big Beef*	*Deschutes River*	*S Fk Skykomish*
1975	1978	3.74%	4.12%	5.0%	13.24%		
1976	1979	3.55%	1.82%	9.8%	16.58%		22.32%
1977	1980	7.52%	1.97%	12.6%	29.07%	21.55%	17.25%
1978	1981	3.17%	2.18%	6.1%	16.97%	21.49%	14.54%
1979	1982	1.43%	6.52%	9.0%	14.66%	20.90%	7.87%
1980	1983	3.47%	3.69%	13.4%	21.61%	27.44%	17.79%
1981	1984	9.51%	3.13%	10.9%	17.47%	23.52%	13.15%
1982	1985	7.22%	4.58%	7.2%	22.32%	19.12%	13.15%
1983	1986	13.37%	9.45%	15.7%	32.16%	26.90%	22.34%
1984	1987	21.53%	11.06%	11.0%	28.76%	29.28%	18.97%
1985	1988	10.78%	8.44%	15.0%	11.06%	28.27%	15.30%
1986	1989	11.28%	5.84%	9.0%	17.93%	10.31%	14.10%
1987	1990	10.38%	0.89%	21.3%	22.54%	16.98%	13.70%
1988	1991	11.19%	1.83%	7.4%	9.83%	6.58%	7.90%
1989	1992	9.42%	0.65%	6.2%	9.01%	13.49%	15.60%
1990	1993	4.69%	0.15%	4.1%	8.90%	3.19%	7.70%
1991	1994	8.31%	0.29%	13.1%	23.50%	18.40%	23.50%
1992	1995	9.62%	6.13%	3.8%			13.70%
	1978-1995 avg.	**8.61%**	**4.04%**	**10.32%**	**18.90%**	**19.16%**	**15.23%**

2E.6 CONCLUSIONS

CONCLUSIONS:

- Preliminary 1993 and 1994 coho returns were analyzed by the Corps against major reservoir physical variables: 1) The radial gates were in operation throughout the 1993 outmigration period. In 1994, the bypass gate was used beginning May 12. This may partially explain the greater differential in between-year survival (1993 vs 1994). 2) Regression analysis revealed a significant relationship between test survival and average inflow (r^2=0.97) and test survival and average outflow (r^2=0.89). and 3) Outlet depth is associated with outflow in explaining project survival (test/control).
- The results of this initial analysis appear to be in agreement with the 1991 and 1992 outmigrant studies (Dilley and Wunderlich 1992, 1993) where outflow explained most variation in daily passage (secondary was outlet depth), and the bypass gate was found to have the highest injury and mortality rates (30% average).

- In addition, it appears to support work by Seiler and Neuhauser (1985) who found that coho emigration stopped when reservoir refill began with outflow releases dropping and switching to the bypass gates.
- AWSP project improvements 1) fish passage, and 2) flow management should greatly improve survival through -- increased outflow, more freshets, an by construction of the high volume, near-surface fish passage facility,
- Results from the study will also be used for future comparison with post-project adult survival/return conditions to verify success of restoration (mitigation) measures.
- The Corps/Tacoma are developing monitoring plans to assess post-project adult survival/return as the feasibility study progresses plans include -- fish passage facility will have PIT-tag sensors, hydroacoustic monitoring equipment, and a sampling station where juveniles can be evaluated.

2E.7 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Aitkin, J.K. 1996. Progress report on the Howard Hanson Project Adult Return Rate Study for CWT coho and chinook salmon, 1994 and 1995. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Johnson, J.K. 1989. Regional overview of coded-wire tagging of anadromous salmon and steelhead in Northwest America. Pacific States Marine Fisheries Commission.

Nielsen, L.A. 1992. Methods of marking fish and shellfish. American Fisheries Society Special Publication 23.

Newman, K., and R. Comstock. 1991. Tests of fishery stock contribution rates based on coded-wire tag recoveries. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Seiler, D., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia.

Seiler, D. 1989.

WDFW. 1997. Puget Sound hatchery and wild coho forecast for 1997. Unpublished data.

APPENDIX A. TABLE A-1. SINGLE FACTOR ANOVA COMPARING RESERVOIR AND DAM PHYSICAL VARIABLES BETWEEN COHO CWT RELEASE GROUPS (RG1 VS RG2 WITHIN-YEAR) AT VARIOUS INTERVALS FOR SIGNIFICANT DIFFERENCES: 7, 14, 21, 28, AND 30 DAY AVERAGES.

Adult Coho CWT Returns

ADULT RETURN TEST	5.60%	0.10%	1.80%	0.03%
ADULT RETURN CONTROL	6.10%	7.80%	0.87%	0.59%
TEST/CONTROL %	**92%**	**23%**	**11%**	**5%**

AVERAGE PHYSICAL VARIABLES AND ANOVA P-VALUES

7-Day Average	**1993 RG1[a]**	**1993 RG2[a]**	**P-VALUE**	**1994 RG1**	**1994 RG2**	**P-VALUE**
OUTFLOW	762.0	1811.1	0.000	778.1	513.9	0.000
DEPTH	91.1	106.4	0.004	88.9	64.0	0.000
REFILL RATE	2381.1	-248.1	0.000	312.9	336.3	0.657
INFLOW	1952.5	1687.1	0.266	934.6	682.0	0.000
ELEVATION	1137.5	1131.7	N/A	1141.0	1139.5	N/A
14-Day Average						
OUTFLOW	1357.3	1342.3	0.950	720.5	415.4	0.000
DEPTH	98.7	105.8	0.022	91.3	65.8	0.000
REFILL RATE	1183.0	5.1	0.010	376.1	385.9	0.831
INFLOW	1948.8	1344.8	0.000	908.6	608.3	0.000
ELEVATION	1137.5	1141.0	N/A	1131.7	1139.5	N/A
21-Day Average						
OUTFLOW	1514.9	1106.8	0.030	651.6	378.2	0.000
DEPTH	101.3	106.0	0.033	83.8	67.7	0.000
REFILL RATE	752.1	47.1	0.036	362.8	374.2	0.746
INFLOW	1891.0	1130.4	0.000	833.1	565.3	0.000
ELEVATION	1137.5	1131.7	N/A	1141.0	1139.5	N/A
28-Day Average						
OUTFLOW	1386.8	1013.9	0.014	567.9	377.8	0.000
DEPTH	102.2	106.0	0.020	79.8	69.2	0.000
REFILL RATE	591.7	2.4	0.020	381.0	304.1	0.046
INFLOW	1682.6	1015.1	0.000	758.4	529.8	0.000
ELEVATION	1137.5	1141.0	N/A	1131.7	1139.5	N/A
30-Day Average						
OUTFLOW	1348.2	1000.6	0.017	550.2	388.3	**N/A**
DEPTH	102.5	106.0	0.020	79.2	69.5	0.000
REFILL RATE	550.4	8.0	0.030	379.3	266.5	0.012
INFLOW	1623.4	1004.6	0.000	739.9	525.5	0.000
ELEVATION	1137.5	1141.0	**N/A**	1131.7	1139.5	**N/A**

a. RG1=Release Group 1, early release during refill; RG2=Release Group 2, later release at full pool.

APPENDIX TABLE A-2. PERCENT EXCEEDANCE FLOW BY HALF-MONTH PERIOD, HOWARD HANSON DAM OUTFLOW, 1964-1995 (SOURCE: CH2MHILL 1997).

	10% Exceedance			25% Exceedance			50% Exceedance			75% Exceedance			90% Exceedance		
CFS	**Baseline**	**Phase I**	**Phase II**	**Baseline**	**Phase I**	**Phase II**	**Baseline**	**Phase I**	**Phase II**	**Baseline**	**Phase I**	**Phase II**	**Baseline**	**Phase I**	**Phase II**
01/01 to 01/15	2596	2596	2596	1561	1561	1561	808	808	808	537	537	537	430	430	430
01/16 to 01/31	4090	4090	4090	2172	2172	2172	1043	1043	1043	675	675	675	484	484	484
02/01 to 02/15	2545	2545	2545	1591	1574	1553	976	976	972	630	629	626	440	437	440
02/16 to 02/28	3441	3340	3192	1647	1546	1387	1065	964	885	697	597	621	529	428	495
03/01 to 03/15	2058	1591	1121	1324	920	601	970	552	491	716	398	483	605	390	476
03/16 to 03/31	1808	1472	951	1225	936	596	854	582	491	671	399	482	568	390	472
04/01 to 04/15	2533	2228	2076	1768	1457	942	1274	989	523	833	552	477	625	416	464
04/16 to 04/30	1846	1941	2211	1407	1482	1749	965	1009	1220	690	673	816	560	479	515
05/01 to 05/15	2242	2627	2608	1484	1970	1876	966	1238	1200	719	957	878	559	636	587
05/16 to 05/31	2189	2325	2377	1527	1789	1747	1037	1136	1082	675	733	717	518	486	527
06/01 to 06/15	1992	1992	1992	1325	1317	1314	812	807	793	530	535	495	358	398	428
06/16 to 06/30	1540	1350	1350	1029	871	865	695	555	517	515	393	399	391	325	350
07/01 to 07/15	849	931	941	546	628	625	368	450	442	295	376	386	260	334	307
07/16 to 07/31	547	629	630	343	425	428	298	380	383	260	340	347	231	308	307
08/01 to 08/15	403	485	417	318	400	396	285	367	366	266	348	342	245	323	309
08/16 to 08/31	379	461	511	307	389	423	282	364	380	256	338	352	242	324	309
09/01 to 09/15	470	552	676	364	446	509	286	368	410	256	338	366	237	320	342
09/16 to 09/30	629	711	792	353	435	516	281	363	429	251	333	377	225	307	347
10/01 to 10/15	663	745	787	426	508	564	297	379	493	246	330	464	215	298	439
10/16 to 10/31	1233	1315	1372	667	749	760	367	449	538	278	359	480	210	296	435
11/01 to 11/15	2611	2611	2646	1445	1444	1492	783	783	827	446	446	496	318	318	371
11/16 to 11/30	2861	2861	2915	1569	1569	1623	1023	1023	1072	667	667	719	433	433	464
12/01 to 12/15	3745	3745	3790	1952	1952	1997	1228	1228	1264	757	757	777	542	542	580
12/16 to 12/31	3037	3037	3093	1542	1542	1598	891	891	947	631	631	687	444	444	500

APPENDIX TABLE A-3. NUMBER OF FLOW EVENTS FROM HOWARD HANSON DAM GREATER THAN OR EQUAL TO 1,800 CFS. ONE FLOW EVENT IS DEFINED AS THE SINGLE CONTINUOUS FLOW EXCEEDING SPECIFIED VALUE WITHOUT REGARD TO DURATION.

	BASELINE						PHASE I						PHASE II					
Year	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total**
1964	1	2	3	2	2	10	1	1	2	3	2	9	0	1	3	2	2	8
1965	3	0	2	0	0	5	3	0	2	2	0	7	4	1	2	1	0	8
1966	0	1	1	1	0	3	0	1	1	3	0	5	0	0	3	2	0	5
1967	4	0	0	2	1	7	4	0	0	5	0	9	4	0	0	3	0	7
1968	2	1	0	0	1	4	2	1	0	0	1	4	2	0	0	0	1	3
1969	0	1	4	2	1	8	0	1	4	3	1	9	0	0	3	2	1	6
1970	1	0	1	3	1	6	1	0	1	4	1	7	1	0	2	4	1	8
1971	2	0	0	3	2	7	2	0	0	3	1	6	2	0	3	3	1	9
1972	2	1	3	2	2	10	2	1	3	3	2	11	2	3	3	2	2	12
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	1	2	3	3	1	10	1	1	2	3	1	8	1	1	2	4	1	9
1975	1	1	0	3	1	6	1	1	0	3	1	6	1	1	0	3	1	6
1976	0	0	2	2	0	4	0	0	2	2	0	4	0	0	2	2	0	4
1977	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0
1979	1	1	2	0	0	4	1	1	1	2	0	5	1	2	2	2	0	7
1980	2	2	3	0	0	7	2	0	3	1	0	6	2	1	2	1	0	6
1981	1	0	2	0	0	3	1	0	2	0	0	3	1	0	2	0	0	3
1982	2	1	0	3	0	6	2	1	0	4	0	7	2	2	1	4	0	9
1983	0	2	0	0	0	2	0	1	0	2	0	3	0	1	2	1	0	4
1984	1	2	1	3	0	7	1	1	0	4	0	6	1	1	2	3	0	7
1985	0	0	2	2	1	5	0	0	3	3	1	7	0	0	2	2	1	5
1986	1	2	0	1	0	4	1	1	0	1	0	3	1	0	0	1	0	2
1987	1	3	2	0	0	6	1	2	2	2	0	7	1	3	2	2	0	8
1988	1	2	1	2	0	6	1	1	2	4	0	8	1	1	2	3	0	7
1989	1	0	2	0	0	3	1	0	2	2	0	5	1	0	2	2	0	5
1990	3	3	3	0	2	11	3	1	1	3	2	10	3	1	3	2	2	11
1991	2	0	1	1	0	4	3	0	1	1	0	5	3	0	1	1	0	5
1992	1	0	1	0	0	2	1	0	1	0	0	2	1	0	1	0	0	2
1993	0	2	2	1	0	5	0	2	1	5	0	8	0	1	3	3	0	7
1994	0	1	0	0	0	1	0	1	0	1	0	2	0	2	3	1	0	6
1995	2	0	0	0	0	2	2	0	0	2	0	4	2	0	1	1	0	4
Total	**36**	**30**	**42**	**36**	**15**	**159**	**37**	**19**	**37**	**73**	**13**	**179**	**37**	**22**	**54**	**57**	**13**	**183**
Average	**1.1**	**0.9**	**1.3**	**1.1**	**0.5**	**5.0**	**1.1**	**0.6**	**1.2**	**2.3**	**0.4**	**5.6**	**1.1**	**0.7**	**1.7**	**1.8**	**0.4**	**5.7**

SECTION 3 HEADWATERS TRIBUTARY STREAM HABITAT

SUBSECTION 3A AVAILABLE TRIBUTARY STREAM AND MAINSTEM HABITAT INUNDATED OR DEGRADED BY DAM CONSTRUCTION OR INUNDATION

3A.1 GENERAL

One of the clearest effects of the construction and operation of Howard Hanson Dam (existing and proposed changes) is the loss of tributary stream and mainstem river habitat -- from building of the dam across the mainstem Green River between 1959 and 1962 to refill of the existing reservoir and the proposed pool raise for the Additional Water Storage Project (AWSP) that seasonally covers miles of stream habitat. However, even with the these effects, the total amount of stream habitat from original dam construction and refill of the existing pool have never been accounted for, nor have means been investigated that could improve remaining stream habitat.

The Water Resource Development Act of 1995 (see EC-1165-2-201), provided a planning authority for the Seattle District to investigate original dam impacts and a means to address and modify these impacts through the Ecosystem Restoration Authority. The AWSP was expanded in 1995 to include Ecosystem Restoration as a project purpose. As such, a limited number of aquatic ecosystem functions affected by the existing project were added to the scope of the AWSP. Stream habitat impacted by original dam construction and existing reservoir inundation was identified as one of three functions/impacts that the AWSP would investigate under restoration with the two other affected functions: 1) connectivity of the Green River watershed above the dam with the lower watershed (downstream fish passage, Section 2), and 2) sediment transport of gravel to cobble sized materials (gravel nourishment, Section 6). Stream inundation associated with the AWSP proposed pool raise was a project purpose originally included in the study and investigated as an adverse impact requiring mitigation. Restoration areas (existing storage) and AWSP impacts (proposed pool raise) requiring mitigation are discussed.

3A.2 INTRODUCTION

Existing data from prior study of Howard Hanson Reservoir tributaries was used to estimate potential stream habitat loss from the existing pool and proposed AWSP pool raise. Additional information for stream lengths below the existing full pool was compiled from large scale topographic maps (Seattle District 1961, 1972). The following report was prepared by the U.S. Fish and Wildlife (USFWS) and describes the details of stream habitat surveys in the AWSP proposed inundation zone and limited surveys in the upper half of the existing inundation zone (*Appendix D; Volume 2*):

- Wunderlich, R.C. and C.M. Toal. 1992. *Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam.* Western Washington Fishery Resource Office, Olympia, Washington.

Provided below is an abbreviated technical discussion of the prior data and results used for the current feasibility study. This discussion includes the stream survey data used, a description of the additional stream lengths below the 1141 ft normal year pool, an analysis of potential habitat quantity and quality changes following dam construction and with the AWSP pool raise, and potential restoration and mitigation measures. Discussion of wetland and riparian area habitat impacts is discussed in the Appendix A: *Wildlife Habitat Mitigation.*

3A.3 USFWS STREAM SURVEY DATA

Much of the existing data from the 1991 USFWS stream surveys was utilized for the current feasibility study. This data consisted of stream surveys of all accessible anadromous stream habitat within the Phase I and Phase II proposed pool raise (1147 to 1177 ft). The specific study objectives were: 1) quantify the amount of tributary rearing and spawning habitat affected by the pool raise; 2) qualitatively assess the value of tributary rearing and spawning habitat affected by the pool raise; and 3) qualitatively assess the impacts of the pool raise on rearing and spawning habitat in the reservoir basin.

Stream surveys in the proposed inundation zone were conducted during spring and late summer to inventory key habitat features important for steelhead and resident trout spawning (spring) and rearing habitat for all anadromous species (late summer). Habitat in the existing inundation zone of each stream (upper 30 ft, 1110-1141 ft elevation, normal year pool) was inventoried to contrast habitat quality in inundated and non-inundated portions of the same stream. Spring habitat survey data collected included: 1) stream widths and depths to approximate potential steelhead spawning area; 2) amount of backwater habitat for winter rearing of coho; and 3) evaluation of potential steelhead barriers (Powers and Orsborn 1985). Late summer surveys (low-flow) were completed using a modified U.S. Forest Service (USFS) stream habitat inventory method (USFS 1990). Streams were classified by habitat unit (pool or riffle), measured for area and depth, and then qualitatively assessed for pool class, substrate type, embeddedness, riparian cover, bank cover, and canopy cover. Total habitat length and area were compiled by stream.

Habitat Suitability Index (HSI) values were estimated for each stream using the USFWS HSI models for chinook salmon (Raleigh et al. 1986), coho salmon (McMahon 1983), rainbow/steelhead trout (Raleigh et al. 1984), and cutthroat trout (Hickman and Raleigh 1982). HSI values for each variable are uniformly scaled on a 0 to 1 basis (0=poorest; 1=best for a given variable). A range of fundamental habitat variables were selected for juvenile and adult life stages. The probable impacts of seasonal inundation of each tributary were assessed by contrasting HSI values for the proposed and existing inundation zones for each life stage.

3A.3.1 Additional Stream Lengths and Area below Existing Full Pool

As the USFWS did not survey stream habitat below the 1110 ft elevation (30 ft below normal year existing full pool, 1141 ft) an estimate of the amount of stream habitat lost under the existing storage pool was calculated from large scale topographic maps: the Seattle District mapped the reservoir basin area at scales of 1 in = 200 ft in 1961, and 1 in = 400 ft in 1972. A planimeter and map wheel were used to measure stream lengths. Late summer habitat area for each stream was estimated by multiplying measured map lengths against average stream widths from the USFWS surveys.

3A.3.2 Flow Modeling to Assess Period of Inundation

Refill scenarios were modeled for Baseline (existing) and AWSP Phase I and Phase II using 32 years of existing flow data: a detailed description of the modeling assumptions, refill parameters, operating rules, computations and model outputs available are provided in *Section 9. Modeling Parameters for Baseline, Phase I, and Phase II.* These refill scenarios included an accounting of the length of time various pool elevations or storage volumes would be exceeded. The period of time pool elevations were exceeded was compared to the measured stream habitat found at various elevations to provide an index of actual habitat loss on an annual basis.

Since this modeling effort, negotiations in the Fall of 1997 resulted in modifications to the proposed project – 1) Phase I was originally planned and modeled to only include drought year storage of the Section 1135 5,000 ac ft; 2) after the negotiations Phase I has been modified to include yearly storage of the 5,000 ac ft. This impact analysis was partially conducted with the original Phase I description and will not be re-assessed.

3A.4 STREAM HABITAT QUANTITY IMPACTED UNDER EXISTING AND ADDITIONAL WATER STORAGE

An estimate of total tributary stream habitat impact (length and area) under existing and AWSP was made from the USFWS stream survey and Corps topographic map data. This estimate provides for no assessment of habitat quality pre- or post-construction of the existing and proposed project. Impacts related to the existing pool and proposed pool raise are discussed in relation to pool elevation (Table 1). Two distinctions in pool elevation are made based on water year. Normal year and drought years vary in pool elevation for the existing and AWSP Phase I. The existing normal year pool elevation, 1141 ft, has occurred every year since inception of the project and the existing drought year (and debris clearing) pool elevation, 1147 ft, has only occurred since 1988. For debris-clearing purposes, the drought year pool elevation is reached every year (since 1988) but is held for only two weeks. During drought years, generally defined as 1 in 5 years, the existing pool is held for up to 2 months using the extra storage to maintain minimum instream flows. The AWSP Phase I normal pool elevation, 1162.5 ft, is met every year, while the AWSP Phase I drought year pool elevation, 1167 ft, is met about 1 in 5 years to maintain minimum instream flows. Pool area comparison for the 1070 ft turbidity pool, the 1141 ft normal year pool, and the AWSP Phase II pool is shown in Figure 1. Areal differences between the 1141 ft pool and AWSP Phase I and AWSP Phase II pools are shown in Figures 2 and 3.

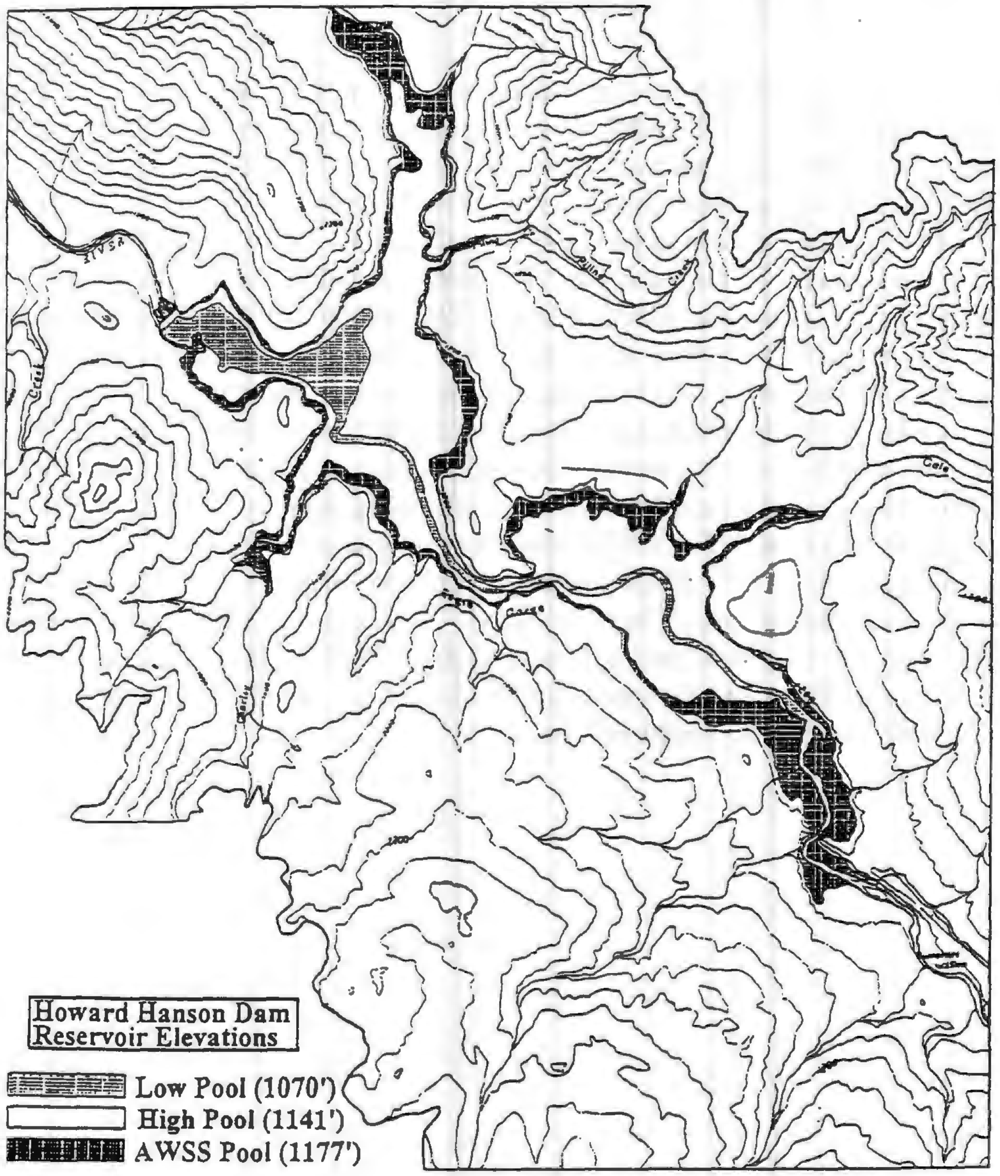


FIGURE 1. POOL AREA COMPARISON OF LOW POOL OR TURBIDITY POOL, TO THE EXISTING FULL POOL OR NORMAL YEAR POOL, AND THE AWSP PHASE 2 POOL.

Areal differences between the 1141 ft pool and AWSP Phase 1 and AWSP Phase 2 pools are shown in Figures 2 and 3.

TABLE 1. DEFINITION OF RESERVOIR POOL ELEVATION LOCATIONS AND RELATION TO TRIBUTARY STREAM INUNDATION.

Vertical Elevation (ft)	Total Storage Volume (ac ft)[a]	Locality	Relation to Tributary Inundation
1015		Outlet of Radial Gates	
1035		Inlet of Radial Gates	
1015-1035			Length of stream covered by dam construction
1070	1200	Turbidity Pool Elevation and Bypass Gate Inlet	
1035-1070			Length of stream inundated by turbidity pool
1141	25400	Normal Year Existing Full Pool Elevation	
1070-1141			Length of stream inundated by existing pool
1147	30400	Drought Year (Section 1135) Pool Elevation	
1141-1147			Length of stream inundated by drought year pool raise and for annual debris clearing
1162.5	45400	Normal Year AWSP Phase I Pool Elevation	
1167	50400	Drought Year AWSP Phase I Pool Elevation	
1147-1167			Length of stream inundated by Phase I pool raise
1177	62400	AWSP Phase IIPhase II Pool Elevation	
1167-1177			Length of Stream inundated by Phase II pool raise

a. Total storage volume differs from active storage. The turbidity pool is considered "dead" or unusable storage so active storage is the difference of total minus dead storage.

3A.4.1 Existing and Additional Water Storage Instream Habitat Quantity Impacts

Existing Inundation Pool. Howard Hanson Dam was built at river mile (RM) 64.5 on the Green River and extends from elevation 1015 ft (dam outlet) to 1035 ft (radial gate inlet). Approximately 0.2 miles of mainstem channel length was permanently channelized through the radial gates and conduits. Since 1962, the Corps has maintained a small storage pool behind the dam to capture suspended sediment during high flow events (turbidity pool). Through time, as more sediment has accumulated behind the dam, the turbidity pool has increased in size from virtually no pool (1035 ft, 0 surface acres) to its current size (1070 ft elevation, 100 ac) (Figure 4). This is the minimum operating pool and is maintained year-round. The turbidity pool now covers about 1.8 miles or 19.6 acres of total stream habitat which includes 1.5 miles of mainstem channel length (Table 2).

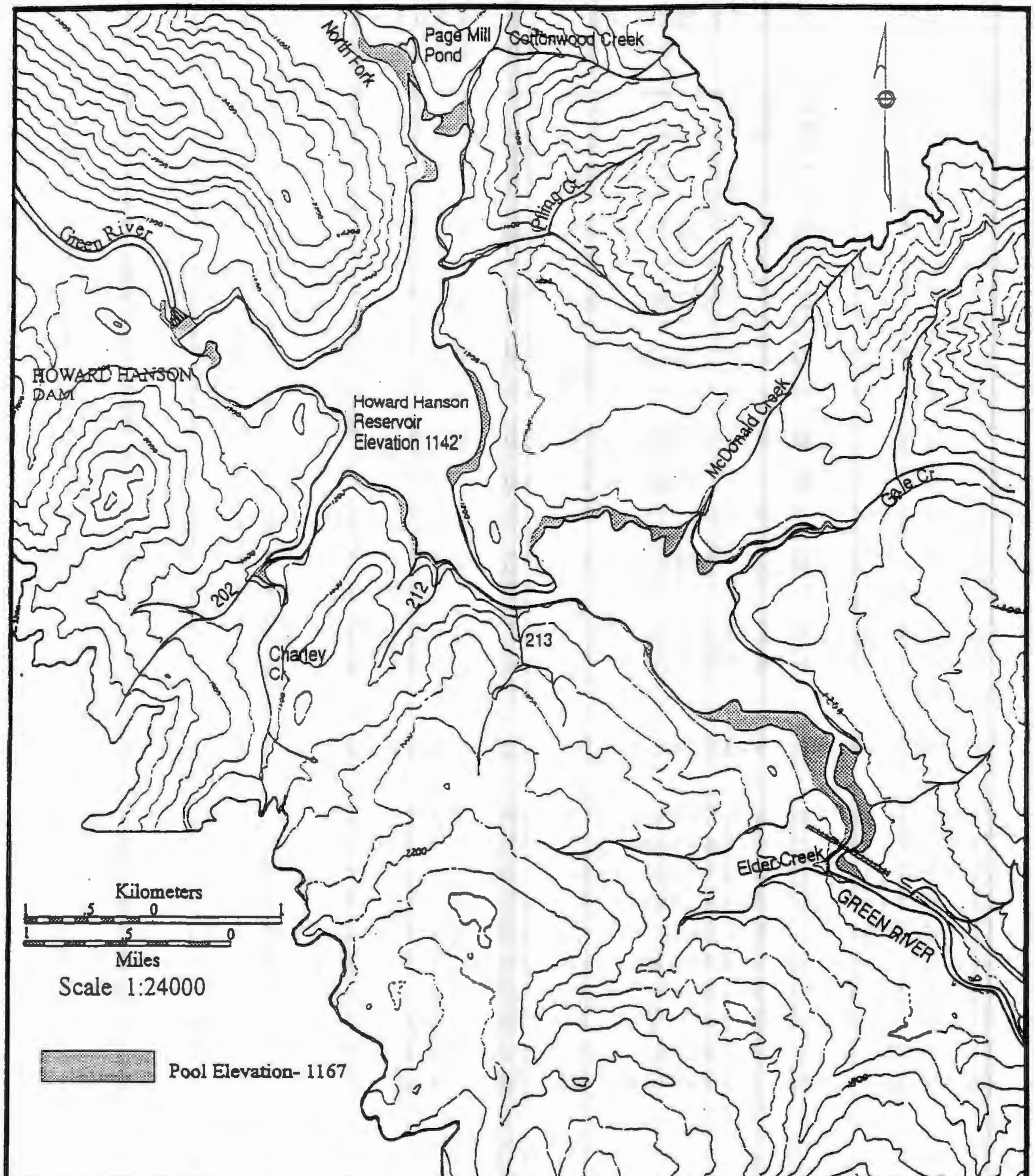


FIGURE 2. COMPARISON OF EXISTING FULL POOL, 1141 FT ELEVATION, TO THE AWSP PHASE I DROUGHT YEAR POOL, 1167 FT.

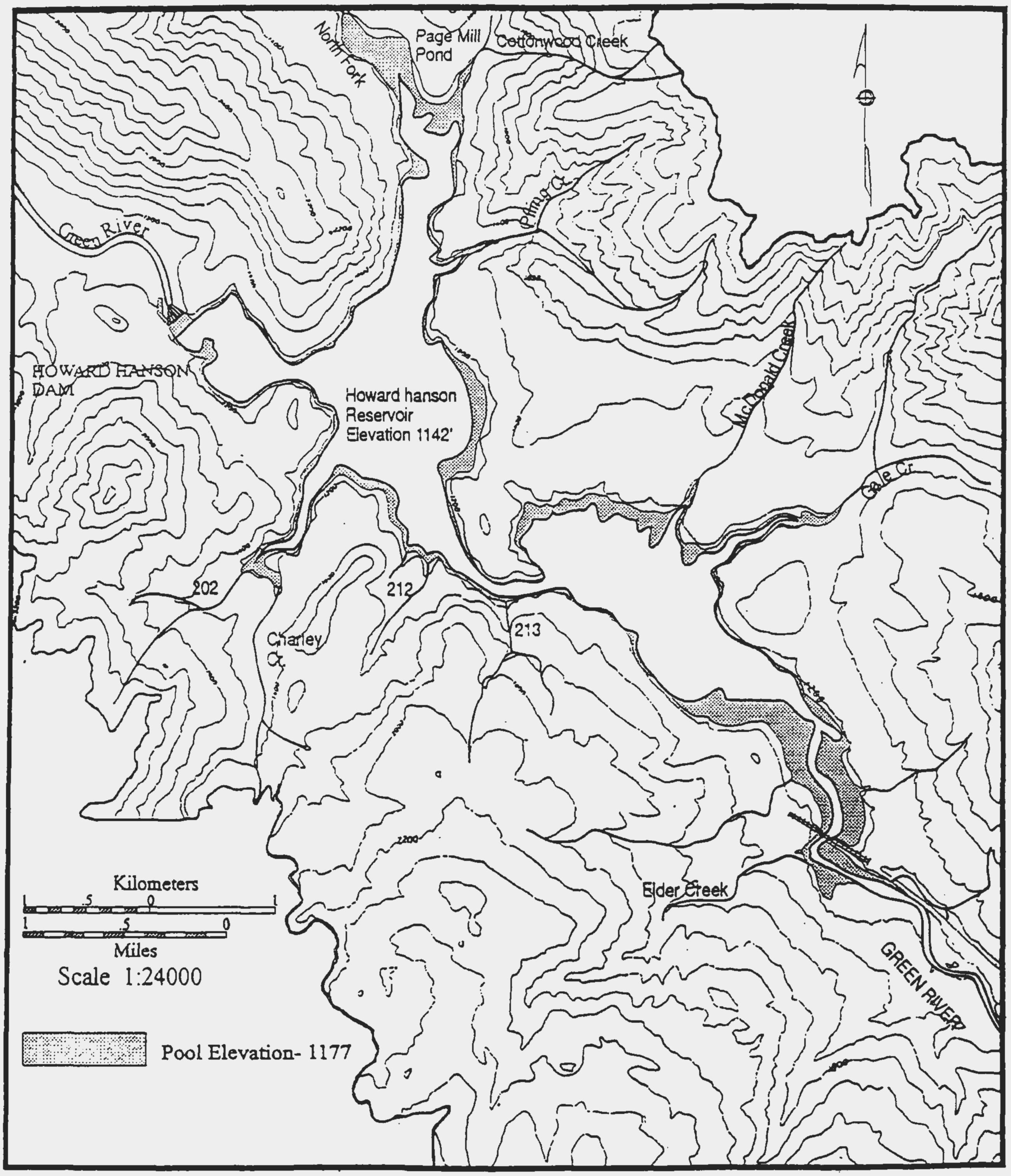


FIGURE 3. COMPARISON OF EXISTING FULL POOL, 1141 FT ELEVATION, TO THE AWSP PHASE II FULL POOL, 1177 FT.

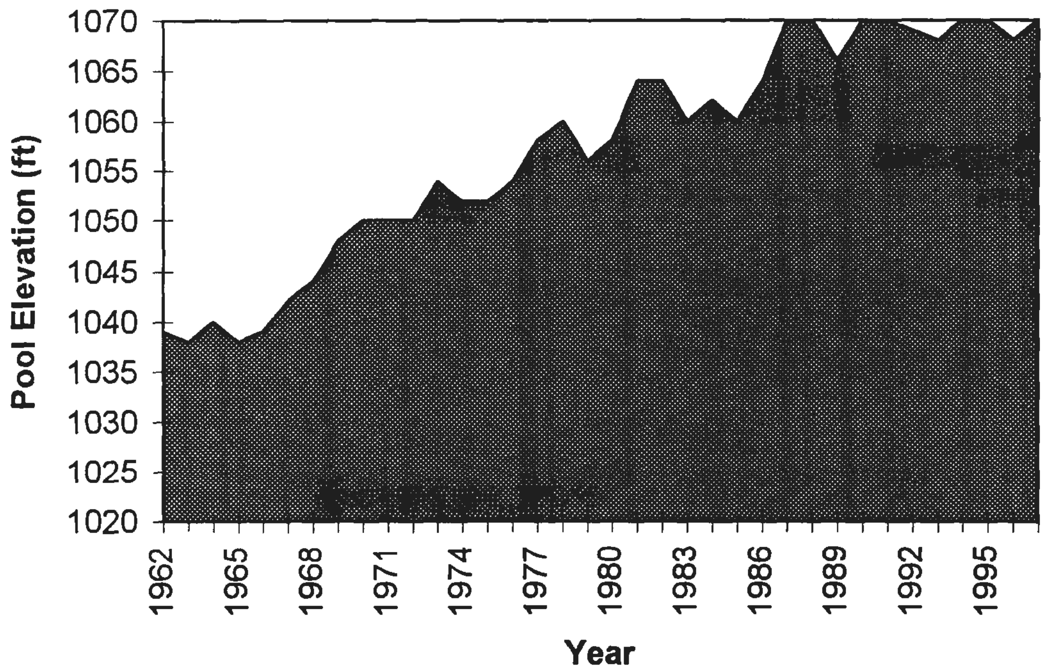


FIGURE 4. CHANGE IN LOW POOL, TURBIDITY POOL, ELEVATION FROM 1962 TO 1996.

From the first year of dam operation, 1962, to 1988, the existing reservoir was normally filled to a pool elevation of 1141 ft. This annual filling of the pool seasonally inundated 5.2 miles or 34.1 acres of total stream habitat which includes 2.8 miles of mainstem channel length. Since 1988, the existing pool was filled to elevations greater than 1141 ft, up to 1147 ft, for one of two reasons, annual debris-clearing and flow augmentation during drought years. The annual debris clearing is short in duration, lasting approximately two weeks, where the pool is raised to a higher elevation. Floating large woody debris (stumps and logs) that have accumulated during the previous winter high flows are collected, hauled, stored in a clearing area, and handled once the pool has dropped to 1141 ft. During drought years, 1992 is the first and only year to date, the pool is brought to the 1147 ft elevation, and provides up to an additional 5,000 ac ft of storage for flow augmentation. Drought year storage is discussed in detail in the Howard Hanson Dam Section 1135 Project Management Report. The short and long term inundation of the pool from 1141 to 1147 ft covers 0.5 miles or 3.1 acres of total stream habitat, including 0.2 miles of mainstem channel length (Table 2).

TABLE 2. SUMMARY OF RESERVOIR TRIBUTARY-STREAM IMPACT FOR EXISTING AND AWSP BY A) LINEAR CHANNEL LENGTH INUNDATED (FT); AND B) LATE SUMMER SURFACE AREA INUNDATED (SQUARE FT): COLUMNS TO LEFT OF BOLD VERTICAL LINE ARE EXISTING DAM IMPACTS, TO THE RIGHT ARE AWSP.

Stream Length Inundated (ft) by Vertical Pool Elevation

Stream Name	WRIA	1015-1035	1035-1070	1070-1141	1141-1147	1147-1167	1167-1178	Stream Total
Large Tributaries								
Green River	90001	900	7970	14810	1105	4232	2130	**31147**
North Fork Green River	90183		1300	4860	357	1216	669	**8402**
Charley Creek	90201		280	2410	191	640	352	**3873**
Gale Creek	90216			1584	346	1160	633	**3723**
Page Creek	none				303	1015	508	**1826**
Elder Creek	90221					90	144	**234**
Large Tributary Subtotal		**900**	**9550**	**23664**	**2302**	**8353**	**4436**	**49205**
Small Tributaries								
Cottonwood Creek	90197			864	202	676	339	**2081**
Piling Creek	90199			1300	105	352	194	**1951**
Unnamed	90202				43	145	73	**261**
McDonald Creek	90215			1465	121	406	223	**2215**
Unnamed	90212				54	182	91	**327**
Unnamed[a]	90213							
Small Tributary Subtotal		**0**	**0**	**3629**	**525**	**1761**	**920**	**6835**
Totals in Linear Feet		**900**	**9550**	**27293**	**2827**	**10114**	**5356**	**56040**
Totals in Linear Miles		**0.2**	**1.8**	**5.2**	**0.5**	**1.9**	**1.0**	**10.6**

Late Summer Stream Surface Area Inundated (ft^2) by Vertical Pool Elevation

Stream Name	WRIA	1015-1035	1035-1070	1070-1141	1141-1147	1147-1167	1167-1177	Stream Total
Large Tributaries								
Green River	90001	90000	797000	1169990	98787	378341	190422	**2724540**
North Fork Green River	90183		48100	179820	11388	38790	21341	**299440**
Charley Creek	90201		9324	80253	5873	19680	10824	**125954**
Gale Creek	90216			27431	7612	25520	13926	**74489**
Page Creek	none				7939	26593	13310	**47841**
Elder Creek	90221					1800	2880	**4680**
Large Tributary Subtotal		**90000**	**854424**	**1457494**	**131599**	**490724**	**252703**	**3276944**
Small Tributaries								
Cottonwood Creek	90197			6048	1414	4732	2373	**14567**
Piling Creek	90199			13325	1076	3608	1989	**19998**
Unnamed	90202				340	1146	577	**2062**
McDonald Creek	90215			7095	593	1989	1093	**10770**
Unnamed	90212				238	801	400	**1439**
Unnamed	90213							
Small Tributary Subtotal		**0**	**0**	**26468**	**3660**	**12276**	**6431**	**48835**
Totals in Square Feet		**90000**	**854424**	**1483962**	**135260**	**503000**	**259134**	**3325780**
Totals in Acres		**2.1**	**19.6**	**34.1**	**3.1**	**11.5**	**5.9**	**76.3**

a. Nonanadromous fish stream.

AWSP Phase I and Phase II Proposed Pool Raise. Under implementation of the entire AWSP, initiation of Phase I is scheduled for the year 2003 and would continue for 5 years. As originally planned, Phase I would store an additional 20,000 ac ft beyond the existing 25,400 ac ft stored in normal years, and 30,400 ac ft stored in drought years, or a total of 45,400 ac ft and 50,400 ac ft, respectively: during Fall of 1997, agency negotiations resulted in a change in Phase I where the 5,000 ac ft of Section 1135 water would be stored yearly instead of 1 in 5 years. As originally planned, this additional storage would raise the normal year full-pool elevation from 1141 ft to 1162.5 ft, and the drought year pool from 1147 ft to 1167 ft: following Fall 1997, the pool raise is from 1147 ft to 1167 ft, we describe the change here but impact analysis will depend on the original definition. Phase I additional storage would cover over 1.9 miles or 11.5 acres of total stream habitat, including 0.8 miles of mainstem channel length. Phase II of the AWSP as proposed would begin 5-8 years following Phase I (dependent on agency consensus and evaluation of monitoring results) in about year 2008 and continue for 45 years until the completion of the project in the year 2053. Phase II would store annually 32,000 ac ft beyond the existing normal year volume, and would store 12,000 ac ft beyond the Phase I drought year volume for a total of 62,400 ac ft. This additional storage would raise the full pool from 1167 ft in Phase I to 1177 ft in all years. Phase II additional storage would inundate an additional 1.0 miles or 5.9 acres of total stream habitat beyond Phase I inundation, including 0.4 miles of mainstem channel length (Table 2).

Total linear stream distance and area inundated. There is a total of 10.6 miles and 76.3 acres of total stream habitat impacted either by dam construction, existing pool inundation or proposed pool inundation. Broken down by existing and total AWSP (Phase I and Phase II):

- Existing storage and dam construction have covered permanently or seasonally 7.7 miles (73% of total) and 58.9 (77%) acres of stream habitat.
- AWSP would inundate 2.9 miles (27% of total) and 17.4 acres of stream habitat (23%): 1.9 miles and 11.5 acres during Phase I and 1.0 miles and 5.9 acres during Phase II.
- Classified by tributary type, large or small, 90% of all stream habitat impacted is mainstem and large tributaries. Large tributary and mainstem inundation represents 83% of all stream miles covered by the AWSP.

3A.4.2 Inundation Duration

Baseline Period of Inundation. Flow modeling applied general refill conditions used during the 1996 spring refill with some specific additions to hindcast baseline conditions through the 32 years of available flow records. A summary of the duration of pool inundation for 2 pool elevations is listed in Table 3. As described above, the turbidity pool is held at 1070 ft elevation year round. Thus, the 1.8 miles of stream habitat located at or below this elevation is permanently inundated and no longer available as functioning stream habitat. For the 5.2 miles of stream habitat between pool elevations 1070-1141 ft, the duration of inundation is progressive with lower elevation streams covered for a longer period than lower elevations. The average total length of time the pool is held at or above elevation 1141 ft, is 79 days, with May 13 the first day during refill equaling 1141 ft and July 30 the last date the pool was above this elevation. All 5.2 miles of stream between 1070-1141 ft are covered at least 79 days (streams at or near 1141 ft) with the duration increasing to 210 days or more for streams at or below 1100 ft elevation (not provided in Table 3). Lastly, there is an average 20 days of inundation for the 0.5 miles of stream found from 1141 to 1147 ft elevation: the pool never exceeds 1147 ft.

TABLE 3. FIRST DAY, TOTAL DAYS, AND LAST DAY HOWARD HANSON RESERVOIR REACHED VARIOUS POOL ELEVATIONS FOR AWSP BASELINE MODELED FLOW YEARS 1964-1995: FIRST, TOTAL, AND LAST DAY IS REPORTED BY 1) AVERAGE OF 32 YEARS; 2) MINIMUM OR FIRST DATE REACHED IN ANY YEAR; AND 3) MAXIMUM OR LAST DAY REACHED FOR ANY YEAR.

Pool Elevation (ft)	Active Storage Storage (ac ft)		First Day	Total Days [a]	Last Day	Years Not Reaching Storage Volume
1141	24200	Average	14-May	71	24-Jul	
		First Date	11-May	36	30-Jun	
		Last Date	26-May	97	15-Aug	
1147	29100	Average	26-May	20	15-Jun	
		First Date	22-May	0	14-Jun	1987
		Last Date	14-Jun	39	30-Jun	

a. Total days=length of time at a pool level: average is 32 year average; first date is minimum length for any year; last date is maximum length for any year.

<u>AWSP Phase I Period of Inundation.</u> Specific refill rules were used to model Phase I conditions by hindcast through the 32 years of available flow records. A summary of length of pool inundation for 6 pool elevations is listed in Table 4. Stream sections at or below 1100 ft elevation are inundated up to 260 days from March 1 to November 15 (not included in Table 4). The average total length of time the pool is held at or above elevation 1141 ft is 163 days with March 30 the first day during refill equaling 1141 ft and September 8 the last date the pool was above this elevation. The stream habitat found between elevation 1141 and 1147 ft is inundated an average of 143 days beginning on April 6 and continuing through August 26. The stream habitat found between 1147-1162.5 ft is inundated an average of 55 days beginning on April 8 and continuing through August 25. The 1167 ft elevation is only reached in dry years. The existing database identified dry years on May 1 are 1977, 1978, 1981, 1987, 1991, and 1992. For these years, the average length of inundation was 5 days.

TABLE 4. FIRST DAY, TOTAL DAYS, AND LAST DAY HOWARD HANSON RESERVOIR REACHED VARIOUS POOL ELEVATIONS FOR AWSP PHASE I MODELED FLOW YEARS 1964-1995: FIRST, TOTAL, AND LAST DAY IS REPORTED BY 1) THE AVERAGE OF 32 YEARS; 2) MINIMUM OR FIRST DATE REACHED IN ANY YEAR; AND 3) MAXIMUM OR LAST DAY REACHED FOR ANY YEAR.

Pool Elevation (ft)	Active Storage Storage (ac ft)		First Day	Total Days	Last Day	Years Not Reaching Storage Volume
1141	24200	**Average**	30-Mar	163	8-Sep	
		First Date	27-Mar	139	30-Aug	
		Last Date	21-Apr	173	19-Sep	
1147	29100	**Average**	6-Apr	143	26-Aug	
		First Date	3-Apr	120	14-Aug	
		Last Date	27-Apr	156	6-Sep	
1150	31800	**Average**	10-Apr	132	19-Aug	
		First Date	7-Apr	110	6-Aug	
		Last Date	30-Apr	141	30-Aug	
1160	41600	**Average**	27-Apr	78	17-Jul	
		First Date	23-Apr	0	9-Jul	1992
		Last Date	24-May	96	31-Jul	
1162.5	44200	**Average**	1-May	55	2-Jul	
		First Date	28-Apr	0	19-May	1992
		Last Date	30-May	83	20-Jul	
1167	49200	**Average**	17-May	5	19-Jun	
		First Date	8-May	0	19-May	
		Last Date	12-Jun	46	30-Jun	

AWSP Phase II Period of Inundation. Specific refill rules were used to model Phase II conditions by hindcast through the 32 years of available flow records. A summary of length of pool inundation for 8 pool elevations is listed in Table 5. Stream sections at or below 1100 ft elevation are inundated up to 275 days from March 1 to November 15 (not included in Table 4). The average total length of time the pool is held at or above elevation 1141 ft is 198 days with March 23 the first day during refill equaling 1141 ft and October 8 the last date the pool was above this elevation. Stream habitat found between elevation 1141 and 1147 ft is inundated an average of 183 days beginning on March 27 and continuing through September 20. The 1.9 miles of stream habitat between 1147-1167 ft is inundated at least an average of 116 days beginning on April 13 and continuing through August 13. The 1.0 mile of stream habitat between 1167 to 1177 ft is annually inundated on average 51 days beginning April 14 and continuing through June 21.

TABLE 5. FIRST DAY, TOTAL DAYS, AND LAST DAY HOWARD HANSON RESERVOIR REACHED VARIOUS POOL ELEVATIONS FOR AWSP PHASE II MODELED FLOW YEARS 1964-1995: FIRST, TOTAL, AND LAST DAY IS REPORTED BY 1) THE AVERAGE OF 32 YEARS; 2) MINIMUM OR FIRST DATE REACHED IN ANY YEAR; AND 3) MAXIMUM OR LAST DAY REACHED FOR ANY YEAR.

Pool	Active Storage					Years Not Reaching
Elevation (ft)	Storage (ac ft)		First Day	Total Days	Last Day	Storage Volume
1141	24200	Average	23-Mar	198	6-Oct	
		First Date	13-Mar	161	17-Sep	
		Last Date	26-Apr	212	10-Oct	
1147	29100	Average	27-Mar	183	20-Sep	
		First Date	17-Mar	130	24-Aug	
		Last Date	4-May	198	30-Sep	
1150	31800	Average	30-Mar	175	19-Sep	
		First Date	18-Mar	114	16-Aug	
		Last Date	11-May	192	25-Sep	
1160	41600	Average	8-Apr	141	31-Aug	
		First Date	25-Mar	0	4-Aug	1992
		Last Date	26-Jun	166	6-Sep	
1162.5	44200	Average	8-Apr	132	25-Aug	
		First Date	27-Mar	0	8-Aug	1973, 1992
		Last Date	23-May	158	1-Sep	
1167	49200	Average	13-Apr	116	13-Aug	
		First Date	30-Mar	0	29-Jul	1973, 1992
		Last Date	5-Jun	145	22-Aug	
1170	52700	Average	14-Apr	103	4-Aug	
		First Date	1-Apr	0	21-Jul	1973, 1978, 1992
		Last Date	9-Jun	137	15-Aug	
1177	61200	Average	22-Apr	51	21-Jun	
		First Date	7-Apr	0	13-May	1973, 1978, 1992
		Last Date	13-Jun	85	30-Jun	

AWSP Increasing Duration of Inundation for Lower Elevations. The length of inundation of the additional water storage in Phase I and Phase II over Baseline on lower elevation stream habitat is additive. The greatest percentage increase occurs for stream habitat between 1100-1141 ft.

- The length of pool inundation for stream habitat near or at the Phase I normal year pool elevation (1162.5 ft) goes from 55 days under Phase I to 132 days (240% increase) under Phase II.
- The duration of inundation for stream habitat near or at the existing full pool elevation 1141 ft goes from 71 days under Baseline to 163 days under Phase I (229% increase) to 198 days under Phase II (278%).

- Stream habitat at or below 1100 ft elevation is inundated 210 days under Baseline and increases to 260 days under Phase I (124% increase) and 275 days under Phase II (131%).

3A.5 CHANGES IN INSTREAM AND RIPARIAN HABITAT QUANTITY AND QUALITY

USFWS Measured Change in Habitat Under Existing Storage. Beyond the actual period of time free flowing stream habitat is covered by the stored water in the reservoir, there are quantitative and qualitative changes that have occurred to instream and riparian habitat. Some of these changes are a result of original land clearing of the reservoir in 1959 and 1960. The USFWS measured a variety of stream and riparian habitat variables in sections of the existing inundation zone and the proposed AWSP inundation zone (now freeflowing or uninundated) to compare changes between inundated and uninundated stream habitat. Table 6 summarizes the measured decline (quantitative and qualitative) in habitat suitability for 7 habitat variables in 5 tributaries of Howard Hanson Reservoir. The HSI multiplicative score for the freeflowing sections varied from 0.64-0.93 while the HSI for the inundated sections varied from 0.27-0.54. This results in an unweighted average decline of 53% in HSI value from uninundated to inundated stream habitat. For individual habitat HSI's, the largest declines occurred between uninundated and inundated in backwater pool (100%), riparian habitat (78%), and bank cover (61%).

TABLE 6. MEASURED DECLINE IN HABITAT SUITABILITY (HSI VALUE, 0-1) FOR SEVEN STREAM VARIABLES FOR STREAM SEGMENTS INUNDATED (EXISTING NORMAL YEAR INUNDATION ZONE 1110-1141 FT) AND THE FREEFLOWING OR UNINUNDATED (PROPOSED POOL RAISE 1147-1177 FT): INUN=EXISTING INUNDATION; UNINUN=PROPOSED INUNDATION.

	Inundated	Freeflowing	Inundated	Freeflowing	Inundated	Freeflowing	Inundated	Freeflowing
Green River	0.75	1	0.6	1	1	1	0.2	1
North Fork Green River	0.5	1	0.2	0.6	0.6	1	0.2	0.5
Charlie Creek	1	1	0.2	0.6	0.6	1	1	1
Gale Creek	0.5	1	0.6	1	0.6	1	0.2	1
Stream 215	0.75	1	0.2	0.6	0.6	0.2	0.2	0.2
	Instream Cover		**Percent Pools**		**Pool Class**		**Percent Fines**	

	Inundated	Free flowing	Inundated	Free flowing	Inundated	Free flowing	Inundated	Free flowing	Percent Decline
Green River	0.1	0.5	0.5	1	0	0.3	0.45	0.83	46%
North Fk Green River	0.2	0.9	0.2	0.9	0	1	0.27	0.84	68%
Charlie Creek	0.5	1	0.5	1	0	0.3	0.54	0.84	36%
Gale Creek	0.1	1	0.2	1	0	0.5	0.31	0.93	67%
Stream 215	0.1	1	0.5	1	0	0.5	0.34	0.64	47%
	Riparian		**Bank Cover**		**Backwater**		**Multiplicative Summary Score**		

Pool habitat is one of the most important instream features necessary to maintain anadromous salmonid populations. Pools are used by virtually all life stages of salmon and steelhead, from adult holding during upstream migration, to spawning in tailcrest areas, to fry rearing along shorelines, to juvenile rearing throughout the water column. The USFWS did not explicitly compare two measures of pool value, pool/riffle ratio (quantity) and pool class (quality), but did provide data values. Table 7 compares these two pool values between uninundated and inundated stream sections of 4 large tributaries. There was an average decline in quantity (pool/riffle) of 50% and quality (class) of 75% from the uninundated to inundated sections.

TABLE 7. DECLINE IN AVERAGE MEASURED POOL VALUE (QUANTITY AND QUALITY) FOR INUNDATED STREAM SEGMENTS (EXISTING NORMAL YEAR INUNDATION 1111-1141 FT) TO FREEFLOWING STREAM SEGMENTS (PROPOSED POOL RAISE 1147 TO 1177 FT): POOL/RIFFLE=RATIO OF POOLS TO RIFFLES; POOL CLASS=PERCENT OF POOLS AS FIRST CLASS.

	Inundated		Freeflowing		Percent Decline	
	Pool/Riffle	Pool Class	Pool/Riffle	Pool Class	Pool/Riffle	Pool Class
Green River	32%	56%	55%	100%	42%	44%
North Fk Green	13%	0%	28%	86%	54%	100%
Charlie Creek	8%	0%	32%	86%	75%	100%
Gale Creek	30%	25%	42%	58%	29%	57%
					Quantity	Quality

3A.6 INDEX SCORE OF TOTAL HABITAT CHANGE

Previously, a simple total of lineal miles or feet and acres of low-flow habitat for existing and AWSP inundation was provided in Section 3A.4.1. The modeled length of habitat inundation was discussed in Section 3A.4.2. The section above (3A.5.1) provided a measured comparison of habitat quantity and quality change from inundation under existing storage. An index of habitat change was calculated for the total stream habitat impacted by the existing dam and pool and the AWSP. The index is a simple multiplicative model of: 1) proportion (0-1) of total stream length by elevation; 2) period of uninundation (0-1), and 3) HSI multiplicative score (from Table 6). Changes in HSI scores from the AWSP pool raise were a simple application of the measured change. Stream sections at elevations from 1141-1177 ft were lowered from the 0.82 HSI for freeflowing to the 0.38 HSI for uninundated. HSI scores for the 1070-1141 ft elevations were decreased by the measured percentage (53%) from uninundated to inundated discussed above.

There are three comparisons of the total index score: 1) Uninundated to Baseline or Existing; 2) Baseline to Phase I; and 3) Baseline to Phase II. Calculated scores are shown in Table 8. Original dam impacts are summarized by comparing Uninundated to Baseline, which shows a total habitat change or decline of 54% (0.82 to 0.38). Impacts from the AWSP pool raise show a decline of from Baseline to Phase I of 51% (0.38 to 0.18) and decline of 69% for Baseline to Phase II (0.38 to 0.1).

TABLE 8. INDEX SCORE OF CUMULATIVE IMPACTS FROM POOL INUNDATION FOR BASELINE(EXISTING DAM INUNDATION), PHASE I, AND PHASE II AWSP PROPOSED POOL RAISE.

Pool Elevation (ft)	Stream Length	Percent of Year Stream is Uninundated	HSI Multiplicative Score	Summary Score
Uninundated Habitat Score				
1015-1070	0.19	1.00	0.82	0.15
1070-1141	0.49	1.00	0.82	0.40
1141-1147	0.05	1.00	0.82	0.04
1147-1167	0.18	1.00	0.82	0.15
1167-1177	0.09	1.00	0.82	0.08
			Total Score	**0.82**
Baseline Inundation Habitat Score				
1015-1070	0.19	0.00	0.00	0.00
1070-1141	0.49	0.62	0.38	0.11
1141-1147	0.05	0.95	0.82	0.04
1147-1167	0.18	1.00	0.82	0.15
1167-1177	0.09	1.00	0.82	0.08
			Total Score	**0.38**
Phase I Habitat Score				
1015-1070	0.19	0.00	0.00	0.00
1070-1141	0.49	0.42	0.21	0.04
1141-1147	0.05	0.61	0.38	0.01
1147-1167	0.18	0.80	0.38	0.05
1167-1177	0.09	1.00	0.82	0.08
			Total Score	**0.18**
Phase II Habitat Score				
1015-1070	0.19	0.00	0.00	0.00
1070-1141	0.49	0.35	0.21	0.04
1141-1147	0.05	0.50	0.38	0.01
1147-1167	0.18	0.59	0.38	0.04
1167-1177	0.09	0.86	0.38	0.03
			Total Score	**0.1**

3A.7 IMPACTS TO RIPARIAN AND WETLAND AREAS

The total lineal and areal extent of impacts to stream habitats has been discussed, however riparian and wetland areas outside of the adjacent stream corridor have not been previously reviewed by the USFWS. The ability of the inundated areas to support vegetation is dependent on the depth and duration of inundation, especially during the growing season. Studies conducted in other lakes and reservoirs suggest certain willow varieties can tolerate inundation depths of up to four feet. However, most species present along and above the drought year pool line (1147 ft elevation) are not inundation tolerant. An analysis of vegetation types using GIS shows Phase I would impact 80 acres of existing emergent wetland habitat, 6 acres of forested wetland, and 2 acres of scrub wetland. Phase II would impact 5 acres of existing emergent wetland habitat, 5 acres of forested wetland, 1 acre of shrub-scrub wetland and would inundate 4 acres of sedge planted for Phase I emergent wetland mitigation. Mitigation plans for selected wetland types are discussed In the Wildlife Mitigation Plan. Within 2 years of inundation, most existing riparian vegetation, sedges to trees, will have died, and in 5-10 years vegetation still standing will only be providing marginal value for riparian functions and maintaining instream habitat.

Riparian Area Estimate Using Buffer Widths. Riparian habitat loss is represented by length of stream habitat loss, 10,110 ft Phase I, and 5356 ft in Phase II and the horizontal width of riparian zones bordering the streams. Based on regulatory definition, a riparian area habitat loss could be considered a measurement dependent on the authority used to define an acceptable riparian buffer. Under federal land management authority, FEMAT, the required width of riparian buffer strips for federal lands (Forest Service and Bureau of Land Management) on large streams and rivers (such as the Green River) is 300 ft going down to 25 ft on small tributaries. Under state authority, Washington State Forest Practices Act (FPA), buffer strips of __ ft for large streams and rivers and __ ft on small stream is recommended on state and private lands. The Tacoma Forest Land Management Plan has more restrictive requirements than the FPA, with riparian areas defined as natural zones and conservation zones. All lands within AWSP project pool raise are City of Tacoma Forest Lands. The recommended buffer strips on these lands is defined by the size of stream and whether they are fish bearing or not (Table 9). Bankfull width was provided for tributary areas within the HHD AWSP inundation zone (Wunderlich and Toal 1992).

TABLE 9. INTERIM REQUIRED RIPARIAN BUFFER WIDTHS ON STREAMS FOUND ON CITY OF TACOMA LANDS (TACOMA FOREST LAND MANAGEMENT PLAN 1996).

Forest Land Buffer Widths

Stream Type	Bankfull Width	Required Riparian Buffer Width
Type 1	> 100 ft	200 ft
Type 1 and 2	> 75 ft	150 ft
Type 1 and 2	< 75 ft	100 ft
Type 3	> 5 ft	75 ft
Type 3	< 5 ft	50 ft
Type 4	Non-fish bearing	25 ft

TABLE 10. HHD TRIBUTARY STREAM BANKFULL WIDTHS (WUNDERLICH AND TOAL 1992), APPLIED TACOMA FOREST LANDS BUFFER STRIPS, AND RESULTING AFFECTED RIPARIAN AREA.

			AWSP Affected Area		
Stream	Bankfull Width	Tacoma Land Buffer Width	Phase I area (ac)	Phase II area (ac)	Total Area
Green River	150-250 ft	200 ft	38.9	19.6	58.5
North Fork	72-160 ft	200 ft	11.2	6.2	17.4
Page Creek	60-200 ft	150 ft	7	3.5	10.5
Charlie Creek	32-79 ft	150 ft	4.4	3.2	7.6
Gale Creek	75-120 ft	150 ft	8	4.4	12.4
Elder Creek	>75 ft	150 ft	0.6	1	1.6
Cottonwood Cr.	25-45 ft	100 ft	3.1	1.6	4.7
Piling Creek	20-65 ft	100 ft	1.6	0.9	2.5
WRIA 202	30-60 ft	100 ft	0.7	0.3	1
WRIA 212	30-70 ft	100 ft	0.8	0.4	1.2
McDonald Creek	25-31 ft	100 ft	1.9	1	2.9
		Total Area (ac)	78.2	42.1	120.3

The Corps would consider the interim riparian buffers recommended by the Forest Plan to be adequate in consideration of the functional area necessary to maintain instream habitat. These buffer widths were applied to each of the streams found within the AWSP pool raise to estimate the potential loss of riparian area. Total affected riparian area, using Tacoma Forest Land required buffer widths, is 78.2 acres in Phase I, an additional 42.1 acres in Phase II for a total of 120.3 acres for the entire AWSP (Table 10). Within 2 years, most existing riparian vegetation, sedges to trees, will have died, and in 5-10 years vegetation still standing will only be providing marginal value for riparian functions and maintaining instream habitat.

SUBSECTION 3B. HABITAT RESTORATION AND MITIGATION OPPORTUNITIES UNDER THE ECOSYSTEM RESTORATION AND ADDITIONAL WATER STORAGE PROJECT

3B.1 GENERAL

Restoration and mitigation options for aquatic resources under the AWSP considers the management of critical or limited habitat at a landscape level. This is an generally an ecosystem approach not limited to a species by species accounting. As such, while impacts to anadromous and resident fish species will be discussed, proposed restoration and mitigation measures will focus on functional habitat protection or improvement.

Wunderlich and Toal (1992) provided two specific estimates of smolt and adult anadromous fish impacts: 1) loss of smolt production; and 2) loss of steelhead spawning habitat. Smolt production loss is listed in Table 11. Estimates of smolt loss are listed by species: 1) coho, 11,710; 2) steelhead, 1787; and 3) chinook, low of 21,013 and a high of 210,135. These estimates were for a 36 ft pool raise, 1141 to 1177 ft, the original extent of the AWSP. Since the beginning of the feasibility study a 5,000 ac ft pool raise during drought years has been studied and restoration measures have been proposed to minimize the 6 ft pool raise from 1141 to 1147. Even the Headwaters is currently underseeded, the tributaries inundated currently provide valuable short-term rearing habitat for chinook, and long-term rearing for coho and steelhead. If the fish passage facility is as successful as hoped, increased numbers of juveniles will be rearing throughout the watershed. The lower elevation stream habitats these tributaries could have provided will be a large measurable loss.

In addition to impacts to smolt production, adult spawning habitat would be impacted by the Phase I and Phase II pool raise. Wunderlich and Toal (1992) estimated that over 640,000 sq ft of potential steelhead spawning habitat would be inundated. Inundation of redds could cause high embryo mortality. The authors made no estimate of coho or chinook spawning habitat. At the time of their survey only steelhead were proposed for release above HHD. This situation has since changed.

During the Agency Resolution Process the WDFW requested that a pilot project begin in the near future whereby up to 10% of the estimated total escapement of adult salmon be released into the Headwaters. Prior to this request, the City of Tacoma had not allowed release of adult salmon into Headwater streams over concerns that the decaying carcasses of the spawned-out adults could effect surface-water quality. The City of Tacoma has a clear interest in protecting the water quality of the watershed as it is the main potable surface water source for much of southern Puget Sound. At the closure of the Process, Tacoma agreed to begin the pilot project within the near future. If water quality concerns are in satisfied in the short and long-term, and full seeding of the watershed occurs, up to 8800 adult salmon could be released above the dam. This number of adults would likely include a fair number that would spawn in lower elevation areas around the reservoir.

To maintain and restore aquatic habitat quantity and quality in areas within and outside the inundation zone, a series of restoration and management measures have been proposed. Projects are identified to fulfill two main functions, increase habitat complexity (increase types and quality) and habitat connectivity (linkages between habitats). Restoration projects will attempt to replace a proportion of the total habitat impacted by the existing project, dam and inundation pool. Mitigation projects will attempt to minimize impacts of the AWSP pool raise by maintaining existing habitat within the 1147-1177 ft zone or by improving habitat in areas outside of the inundation zone. Listed below is a series of recommendations for the restoration and mitigation projects. Selected projects and project descriptions are provided *in Section 8. Restoration and Mitigation Plan Summary* with selected items discussed in the Wildlife Mitigation Plan (i.e., planting of water tolerant plants).

3B.2 RECOMMENDATIONS FOR RESTORATION

Below Howard Hanson Dam --

- reconnect and restore two Upper Green River side-channels at RM 58-59;
- large woody debris collected in the reservoir should be stored and made available for use in restoration projects throughout the basin.

Above Howard Hanson Dam, In and above the proposed inundation zone --

- in the existing inundation zone maintain instream habitat through addition of large structural elements (1080-1141 ft elevation);
- above the existing and proposed inundation zones improve instream habitat through addition of large structural elements (above 1177 ft).

3B.3 RECOMMENDATIONS FOR MITIGATION

In the proposed inundation zone --

- retain existing standing timber to partially maintain riparian and instream habitat;
- maintain existing instream habitat through placement of large structural elements and planting of water tolerant riparian zone vegetation;
- maintain reservoir perimeter vegetation by planting of water tolerant vegetation;
- enhance reservoir habitat by creation of sub-impoundments and addition of floating debris.

Above the proposed inundation zone --

- protect important mainstem and large tributary drainages through reserve and management of forests for late-successional characteristics (this management type is more fully described in the Wildlife Mitigation Plan);
- improve fish passage to one or more tributaries by replacing impassable culverts;
- improve selected areas of mainstem and large tributary instream habitat through placement of large woody debris or boulders.

TABLE 11 (FROM WUNDERLICH AND TOAL 1992). FISH HABITAT AND POTENTIAL ANADROMOUS FISH PRODUCTION IN STREAM REACHES INUNDATED BY THE POOL RAISE OF THE HOWARD HANSON RESERVOIR POOL. LOW-FLOW MEASURES WERE TAKEN IN LATE AUGUST AND SEPTEMBER 1991.

River or Tributary	WRIA No.	Thalweg length (ft)	Mean width (ft)	Wetted areas (ft2)	Discharge (cfs)	Spring wetted area (ft2)	Mean gradient (%)	low	high	Coho	Steelhead
Green River		6658	85	595146	175	998700	0.5	15535	155355	5548	1135
North Fork Green	09-0163	2148	32	68484	36	161100	1.7	2506	25060	1790	213
Page Creek	None	1826	26	47866	17	47866	1.9	745	7446	1522	149
Charley Creek	09-0181	1152	31	35418	26	40320	3.1	627	6272	960	110
Gale Creek	09-0196	2083	22	45772	11	62490	1.7	972	9721	1735	142
Cottonwood Creek	09-0197	1218	7	1614	1	24360	3	379	3789	16	4
Piling Creek	90199	633	10	6489	1	7596	5.7	118	1182	66	16
Unnamed	09-0202	261	8	2060	2	3132	5.6	49	487	21	5
McDonald Creek	09-0212	327	4	1435	1	1635	11.1	25	254	15	4
Unnamed	09-0213	732	5	3588	1	3660	4.9	57	569	37	9
	Totals	**17038**		**807872**		**1350859**		**21013**	**210135**	**11710**	**1787**

Chinook smolts computed at 0.14 smolts/yd^2 (low) and 1.4 smolts/yd^2 (high) spring wetted area.
Coho smolts computed at 2.5 smolts/lineal yd of large tribs (larger than 18 ft low-flow width) or 0.092 smolts/yd^2 of small tributary low-flow area.
Steelhead smolts computed at 4.10 parr/100 m^2 mainstem low-flow area; 6.68 parr/100m^2 low-flow area of other large tribs; and 5.11 parr/100m2 low-flow area of small tribs; and 50% parr-smolt survival.

3.1 LITERATURE CITED

Baranski, C. 1989. Coho smolt production in ten Puget Sound streams. Technical Report Number 99. Washington Department of Fisheries, Olympia.

Hickman, T. and R. Raleigh. 1982. Habitat suitability index models: cutthroat trout. . U.S. Fish and Wildlife Service FWS/OBS-82/10.5.

Laufle, J.C. and R.A. Cassidy. 1988. Retention of standing timber for fish and wildlife habitat in reservoirs. Lake and Reservoir Management 4(2):271-279

King, D.N. 1968. Evaluation of fish food production on standing dead timber, Crane Prairie Reservoir, June 22, 1966 to September 8, 1967. Rep. 68-1 Oregon State Game Commission Central Region Administration ***(in Laufle)***

McMahon, T. 1983. Habitat suitability index models: coho salmon. . U.S. Fish and Wildlife Service FWS/OBS/82/10.49.

Raleigh, R.F., T. Hickman, R. Solomon, and P. Nelson. 1984. Habitat suitability information: rainbow trout. . U.S. Fish and Wildlife Service FWS/OBS-82/10.60.

Raleigh, R.F. W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish and Wildlife Service Biological Report 82 (10.122).

U.S. Forest Service. 1990. Stream inventory handbook. Version 5.0. Region 6 Publication.

Wunderlich, R.C. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. Western Washington Fishery Resource Office, Olympia, Washington.

SECTION 4 GREEN RIVER AQUATIC HABITAT RESTORATION OPPORTUNITIES

SUBSECTION 4A LOWER TO UPPER GREEN RIVER WATER QUANTITY AND WATER QUALITY IMPROVEMENTS

4A.0 EXECUTIVE SUMMARY

The Additional Water Storage Project (AWSP) is a proposal to store up to 37,000 ac-ft (acre feet) of additional water behind Howard Hanson Dam (HHD) for municipal and industrial purposes and to augment Lower and Middle Green River Basin instream flows (Figure 1). Under proposed operating regimes, water will be stored primarily in the early spring to augment downstream releases later in the year. Effects of storing additional water in the spring are discussed in previous and following sections. Augmenting flows in the Green River during the summer and early fall alters the flow regime from HHD (RM 64) to the estuary (RM 7) during the period when 1) juvenile salmonids are rearing in the river; 2) steelhead eggs are incubating and fry are emerging, 3) adult chinook and coho salmon are migrating upstream; and 4) chinook salmon are spawning in the river.

All of the anadromous salmonids in the Green River begin their life cycles as embryos incubating within the substrate of the stream bed, with most incubation occurring from fall to early spring. A portion of steelhead egg and fry incubation can continue in early summer. Egg and fry incubation is dependent on maintaining intragravel flow over the eggs and fry within a specified range of water quality factors: temperature, dissolved oxygen, and suspended sediment. Failure to maintain water quantity and exceeding water quality factors can lead to desiccation (drying) and mortality of eggs and fry. Following emergence, juvenile anadromous salmonids can spend up to two years or more rearing in the stream before beginning their downstream migration. Juvenile rearing success is dependent on the amount of useable habitat, instream cover, riparian vegetation, clean substrates, flow (minimum water quantity), and good water quality: temperature, dissolved oxygen, optimum nutrient loading. Researchers have shown a positive relationship between the amount of summer and fall flow and population success of coho and steelhead populations in Puget Sound. Summer stream temperatures in the Green River typically exceed the recommended temperature range for rearing and often reach lethal temperatures.

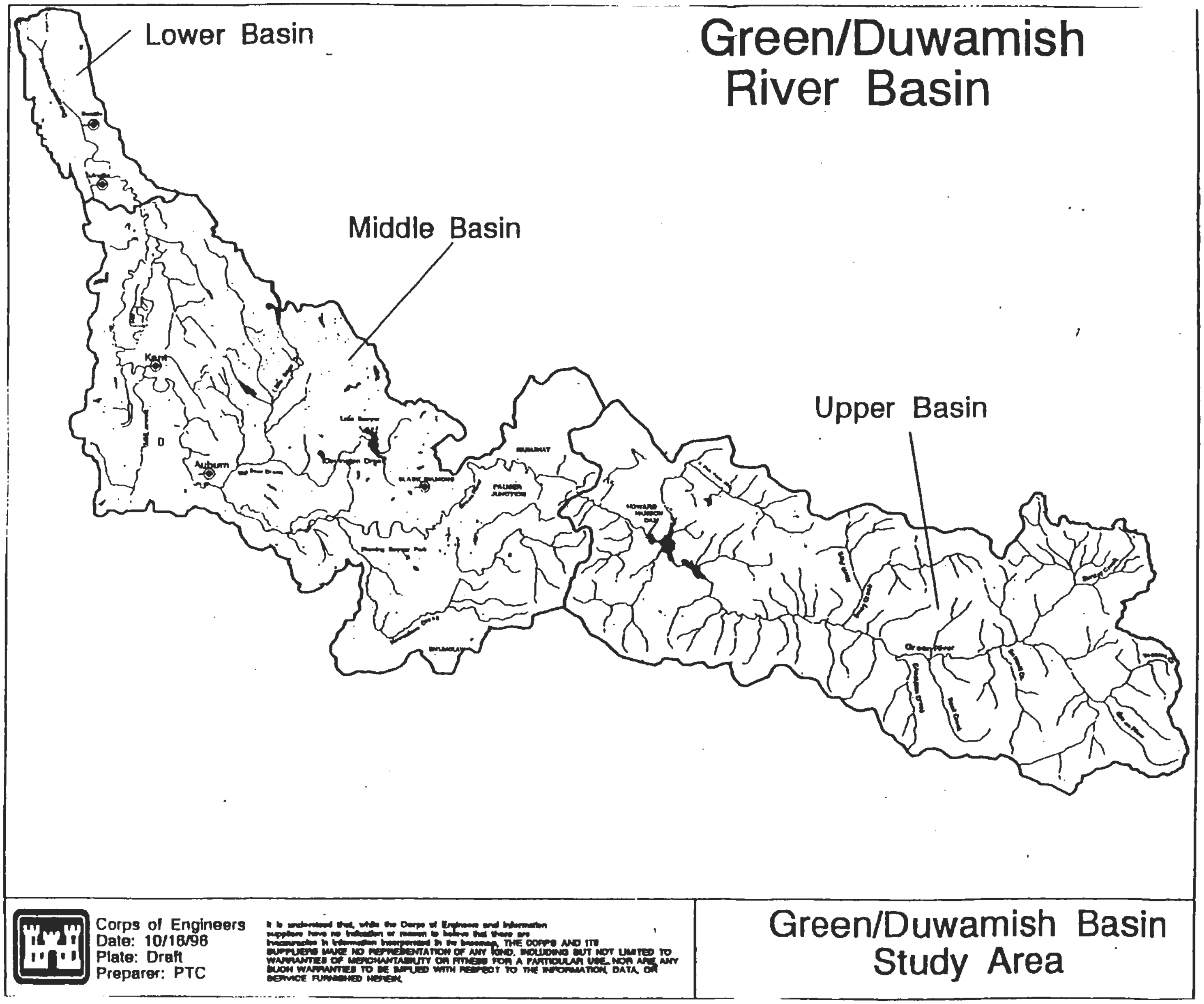
Adult salmon upstream migration and spawning is also dependent on adequate water quantity and water quality. Adult chinook salmon require a minimum flow volume, flow depth, and temperature range to migrate upstream to preferred spawning areas. In recent decades, the channel shape of the Green River has become wider and shallower and during low flow years adult chinook salmon have become trapped in lower river areas. In addition, riparian areas along the river are almost non-existent through the lower 35 miles of river. In most years, summer temperatures in the Green River may reach a point where chinook salmon are delayed on their upstream migration for extended periods. Researchers have established an optimum or preferred range of flows for spawning of salmon in the Green River. Successful spawning requires a useable range of stream temperatures for adult salmon migration, spawning and egg incubation. Fall stream temperatures in the Green River often exceed this range for days to weeks.

Mitigation for the effects of the AWSP during spring refill include increased baseflows, release of artificial freshets, augmentation of summer and fall flows. Flow augmentation will restore a major limiting factor for the Green River, low flows during summer and early fall. Surface water withdrawal from Howard Hanson Reservoir will also restore Green River instream temperatures to near ambient conditions for up to 6 miles below the dam.

AWSP flow augmentation can be used to increase summer and fall flows which will increase available rearing habitat with potential improvements in water temperature from increased stream velocities, pool depths, and wetting of side-channel areas (cool-water refugia). AWSP flow augmentation can also be used to increase summer and fall flows for meeting or exceeding -- 1) minimum flow volumes and depths for adult upstream migration; 2) increasing adult holding habitat; 3) creation of late-summer freshets to draw salmon to preferred upstream spawning areas; 4) meeting preferred fall spawning flows; and 5) potential reduction in stream temperatures that can stress or kill adults, delay spawning, and kill incubating eggs.

The presentation of AWSP flow augmentation benefits includes several untested assumptions. First, it is unclear whether changes in riparian and channel conditions will be restricted so the channel shape and nearshore area will remain close to existing conditions (the Corps Green/Duwamish GI study is attempting to address some of these issues). If riparian and channel shape can be improved some aspects of flow augmentation benefits could be more beneficial or additive. Gravel nourishment is a second management measure of the AWSP that can address aquatic limiting factors by maintaining habitat conditions (not improving) in the Middle Green River. Intergravel flow during the lowflow season could conceivably be maintained in this river section with the combination of flow augmentation and nourishment.

FIGURE 1. THE GREEN/DUWAMISH RIVER BASIN. HOWARD HANSON DAM IS AT RIVER MILE 64.



Second, impacts of AWSP refill are uncertain, they may be lower than presented, or could be greater. If impacts are lower, then flow augmentation benefits could be greater or conversely, if impacts are greater -- than flow augmentation benefits could be minimized or negated. In order to minimize the risk of unforeseen, or underestimated project impacts, a monitoring plan is recommended for spring refill impacts. The monitoring plan incorporates an adaptive management process to adjust storage and release regimes in response to the observed behavior of target species.

4A.1 PROJECT PURPOSE

This section presents the potential uses of AWSP flow augmentation storage for flow augmentation during the low flow period. The purpose is to describe existing instream habitat conditions in the Green River, water quantity (flow volume) and water quality (temperature) and how AWSP flow augmentation could improve these aquatic habitat limiting factors. The objective is to show the potential benefits that occur in the river downstream of HHD and that modeled years will have a reliability of meeting 1) target temperature regimes; and 2) flow augmentation storage and release targets.

Existing water quality (temperature) and water quantity conditions are data sets maintained by two federal agencies, U.S. Geological Survey, and the Corps. Additional temperature information was provided by a recent technical report (Caldwell 1994).

Modeled temperature and flow regimes were provided from two AWSP analyses, flow modeling by CH2M Hill (Section 9), and HHD Temperature Analysis (Valentine 1996, Hydraulics and Hydrology Appendix). Modeled flow augmentation utilized refill rules developed by a interdisciplinary group of hydrologists, engineers, planners and biologists. Flow release targets were a combination of existing instream flow requirements, IFIM optimum spawning flows, maximum spring refill baseline flows, and conceptual artificial freshets (mimicked natural flow increases for migration and habitat connection flows). Modeled temperature mimicked target inflow regime and utilized proposed operation of the selected fish passage alternative. Detailed analysis was completed for one dry, warm sample year, 1992.

4A.2 EXISTING CONDITIONS

Anadromous Fish Stocks in the Green River

Eight anadromous salmonid species historically or currently use the Green River system. These native species include chinook, coho, chum and sockeye *salmon (Oncorhynchus tshawytscha, O. kisutch, O. keta, O. nerka*), steelhead and sea-run cutthroat trout (*O. mykiss, O. clarki clarki*), Dolly Varden and bull trout (char; *Salvelinus malma, S.*

confluentus). Races of salmon and steelhead historically or currently present include spring, summer, and fall chinook, winter and summer steelhead. Native, resident salmonids include rainbow and cutthroat trout and mountain whitefish (*Prosopium williamsoni*). Timing of migration, spawning, rearing, and egg incubation for the salmon and trout species is presented in Figure 2. Additional information on life-history types and stock status is discussed in *Section 5. Downstream Migration of Anadromous Salmonids Through the Lower Green River*.

Green River Flow Conditions

Since 1906, there has been a large decrease in late spring, summer, and early fall instream flows of the Green River from RM 61 to the Duwamish. These losses of flow were from -- 1) in 1906, the White River was diverted to the Puyallup River affecting flows downstream from RM 35; 2) in 1917, the Cedar River was diverted into Lake Washington affecting flows downstream from RM 11; 3) from 1913 to 1948, 85 cfs was diverted by the City of Tacoma at their Diversion Dam at RM 61; and 4) from 1948 to present, 113 cfs has been diverted at RM 61. Without current HHD conservation storage, it is estimated that in about 2 of every 10 years the river would de-water for at least one day (King County SWM unpublished data).

In a summary of aquatic habitat limiting factors in the Green River, King County researchers considered summer low flows and high stream temperatures as factors limiting not only anadromous salmonid production but resident fish and other aquatic organisms such as insects and mollusks (Fuerstenberg et al. 1997).

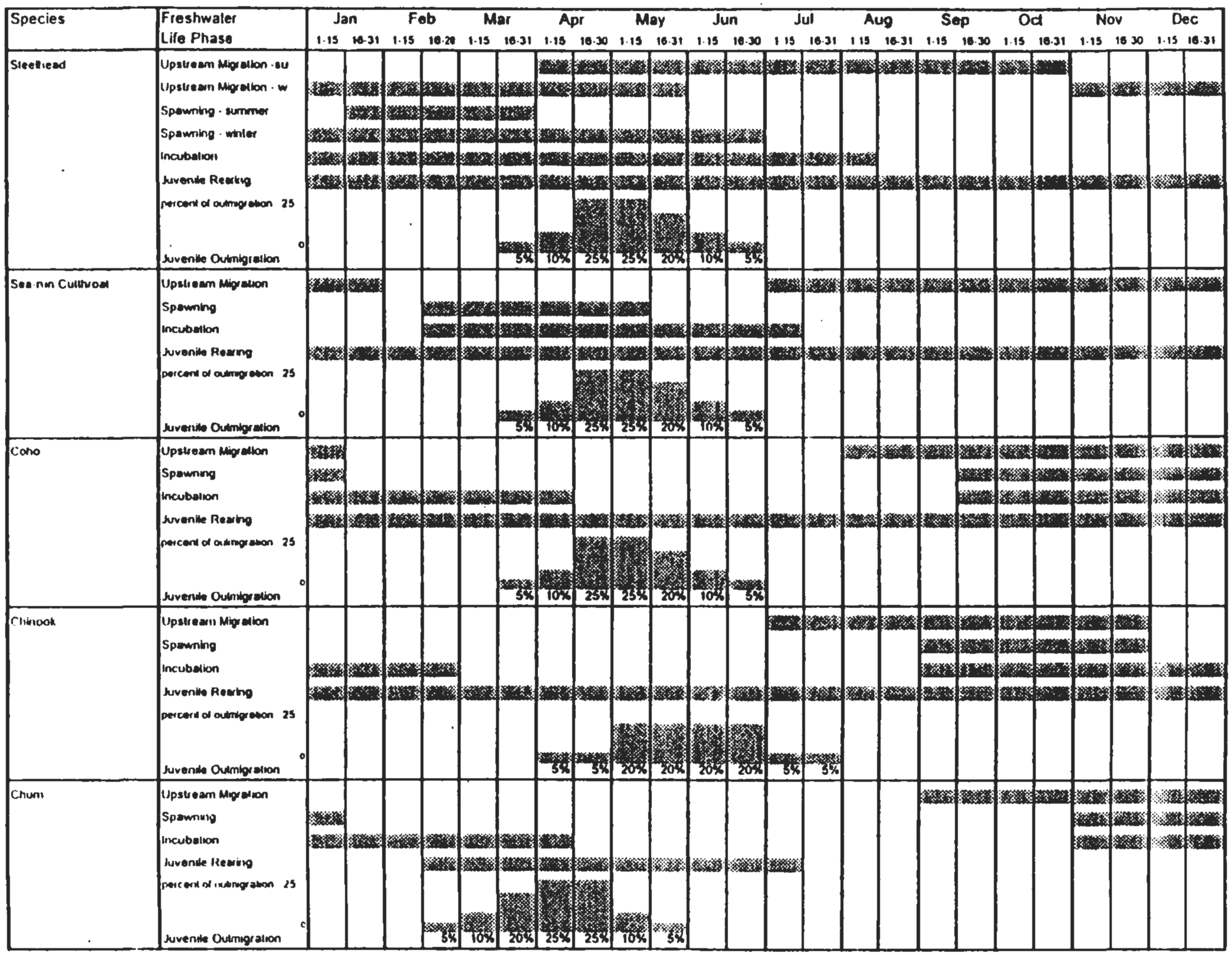
Causal factors for lower instream flows (in addition to re-alignment of the White and Cedar Rivers) include surface water resource development projects, depletion of groundwater resources, increases in impervious surfaces in the lower watershed, hydrologic disconnection of the lower river from its floodplain (and hyporheic interchange) and upper watershed forest land clearcutting. Most of the factors that have lead to lowered Green River flows cannot be corrected without major social and policy changes throughout western Washington.

Low summer and early fall flows in the Green River represent water quantity and water quality concerns for anadromous salmon and steelhead. In a 1975 report, the Washington State Department of Fisheries stated that low summer flows and poor water quality are principal limiting factors for salmon production in the Green River. They indicated that although operation of HHD has augmented summer flows, releases from HHD were often too low to completely alleviate poor water quality conditions in August and September, and too low to provide adequate adult salmon transportation water. Below RM 5.2, dissolved oxygen levels sometimes dropped to levels that imperil upstream migrating adult chinook (Williams et al. 1975).

Lack of summer flow under Baseline conditions has resulted in actual entrapment of migrating adult salmon. In 1987, flows were so low that Washington Dept. of Fish and

Wildlife (WDFW) and Muckleshoot Indian Tribe (MIT) personnel had to excavate a low flow channel to free chinook salmon trapped in downriver areas (H. Cocolli, pers. comm., 1995) .

FIGURE 2. TIMING OF SALMON FRESHWATER LIFE PHASES IN THE GREEN-DUWAMISH BASIN PROPORTION OF SMOLT OUTMIGRATION DEVELOPED FOR AVERAGE WATER YEARS.



Production of coho and steelhead has been consistently identified as being limited by the availability of summer rearing habitat throughout their range (Bisson 1987; Reeves et al. 1991) Many researchers agree that quantity of water during critical summer lowflow periods is a key factor limiting freshwater production of coho and steelhead (Reiser and Bjornn 1979; Marshall and Britton 1980; Bottom et al. 1985; Everest et al. 1985; Bisson 1987; Jenks 1989; McEwan and Nelson 1991; Reeves et al. 1991; Healey 1991; and Sandercock 1991). Burns (1971) demonstrated that decreased rearing area, dictated by the level of streamflow during summer low flow period, resulted in increased mortality of salmonid juveniles.

In Puget Sound streams, Bisson (1979) suggested that the amount of available summer juvenile rearing habitat, determined primarily by instream flows, determines the level of salmonid smolt production. Other researchers confirm this relationship stating "the volume of flow in summer determines the carrying capacity of the stream for juvenile salmonids" (Everest et al. 1985). Research over a 14-year period in Bingham Creek, Washington, showed that the quantity of water during summer accounted for over 95 percent of the inter-annual variation in smolt production (J. Parkhurst, WDFW, pers. comm., 1994). Similarly, extensive research has indicated that production of coho salmon in Oregon streams was found to be most strongly correlated with the amount of useable rearing habitat rather than other parameters (Mason and Chapman 1965; Everest et al. 1985).

Green River Temperature Conditions

Three previous investigations indicated that high water temperatures in parts of the Green River could be creating adverse habitat conditions for anadromous and resident salmonid fish. In the lower river, a report by Fishery Sciences (1984), found summer maximum temperature were 71.6-75^{0}F(22-24^{0}C) near RM 11. In a more recent study in 1992, maximum equilibrium temperatures were found in the 71.6-75^{0}F range in the river from RM 13-45 (Caldwell 1994). These temperatures were considered below lethal limits but at or near the temperature range that salmonid fish avoid (Bjornn and Reiser 1991). In addition, temperatures in shallow nearshore areas, potential juvenile rearing areas, were 1.0-3.6^{0}F (0.5-2.0^{0}C) warmer depending in whether the water was flowing or standing. A third study, Grette and Salo (1986), stated that delayed upstream migration of early-run fall chinook was the only "identified impact" of elevated river temperature, but that "elevated summer temperature may also influence utilization of the lower Green River by juvenile" salmonids. Caldwell (1994) concurred that a blockage or delay of chinook and steelhead adult migrants can occur in August when temperatures rise above 70^{0}F. In 1992, a dry-warm year, a cooling trend by mid-September may have removed a thermal block that could have delayed or trapped upstream migrating salmon and steelhead from July to mid-September.

Bilby (1984) presented the concept of coolwater "thermal refugia" in small western Washington streams. These refugia were caused by various sources of water flow and were found by seeps of groundwater inflow, cool tributaries, or water flowing through stream substrates. In larger streams and rivers in Pacific Northwest, cool-water can be found in stratified pools and maybe used for extended periods by salmon and steelhead (Pickett 1992). The Green Duwamish GI Reconnaissance Study is investigating various means of creating additional thermal refugia, including addition of large structural elements to create more deepwater pools in the Middle Green to possible re-creation of limited wetland areas in the Lower Green.

Green River Flow and Temperature Requirements

Green River Instream Flow Requirements. Above the existing Washington state standards, the Muckleshoot Indian Tribe negotiated an instream flow agreement with the City of Tacoma (Agreement). For a particular year, instream flows are set by the summer month conditions, beginning on July 1. The summer month flow conditions as stated in the Agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*"

Washington State Water Quality Standard. The Green River is managed as a Class A stream from the confluence of the Black River, RM 11, to RM 42.3, the western boundary of Flaming Geyser State Park. Upstream of the Class A boundary, RM 42.3 to the Green River headwaters, RM 88, the river is managed as a Class AA stream. These stream categories have an upper temperature limit resulting from changes in water temperature from human activities. For class A waters the upper limit is 64.4°F (18°C) and for class AA it is 60.8°F (16°C) (WAC 173-201).

4A.3 PROJECT DESCRIPTION

The last section, Section 9, describes the process and parameters used to model 32 years of historic data under Baseline, Phase I and Phase II conditions (CH2M Hill, 1997). Selected results of this modeling are used to assess project impacts and benefits. The entire modeling results sections are available upon request.

Definitions of Baseline, Phase I, and Phase II:

Baseline is the operation of Howard Hanson Dam (HHD) utilizing the existing 98 percent rule curve, and assuming Pipeline 5 is operational in accordance with, "Agreement Between The Muckleshoot Indian Tribe and The City of Tacoma Regarding the Green/Duwamish River System, 1995" (the Agreement). In addition, the 5,000 ac-ft (ac ft) from the HHD Section 1135 Environmental Restoration project is assumed to be available for drought years. Total storage volume in normal years is 25,400 ac ft, pool elevation is 1141 ft, and total storage volume in drought years is 30,400 ac ft, elevation 1147 ft.

Phase I of the Additional Water Storage Project (AWSP) adds to Baseline the fish passage facility at the dam, a larger volume of storage behind the dam in the spring to store water for augmenting fish flows at Auburn, and 20,000 ac ft of additional active Municipal and Industrial (M&I) water storage collected by storing Tacoma's Second Supply water right. Total storage volume (Baseline + Phase I) in normal years is 45,400 ac ft, pool elevation 1162 ft, and total storage in drought years is 50,400 ac ft, elevation 1167 ft.

Phase II of the AWSP replaces the Phase I storage with 14,600 ac ft of water for fish use in the summer and fall and an additional 22,400 ac ft for M&I for a total additional volume of 37,000 ac ft. Total storage volume (Baseline + Phase II) all years is 62,400 ac ft, pool elevation 1177 ft.

4A.2.4 FLOW MODELING

The Green River Watershed was modeled from the USGS gage in Auburn upstream to the USGS gage at Palmer and finally upstream to the Howard Hanson Dam. The models runs on a daily time step and will provide information regarding reservoir volume and level, flow into and out from the dam, flow at Palmer, diversion to Tacoma's pipelines 1 and 5, and flow at Auburn. The model simulates the storage of water behind the dam in the winter for flood control, using 12,000 cfs as the control flow at the Auburn gage (including local inflow) any water stored behind the dam during flood control operations is released in a manner that does not exceed the 12,000 cfs Auburn target. In the summer, 24,200 ac ft of (active) storage is used for fisheries instream flow protection and 5,000 ac ft for debris removal in the Baseline Condition. In Phase I and II, the active storage volume is increased to 44,200 and finally 61,200 ac ft for fish and water supply. Outflow from the dam is determined by inflows to the dam, downstream instream flow requirements established at Palmer and Auburn USGS gages, water supply diversions and maximum levels and rates of change allowed behind the dam and in the lower river.

The storage behind Howard Hanson Dam is hypothetically split into a maximum of 3 modeled storage allocations, each with different rules for use. The first is called Fish Dam 1 and it is the existing storage which strictly follows the 98 percent rule curve and meets a 110 cfs base flow, at Palmer, all summer for instream flow protection. The second is called Fish Dam 2 and it represents the storage volume available to protect and improve instream flow conditions. The third is called the Diversion Dam and it is storage volume available to Tacoma for M&I water uses.

Water inflow records for the modeling simulation are comprised of three sets of data, flow into the reservoir behind the dam, flow into the river between the dam and the Palmer gate, and flow into the river between the Palmer and Auburn gages. The inflow records into the reservoir were computed by the Corps and the record extends from calendar year 1964 to 1995. The daily Corps data was used unaltered in this study. The flow between the dam and Palmer is calculated by multiplying the inflow to the reservoir by 0.03 (The Corps has found that the runoff observed in the reach between the outflow and the diversion intake average approximately 3 percent of the inflow to Howard Hanson Dam during the low-flow seasons such as during 1973 and 1987. The inflow between Palmer and Auburn is determined by subtracting the observed Palmer gage reading from the observed Auburn gage reading. This calculation produces occasional negative values, which are set to zero.

Modeling Characteristics

Modeling rules were developed during a succession of meetings among a team of water managers, fish biologists, and other engineers-planners experiences with the regulated hydrologic cycle and biological resources of the Green River. The purpose of the meeting was to update the water resource development proposed as Scenario no. 7 into a more detailed simulation that matched biological need with increments of water storage as they became available in future phases in an adaptive management process.

Modeling computations were performed using an Excel spreadsheet in Windows 95 operating environment. Operating rules are input to the model as a series of macros that are methodically applied to the daily inflow data stream. Modeling characteristics that simulate the Green River/Howard Hanson Reservoir system are fully described in Section 9. A discussion of refill, release and instream flow targets for Baseline, Phase I, and Phase II are discussed below. Diversion Dam storage, M&I water supply, and Tacoma instream diversions are discussed in Section 9.

Baseline Flow Conditions

The refill targets for active storage, as shown in Table 1 are:

TABLE 1

Date	Fish Dam 1 Average (Ac-ft)	Fish Dam 2 Average (Ac-ft)	Fish Dam 1 Dry (Ac-ft)	Fish Dam 2 Dry (Ac-ft)
15 March	0	0	0	0
1 April	0	5,100	8,100	0
15 April	0	5,100	20,300	0
1 May	8,100	5,910	23,800	0
15 May	20,300	5,910	26,700	2,500
1 June	23,800	5,400	26,700	2,500
15 June	29,200	0	26,700	2,500(1)
30 June	24,200	0	26,700	0

(1) 2,500 ac-ft are in Fish Dam 2 for use in fisheries protection.

The maximum volume of water stored in Fish Dam 2 (Fish Dam 2 being the facility that stores water to augment flows at Auburn when the natural inflows drop below the instream flow levels) is equal to the difference between the refill rates shown above and the existing 98 percent Corps refill rule curve as shown in Table 1 under Fish Dam 1.

The instream flow level for refill of Fish Dam 2 is 900 cfs from 15 March to 1 May. Water will be stored in the dam when flow exceeds 900 cfs at Auburn; up to a maximum equal to the storage levels and fill rates discussed in 2, 3, and 4 above. Water will be released from storage in Fish Dam 2 when flows begin to dip below 900 cfs at Auburn; up to the volume stored in Fish Dam 2. The instream flow levels linearly decrease from 900 cfs on 1 May to 400 cfs on 1 July. There are no induced freshets or shaving of peaks.

For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the Agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*"

Phase I Conditions

The refill targets for active storage, as shown in Table 2 are:

TABLE 2

Date	Fish Dam 1 Wet & Average (Ac-ft)	Fish Dam 1 Dry (Ac-ft)	Diversion Dam Wet, Average, & Dry (Ac-ft)	Fish Dam 2 Wet & Average (Ac-ft)	Fish Dam 2 Dry (Ac-ft)
February 15	0	0	0	0	0
March 1	0	0	3,000	0	0
March 15	0	0	6,000	9,000	9,000
April 1	0	0	9,000	18,800	18,800
April 15	0	8,100	12,000	24,800	16,700
May 1	8,100	20,300	15,000	21,100	13,700
May 15	20,300	23,800	18,000	5,900	7,400
June 1	23,800	26,700	20,000	400	2,500
June 15	24,200	26,700(1)	20,000	0	2,500(1)
June 30	24,200	26,700	20,000	0	0

(1) 2,500 ac-ft are in Fish Dam 2 for use in fisheries protection.

The maximum volume of water stored in Fish Dam 2, is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1.

The conditions in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March and if it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. In addition, the snow water equivalent is measured again on 1 May. If it exceeds 12 inches, the summer is average or better and if it is 12 inches or less, then drought conditions are implemented in accordance with the Agreement.

The instream flow levels for refill of Fish Dam 2 are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

Freshets, at a duration of 38 hours and a level of 2,500 cfs, as measured at the Auburn gage, are delivered on 1 May and 15 May under wet and average conditions, and at a level of 1,250 cfs on only one day, 1 May, under dry conditions.

For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

From July 1 through the end of reservoir operation (generally December 8), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, *"For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought."*

Phase II

The refill targets for active storage, as shown in Table 3 are:

TABLE 3

Date	Fish Dam 1 Wet & Average (Ac-ft)	Fish Dam 1 Dry (Ac-ft)	Diversion Dam Wet & Average (Ac-ft)	Diversion Dam Dry (Ac-ft)	Fish Dam 2 Wet & Average (Ac-ft)	Fish Dam 2 Dry (Ac-ft)
Feb 15	0	0	0	0	0	0
March 1	0	0	0	0	5,000	5,000
March 15	0	0	13,500	13,500	14,000	14,000
April 1	0	0	22,400	22,400	29,100	29,100
April 15	0	8,100	22,400	22,400	38,800	30,700
May 1	8,100	20,300	22,400	22,400	30,700	18,500
May 15	20,300	23,800	22,400	22,400	18,500	15,000
June 1	23,800	24,200	22,400	22,400	15,000	14,600
June 15	24,200	24,200	22,400	22,400	14,600	14,600
June 30	24,200	24,200	22,400	22,400	14,600	14,600
July 1	24,200	26,700	22,400	21,150	14,600	13,350

The maximum volume of water stored in Fish Dam 2, is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1.

In Phase II, the level of snow in the watershed and the level of water stored in the Fish Dams are evaluated four times between March and September (Four decision points) to set the condition for that particular season, for example, wet, average, or dry, in accordance with the following criteria:

The snow water equivalent levels in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March if it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. The conditions are reevaluated on 1 July, 15 September, and 30 September (Table 4).

If the total storage in Fish Dam 1 and 2 exceeds 37,000 ac-ft, then the summer is considered average; less than 37,000 ac-ft and it is considered dry. This requirement designates a condition which sets the requirements for Fish Dam 2 but it also is proposed to be used instead of 1 May to set the summertime condition under the Agreement.

The conditions are examined again on 15 September and if Fish Dam 1 is in Zone 1, storage exceeding 15,740 ac-ft, and the summer condition was average, then the condition is reset to wet for the fall. If Fish Dam 1 is outside Zone 1 or the summer condition was dry, then no change to the condition is made on 15 September and the summer condition remains in effect until 30 September.

The amount of water in storage on 30 September in Fish Dam 1 sets the fall condition. If Fish Dam 1 is in Zone 1, then the condition is set as wet, if it is in Zone 2 or 3 then it is average, if it is in Zone 4 , below 8,261 acre-feet, then it is set as a dry fall.

The instream flow levels are set in accordance with the conditions set on the four decision points. The various flow levels are:

- For refill of Fish Dam 2 and Diversion Dam, the instream flow requirements are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.
- For the summer, Fish Dam 1 supports 350, 300, 250, and 225 cfs in an average summer and 250 and 225 cfs for a dry summer. Fish Dam 2 supports 300 cfs in an average summer and 250 cfs in a dry summer.. In Phase II, no condition anticipates having the flow at Auburn drop below 250 cfs.
- A wet condition set on 15 September increases the flow provided by Fish Dam 2 to 400 cfs for the period 16 September to 30 September.

On 30 September, the flow in the river at Auburn is supported by Fish Dam 2 at a level of 450 cfs for the month of October in a wet condition, 400 cfs in an average condition, and 350 cfs in a dry condition. The levels set on September are supported by the water stored in Fish Dam 2 through the remainder of the year, until Fish Dam 2 is empty or until the rains return and the water is spilled to provide the needed flood control storage.

TABLE 4. GREEN RIVER HYDROLOGICAL CONDITIONS BASED ON SEASON-SPECIFIC CRITERIA DURING THE PERIOD 1964-1995 (SOURCE: CH2MHILL 1997).

Year	Seasonal Flow Condition Set on			
	1-Mar	1-Jul	15-Sep	30-Sep
1964	Average	Average	Wet	Wet
1965	Average	Average	Average	Average
1966	Average	Average	Average	Average
1967	Average	Average	Average	Average
1968	Dry	Average	Wet	Wet
1969	Wet	Average	Wet	Wet
1970	Average	Average	Average	Average
1971	Average	Average	Wet	Wet
1972	Wet	Average	Wet	Wet
1973	Dry	Dry	Average	Average
1974	Wet	Average	Wet	Average
1975	Wet	Average	Wet	Wet
1976	Average	Average	Wet	Wet
1977	Dry	Average	Wet	Wet
1978	Average	Dry	Average	Average
1979	Average	Dry	Average	Average
1980	Average	Average	Wet	Wet
1981	Dry	Average	Wet	Wet
1982	Average	Average	Wet	Wet
1983	Average	Average	Wet	Wet
1984	Average	Average	Wet	Wet
1985	Average	Average	Average	Average
1986	Dry	Average	Average	Average
1987	Average	Dry	Average	Average
1988	Average	Average	Average	Average
1989	Average	Average	Dry	Dry
1990	Wet	Average	Wet	Average
1991	Dry	Average	Average	Average
1992	Dry	Dry	Average	Average
1993	Average	Average	Wet	Average
1994	Average	Dry	Average	Average
1995	Average	Dry	Average	Average

Freshets, at a duration of 38 hours and a level of 2,500 cfs as measured at the Auburn gage, are delivered on April 1, April 15, May 1, and May 15 under wet and average conditions, and at a level of 1,250 cfs on the same four days under dry conditions. Whenever Fish Dam 2 is below 65 percent of full on any of the four days where freshets are to be sent, then the freshet for that day is skipped. On September 1 in all years, a summertime freshet 700 cfs, as measured at Auburn, is delivered.

For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, *"For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought."* In addition, Fish Dam 2 in Phase II has the ability to increase flows during the summer and fall.

4A.5 TEMPERATURE MODELING

Reservoir temperature were modeled for 33 years, 1962-1994, and compared to historic outflow temperatures for four years, 1991-1994. The objective was to develop a target temperature regime that benefits instream resources downstream of the dam and that modeled years would have some degree of reliability. Full discussion of the temperature modeling methods and results is presented in the water quality appendix.

Temperature modeling and analysis considered two AWSP alternatives, the existing tower with no modification, and the existing tower with a selective water withdrawal structure. The selective withdrawal structure is referred to as the fish passage facility. The analysis used a thermal budget model, WESTEX one-dimensional, numerical model modified to mimic the unique design of the fish passage facility.

Corps staff worked with fish biologists to identify a range of preferred temperatures for a target temperature regime. A primary objective of the temperature regime was to mimic natural temperature fluctuations and in particular, decrease temperatures in the late summer and fall, during the period of fall chinook upstream migration, spawning and egg incubation. The natural inflow to HHD exceeds the class AA temperature 60.8 F at some point most years. Results were presented in "degree days" for September and October as a measure of reservoir performance. Degree days are defined as the number of

Celsius degrees (°C) that the release temperature is above or below a certain target each day.

4A.6 RESULTS

4A.6.1 AWSP Baseflow Increases

Classification of Green River Hydrologic Conditions

One result of the AWSP flow modeling was a categorization of hydrologic conditions in the Green River basin for management of reservoir storage and outflow releases during spring and summer. For the 32 years of available flow records, seasonal hydrologic conditions were categorized for March 1, July 1, September 15, and September 30 (Table 4). Criteria used to classify each season is discussed in sub-section 2.0. A summary of years classified as wet, average, and dry for each seasonal decision point is listed in Table 5.

TABLE 5. SUMMARY OF WET, AVERAGE AND DRY SEASONS FOR 32 MODELED YEARS, 1964-1995: SEPTEMBER 15 DECISION POINT DOES NOT INCLUDE DRY CATEGORY.

	Seasonal Flow Condition Set on			
	1-Mar	1-Jul	15-Sep	30-Sep
Number of years meeting criteria				
Wet	5	0	16	13
Average	20	25	16	18
Dry	7	7		1

Phase I Storage Reliability and Flow Conditions

Phase I of the AWSP does not include additional storage for flow augmentation after July 1. It includes drought year storage of the 5,000 ac-ft approved under the HHD Section 1135 Feasibility Study and provides for additional flexibility for maintaining instream flows during the spring refill period, February 15-July 1 and providing freshets on May 1 and May 15 in most years. Table 6 shows a variety of flow and storage conditions under Phase I.

An average of 1.7 freshets were provided during the 32 years, 2, 2500 cfs freshets in wet to average years, and 1, 1250 cfs release in dry years. Wet, average and dry year spring refill target baseflows at Auburn were met in 26 of 32 years (81% of the time): 1) wet year targets -- 900 cfs minimum from March 1-May 1, and 900 cfs to 400 cfs decline from May 1 to July 1; 2) average year targets -- 750 cfs March 1-May 1, and 750 cfs to 400 cfs decline May 1-July 1; and 3) drought year targets -- 575 cfs March 1-May 1, and 545 cfs to 250 cfs decline from May 1-July 1. Only years not providing spring refill target flows were 1979, 1983, 1987, 1992, 1994 and 1995. Shortfalls occurred during the decline in stage from May 1 to July 1, dropping below baseflow targets between May 25 and June 20.

TABLE 6. PHASE I HYDROLOGIC AND RESERVOIR CONDITIONS FOR MEETING STORAGE AND RELEASE TARGETS FOR 1) FRESHETS; 2) SECOND SUPPLY STORAGE (DIVERSION DAM); 3) EXISTING FLOW AUGMENTATION STORAGE (FISH DAM 1);MARCH, APRIL, MAY, AND JUNE FILL LIMITS; AND 4) SECTION 1135 DROUGHT YEAR STORAGE.

Year	Number of Spring Freshets	Diversion Dam Full 1-Jul	Fish Flow Levels Met	Condition Set 1-Mar		Condition Set 1-May	Volume In Diversion Dam 30-Jun	Volume In Fish Dam 1 30-Jun	Volume In Fish Dam 2 30-Jun
1964	2	Yes	Yes	Average		Average	20,000	24,200	0
1965	2	Yes	Yes	Average		Average	20,000	24,200	0
1966	2	Yes	Yes	Average		Average	20,000	24,200	0
1967	2	Yes	Yes	Average		Average	20,000	24,200	0
1968	1	Yes	Yes	Dry		Average	20,000	24,200	0
1969	2	Yes	Yes	Wet		Average	20,000	24,200	0
1970	2	Yes	Yes	Average		Average	20,000	24,200	0
1971	2	Yes	Yes	Average		Average	20,000	24,200	0
1972	2	Yes	Yes	Wet		Average	20,000	24,200	0
1973	1	Yes	Yes	Dry		Average	20,000	24,200	0
1974	2	Yes	Yes	Wet		Average	20,000	24,200	0
1975	2	Yes	Yes	Wet		Average	20,000	24,200	0
1976	2	Yes	Yes	Average		Average	20,000	24,200	0
1977	1	Yes	Yes	Dry		Dry	20,000	26,700	2,500
1978	1	Yes	Yes	Average		Dry	20,000	26,700	2,493
1979	2	Yes	No-6/10	Average		Average	20,000	23,746	0
1980	1	Yes	Yes	Average		Average	20,000	24,200	0
1981	1	Yes	Yes	Dry		Dry	20,000	26,700	2,500
1982	2	Yes	Yes	Average		Average	20,000	24,200	0
1983	2	Yes	No-6/1	Average		Average	20,000	24,200	0
1984	2	Yes	Yes	Average		Average	20,000	24,200	0
1985	2	Yes	Yes	Average		Average	20,000	24,200	0
1986	1	Yes	Yes	Dry		Average	20,000	24,200	0
1987	2	Yes	No-6/20	Average		Dry	20,000	26,700	0
1988	2	Yes	Yes	Average		Average	22,810	24,200	0
1989	2	Yes	Yes	Average		Dry	20,000	26,700	1,947
1990	2	Yes	Yes	Wet		Average	21,620	24,200	0
1991	1	Yes	Yes	Dry		Average	20,000	24,200	0
1992	1	No	No-6/1	Dry		Dry	13,083	26,186	0
1993	2	Yes	Yes	Average		Average	23,600	24,200	0
1994	1	Yes	No-5/25	Average		Average	20,000	24,200	0
1995	2	No	No-6/1	Average		Average	18,838	24,091	0
Avg.	1.69	Yes-30	Yes-26				19,998	24,635	295
		No-2	No-6						

Phase II Storage Reliability and Flow Conditions

Phase II of the AWSP provides for up to an additional 14,600 ac-ft of water storage for flow augmentation after July 1 and until October 30. The 5,000 ac-ft of drought year storage is absorbed into yearly storage with an additional 9,600 ac-ft. Freshets are increased from 2 in Phase I to 4 in Phase II. Flow release of the additional storage water for flow augmentation was a modified form of Scenario 7, a flow release regime coordinated through all resource agencies early in the AWSP. This release scenario seeks to maintain and increase summer baseflows and optimize spawning flows for chinook salmon in late summer to early fall, September 15-October 30. Table 7 shows seasonal storage and release conditions under Phase II.

An average of 2.9 freshets were provided during the 32 years. Freshet targets were 4, 2500 cfs releases in average to wet years, and 2, 1250 cfs releases in dry years. Normal and dry year spring and summer/fall target baseflows were met in 29 of 32 years or 91 percent of the time. Spring refill and summer release baseflow targets are shown below (Table 8). The only years not meeting summer and fall flow augmentation targets were 1987, 1989, and 1991. In these years, flow augmentation storage was depleted between October 16 and October 30 dropping spawning flows (350-400 cfs) to existing minimums (225-250 cfs). Augmentation ran short for 1 day in 1991, 6 days in 1987, and 16 days in 1989. This shortfalls could be compensated for. Tacoma has supported shortfalls under existing storage in meeting instream flow requirements in 3 of the last 5 years and they have expressed commitment to cooperate in meeting flow augmentation shortfalls under the AWSP.

TABLE 8. PHASE II SPRING REFILL AND SUMMER/FALL RELEASE BASEFLOW TARGETS.

Seasonal	Baseflow Target	Stage Decline	Low-Flow Targets		
Flow Condition	February 15-April 30	May 1 to June 30	July 1 to Sept-15	Sept 16-30	Oct 1-31
Wet	900 cfs	900-400 cfs	300 cfs	400 cfs	450 cfs
Average	750 cfs	750-400 cfs	300 cfs	300 cfs	400 cfs
Dry	575 cfs	575-250 cfs	250 cfs	250 cfs	350 cfs

TABLE 7. SEASONAL PHASE II HYDROLOGIC AND RESERVOIR CONDITIONS FOR MEETING STORAGE AND RELEASE TARGETS FOR 1) FRESHETS; 2) SECOND SUPPLY STORAGE (DIVERSION DAM); 3) SPRING REFILL BASELINE FLOWS; AND 4) AWSP FLOW AUGMENTATION STORAGE FOR EARLY AND LATE SUMMER (FISH DAM 2).

Year	Number of Spring Freshets	Diversion Dam Full 15-Apr	Fish Flow Levels Met	Condition Set 1-Mar		Condition Set 1-Jul	Volume In Diversion Dam 30-Jun	Volume In Fish Dam 2 30-Jun	Condition Set 15-Sep	Volume In Fish Dam 2 15-Sep	Condition Set 30-Sep	Volume In Fish Dam 2 30-Sep
1964	4	Yes	Yes	Average		Average	22,400	14,600	Wet	12,981	Wet	10,633
1965	3	No	Yes	Average		Average	22,400	14,584	-	12,668	Average	10,633
1966	3	Yes	Yes	Average		Average	22,400	14,600	-	12,981	Average	10,633
1967	1	No	Yes	Average		Average	22,400	14,582	-	11,977	Average	10,489
1968	3	Yes	Yes	Dry		Average	22,400	14,600	Wet	12,981	Wet	10,633
1969	3	Yes	Yes	Wet		Average	22,400	14,600	Wet	12,882	Wet	10,633
1970	3	Yes	Yes	Average		Average	22,400	14,555	-	11,205	Average	10,633
1971	3	Yes	Yes	Average		Average	22,400	14,600	Wet	12,981	Wet	10,633
1972	4	Yes	Yes	Wet		Average	22,400	14,600	Wet	12,981	Wet	10,633
1973	0	No	Yes	Dry		Dry	12,712	5,538	-	5,010	Average	5,319
1974	4	Yes	Yes	Wet		Average	22,400	14,600	Wet	12,931	Average	10,633
1975	1	No	Yes	Wet		Average	22,400	14,600	Wet	12,981	Wet	10,534
1976	3	Yes	Yes	Average		Average	22,400	14,600	Wet	12,981	Wet	10,534
1977	2	Yes	Yes	Dry		Average	22,400	14,600	Wet	12,947	Wet	10,633
1978	0	No	Yes	Average		Dry	16,787	10,638	-	10,481	Average	8,133
1979	4	Yes	Yes	Average		Dry	22,400	12,375	-	10,481	Average	8,127
1980	4	Yes	Yes	Average		Average	22,400	14,422	Wet	12,981	Wet	10,633
1981	1	No	Yes	Dry		Average	22,400	14,600	Wet	12,897	Wet	10,633
1982	3	No	Yes	Average		Average	22,400	14,600	Wet	12,981	Wet	10,633
1983	4	Yes	Yes	Average		Average	22,400	14,162	Wet	12,981	Wet	10,633
1984	4	Yes	Yes	Average		Average	22,400	14,600	Wet	12,981	Wet	10,534
1985	3	Yes	Yes	Average		Average	22,400	14,600	-	11,032	Average	10,633
1986	4	Yes	Yes	Dry		Average	22,400	14,600	-	12,416	Average	10,633
1987	4	Yes	No-10/26	Average		Dry	22,400	12,132	-	8,987	Average	8,034
1988	4	Yes	Yes	Average		Average	22,400	14,541	-	12,981	Average	10,633
1989	4	Yes	No-10/16	Average		Average	22,400	14,047	-	7,198	Dry	4,736
1990	4	Yes	Yes	Wet		Average	22,400	14,600	Wet	12,964	Average	10,549
1991	3	Yes	No-10/30	Dry		Average	22,400	14,600	-	12,751	Average	10,483
1992	0	No	Yes	Dry		Dry	10,574	2,353	-	1,103	Average	5,885
1993	4	Yes	Yes	Average		Average	22,400	14,600	Wet	12,882	Average	10,340
1994	4	Yes	Yes	Average		Dry	22,400	12,113	-	10,042	Average	8,133
1995	2	No	Yes	Average		Dry	22,400	11,252	-	8,622	Average	8,034
Avg.	2.91	Yes-23	Yes-29				21,552	13,440		11,477		9,707
		No-9	No-3									

Comparison of Baseline and AWSP Flow Conditions
Storing additional water behind HHD provides the opportunity to augment downstream releases to benefit a variety of instream resources. The potentially deleterious effects of storing additional water were described in previous sections of this document. This section describes the potential benefits of releasing that water.

Storage of additional water provides opportunities to benefit instream resources downstream of HHD. Storage of the water entails risk to the lifestages of some fish, but may benefit other lifestages and other resources. The actual benefit of flow releases depends on the life history of a species and the timing and duration of releases. Alternate release schedules may include regimes designed to:

- speed the outmigration of juvenile salmonids through the lower river;
- improve the quantity and quality of side channel habitat;
- increase the frequency and duration of side channel connections to the mainstem;
- improve performance in meeting steelhead target spawning flows;
- improve summer water quality conditions;
- increase summer rearing for stream-type salmonids and other aquatic organisms;
- improve upstream passage of adult salmon; and/or
- increase fall spawning habitat for salmon.

Construction of HHD in the early 1960s provided up to approximately 100 cfs of additional flow in the Green River at Auburn during August and September. Even with the low flow augmentation provided by the original project, since 1962 flows in the Green River at Auburn have dropped below 250 cfs for extended periods and have dropped below 200 cfs during extreme drought conditions. The quantity of water during summer low flow periods is a key factor limiting production of coho, steelhead and other stream-rearing organisms and augmenting summer low flow conditions is a proven method of enhancing instream resources.

Under Baseline drought conditions, up to 5,000 acre-feet of water is stored behind HHD for summer low flow augmentation as part of the Section 1135 Project. Analysis of the effects of the Section 1135 Project assumed that under drought conditions, up to 5,000 acre-feet of water would be used to maintain a minimum instream flow of 250 cfs in the Green River at Auburn (Project Modification Report and Environmental Assessment, September 1996). Up to 8,487 acre-feet of water would be required to maintain a flow of 250 cfs at Auburn during extreme droughts; however, the City of Tacoma volunteered to supplement storage shortfalls. Analysis of the AWSP assumed that the Section 1135 Project, and commitment of the City to supplement flows if necessary, would ensure a minimum instream flow at Auburn of 250 cfs under Baseline conditions.

Phase I of the AWSP expands storage and release capability and flexibility during spring months, but does not expand the storage of water for summer flow augmentation beyond the 5,000 acre-feet available under Baseline drought conditions. Phase I of the AWSP provides increased baseflow levels and release of artificial freshets during spring refill months and maintenance of a minimum flow of 250 cfs in the Green River at Auburn throughout the year.

Phase II of the AWSP provides for storage of up to 14,600 acre-feet of water each year for instream flow augmentation, instead of the 5,000 acre-feet stored under Baseline and Phase I drought conditions. In addition to storing 14,600 acre-feet of water for instream augmentation, up to 22,400 acre-feet of additional water is stored for M&I purposes.

The 14,600 acre-feet of water stored for instream augmentation under Phase II could be released to provide a variety of instream benefits. A volume of 14,600 acre-feet of water could augment instream releases by 120 cfs over a two month period, or provide 7,361 cfs-days. During extreme droughts, the need to satisfy minimum instream conditions during reservoir refill prevents storage of the full 14,600 acre-feet of water. During 30 out of the 32 years modeled, at least 10,000 acre-feet of additional water would be available for release on 30 June each year. Releasing an additional 10,000 acre-feet of water would provide a volume equal to a continuous flow of 82.6 cfs for a two month period, or 5,042 cfs-days. Releasing this volume during summer low flow months would benefit coho and steelhead rearing and increase overall production of aquatic-based organisms.

Selecting a particular release schedule provides benefits to specific downstream resources but limits the opportunity to address other instream needs. Timing of instream releases may entail trade-off between species. Selecting between competing release schedules requires knowledge of the effects of releases which may not be known until after several years of project operation and monitoring. Under the AWSP adaptive management process, the release scenario can be modified. For planning purposes, analysis of Phase II effects of the AWSP assumed that the water would be held and released in the late summer and fall to benefit adult salmon migration and spawning.

Adult chinook and coho salmon begin their upstream migration into the lower Green River during August and September. Even with the benefit of increased summer flows provided by HHD and the Section 1135 Project, poor water quality conditions in the lower river during this time may block or delay upstream migration. Water temperatures may approach lethal limits and sub-lethal levels contribute to increased incidence of disease. The condition of adult salmon holding in pools in the lower river begins to deteriorate as the salmon wait for higher flows to continue their upstream migration. In order to partially alleviate potential blockages or delay, a 700 cfs freshet, or pulse of water would be released from HHD for a 38 hour period on 1 September each year. Releasing this freshet would require approximately 1,400 acre-feet of water. Even during extreme drought conditions, this volume of water is available in Fish Dam 2 under Phase II of the AWSP.

In addition to releasing a 700 cfs freshet on 1 September, analysis of Phase II of the AWSP assumed water would be released to increase base instream flows during late

September and October. Under Baseline and Phase I Conditions, baseflows from 1 July through early December are 350 cfs during wet years, 300 cfs during wet to average years and 250 cfs during average to dry years. As previously mentioned, the Section 1135 Project and supplementation by Tacoma provides a minimum baseflow of 250 cfs during drought years.

Under Phase II, the same baseflow requirements would be satisfied and even during severe droughts, additional flow supplementation by the City of Tacoma would not be required. On 15 September, hydrological conditions would be assessed and baseflows increased depending on the volume of storage available. Under wet conditions, defined as more than 15,740 acre-feet of storage in Fish Dam 1 and an average summer condition, baseflows would be increased to 400 cfs from 16 September through 30 September.

Flow conditions would be reassessed on 30 September and baseflows increased according to the volume of storage available. Baseflows at Auburn 1 October through 31 October would be increased to 450 cfs under wet conditions, 400 cfs during average conditions and 350 cfs during dry conditions. During 29 of 32 years modeled, sufficient storage volume would be available to maintain baseflows of at least 400 cfs from 1 October through 31 October (Table 9). During 3 of the 32 years modeled, the volume of storage in Fish Dam 2 would be fully utilized and flows could drop as low as 250 cfs during late October. Since the City of Tacoma would not be required to curtail withdrawals to maintain summer baseflows as part of the Section 1135 Project, they would have the ability to supplement flows during late October to avoid temporary shortfalls during extreme droughts.

Releasing stored water during October would increase average flows at Auburn by approximately 66 cfs (Figure 3). This increase would improve instream conditions for upstream migrating adult chinook, coho and chum salmon and would increase potential spawning area for chinook salmon. An instream flow study of the Green River conducted by the Washington State Department of Ecology (Caldwell and Hirschey 1989) indicated an increase in average flows from 373 cfs to 439 cfs would provide an additional 3,484 ft^2 of potential chinook spawning area (weighted usable area (WUA)) for every thousand feet of river. The 9.7 percent increase in potential chinook spawning habitat (WUA) would be offset by a 4.8 percent decrease in potential coho spawning area. Because the availability of potential coho spawning area peaks at 314 cfs, flow increases from 373 to 439 would decrease the availability of potential coho spawning area (WUA).

Sufficient storage volume is available during many years to augment fall baseflows. Analysis of the 32 years of modeled daily flows indicates that while average flows during November would not be significantly increased, flow augmentation under Phase II would increase 7-day low flow levels during November. During 18 of the 32 years modeled, the 7-day low flow during November would increase at least 50 cfs compared to Baseline conditions.

Table 9
Effect of project alternatives on instream flow levels in the Green River at Auburn using modeled daily flows (1964 - 1995)
(Source: CH2MHill 1997)

7-Day Low Flow

Year	September Baseline	September Phase 2	October Baseline	October Phase 2	November Baseline	November Phase 2
1964	465	500	442	515	518	568
1965	250	300	254	400	446	456
1966	300	300	300	400	464	513
1967	250	300	251	400	613	677
1968	400	419	659	711	855	911
1969	300	350	388	450	479	485
1970	250	300	300	400	469	476
1971	350	400	350	450	1,227	1,281
1972	365	366	356	450	458	460
1973	250	250	283	400	503	522
1974	314	350	300	400	349	401
1975	314	400	314	450	1,554	1,609
1976	343	400	329	450	468	477
1977	299	357	326	450	1,254	1,307
1978	398	373	379	458	850	904
1979	250	291	231	400	314	400
1980	373	416	300	450	858	670
1981	299	381	419	498	563	580
1982	300	300	406	458	678	733
1983	407	413	308	450	1,642	1,697
1984	354	414	307	450	944	998
1985	250	300	250	400	665	709
1986	250	300	300	400	657	696
1987	250	250	225	225	225	225
1988	250	300	301	400	1,708	1,762
1989	250	293	224	229	420	314
1990	300	350	314	400	2,321	2,377
1991	223	300	213	315	255	255
1992	250	250	359	400	770	826
1993	300	350	254	400	345	400
1994	250	250	228	400	868	922
1995	207	250	318	402	804	860
Avg.	300	337	318	421	767	796

FIGURE 2. HALF-MONTH AVERAGE FLOWS AT AUBURN UNDER BASELINE, PHASE 1, AND PHASE II FOR 1964-1995.

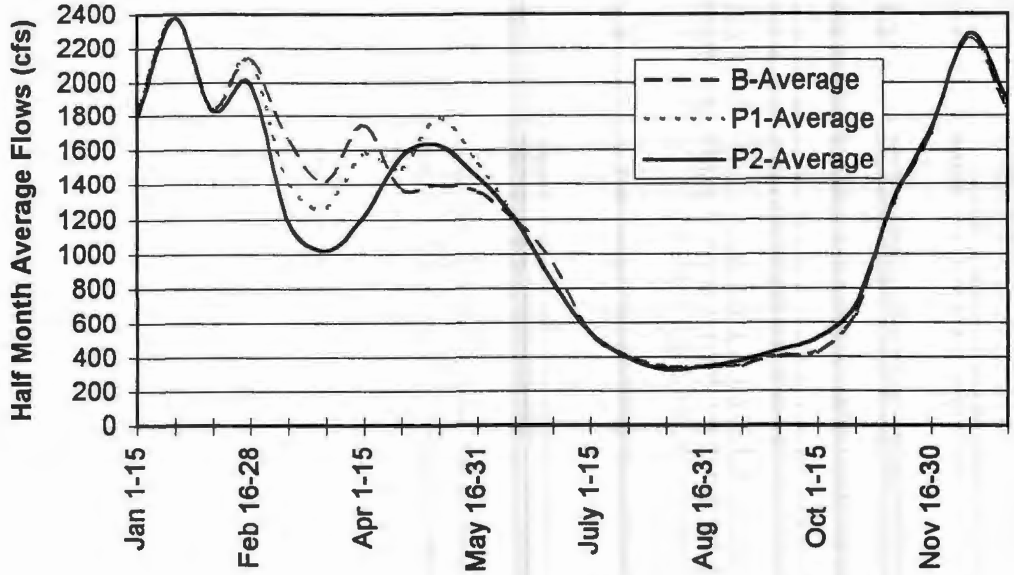


FIGURE 3. HALF-MONTH AVERAGE FLOWS AT AUBURN UNDER BASELINE, PHASE I, AND PHASE II FOR 1964-1995.

4A.7 HOWARD HANSON DAM TEMPERATURE RELEASE

Under existing project conditions, spring and summer flows totaling less than 500 cfs are released from HHD through the 48-inch bypass pipe at elevation 1069 ft MSL. Withdrawing water from this relatively deep outlet results in the use of water during early summer that is colder than inflow.
By mid-August, the volume of colder water below the thermocline has been consumed and reservoir releases are warmer than inflow. The effect of HHD releases that are warmer or colder than inflow temperatures persists for only a few miles below HHD. Water temperatures in the river below HHD reach equilibrium with ambient air temperatures within 6-8 miles from the dam.

Under the AWSP, spring, summer and fall flows will be released from HHD through selective withdrawal from a combination of the new fish passage facility, 5-20 ft depth, and from the radial gates, 35-130 ft depth.

Modeling Results. The natural inflow to HHD exceeds the class AA temperature 60.8 F at some point most years. Modeled results for the AWSP showed releases only exceeded this temperature in 1 of 33 years. The preferred alternative therefore has a reliability of 97% for maintaining HHD release temperatures below the state standard.

A sample year simulation (1992) of a warm, dry, summer and fall is presented in Figure 4. This year was one of the driest, warmest years for the period of record since HHD went into operation. Two threshold temperatures are shown in the figure, 58°F, and 60.8°F. The existing state water quality standard is the 60.8°F. The 58°F target is the upper limit of preferred temperatures for two life stages of anadromous salmonids: 1) rearing of steelhead, coho, and chinook salmon; and 2) spawning and incubation for chinook and coho salmon. The final selected target temperature for the AWSP was 59 °F, or an intermediate between the 58 and 60.8 °F thresholds. In 1992, modeled release temperature shows the target temperature was only exceeded for a few days in July, under some of the worst conditions expected for stream temperatures.

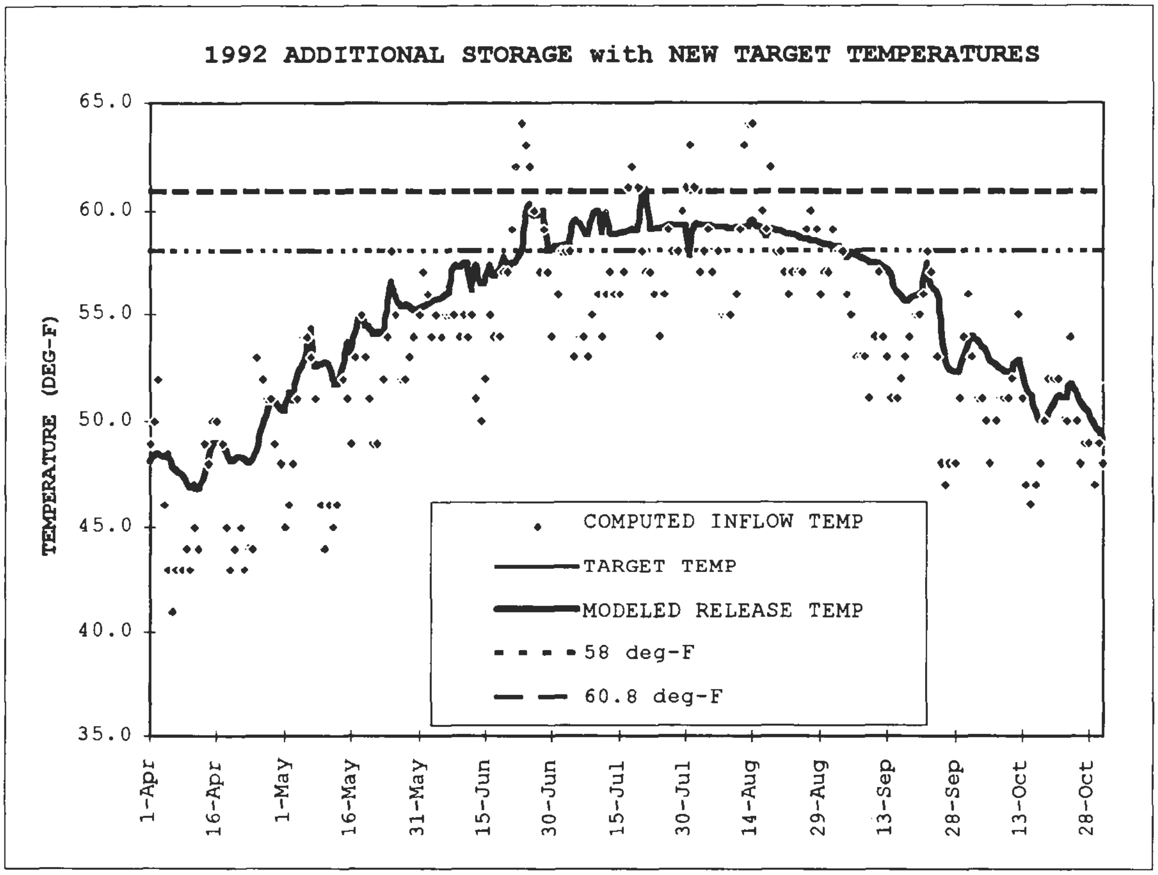


FIGURE 4. 1992 SIMULATION USING THE NEW TEMPERATURE TARGETS.

Degree days were used to compare existing with AWSP temperature releases for September and October as a measure of reservoir performance. Degree days are the number of Celsius degrees that the realer temperature is above or below a certain target each day. Three comparisons were made:

1. Modeled temperatures of the proposed AWSP releases with the preferred alternative (selective withdrawal) outlets, minus the 5-day average inflow temperature (1962-1994).
2. Modeled temperatures of the AWSP with the existing outlets minus the 5-day average inflow temperature (1962-1994).
3. Historic releases minus the 5-day average inflow temperature (1991-1994).

The sum of degree days of heating and cooling for September and October are given in Table 10. Comparing AWSP releases for the selective withdrawal vs. existing outlet releases, there was an improvement in total degree days for 27 of 34 years. Comparison of AWSP degree days and historic temperature (1991 to 1994) are presented in Table 11. The AWSP preferred alternative improves outflow releases for each year over current temperature releases. The improvement ranges from 41-76 °C total degree days or a daily temperature improvement range of 1.2-2.2 F.

TABLE 10. COMPARISON OF "DEGREE DAYS" SUMMED OVER SEPTEMBER AND OCTOBER FOR EACH YEAR SIMULATED. "DEGREE DAYS" ARE DEFINED AS THE NUMBER OF CELSIUS DEGREES THAT THE RELEASE TEMPERATURE IS ABOVE OR BELOW A CERTAIN TARGET EACH DAY. THE RELEASES UNDER EACH CONDITION ARE COMPARED WITH INFLOW TEMPERATURE.

YEAR	ADDITIONAL STORAGE WITH PREFERRED ALTERNATIVE	ADDITIONAL STORAGE WITH EXISTING OUTLETS	HISTORIC RELEASES
	Celsius degrees/day	Celsius degrees/day	Celsius degrees/day
1962	90	244	
1963	53	33	
1964	157	113	
1965	90	168	
1966	73	155	
1967	120	173	
1968	126	110	
1969	113	116	
1970	70	117	
1971	120	119	
1972	158	124	
1973	58	138	
1974	84	124	
1975	108	123	
1976	105	137	
1977	130	122	
1978	105	124	
1979	76	138	
1980	77	127	
1981	195	116	
1982	109	141	
1983	128	133	
1984	96	142	
1985	91	126	
1986	67	123	
1987	19	114	
1988	84	132	
1989	35	135	
1990	88	144	
1991	46	153	124
1992	74	120	111
1993	71	118	112
1994	53	148	126
sum 1962-94	**3069**	**4350**	
sum 1991-94	**244**	**539**	**473**

TABLE 11. COMPARISON OF "DEGREE DAYS" SUMMER OVER SEPTEMBER AND OCTOBER FOR 1991-1994 SIMULATED YEARS FOR 1) AWSP WITH FISH FACILITY; 2) AWSP WITHOUT FACILITY; AND 3) HISTORIC TEMPERATURE RELEASES. SUM OF 1962-1994 MODELED YEARS ARE ALSO PRESENTED.

	ASWP With Preferred Alternative C°/day	AWSP With Existing Outlets C°/day	Historic Releases C°/day
1991	46	153	124
1992	74	120	111
1993	71	118	112
1994	53	148	126
1991-1994	244	539	473
Sum 1962-1994	3069	4350	

Conditions at Palmer. To compare the potential benefits of the AWSP for areas downstream of HHD, the stream temperature below the Tacoma Diversion was modeled for the current flow regime and under the proposed AWSP. The analysis was limited to September, the beginning of the fall chinook salmon spawning and egg incubation period, one of the most critical lifestages for salmon. With the current dam configuration, outflow temperature is generally highest in September. The year chosen for this analysis, 1992, experience normal temperature and less than normal precipitation (60% of normal) in September.

Assuming that the stream channel conditions between HHD (RM 64.5) and the Tacoma Diversion (RM 61) remain the same, RM 61 to RM 58 or 59 would experience lower water temperature during September under the AWSP. This is due to two factors: 1) dam outflow temperatures are lower, and 2) stream flows are greater (under the AWSP reservoir outflow in September (400-600 cfs) will be significantly higher earlier in the summer under Baseline conditions-223 cfs). For the month of September 1992, stream temperature at RM 61 would be 23 C degree days lower (41.5 degrees Fahrenheit) under the AWSP than under current flow conditions. By the time the water reaches the downstream end of the Palmer spawning reach (RM 58-61), the benefit would be diminished somewhat.

Figure 5 shows a comparison of current and AWSP modeled conditions at RM 61. There is a daily stream temperature difference of between 0-3 F or average daily improvement of 1.4°F. The higher stream temperatures under current flow conditions can results in accelerated development of eggs and early emergence of fry from 1-8 days earlier than under AWSP modeled conditions (Alderdice and Velsen 1976). Under lab conditions, chinook salmon eggs incubated at 59 °F had a 74% survival rate, eggs incubated at 53 °F had a 99% survival rate (Garling and Masterson). A nominal comparison shows this would equate to a 6% improvement in egg to fry survival for each 1 °F decrease in stream temperature. For September of 1992, the AWSP had an daily average improvement of 1.4 °F, which could lead to improved egg to fry survival of 1-10%.

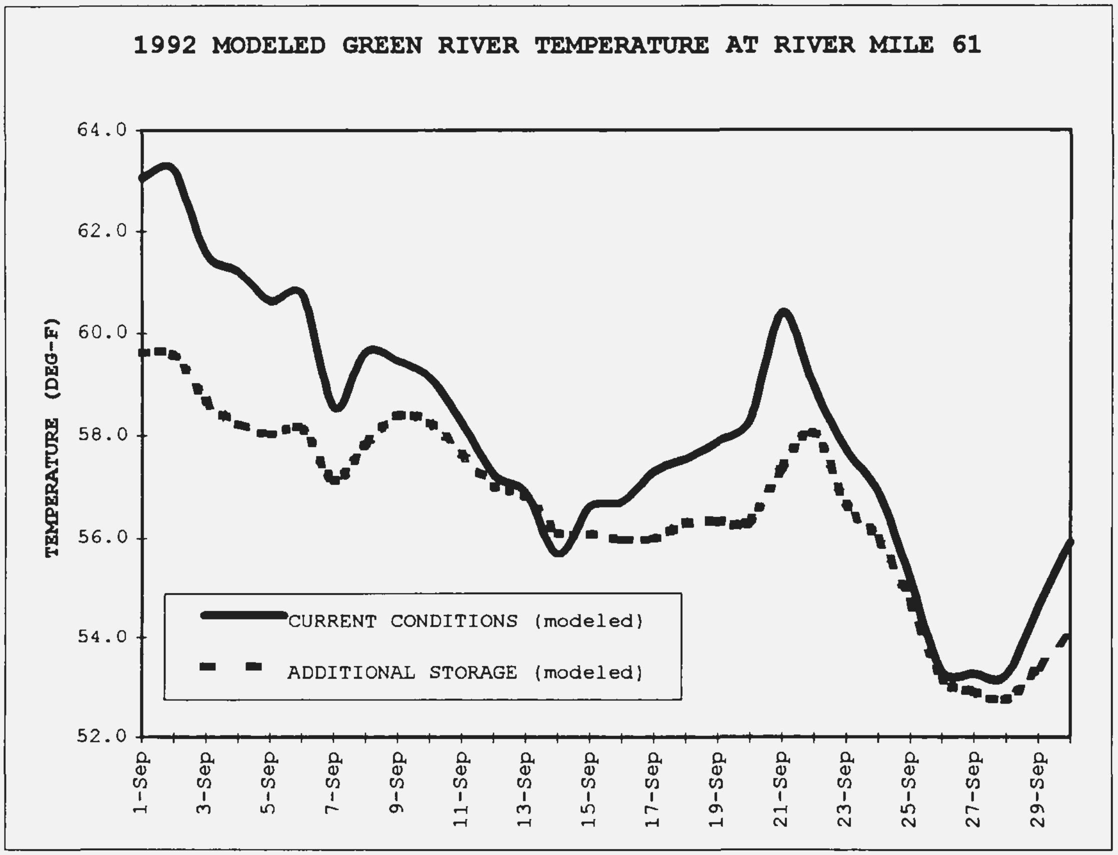


FIGURE 5. MODELED STREAM TEMPERATURE AT RM 61, DOWNSTREAM OF THE TACOMA DIVERSION DAM, UNDER CURRENT AND AWSP FLOWS.

4A.8 LOWER WATERSHED TEMPERATURES

Data from the USGS at RM 35 show that maximum water temperatures at Auburn during July and August exceed the state water quality standard (64.4°F) in virtually every year of record, 1964-1984 (Figure 6). Since 1984, conditions in the lower river likely have not improved and may actually have worsened with additional development of the river corridor removing riparian vegetation and decreased summer flows from lower water tributaries. Temperatures in 1992, a dry-warm year, exceeded 72-75°F for extended periods throughout the lower river, RM 13-45, (Caldwell 1994).

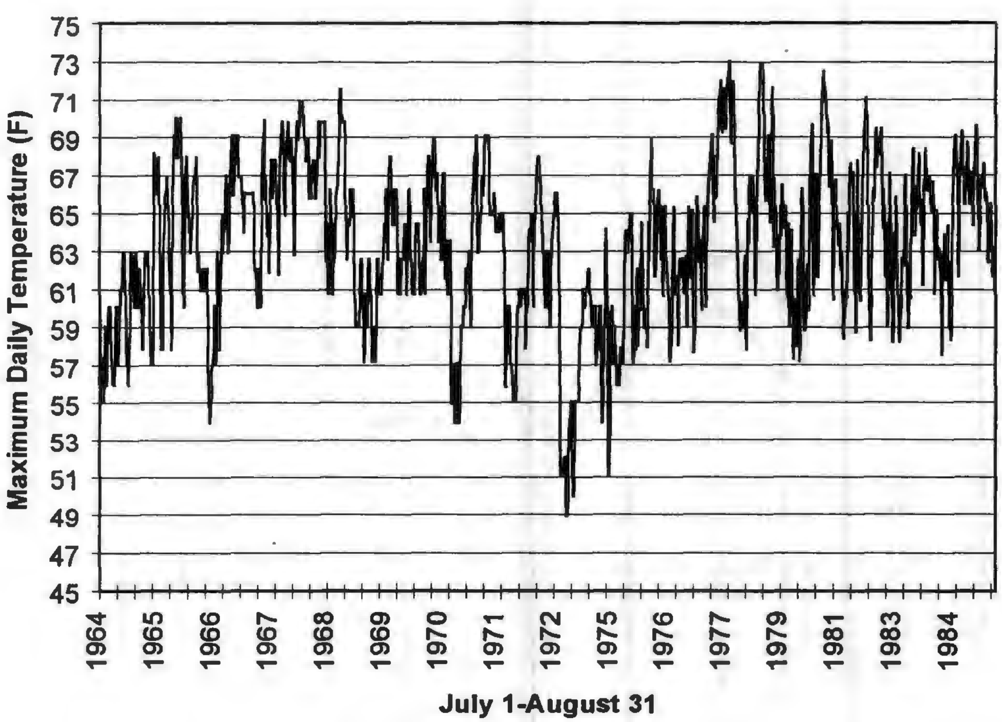


FIGURE 6. MAXIMUM DAILY STREAM TEMPERATURES IN THE GREEN RIVER FOR JULY AND AUGUST AT THE USGS AUBURN GAGE, 1964-1984: 1973 AND 1980 REMOVED BECAUSE OF INCOMPLETE DATA.

In greater than 75% of the years of record, from 1964-1984 and 1992, stream temperatures in the lower river exceeded the range of avoidance for salmon and steelhead, 70 °F, for 1 or more days (Table 12). In 1992, at RM 35, there were over 40 days with temperatures greater than the avoidance temperature (although this location may overestimate totals for later August/September, Caldwell 1994). This temperature range could lead to delay of salmon and summer steelhead in reaching their spawning grounds (Armour 1991; Caldwell 1994). Delay beyond a period of time can result in stress, spawning in lower river areas, and potentially pre-spawning mortality.

TABLE 12. SUMMARY OF DAYS WITH WATER TEMPERATURES GREATER THAN 70°F MEASURED AT THE USGS AUBURN GAGE AND BY CALDWELL, NEALY BRIDGE, (1994): 1973, 1975, 1980, 1983 WERE ALSO MISSING MAJOR PERIODS OF TIME FLOW CONDITION SET FOR HHD REFILL AND RELEASE IS PRESENTED FOR MARCH 1 AND JULY1.

Year	Days Above 70°F	Months	1-Mar	1-Jul
1964	0		Average	Average
1965	6	July	Average	Average
1966	5	July, August	Average	Average
1967	27	June-August	Average	Average
1968	14	July, August	Dry	Average
1969	0		Wet	Average
1970	9	July-August	Average	Average
1971	6	July-August	Average	Average
1972	0		Wet	Average
1973	Incomplete		Dry	Dry
1974			Wet	Average
1975	Incomplete		Wet	Average
1976	1	July	Average	Average
1977	19	July, August	Dry	Average
1978	18	June-August	Average	Dry
1979	10 (partial)	July	Average	Dry
1980	Incomplete		Average	Average
1981	11	July-August	Dry	Average
1982	12 (partial)	June-August	Average	Average
1983	Incomplete		Average	Average
1984	6	July-August	Average	Average
1992	40	June-Septem.	Dry	Dry

Most years of longer periods above 70°F were categorized as average to dry years on March 1 and July 1 during AWSP modeling . These years should be expected to have lower base-flows, lower groundwater inflow, and higher air temperatures than wet or wet-average years. In particular, 1992, the longest period above 70°F, was the only year with two dry categories.

Armour (1991) found that temperatures above 70°F can result in avoidance by sockeye salmon, avoidance temperatures for spring or summer run chinook can be much lower. Studies in the Willamette Basin have shown a prolonged delay for upstream migrant spring and summer chinook when temperatures exceed 60 °F (Willamette Temperature Control Feasibility Report 1996). Fish exposed to temperatures greater than 68°F can also experience reduced growth or early mortality (Nielsen et al. 1994). Green River spring chinook salmon are considered extirpated from the Green River while the migration and spawn time of summer-fall chinook appears to be delayed by low flows and high stream temperatures compared to other river basins (Grette and Salo 1986). Re-introduction of spring chinook and maintenance of summer and fall chinook appears to be limited by lower watershed flows and associated high stream temperatures.

Cool-water temperature refugia may exist in the lower watershed. A 1992 study of the mainstem river, RM 13-64.5, did not document any such areas. Caldwell (1994) found no thermal stratification of pools, with cooler lower depths, or lateral cool-water inflow from intragravel flow or from tributaries. In 1995, monitoring by King County did find limited cool water areas near Auburn (King County, unpublished data). At Big Soos Creek, RM 34, a layer of intragravel flow through the tributary delta fan appears to cool mainstem temperatures from 1.5-3 °F for up to 1 mile downstream. As part of the AWSP, mainstem and side-channel temperatures were collected in early October of 1996, baseflow below 300 cfs (*Section 7. Green River Side Channel Inventory*). Even during measurement in a period of less than maximum air and water temperatures, early October, side-channel areas were found to range from 2-4°F less than mainstem reaches. Maximum differences in side-channel vs. mainstem temperature, up to 6 °F, were observed in side-channels with significant groundwater or intergravel flow. These side-channels were limited in area and often had juvenile coho rearing in available pools. In contrast to these flowing or slow velocity side-channel areas, Caldwell (1994) noted that shallow, stagnant, nearshore areas of the mainstem were from 1-4 °F warmer than the main channel.

Salmonids actively seek cold water areas when ambient stream temperatures are high (Gibson 1966; Berman and Quinn 1991). Thermal refuges are known to be important for salmonids and other species in marginal aquatic habitats (Goetz 1994; Magnuson et al. 1979; Coutant 1985). A variety of structural features acting alone or with other features, including gravel bars and large woody debris, can protect areas of pools from warm water inflow creating areas of cool or cold water (Keller and Hofstra 1983; Nielsen et al. 1994). Bilby (1984) found that thermal refugia in western Washington streams were caused by various sources of water flow and were found by seeps of groundwater inflow, cool tributaries, or water flowing through stream substrates.

Nielsen et al. (1994) found 65% of juvenile steelhead in a California tributary using stratified pools during periods of high ambient stream temperatures (>73°F). These thermally stratified pools provided refuge habitat for young-of-the-year, yearling and adult steelhead in areas where stream temperatures reach lethal limits. Thermally stratified pools were typically 5-15°F cooler at the bottom than surface temperatures. Cold water entered from tributaries, intergravel flow through river bars, and streamside subsurface sources.

High temperatures in the Green River during late spring and early summer could cause the early emigration of juvenile chinook as well as affecting the basin wide distribution of all juvenile salmon and steelhead. Juvenile anadromous salmonids are commonly segregated in streams and in river basins along abiotic gradients of depth, velocity, substrate and temperature. Biotic and abiotic characteristics of streams change from upstream to downstream reaches within a basin and therefore the distribution and relative abundance of salmonid species between reaches and within a reach will also change (Vannote et al. 1981; Platts 1979).

In one Oregon study, water temperature was an important abiotic factor associated with the uneven distribution of juvenile chinook salmon and steelhead. Temperatures ranged from the preferred range of salmonids (50-58 F) in upper sections to near lethal temperatures in lower reaches (Roper et al. 1994). Other studies have shown that high water temperature influences the distribution and abundance of salmonids. High water temperatures have been related to the early emigration of juvenile salmonids, including chinook, steelhead and coho (Roper et al. 1994; Holtby 1988) and decreased survival rates (Bisson and Davis 1976). On a basin-wide scale, ago-0 chinook salmon were shown to have a strong preference for deep-water (pool) habitat (Roper et al. 1994) which is consistent with results of other studies of chinook ecology (Hillman et al. 1987; Bisson et al. 1988).

Studies of the mainstem Green River have documented few primary pools. Overall, most areas of the channel have become wider and shallower since development of the basin. These channel changes are a result of water resource and floodplain development (Blomberg 1996; Fuerstenberg 1997). Howard Hanson has decreased peak flows and sediment transport with resultant changes in channel formation (*Section 6D Gravel Bar Nourishment*). Floodplain areas have been developed with 46% of floodplain isolated from the river and 98% of estuary wetland habitat permanently lost (Green/Duwamish Reconnaissance Study 1997). Loss of floodplain areas has decreased riparian zone habitat and limited hydrologic connection to the mainstem.

4A.9 ADDITIONAL WATER STORAGE PROJECT RESTORATION FEATURES

In addition to the AWSP Ecosystem Restoration component, the Corps is participating with King County and the Muckleshoot Indian Tribe in developing a parallel General Investigation ecosystem study of the entire Green/Duwamish River basin. In this study they identify limiting factors and restoration goals and objectives for basin. They identified four basin-wide restoration goals which include: 1) increasing sediment transport; 2) increasing summer flows and altering dam flow/release patterns; 3) under riparian vegetation/large woody debris, decreasing water temperatures in the lower basin; and 4) increase channel structure and improve fish passage.

Through the AWSP, three restoration goals (limiting factors) for the lower watershed can be addressed: 1) increasing low flows and dam flow/release patterns (non-flood season), 2) decreasing water temperatures; and 3) increasing sediment transport. Flow augmentation, improved HHD outflow temperature releases, and gravel nourishment are three AWSP management measures, mitigation and restoration, that are recommended for implementation *(Section 8. Restoration and Mitigation Plan Summary)*. Implementation of these measures could potentially ameliorate mainstem temperature limitations. These measures are not treating the cause of low flows, high temperatures (other than from HHD), or sediment transport, but are compensating for these aquatic limiting factors in other ways.

Flow augmentation has a variety of options to address low summer flows and high stream temperatures effects on salmonids. For example, flow augmentation can be used during the low flow period to -- 1) increase baseflows; and 2) create brief, artificial freshets, or mimic natural freshets that would not occur under Baseline conditions.

Increased baseflows will increase velocities throughout the river with resultant increases in river depth, lateral habitat area and mixing of upper river coolwater with warmwater in stagnant or low-velocity areas of the lower river. Increased baseflows will also increase intergravel flow in the mainstem and in limited off-channel areas. Lowflow conditions in the Green River cause side-channel and backwater areas to be isolated from main channel flows. Intragravel flow has already been shown to create thermal refugia in the Green River, however, the total increase in this type of flow or areal dimensions cannot be estimated with existing information.

Artificial or mimicked natural freshets could be used at anytime during the low flow period. Freshets can be a cue for movement or could conceivably reduce temperatures in all habitat types from mixing, increased velocities, and intergravel flow. All life-stages of salmon and steelhead from juvenile to adults, have shown positive movement, downstream or upstream, with changes in flow (Williams et al. 1996). In 1992, at Agency request, the Corps released a short freshet in late September to move summer/fall chinook from the lower river upstream to the main spawning grounds. Mainstem river temperatures were falling naturally (but were still in the high 60's °F) but flows may have been too low for adult chinook to move through shallow riffle areas. This type of freshet could also be used as a cue to move late juvenile outmigrants or rearing juveniles into or out of side-channel areas. Chum, chinook, and coho salmon have been observed in Green River side-channels in late June and in early October (King County unpublished data, AWSP data).

Under Baseline conditions, natural freshets from the upper watershed (Headwaters above HHD) during summer and early fall are typically not released in average to dry years. Currently, any increases in HHD inflow during the lowflow season are stored to improve reliability of maintaining instream flows through October. Experience in the past 10 years has shown that the existing storage volume during dry years is insufficient to maintain instream flows through late summer and early fall. In 3 of the past 5 years, existing storage has been inadequate to maintain instream flows and Tacoma has had to reduce their existing instream diversion from days to weeks. This lack of storage resulted in the HHD Section 1135 project. Even with this storage volume increase, the storage management plan in average to dry years involves capture of any flows greater than required instream minimum flows. The constant outflow from HHD and reduced variation in lower river flows could have other undocumented impacts beyond those discussed in this section.

Gravel nourishment, another AWSP management measure, could help maintain channel conditions in the Flaming Geyser reach, RM 46-40.2. This area of the lower river has an armored bed with little or no intergravel flow and this "hungry river" is estimated to be advancing downstream from 700 to 900 ft/year. Addition of gravel at some increment of the natural sediment transport rate should hold the "hungry river" in place and maintain channel conditions in selected areas gravel accumulates. These areas should have some respite in maximum temperatures from resultant intergravel flow.

4A.10 CONCLUSIONS

(to be PROVIDED)

4A.11 LITERATURE CITED

Armour, C.L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish and Wildlife Service, Instream Flow Information paper 28, Washington D.C.

Berman, C.H., and T.P. Quinn. 1991. Behavioral thermoregulation and homing by spring chinook salmon, *Oncorhynchus tshawytscha* (Walbaum) in the Yakima River. Animal Behaviour 39:301-312.

Bilby, R.E. 1984. Characteristics and frequency of cool-water areas in a Western Washington stream. Journal of Freshwater Ecology 2(6):583-602.

Bisson, P.A., and G.E. Davis. 1976. Production of juvenile chinook salmon, *Oncorhynchus tshawytscha,* in a heated model stream. U.S. National Marine Fisheries Service Fishery Bulletin 74:763-774.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Bisson, P.A. 1987. Importance of identification of limiting factors in an evaluation program. Weyerhaeuser Company, Tacoma WA. 22 p.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Page 83-138 in: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, MD.

Bottom, D.L., P.J. Howell, and J.D. Rogers. 1985. The effects of stream alterations on salmon and trout habitat in Oregon. Oregon Department of Fish and Wildlife, Portland, Oregon.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some California streams. Calif. Fish and Game 57:44-57.

Caldwell, B., and S. Hirschey. 1989. Green River fish habitat analysis using the Instream Flow Incremental Methodology. Washington Department of Ecology, Olympia.

Caldwell, J.E. 1994. Green River temperature investigation 1992. Technical Report Prepared for the Muckleshoot Tribe Fisheries Department.

Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Transactions of the American Fisheries Society 114:31-61.

Everest, F.H., G.H. Reeves, J.R. Sedell, J. Wolk, D. Hohler, and D.A. Heller. 1985. Abundance, behavior, and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon, as influenced by habitat enhancement. Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon. Project No. E4-11.

Fishery Sciences, Inc., 1984. Green River water temperature characteristics. Seattle, WA.

Fuerstenberg, R.R., K. Nelson, and R. Blomquist. 1996, Ecological conditions and limitations to salmonid diversity in the Green River, Washington, U.S.A: Structure, function, and process in river ecology. King County Surface Water Management.

Goetz, F.A. 1994. Distribution and juvenile ecology of bull trout *(Salvelinus confluentus*) in the Cascade Mountains. M.S. Thesis, Oregon State University, Corvallis.

Grette, G. and E.O. Salo. 1986. The status of anadromous fishes in the Green/Duwamish River system. Prepared by Evans-Hamilton, Inc. for the Seattle District U.S. Army Corps of Engineers.

Healey, M.C. 1991. Chinook Salmon (*Oncorhynchus tshawytscha*). Pages 311-393 *In* Groot, C.and L. Margolis (eds.). Pacific Salmon Life Histories. UBC Press, Vancouver, British Columbia. 564 p.

Hillman, T.W., J.S. Griffith, and W.S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185-195.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Jenks, S.P. 1989. Stillaguamish River coho salmon (*Oncorhynchus Kisutch*) off-channel habitat enhancement project. Washington Department of Fisheries, Olympia, WA. Pages 148-155.

Keller, E.A., and T.D. Hofstra. 1983. Summer cold pools in Redwood Creek near Orick, California, and their importance as habitat for anadromous salmonids. Pages 221-224 in Proceedings of the first biennial conference of research in California national parks. U.S. National Park Service, Cooperative Park Studies Unit, Davis, California.

Li, H.W, and 6 co-authors. 1994. Cumulative effects of riparian disturbances along high desert trout streams of the John Day Basin, Oregon. Transactions of the American Fisheries Society 123:627-640.

Mason, J.C., and D.W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavior ecology of juvenile coho salmon in stream channels. Journal Fisheries Research Board of Canada 22:173-190

McEwan, D. and J. Nelson. 1991. Steelhead Restoration Plan for the American River. State of California, The Resources Agency, Department of Fish and Game. Under Direction of: Robert R. Rawstron (Inland Fisheries Division) and James Messersmith, (Manager - Region 2).

Magnuson, J.J., L.B. Crowder, and P.A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19:331-343.

Marshall, D.E., and E.W. Britton. 1980. Carrying Capacity of Coho Streams. Fisheries and Oceans Enhancement Services Branch. Vancouver, British Columbia.

Nielsen, J.L., T.E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Transactions of the American Fisheries Society 123:613-626.

Pickett, P.J. 1992. Historical data sources and water quality problems in the Chehalis Basin; first interim report for the Chehalis River TMDL study. Washington Department of Ecology (EILS), Olympia WA.

Platts, W.S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4(2):5-9.

Reeves, G.H., J.D. Hall, T.D. Roelofs, T.L. Hickman, and C.O. Baker. 1991. Rehabilitating and modifying stream habitats. Pages 519-557 *In* Influences of forest and rangeland management on salmonid fishes and their habitats (W. R. Meehan, ed.). American Fisheries Society Special Publication 19, Bethesda MD.

Reiser, D.W., and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada: Habitat Requirements of Anadromous Salmonids. Pacific Northwest Forest and Range Experiment Station. U.S.D.A. Forest Service General Technical Report PNW-96. Portland, Oregon. 54 p.

Roper, B.B., D.L. Scarnecchia, and T.J. La Marr. 1994. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Transactions of the American Fisheries Society 123:298-308.

Sandercock, F.K. 1991. Coho Salmon (*Oncorhynchus kisutch*). Pages 395-445 *In* Groot, C. and L. Margolis (eds.). Pacific Salmon Life Histories. UBC Press, Vancouver, British Columbia. 564 p.

Schneider, M.L., and R.E. Price. 1988. Temperature analysis of Howard A. Hanson Reservoir, Washington. Waterways Experiment Station, US Army Corps of Engineers, Vicksburg, MS.

Valentine, M. 1996. Water Quality Narrative for the Howard A. Hanson Reservoir Additional Storage Project, Part I: Temperature Analysis.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1981. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Williams, R. W., R. M. Laramie and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization. Volume I. Puget Sound Region. Washington Department of Fisheries, Olympia, WA.

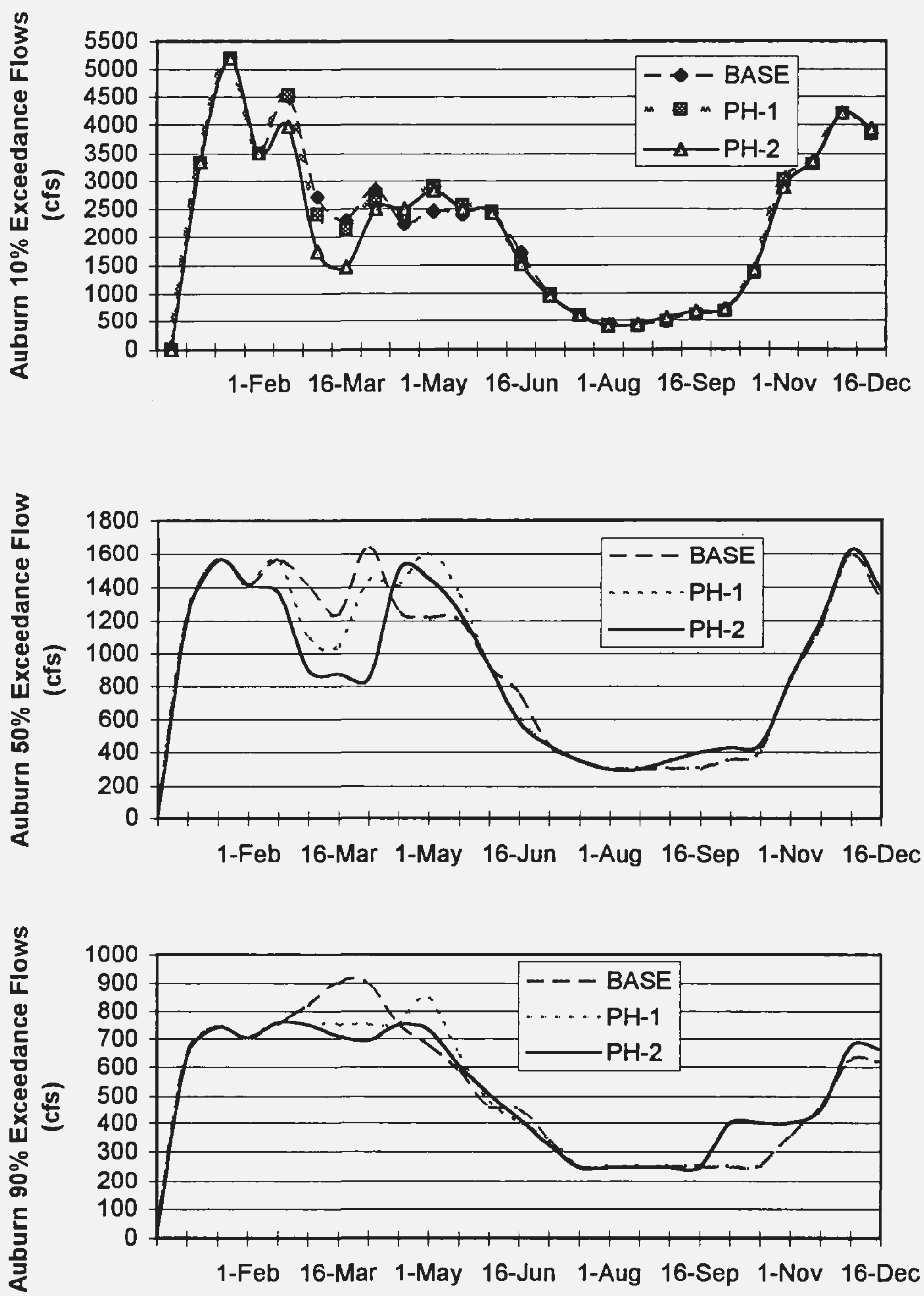


FIGURE __. AUBURN 10, 50, AND 90 PERCENT EXCEEDANCE FLOWS UNDER BASELINE, PHASE I, AND PHASE II STORAGE AND RELEASE CONDITIONS.

SECTION 4B GRAVEL NOURISHMENT IN THE MIDDLE AND UPPER GREEN RIVER

4B.0 SUMMARY

Stream processes supplying gravel-sized sediments may be an important component to the successful reproduction of salmon and steelhead in rivers containing large water storage projects. Construction and operation of the Howard Hanson Dam (HHD) Project in Washington State has modified sediment transport processes in the Green River. Modification of the sediment transport regime has created a zone of streambed armoring immediately downstream of the project and affected the amount of gravel-sized sediments available to spawning anadromous salmonids. Continued operation of the HHD Project may cause the zone of armoring to extend further downstream and affect reaches of the Green River presently supporting extensive natural salmonid spawning.

Gravel nourishment could be used to replenish areas presently deficient of spawning-sized sediments and slow or stop the downstream extent of streambed armoring. Slowing or stopping the downstream extension of streambed armoring was evaluated as part of the HHD Additional Water Storage Project (AWSP) since the effects of springtime water storage on fish in the lower river are influenced by ongoing stream processes. Reductions in flow resulting from implementation of the AWSP between 15 February and 31 May will not increase the rate of gravel movement through the Green River; however, gravel nourishment provides an opportunity to restore natural stream processes. The results of a preliminary analysis of sediment transport relations indicate that up to 11,800 cubic yards of gravel could be placed annually below HHD to benefit the sediment transport regime of the Green River.

4B.1 INTRODUCTION

The Green River below River Mile 64.5 has been regulated by the HHD Project since 05 December 1961. The reservoir is formed by an earth-fill dam, completed on 31 March 1962. The U.S. Army Corps of Engineers (Corps) operates the reservoir to provide downstream flood protection and to augment summer low flows.

Howard Hanson Dam has influenced sediment transport in the Green River below RM 64 in two ways. The dam has altered the hydrologic regime by eliminating flows greater than 12,000 cfs. Flood flows are temporarily stored in Howard Hanson Reservoir before being slowly released after the flood peak has subsided. Construction of HHD also dramatically reduced the sediment load supplied to the lower Green River. Since completion of the project, the reservoir has served as an efficient sediment trap, storing the majority of sediment generated in the upper watershed.

A number of downstream geomorphic responses might be expected in response to the decreased magnitude of flood flows and reduced sediment supply. Bedload sediment and much of the suspended sediment is deposited in the reservoir pool; thus, water released from the reservoir has a greater capacity to erode sediment from the channel bed and banks downstream (Kondolf and Matthews 1993). Downcutting continues until an armor layer forms, composed of larger particles that are less easily mobilized.

The reduction in flood flows would be expected to result in a reduction in channel width and depth (Dunne and Dietrich 1978). Vegetation encroaches onto surfaces which were formerly frequently inundated, resulting in decreased channel width. The channel depth may decrease where flows are no longer adequate to transport excess sediment.

The interruption of downstream sediment transport by Howard Hanson Dam is believed to have resulted in armoring downstream of Howard Hanson Dam (Perkins 1993). Changes in channel morphology since 1962 are consistent with a reduction in sediment supply. Perkins (1993) noted stable islands supporting dense stands of 8-12 inch alder were located between the Palmer gage and Kanasket State Recreation Area, and within Flaming Geyser State Park. These islands were most likely active bars prior to construction of Howard Hanson Dam. She also reported that from RM 45.7 to RM 40.2, "braided areas have diminished, the channel has narrowed [and] active sediment storage sites have decreased in size and number" since construction of HHD, indicating that the river is responding to both flood reduction and sediment supply. In contrast, she reports that the presence of numerous large, active gravel bars below RM 40.2 indicate that the sediment load continues to exceed transport capacity, suggesting that the reduction in sediment supply has not yet impacted this reach. Armor layer formation was estimated to be advancing downstream at 700 to 900 feet per year in the Green River (Perkins 1993).

The AWSP involves annual storage of additional water behind HHD beginning 15 February. A slight reduction in peak spring flow events will be offset by a slight increase in spring, summer and fall baseflow conditions. The net result may be a slight reduction in the rate of gravel movement through the Green River system, but the effect will be negligible. The relative magnitude of the expected flow changes are not expected to significantly alter the existing sediment transport regime.

The following sections describe a preliminary analysis of the potential for restoration of sediment transport relations in the Green River below Howard Hanson Dam. Analyses are based on available hydrologic, geomorphic and sediment transport data for the Green River. Because available data were limited, a number of assumptions were required to conduct the analysis. Key assumptions are listed in Section 4B.2, and methods and results of the analysis are described in Section 4B.3. Section 4B.4 contains recommendations for potential gravel nourishment opportunities.

4B.2 ASSUMPTIONS

- The rate of sediment delivery and transport to HHD has not changed since construction of Howard Hanson Dam.

- The annual sedimentation rate observed in Howard Hanson Reservoir during the period from 1979 to 1993 accurately represents a portion of the total sediment load which would have been delivered to downstream reaches had the project not been constructed.

- Reservoir deposits were assumed to consist of 15 percent gravels and larger, 25 percent sand, 40 percent silt and 20 percent clay. This particle size distribution is representative of the composition of sediment deposits which have been sampled in other Western Washington Reservoirs (Elwah River Ecosystem Restoration DEIS 1996). Using this size gradation, the density of reservoir deposits = 77 lb/ft^3.

- For the purpose of calculating reservoir trap efficiency, it was assumed that the period including water years 1976 (wet year) and 1977 (dry year) is representative of long-term reservoir operations.

- Bedload equals 15 percent of the suspended load.

- No significant sediment contributions occur between HHD at RM 64 and Newaukum Creek (RM 40.8).

4B.3 ANALYSIS

4B.3.1 Approach

The geology of the Green River watershed was examined to identify the nature and primary sources of sediment within the Green River Watershed. Data on the reservoir sedimentation rate were used to estimate the amount of bedload transport trapped by Howard Hanson Dam. Hydrologic data were examined to determine how construction of the dam had altered the flow regime. The critical flow required to mobilize sediment inputs was assessed using sediment transport formulae developed by Schoklitsch (1934 and 1949) and Meyer-Peter and Muller (1948).

4B.3.2 Sediment Sources

Analysis of alluvial deposits just downstream of the Green River gorge suggest that most material transported by the river originates from tertiary andesitic rocks of the Cascade Range. This geologic type is characteristic of headwater areas in the Green River watershed. Only a few percent of the pebbles found in alluvial deposits below the gorge were derived from arkose of the Puget Group through which the Green River gorge has cut. (Mullineaux 1970). This indicates that prior to construction of Howard Hanson dam, the majority of material carried as bedload entered the Green River upstream of the Green River gorge.

During a float trip conducted in November 1996, only a few sediment sources were identified within the Green River gorge, primarily slope failures less than 5,000 ft^3. In addition, sandstones such as those characteristic of the Puget Group are easily abraded, thus coarse material entering the system from within the gorge is quickly reduced to fine sediment through collusion (Dunne and Dietrich 1978). A few other landslides contributing material directly to the stream were identified in the Middle Green River in locations where the channel undercuts high, steep banks composed of poorly indurated sands and clay of the Hammer Bluff formation (Perkins 1993). The scarcity, episodic nature and fine composition of such inputs means that they supply only a minor amount of the bedload carried by the Green River. No other sources supply significant amounts of coarse material to the Green River until Newaukum Creek enters at RM 40.8.

4B.3.3 Sedimentation rate

Howard A. Hanson Reservoir accumulated 1,769 acre-feet of sediment between 1961 and 1993 (U.S. Army Corps of Engineers 1993). The average rate of accumulation during this 32-year period was 55.3 acre-feet per year. Typical reservoir operation was assumed to include moderate to considerable drawdown, and the size gradation of incoming gravels was assumed to be 15 percent gravel or larger, 25 percent sand, 40 percent silt and 20 percent clay. Under these conditions, the density of reservoir deposits was determined to be 77 lb per ft^3 . The average annual rate of accumulation was therefore determined to be 92,700 tons.

Reservoir trap efficiency was estimated using the method of Churchill (1947). This method is recommended by the U.S. Bureau of Reclamation (1987) for flood retarding structures. Calculation of trap efficiency was based on USGS data for the period including water years 1976 and 1977, which was assumed to be representative of long-term reservoir operations. This period includes both a wet year (1976) and a dry year (1977), as shown in Figure 1. During this period, the average water surface elevation in the reservoir was 1095.08 ft and the average discharge was 1,339 cfs, as shown in Figure 2. The period of retention (2.2 days) was determined by dividing the capacity at mean pool (about 5,740 acre feet) by the average inflow (1,339 cfs). The mean velocity (4.2 feet per minute) was determined by dividing the reservoir length at mean pool (approximately 2.5 miles) by the period of retention. Using these values, the reservoir trap efficacy was determined to be 71 percent. This means that 71 percent of the sediments entering the HHD reservoir remain trapped in the reservoir pool. The 29 percent of sediments that continue downstream primarily consist of silts and smaller-sized sediments carried in suspension. This estimate of reservoir trap efficacy should be refined by examining proposed reservoir operations under each additional storage alternative prior to implementing gravel nourishment measures.

The total rate of sediment inflow was therefore estimated to be 130,600 tons per year (92,700 tons/0.71). In a gravel bed stream, bedload typically ranges from 5 to 15 percent of the suspended load (U.S. Bureau of Reclamation 1987). The bedload of the sediment inflow to Howard A. Hanson Reservoir was assumed to be 15% of the suspended load. Under these conditions, the maximum average annual bedload and suspended load were estimated to be 19,600 tons per year and 111,000 tons per year respectively. This estimate of average annual suspended load is larger than the average suspended load of 59,700 tons per year measured by the USGS at the Palmer gage (Gage No. 12106500) from water years 1951 to 1957 (Richardson et al. 1968). However, the values of suspended load measured by the USGS varied significantly, from a minimum value of 6,370 tons in 1952 to a maximum of 125,000 tons in 1956; thus, our estimate is well within the recorded range of values. The limited period of record over which suspended sediment data are available may not be long enough to obtain a good estimate of the long-term average annual sediment load. Using the same conditions, but assuming that bedload represents only 5% of the average suspended load suggests a minimum average annual pre-HHD contribution of approximately 6,500 tons per year. However, this estimate is less likely because the corresponding suspended load (124,100 tons) would be even further away from the average value for the 1951 to 1957 period (59,700 tons).

4B.3.4 Hydrology

Howard Hanson Dam has altered the hydrologic regime by preventing flows greater than 12,000 cfs. Annual instantaneous flood flows at the Auburn Gage (USGS gage 12113000) for the water years 1937 to 1993 are shown in Figure 3. Prior to water year 1962, the design flood level of 12,000 cfs was exceeded 14 times during the 25-year period from 1937 to 1961. Since construction of the dam, flood flows are temporarily stored in the reservoir then gradually released such that the maximum outflow from the project combined with downstream tributary inflows does not exceed 12,000 cfs at Auburn. The flood-frequency relationships for the Auburn gage for both pre-dam and post dam conditions are shown in Figure 4. Prior to construction of Howard Hanson Dam, the return period for the 12,000 cfs flood was approximately 1.8 years. Since completion of the project, the 1.8 year return interval flood is approximately 8,800 cfs.

Daily flow duration curves for the Auburn gage are shown in Figure 5 for both the pre-dam and post-dam conditions. The primary effect of the project has been to alter the frequencies of flows in excess of about 3,000 cfs. Flows ranging from 3,000 to 9,000 cfs have occurred more frequently since completion of the dam, while flows greater than 9,000 cfs have occurred less frequently. No daily flow greater than 12,000 cfs has occurred since 1962.

4B.3.5 Sediment transport capacity

The critical flows required to mobilize gravel inputs to the stream were estimated to determine where these gravels would be likely to deposit. To facilitate these analyses, three channel segments were identified. These segments differ geomorphically, and thus could be expected to have different capacities for transporting sediments.

The Palmer Segment (RM 60.3 to RM 57.0) extends from the City of Tacoma Purification Plant to the Kanasket Palmer State Recreation Area. This segment is relatively steep and confined compared to the lower Green River. Field observations during a survey of side channel habitat conducted in October 1996 suggest that armor layer development had reduced the amount of gravel and cobble size sediments within this reach. The Flaming Geyser segment (RM 46 to RM 40.2) is located just below the Green River gorge. This segment has a low gradient and wide floodplain, but is periodically constrained on one bank where the river flows along the base of steep bluffs. As described previously, stable in-channel bars and channel narrowing indicate that this segment may be experiencing the effects of reduced sediment supply. The Metzler-O'Grady segment extends from RM 40.2 to the Neely Bridge (RM 34.8). This segment has a very low gradient, and contains many large active bars and occasional braided segments. Extension of armoring is not yet believed to have impacted this portion of the river.

The optimum size of material for gravel nourishment purposes is gravel to small cobble size material which would provide suitable spawning gravel for salmonids. Size distribution specifications for spawning gravel have been reported by the Washington State Department of Fish and Wildlife (Allen and Meekin 1973) and are listed in Table 1. This mixture of gravel has a minimum particle size of 1.5 mm, a D_{50} of 32 mm and a maximum particle size of 100 mm. The size gradation of bedload entering Howard Hanson Reservoir is not known, but is likely to be coarser than the distribution shown in Table 1.

The flows required to mobilize the D_{50} of this particle size mixture was estimated using equations developed by Schoklitsch (1934 and 1949) and Meyer-Peter and Muller (1948). Because of the relatively large uncertainty of bed-load transport formulas, results of the modelling should be used for comparisons between reaches or hydraulic regimes rather than as absolute values. The discharges at which sediment may be mobilized are based on the assumptions that all particles are equally capable of being entrained, and that velocity is constant across the channel. The former may be appropriate assumptions for gravel nourishment activities, where large amounts of well-sorted material is input en masse, but may underestimate the flow required to initiate transport in poorly sorted channels with well-developed armor layer. The assumption of uniform velocity profiles rarely holds true for natural channels.

The results of the sediment transport capacity analyses indicate that the Palmer segment has a much higher sediment transport capacity than either the Flaming Geyser or Metzler-O'Grady segments (Table 2). The three methods suggest that sediment 32 mm in diameter may be mobilized at flows ranging from approximately 400 to 1,000 cfs, which are exceeded about 49 to 77 percent of the time under the current flow regime. The high sediment transport capacity of this reach is confirmed by the coarse bed and scarcity of gravel size material noted during field studies. Gravel of the recommended size range is therefore expected to have a short residence time in this segment. Attempts to enhance gravel retention by putting large amounts of gravel into the main channel are unlikely to be successful. An alternative strategy to increase the amount of material suitable for salmonid spawning would be to identify individual placement sites with appropriate local hydraulic conditions. Examples of such sites are the two major side channels located at RM 59.8 and RM 58.8; however, detailed investigation of individual placement sites is beyond the scope of this investigation.

The Flaming Geyser segment has a somewhat lower capacity to transport sediment. According to the three methods, flows ranging from about 1,300 to 2,900 cfs are required to transport particles 32 mm in diameter. Flows of these magnitudes would be exceeded approximately 9 to 38 percent of the time under current flow conditions (Figure 5). It is not known at this time how the altered hydrology has influenced the ability of this segment to transport the largest particles, however the current flow regime appears to be capable of redistributing material of the size recommended for gravel nourishment.

Because of its low gradient and unconfined floodplain, the Metzler-O'Grady Reach is expected to have a much lower sediment transport capacity. Modelling using the three methods indicate that flows ranging from approximately 8,200 to 15,800 cfs are required to mobilize sediment 32 mm in diameter or greater in this reach. Flows of these magnitudes would be exceeded approximately 0.0 to 0.8 percent of the time under current flow conditions (Figure 5). Because gravels are currently relatively abundant in this segment, the goal of enhancement should be to prevent downstream migration of armoring through this reach by maintaining an appropriate supply of sediment from upstream reaches.

4B.4 RECOMMENDATIONS

Based on this preliminary analysis, it is recommended that up to 11,800 cubic yards of gravel with the size gradation shown in Table 1 be added annually to the Green River below the Green River gorge, at or upstream of RM 46. This figure is based on an assumed maximum average annual pre-HHD bedload of 19,700 tons per year and assuming 0.6 cubic yards of gravel per ton. The goal of this gravel nourishment would be to halt the downstream migration of bed armoring by maintaining the supply of gravel sized material delivered to RM 40.2 during annual high flows, and to replenish gravels suitable for salmonid spawning which may have been lost as a result of armoring between RM 46 and RM 40.2. Angular pit run gravel input at RM 46 are expected to become rounded by abrasion within approximately 3 km of the input site (Kuennen 1956). Arkosic sandstones from the Puget group wear quickly (Dunne and Dietrich 1978), and would be expected to decrease in size by up to 20% between RM 46 and 40 (Kuennen 1956). Gravels originating from more resistant volcanic andesite or basalt should decrease by only about 8% (Kuennen 1956).

Prior to undertaking gravel nourishment activities, a more detailed analysis of sediment transport within the Project Reach should be considered. Sediment from other sources may reduce the downstream rate of armor extension. Newaukum Creek currently supplies the majority of the sediment to the Metzler O'Grady Reach, and its contribution should be quantified in order to further refine the amount of gravel appropriate for nourishment. If too much gravel were added, excess gravel would deposit in the channel, particularly in the Metzler-O'Grady Reach. The resultant aggradation would counteract ongoing efforts to reduce flooding and bank erosion at depositional sites. A detailed analysis of the sediment transport capacity within the Green River should determine:

1. how the size gradation shown in Table 1 compares with the size gradation of bedload entering Howard Hanson Reservoir;

2. how operation of Howard Hanson Dam has altered bedload transport capacity of flows released to the Green River;

3. the extent to which operation of Howard Hanson dam has altered channel morphology at the USGS gage sites immediately below the dam and at Palmer; and

4. the relative contribution of Newaukum Creek, and whether inputs from this basin are believed to have changed since 1962.

Detailed sediment transport modeling of the segment between RM 46 and RM 40.2 should be conducted prior to actual gravel placement to better quantify the amount of material which may be transported into and out of the reach, the rate at which redistribution of sediment inputs would be expected to occur and specific locations within that reach which may be vulnerable to localized deposition and an increased risk of flooding. Cross-sections and HEC-2 flood flow modeling conducted by the King County Surface Water Management, supplemented by field measurement of selected cross-sections and sediment distribution data, would be useful for more detailed analysis of this channel segment.

A second alternative would be to experimentally place the estimated minimum pre-HHD contribution of 3,900 cubic yards of gravel (6,500 tons x 0.6 yd^3 per ton) below the Green River gorge. A monitoring plan to track the travel distance, redistribution and deposition of the added gravel could be implemented to minimize the risk of major downstream ramifications. Annual placement would be reduced or halted if monitoring identified problematic aggradation.

4B.5 LITERATURE CITED

Churchill, M.A. Discussion of "Analysis and use of reservoir sedimentation data" by L.C. Gottschalk. In *Proceedings of Federal Interagency Sedimentation Conference,* Denver, CO January 1948 pp 139-140

Dunne, T and W.E. Dietrich. 1978. Geomorphology and hydrology of the Green River. Appendix A in: Jones and Jones eds., A River of Green. Report to King County. p. A1-A33.

Elwah River Ecosystem Restoration Implementation. Draft Environmental Impact Statement. April 1996. Olympic National Park, WA.

Kondolf, G.M. and W.V.G. Matthews, 1993. Management of coarse sediment on regulated rivers. California Water Resources Center, University of California. Report No. 80, ISSN 0575-4968. 128 p.

Kuennen, P.H. Experimental abrasion of pebbles 2: Rolling by current. Journal of Geology. 64:336-368.

Meyer-Peter, E. and R. Muller. 1948. Formula for bed-load transport. Proceedings of the International Association for Hydraulic Research, 2nd Meeting, Stockholm.

Mullineaux, D.R. 1970. Geology of the Renton, Auburn and Black Diamond Quadrangles, King County Washington. USGS Professional Paper 672, Washington D.C. 91 p.

Perkins, S. 1993. Green River channel migration study. Unpublished report, King County Department of Public Works, Surface Water Management Division. 46 p.

Richardson, D., J.W. Bingham and R.J. Madison. 1968. Water resources of King County, Washington. U.S.G.S. Water-supply Paper 1852. 74 p.

U.S. Army Corps of Engineers, Seattle District. 1993. Howard A. Hanson Dam reservoir sedimentation study, 1979 to 1993. Unpublished report

Schoklitsch, A. 1934. Der geschiebetrieb und die geschiebefracht. Wasserkraft und Wasserwirtschaft. Vol. 29, No. 4, pp. 37-43.

Schoklitsch, A. 1949. Berechnung der geschiebefracht. Wasser und Energiewirtschaft. Nr. 1.

Shields, A. 1936. Application of similitude and turbulence research to bed load movement. Mitteilungen der Prussischen Versuchanstalt fur Wasserbau and Schiffbau. Berlin, No. 26, 1936.

Snyder, D.H., P.G. Gale and R.F. Pringle. Soil Survey of King County Area, Washington. USDA Soil Conservation Service, Washington D.C. 100 p.

U.S. Bureau of Reclamation 1987. Design of small dams. A Water Resources Publication. pp.539-543

TABLE 1. RECOMMENDED SPAWNING-GRAVEL SIZE DISTRIBUTION (ALLEN AND MEEKIN 1973).

Sieve Size (mm)	Percent passing by weight
101.6	100
63.5	80-90
50.8	70-85
38.1	55-70
25.4	25-50
19	0-20
12.7	0

TABLE 2. DISCHARGE (Q) REQUIRED TO MOBILIZE D_{50} OF THE GRAVEL MIXTURE IN VARIOUS CHANNEL SEGMENTS OF THE GREEN RIVER.

	Channel characteristics				Critical Q (cfs)		
Segment	Active Width[1] (m)	Depth[2] (m)	Slope[3]	D_{50}[4] (mm)	Schoklitch (1934)	Schoklitch (1949)	Meyer-Peter and Muller (1948)
Palmer (RM 60.3-RM 57.0)	25	2	0.007	32	400	1,000	500
Flaming Geyser (RM 46.0-RM 40.2)	38	1.9	0.004	32	1,300	2,900	1,400
Metzler-O'Grady (RM 40.2-RM 34.8)	100	0.9	0.002	32	8,700	15,800	8,200

[1]Estimated for Palmer segment; from Perkins 1993 for Flaming Geyser and Metzler-O'Grady segments.
[2]Estimated for Palmer segment; from cross-sections obtained from KCSWM for Flaming Geyser and Metzler-O'Grady segments.
[3]Estimated from USGS topographic maps for Palmer segment; from Perkins 1993 for Flaming Geyser and Metzler-O'Grady segments.
[4]Allen and Meekin (1973).

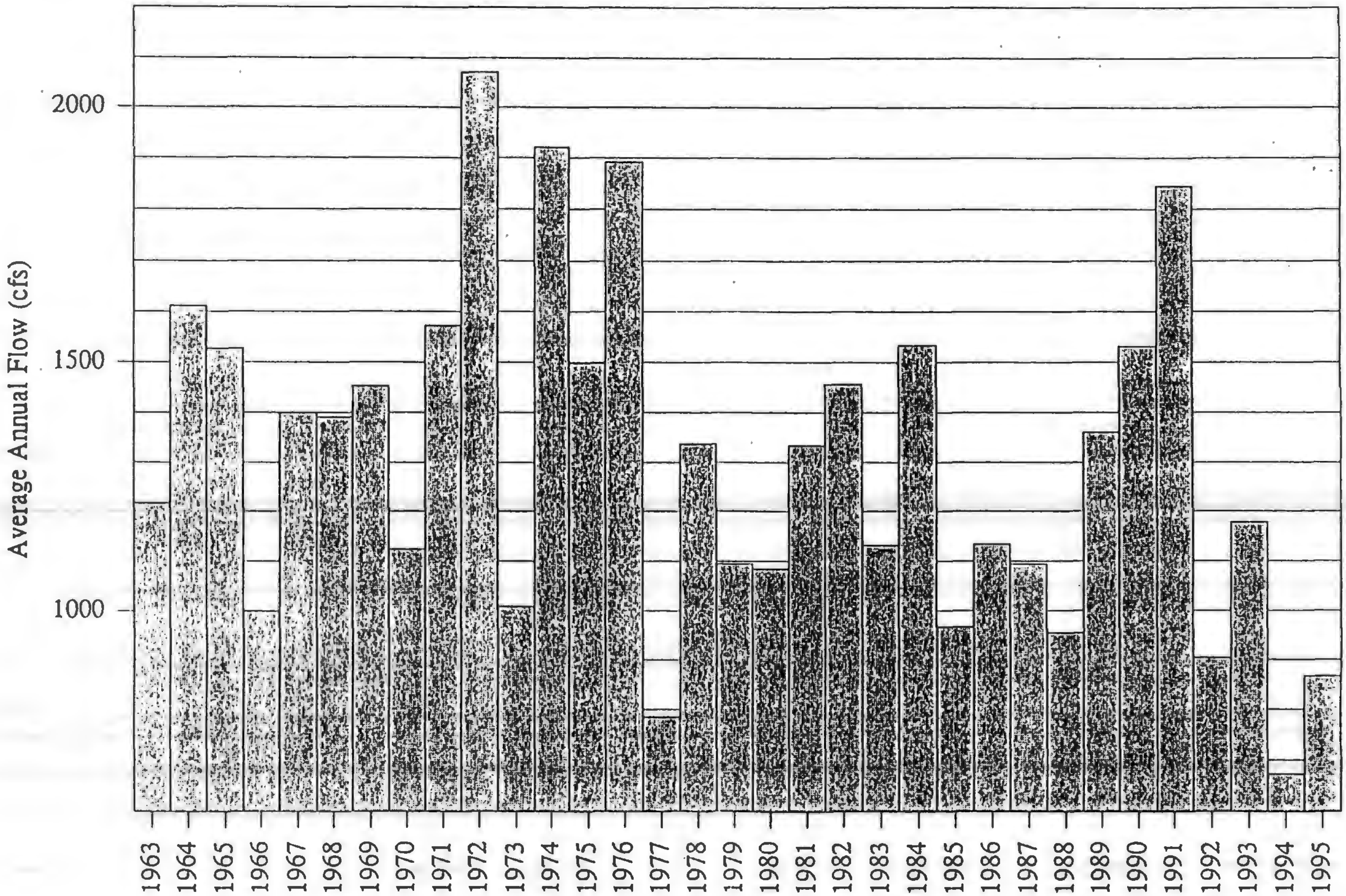


Figure 1. Average annual flow at Green River Below Howard A. Hanson Reservoir (USGS Gage No. 12105900), water years 1963 - 1995.

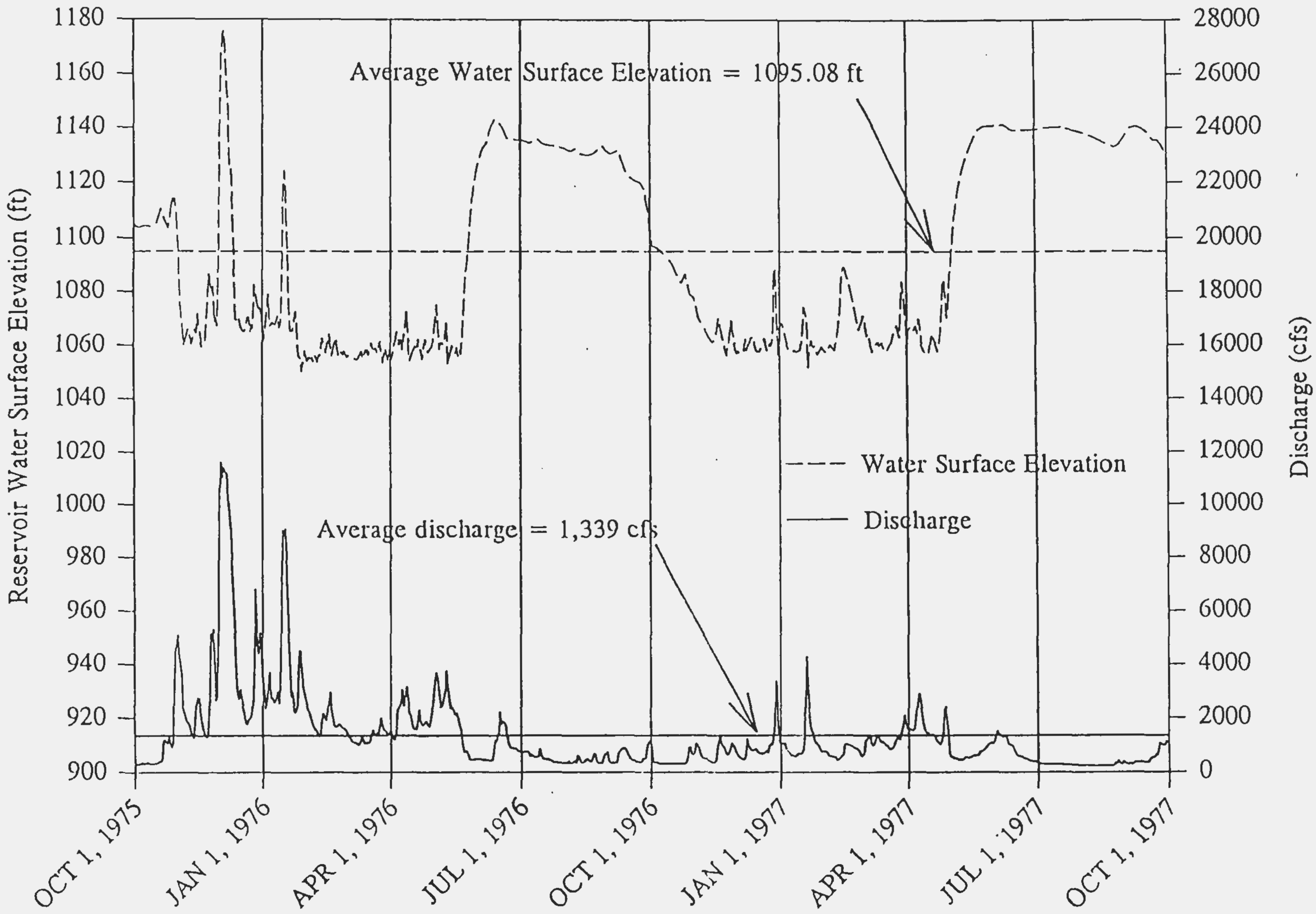


Figure 2. Daily water surface elevation in Howard A. Hanson Reservoir near Palmer (USGS Gage No. 12105800) and daily flows in Green River Below Howard A. Hanson Reservoir (USGS Gage No. 12105900) in a wet year (1976) followed by a dry year (1977).

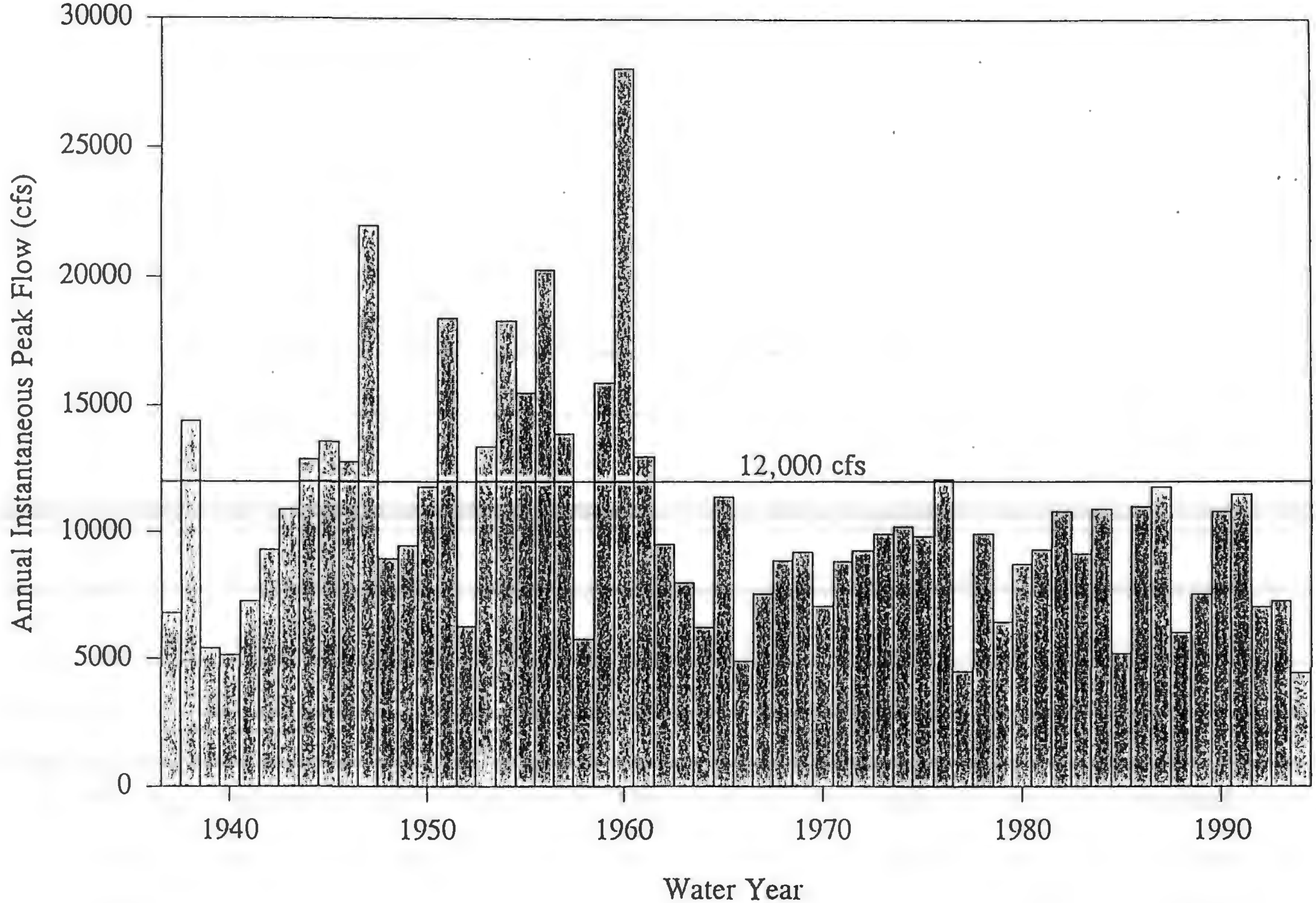


Figure 3. Annual instantaneous peak flows, USGS Gage 12113000, Green River near Auburn, Washington.

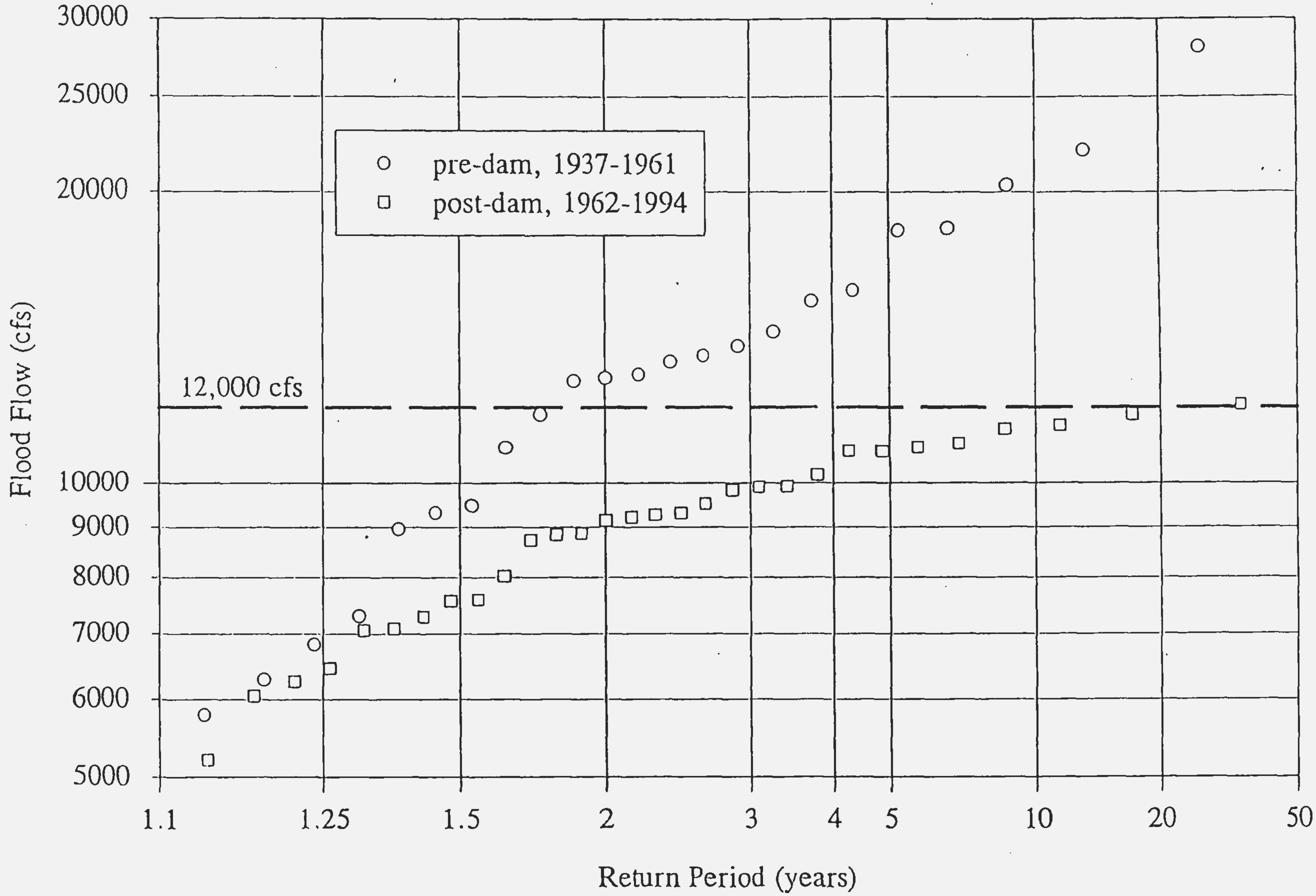


Figure 4. Flood-frequency relationships for USGS Gage No. 12113000 Green River near Auburn, Washington, prior to and after construction of Howard A. Hanson Dam

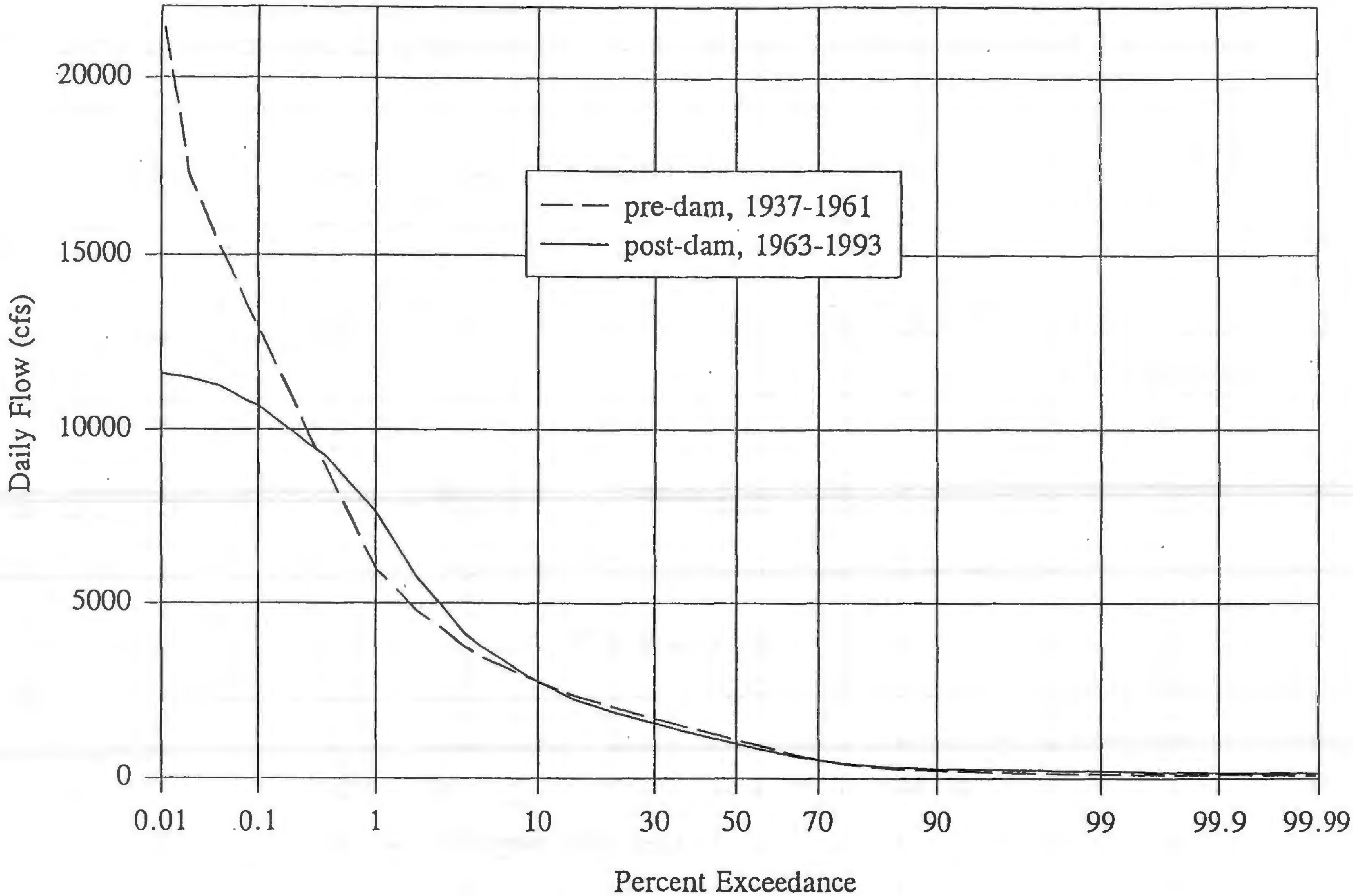


Figure 5. Daily flow duration curves, USGS Gage 12113000, Green River near Auburn, Washington, prior to and after construction of Howard A. Hanson Dam.

SECTION 5 GREEN RIVER JUVENILE SALMON AND STEELHEAD MIGRATION

5.0 EXECUTIVE SUMMARY

The Additional Water Storage Project (AWSP) is a proposal to store up to 37,000 acre-feet of additional water behind Howard Hanson Dam for municipal and industrial uses and to supplement Green River instream flows. Under proposed operating regimes, water will be stored primarily in the early spring to augment downstream releases later in the year. Storing additional water alters the flow regime in the lower Green River during the period when juvenile salmonids are migrating downstream to saltwater. Altering flows during juvenile downstream migration can affect salmonid growth and survival and may expose the juvenile salmonids to increased predation by other fish, birds and mammals.

All of the anadromous salmonids in the Green River begin their life cycles as embryos incubating within the substrate of the stream bed. Following emergence, juvenile anadromous salmonids either begin migrating to saltwater or rear for up to two years or more in the stream environment before beginning their downstream migration. Their downstream migration primarily occurs February through June and may be affected by a variety of factors including water velocity, temperature, turbidity and the innate behavior of the fish. Although most researchers believe a general positive relationship between flow and survival seems reasonable, defining that relationship on Northwest rivers has proven difficult and contentious.

In the Green River, researchers in the early 1970's conducted experiments using marked releases of hatchery chinook salmon. They identified a general trend associating increased survival with increased flow in the lower river. Using these data, a flow-survival hypothesis was developed and used to assess alternate flow regimes of the AWSP. An analysis using daily flow records for a 32 year period suggested survival of chinook salmon during outmigration would increase up to 2 percent and survival of coho and steelhead juveniles would increase up to 3 percent. Chum salmon outmigrant survival would decrease less than one percent under Phase I of the AWSP and decrease up to five percent under Phase II of the AWSP. The increased survival of chinook, coho and other outmigrant species contrasts with the predicted increased mortality of chum salmon outmigrants. Chum salmon juveniles outmigrate early in the spring during the period of greatest reservoir refill. Chinook, coho and steelhead juveniles outmigrate later in the spring when the majority of the additional water has already been stored and coincides with increased baseflows and freshets in the lower river.

Mitigation for the effects of the AWSP include increased springtime baseflows, augmentation of fall spawning flows and release of artificial freshets. Artificial freshets consist of releases from HHD to maintain a flow of 2,500 cfs at Auburn for a 38 hour period. Between 1992 and 1996, an average of 732,000 chum fry were released into the Green River from hatcheries. During this period, hatchery-origin chum fry have been released into the Green River at an average flow of 1,473 cfs. If hatchery managers conduct hatchery releases during scheduled artificial freshets, survival of hatchery released chum fry would increase by 178,000 fry each year. The increased survival of hatchery fry during the 2,500 cfs freshets may partially mitigate for expected losses of wild chum outmigrants.

The analysis of AWSP effects on salmonid outmigration through the lower river includes several untested assumptions. For example, the analysis for each species assumes that increased mortality during February and March can be offset by increased survival during April and May. This particular assumption could lead to shifts in downstream migration patterns and cause unanticipated effects. In order to minimize the risk of unforeseen project impacts, a monitoring plan is recommended. The monitoring plan incorporates an adaptive management process to adjust storage and release regimes in response to the observed behavior of target species.

5.1 INTRODUCTION

Since 1962, the ability to store water behind Howard Hanson Dam has allowed water managers to shape the annual hydrograph of the mainstem Green River. Peak flow events have been reduced to prevent flooding of the lower basin and water has been stored for later release for municipal and instream uses. The Additional Water Storage Project (AWSP) expands that ability by storing additional water during the spring for later release. Further alterations to the flow regime will benefit municipal and industrial uses and will affect instream resources. Salmon and steelhead are keystone species in the Green River watershed and while some effects of the AWSP are beneficial, other effects will be detrimental to salmon and steelhead production.

The impacts of storing that springtime water involves risks to riverine resources that are poorly understood. Salmon have evolved under a natural flow regime and our understanding of the scope and magnitude of the effect of changing that flow regime is uncertain. Reduced springtime releases to the lower river during reservoir refill may slow water velocities and reduce the survival of juvenile salmonids outmigrating to the ocean. At lower flows, juvenile fish may take longer to migrate out to the ocean and may prolong and increase their susceptibility to predation by other fish, birds and mammals. The timing, duration, frequency and magnitude of side channel connectivity to the mainstem river will be affected and the availability and protection of steelhead spawning habitat may be reduced. All changes to the natural flow regime may not be detrimental to salmonid productivity. Augmenting natural low flows during springtime droughts may increase smolt survival and releasing freshets may partially offset longer smolt travel times expected under reduced average flow regimes.

The following section evaluates the impact of storing water in the spring on the migration of salmonid juveniles through the lower river. A brief description of the project and life history characteristics of the various species of Green River salmon and steelhead are described under the Existing Conditions section. The impacts of changes to the flow regime are quantified in Section 5.3 and alternate analyses and potential errors with the proposed process are described in Section 5.4. Due to our uncertain understanding of the influence of altering flow regimes on outmigrating salmonids, an adaptive management and monitoring process is proposed to minimize risk to instream resources. An adaptive management process is outlined in Section 5.5 and conclusions are presented in Section 5.6.

5.2 EXISTING CONDITIONS

5.2.1 Project Description

Brief description of project objectives and Baseline, Phase I and Phase II Scenarios (to be added) insert table of seasonal flow conditions (Table 2.1) - also need description of criteria used to set seasonal flow conditions from CH2MHill

5.2.2 Environmental Setting

(brief description of hydrology to be added)
(insert table of half-month exceedance flows (Table 2.2)

5.2.3 Salmon and Steelhead Resources

Anadromous Fish

At least five species of anadromous salmonids can be found in the Green River today. The Green River currently supports populations of coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*), cutthroat trout (*O. clarki*), chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*). Char (*Salvelinus spp.*) are a native anadromous salmonid species that may be found in the Green River system (Goetz 1994, Mongillo 1992), but little information is available on their present status.

Although the timing of the life history stages varies among species and races of Pacific salmon and steelhead, the life history of these species involves constructing nests in gravel beds for spawning, followed by migration to the ocean for feeding and maturation, then returning to the natal sites for spawning and completion of the life cycle. All of the naturally spawning salmonids begin their life cycles as embryos incubating within the substrate of the stream bed. Throughout the embryonic incubation period until emergence of the fry from the gravel, the various species and races of Pacific salmon and steelhead are similar in their requirements for suitable water temperatures, an adequate supply of dissolved oxygen, water transfer to remove metabolic wastes, and minimal physical disturbance. Following emergence, the various species and races of Pacific salmon and steelhead exhibit very different behavior throughout the remainder of the freshwater phase of their life cycles. These behavioral and life history differences, particularly differences in the duration of the freshwater phase, are reflected in different habitat requirements and different responses to changes in the Green River flow regime associated with the AWSP.

The effect of the AWSP is specific to each life history stage; but species or races of anadromous salmonids with similar life histories may have similar responses. Pacific salmon and steelhead may be considered within the context of two distinct general categories composed of those fish characterized by a relatively short freshwater residence period, or those fish characterized by a relatively long freshwater residence period, as follows:

Ocean-type Life Cycles - Fish which migrate out of the streams into marine environments within days or a few weeks after fry emergence (e.g. chum salmon); and

Stream-type Life Cycles - Fish which reside in freshwater for extended periods (e.g., months to years). Those species rearing in freshwater for at least one year prior to migrating into marine environments (e.g., coho salmon, steelhead and sea-run cutthroat trout are those species most appropriately characterized as having a "long" freshwater life cycle. Fall-run (and summer/fall-run) chinook salmon rear in their natal streams for several months before migrating to the ocean and are perhaps best characterized as "intermediate" with regards to the length of their freshwater residency period.

The specific timing of the various life history stages of anadromous salmonids, including freshwater rearing, varies among species and races, among stocks within broad geographic areas, and among stocks specific to particular rivers within basins. For a single river system there are year-to-year variations in the timing of smolt migration that are related to environmental factors. For example, Achord et al.(1996) noted that outmigration of chinook smolts can be delayed up to two weeks by cold spring temperatures. Factors that tend to affect the time of outmigration include: the size and stock of the fish, flow conditions, water temperature, dissolved oxygen levels, day length and the availability of food. Although the timing of life history phases may vary year to year, certain patterns have emerged. For AWSP planning purposes, assumptions regarding the proportion of juvenile fish outmigrating in certain periods have also been identified (Figure 2.1). The proportion of juvenile outmigrants in a given half-month period may change from year to year but the general pattern is expected to remain over time. A brief description of the life cycle and current status of common anadromous salmonid species is provided in the following section.

Coho salmon. Juveniles coho salmon rear in freshwater for approximately 15 months prior to migrating downstream to the ocean, but may extend their rearing time for up to two years (Sandercock 1991). Newly emergent fry usually congregate in schools in pools of their natal stream. As juveniles grow, they move into more riffle habitat and aggressively defend their territory, resulting in displacing excess juveniles downstream to less favorable habitat (Wydoski and Whitney 1979). This aggressive behavior may be an important factor maintaining the numbers of juveniles within the carrying capacity of the stream, and distributing juveniles more widely downstream. Once territories are established, individuals may rear in selected areas of the stream feeding on drifting benthic organisms and terrestrial insects until the following spring (Hart 1973). After several years in the marine environment, adult coho return to the Green River and migrate upstream from early August through late January. Spawning occurs from mid-November through late January (Caldwell 1994).

The peak outmigration of coho smolts varies between late April and late May (Figure 2.1). Bostick (1955) sampled outmigrating smolts in the Duwamish estuary in 1953 and observed the peak outmigration of coho smolts in late May. Dunstan (1955) fished fyke traps in the Green River from 18 February through 20 May 1955 and observed a peak outmigration of coho smolts during late April. Dunstan also captured newly emerged fry late February through April but characterized these early movements as being an instream redistribution rather than an active seaward migration. Weitkamp and Campbell (1979) and Meyer et al. (1980) observed the greatest abundance of coho smolts in the Duwamish estuary during late May. Meyer et al. (1980) noted that by early June coho smolts appeared to move quickly through the estuary and that few coho were present in the estuary after June 4. Observations of peak coho smolt movement in the Duwamish estuary may occur up to several weeks following peak movement through the lower Green River.

During 1983, Washington Department of Fisheries researchers planted coho fry in the upper watershed and operated a scoop trap below HHD during 1984 to monitor the outmigration of coho smolts (Seiler and Neuhauser 1985). They operated the trap at regular intervals between 5 April through 18 June and observed the peak outmigration of coho smolts between early May and early June. Over 90 percent of the smolts captured were taken during the hours of darkness. Low catches during the initial days of trapping suggested the migration began during early April, but data on the end of migration were obscured by closure of the main discharge gates at HHD on 6 June. Based on the number of coho yearlings captured during gill net sampling in the reservoir in September 1984, Seiler and Neuhauser (1985) suggested downstream migration would have continued into June.

Fyke traps were fished above HHD 18 April through 21 November 1991 by USFWS researchers. They observed the peak downstream movement of coho yearlings into the reservoir during May and early June (Dilley and Wunderlich 1992). During 1992 they expanded their trapping activities to extend from mid-February through the end of November. Unusually warm, wet weather during February 1992, and a high early runoff coincided with downstream movement of coho yearlings into the reservoir beginning in late February and extending through May. Even though downstream migration began in

February, downstream movement into the reservoir peaked during late April and early May (Dilley and Wunderlich 1993).

Two coho stocks have been identified in the Green River Basin (WDFW 1994). The Green River/Soos Creek stock is of mixed origin. Releases of both native and non-native hatchery- origin coho in this system date back to the early 1950s. Currently, approximately 3 million yearling coho are released annually from hatcheries on Soos and Crisp Creeks. Natural reproduction in Soos Creek derives from hatchery-origin adults passed above the hatchery. Production above HHD is derived from off-station fry and fingerling releases. Escapement data are limited, however run reconstruction data indicates stable escapement and the stock is considered healthy.

Coho returning to Newaukum Creek have been identified as a separate stock within the Green River basin, based on geographic separation and differences in spawning timing (WDFW 1994). Multiple peaks and an extended spawning timing suggest that there may be a unique genetic component in the Newaukum Creek Stock. This stock is believed to be a mixture of native and introduced non-native stocks. Production occurs through both natural spawning and a comprehensive fingerling release program. Since 1987, this stock has experienced a severe short-term decline and is considered depressed.

<u>Steelhead</u>. Steelhead are typically differentiated into two types: winter steelhead and summer steelhead (Barnhart 1991). Winter and summer steelhead are differentiated by timing of adult return but share common juvenile behavior patterns. Both winter and summer juvenile steelhead rear in freshwater for one or more years, mostly two, before migrating to the ocean (Barnhart 1991). Juvenile downstream migration occurs from April through July, with peak migration in mid-April (Wydoski and Whitney 1979). An early study of steelhead smolt emigration by Pautzke and Meigs (1940, *in* Grette and Salo 1986) found that steelhead smolts emigrated from the Green River primarily during April and May. Seiler and Neuhauser (1985) planted steelhead fry in the upper watershed during the fall of 1982 and operated a scoop trap below HHD during 1984 to monitor the outmigration of smolts. They operated the trap at regular intervals between 5 April through 18 June and observed the peak outmigration of steelhead smolts were similar to coho smolts, occurring between early May and early June (Seiler and Neuhauser 1985). For planning purposes, steelhead smolt outmigration patterns were considered similar to the timing and distribution of coho smolt outmigration.

Winter steelhead adults return to the Green River from November through early June and summer adults from April through November (Caldwell 1994). Summer steelhead spawning occurs from mid-January through early April, and winter steelhead spawning occurs from January through June. Hatchery-origin winter steelhead typically spawn early in the season and may complete spawning by mid-March. Wild winter steelhead spawn later in the spring period (see Steelhead Spawning and Incubation Report elsewhere in the EIS). A significant difference between steelhead and Pacific salmon life history is that not all steelhead adults die after spawning. Steelhead are capable of repeat spawning, although the incidence is relatively low and specific to individual streams. Repeat spawning in Washington ranges from 4.4 to 14.0 percent of total spawning runs (Wydoski and Whitney 1979).

The Green River summer steelhead stock is of non-native hatchery origin (WDFW 1994). Skamania steelhead smolts were introduced into the Green river system in 1965. Currently, about 70,000 summer steelhead smolts are released into the Green River system annually. The stock is managed to provide a recreational fishery, and the stock status is healthy.

The Green River system also supports a run of winter steelhead of native stock. In addition to the naturally-reproducing run, approximately 100,000 hatchery-origin smolts from the Chambers Creek stock are planted annually. The returning hatchery adults support tribal and sport fisheries with a combined exploitation rate of approximately 90% (WDFW 1994). Because of the high exploitation rate and differences in spawn timing, these fish are not believed to interbreed with the native stock. Wild spawner escapement is close to or exceeds goals in most years, and the status of this stock is healthy.

Cutthroat trout. Sea-run cutthroat trout exhibit early life history characteristics similar to coho and steelhead. Juveniles rear in freshwater for more than one year, generally two to nine (Wydoski and Whitney 1979). The seaward migration of smolts occurs in April and May and coincides with steelhead smolt emigration (Grette and Salo 1986). Adult upstream migration in the Green River occurs from July through early February (Caldwell 1994) with the peak occurring in October and November (Grette and Salo 1986). Spawning occurs from March through early May in small streams slightly earlier than winter steelhead. For planning purposes, sea-run cutthroat smolt outmigration patterns were considered similar to the timing and distribution of coho smolt outmigration.

Chinook salmon. Chinook salmon are differentiated into two types: ocean-type and stream-type. Juvenile ocean-type chinook salmon migrate to the marine environment in the first year of life, generally within three to four months of emergence (Lister and Genoe 1970). Juvenile stream-type chinook salmon rear in freshwater for an extended period of one year or more prior to migrating to the ocean. The principal race of chinook salmon populating the Green River is summer/fall chinook salmon which have an ocean-type early life history. Adult summer/fall chinook migrate upstream in the Green River from late June to mid-November. Spawning takes place from late mid-September through mid-November.

A large downstream movement of chinook fry occurs immediately after emergence. The early downstream migration of newly emerged fry is probably a dispersal mechanism that helps distribute fry among downstream rearing habitats (Lister and Genoe 1970). Lister and Walker (1966) observed a bimodal distribution of chinook fry in the Big Qualicum River, British Columbia. They found that chinook fry migrated either within a short time of their emergence or after six weeks or more of rearing. The early group of fry measured

40-48 mm in length and migrated downstream during late March and April. A later pulse of fry migrated downstream during May and early June and measured 60-90 mm in length. Downstream movement of chinook fry in Northwest rivers may occur between February and July and the timing of peak downstream migration can vary substantially from year to year. The beginning and end of the chinook outmigration season appears to vary less than the timing of the peak of downstream migration (Healey 1991).

Dunstan (1955) used fyke nets to sample the middle Green River between 18 February and 20 May 1955 and captured newly emerged fry in late February through April. They identified the peak outmigration occurring between 7 April and 17 April. The Duwamish estuary was sampled during 1953 by Bostick (1955) and during 1977-78 by Weitkamp and Campbell (1979); both groups reported the peak chinook fry abundance in the Duwamish estuary during late May. Meyer et. al. (1980) used beach seines in the Duwamish estuary to collect juvenile salmonids and found the greatest abundance of chinook juveniles during early May. They noted that chinook juveniles appeared to have an extended residency and collected chinook juveniles in the estuary throughout their sampling period of 8 April though 31 July 1980.

During recent studies of juvenile fish passage at HHD, USFWS researchers used fyke traps to gauge trends in downstream movement of subyearling chinook planted above the reservoir. During 1991, 979,446 subyearling chinook were planted on 21-25 February and 960,084 were planted 6-7 March. Fyke trapping above HHD was conducted April 18 through November 21 and the peak movement of subyearling chinook into the reservoir was observed during late May and early June (Dilley and Wunderlich 1992). During 1992 they expanded their trapping activities to extend from mid-February through the end of November. They noted a large downstream movement into the reservoir during late March and April, which they assumed to be displacement coincident with outplanting of hatchery juveniles. They observed a peak downstream movement out of the reservoir in early June coinciding with peak ATPase levels (Dilley and Wunderlich 1993). Based on available data, timing of chinook smolts was assumed to occur between April and July in the Green River (Figure 2.1).

Summer/fall chinook of the Duwamish/Green River basin are distinguished from other Puget Sound stocks by geographic isolation. The stock origin is mixed, and production is supplemented by hatchery releases from the Green River Hatchery on Soos Creek. Coded-wire tag recoveries indicate that some hatchery strays are spawning naturally in the river (WDFW 1994). Genetic impacts from this straying are unknown. Escapement in the mainstem Green River averaged 7,600 from 1987 through 1992 with an increasing trend (WDFW 1994). Stock status is healthy.

<u>Chum salmon</u>. Juvenile chum salmon have an ocean-type early life history, rearing in freshwater for only a matter of days to weeks before migrating downstream to saltwater (Pearcy 1992). Downstream movement in the Green River may occur from mid-February through late July but varies annually and between river systems. Chum fry that migrate to

sea within several days after emergence exhibit little growth, but fry that rear for longer periods may exhibit up to 22 percent increase in length in less than four weeks (Kobayashi and Abe *1977 in* Hale et al. 1985). Kobayashi and Ishikawa (1964 *in* Hale et al. 1985) found that chum fry grew slowly in March and April when most fry migrated to the sea, but as water temperatures rose, growth of remaining fry was more rapid. After feeding in saltwater for two to four years, adult chum salmon migrate up the Green River from the early November to the first week in December. Spawning takes place from mid-November through December, in the mainstem Green River between Burns and Crisp Creeks (WDFW 1994). Chum stocks from the Green River basin are harvested in both pre-terminal and terminal commercial net fisheries. The combined harvest rate averaged 81 percent between 1988 and 1991 (WDFW 1994).

The peak downstream migration of chum salmon occurs in late March through May (Figure 2.1). Dunstan (1955) fished fyke traps in the Green River at RM 34 and RM 36 from 18 February through 20 May 1955 to identify the timing and number of downstream migrating salmon juveniles. They captured an initial small surge of chum fry in late February, but believed the peak of chum fry outmigration occurred between March 20 and April 3. They reported that most chum seemed to be produced in Burns and Newaukum Creeks rather than the mainstem river (Dunstan 1955). While their capture process could not differentiate between fry produced in side channel, tributaries and mainstem habitats, spawning surveys during the 1950's identified large numbers of chum spawning in Burns Creek. Muckleshoot Indian Tribal biologists surveyed the Green River during 1996 and reported significant chum spawning in side channels in the middle and lower Green River reaches.

Observations of chum fry abundance in the Duwamish estuary may also indicate movement from the Green River, but peak movement in the estuary may be several days or weeks following peak movement in the river. Meyer et al. (1980) sampled juvenile salmonids in the Duwamish estuary using beach seines and found chum fry present from early April through early July. They noted an initial peak abundance of chum fry in late April prior to any plants of hatchery chum in the system. A second, larger peak of chum abundance occurred in mid-May, several days after the Muckleshoot Indian Tribe released 750,000 chum fry in Crisp Creek at RM 40. Bostwick (1955) observed peak abundance of chum in the Duwamish estuary in early May 1953 and Weitkamp and Campbell (1979) observed peak chum abundance in late April 1978. Using beach seines to collect salmonid fry in the Duwamish estuary during the spring months of 1994, 1995 and 1996, Muckleshoot tribal researchers observed chum fry in the estuary from February through July (Warner 1996). During all three years of study, they observed peak abundance of chum fry in the estuary in April.

Two chum stocks are recognized in the Green River system (WDFW 1994). The Crisp (Keta) Creek fall chum stock originated from releases of Quilcene and Hood Canal stocks from the Keta Creek Hatchery in the early 1980s. This stock is considered healthy. The Duwamish/Green stock may be a remnant native stock and their status is unknown. The origin of this stock is unknown, but it is likely that hatchery plants have affected the gene pool (WDFW 1994).

Resident Fish

<u>Cutthroat trout</u>. Cutthroat trout exhibit a nonmigratory form in many Pacific Northwest streams (Wydoski and Whitney 1979). It is unclear whether the migratory trait is controlled by heredity or environment, and may be a combination of both. Resident cutthroat trout juveniles frequently spend their first year of life in the small headwater streams in which they were spawned. They generally move downstream to larger tributaries during the second year (Wydoski and Whitney 1979). A stable stream environment is critical to resident cutthroat trout since they establish a home territory, usually a gravelly pool, in which they may spend the entirety of their lives (Miller 1957).

<u>Other resident species</u>. Common resident species in many Pacific Northwest rivers are: mountain whitefish (*Prosopium williamsoni*); largescale sucker (*Catostomus macrocheilus*); and various cottids, such as the torrent sculpin (*Cottus rotheus*) and prickly sculpin (*C. asper*). Life history information on these and other resident fish species potentially inhabiting the Green River can be found in Wydoski and Whitney (1979). For planning purposes, the analysis of AWSP effects on instream resources focused on anadromous fish species. Protection of anadromous salmonids with stream-type early life histories, such as coho, steelhead and sea-run cutthroat trout was assumed to provide adequate protection for resident fish species.

5.3 IMPACT ANALYSIS AND MITIGATION

5.3.1 FLOW : SURVIVAL FUNCTIONS

a. Factors Affecting Salmonid Outmigrant Survival

The natural flow regime of the Green River has been modified by operation of Howard Hanson Dam, the City of Tacoma's diversions for water supply, logging in the upper watershed and development and urbanization of the Green River basin. Changes to the Green River flow regime associated with these anthropomorphic actions affect salmon production in ways poorly understood. The AWSP will further modify the Green River flow regime; some changes will benefit salmon production, while other changes may be harmful. This analysis of the AWSP attempts to quantify the effects of AWSP flow changes on the instream migration of juvenile salmonids through the lower Green River. Attempts to understand the effects of flow changes will help to design a storage and release strategy to minimize impacts while enhancing benefits to instream resources in the Green River.

Our ability to anticipate the effects of the AWSP is limited by our incomplete understanding of the relationship between flow and survival of downstream migrating salmonids. An examination of available literature on downstream migration yields a variety of biological and physical variables which have been shown to affect the downstream movement and ultimately the survival of the juvenile salmon migrants. Biological mechanisms of mortality include predation, disease, competition, and loss of physical conditioning; physical mechanisms may include reduced water quality (e.g. high water temperatures, low dissolved oxygen, etc.) and traumatic death. These factors may individually, or in concert, affect outmigrant survival (see Figure 3.1), and complicate the task of quantifying project impacts. Factors affecting the timing, frequency and duration of downstream migration of juvenile salmonids include:

FLOW

Although most researchers agree that an increase in flow will have a corresponding increase in salmonid outmigrant survival, there has been little agreement on attempts to define site-specific functions between flow and outmigrant survival. Water velocity and travel time are often used as surrogates for flow during discussions of salmonid outmigrant behavior but may not be directly comparable. The effects of changes in flow on water travel time through a river system are complex and involve vertical, horizontal and longitudinal mixing, shoreline dampening, lateral spreading and wave effects.

Sims and Ossiander (1981) reported yearling chinook and steelhead smolt survival improved with increasing flow in the Columbia river; other authors, however, failed to confirm their findings.

Chapman et al. (1994) found no relationship between the rate of migration speed and flow volume for subyearling chinook salmon through the impounded mid-Colombia reach. They theorized that sub-yearling chinook may temporarily hold and feed during downstream migration independent of flow volume.

Thorpe et al. (1981) demonstrated a positive correlation between Atlantic salmon smolt migration rates and drogue velocities. Their analysis suggested that fish generally swam faster than the drogue drifted, indicating active movements when fish encountered slow currents.

Neave (1955) reported that when encountering slow velocity areas, chum fry exhibited swimming speeds "much greater than the current".

Although several studies indicate water velocity is a primary determinant of smolt migration speed (Smith 1982; Buettner and Brimmer 1995; Berggren and Filardo 1993), other studies suggest factors other than flow may be affecting the dynamics of out-migration (Achord et al. 1995; Beeman and Rondorf 1992; Chapman et al. 1994).

WATER TEMPERATURE

Some researchers have reported that smolts will initiate downstream movement when exposed to a cumulative number of temperature units (i.e. degree-days). Others believe that the number of degree-days or reaching a specific temperature is not as important to onset of migration as a combination of an increase in the ambient temperature level in the spring and a sharp temperature increase.

Achord et al. (1996) and Raymond (1979) reported that migrations occurring during a cold spring may exhibit a two week delay in migration; migration may occur two weeks earlier than average during a warm spring.

Solomon (1978) believed that water reaching a temperature threshold (9°C) will trigger outmigration.

Laboratory evidence suggests that water temperatures in excess of 20°C for about 20 days, or delaying migration beyond the end of June, may cause steelhead smolts to revert to parr (Chapman et al. 1994; Adams et al. 1975).

PHOTOPERIOD

Increased day length can result in faster rates of downstream migration of chinook salmon smolts. The rate of downstream migration can be increased up to 60 percent by a combination of increased temperature and increased day length (Muir et al. 1992).

Increasing day lengths has been shown to advance smoltification in salmon having stream-type juvenile life histories such as coho and steelhead. Chum and ocean-type chinook salmon do not appear to be sensitive to photoperiod as demonstrated by Clarke et al. (1992) under controlled hatchery conditions.

LUNAR PERIODICITY

Some researchers have reported that the peak downstream movement of chinook salmon fry occurs on the new moon or during dark nights (Mason 1975, Miller 1970).

Reimers (1971) observed that downstream movement of juvenile chinook was inhibited by bright moonlight.

Although the light of the moon may inhibit migratory behavior, Grau (1981) reported evidence that lunar periodicity may act in concert with photoperiod and temperature to synchronize the development of migratory readiness and to stimulate the onset of migration. The lunar phase may stimulate the production of migration-regulating hormones.

TURBIDITY

Turbidity may reduce the reactive distance of both juvenile salmonids (Gregory 1991) and their predators (Barrett et al. 1992).

Laboratory studies have shown that chinook salmon feeding rates were highest in moderate turbidities and low in clear water (Gregory and Northcote 1993).

DIURNAL ACTIVITY

Henrickson (1986) observed that the majority of outmigrating juvenile salmonids in the Green River move between 1800 and 0600.

ATPase LEVELS

The enzyme Na^{+}-K^{+}ATPase (adenosine triphosphate) has been identified as important to the maintenance of electrolyte balance during parr-smolt transformation and is an indicator of smoltification. Under controlled conditions, increases in ATPase activity and initiation of downstream movement occur simultaneously in juvenile anadromous salmonids (Zaugg 1981).

Hatchery releases of fish at different levels of smoltification indicate fish migrate faster when more fully advanced (Muir et al. 1992, Zaugg et al. 1985).

Salmon and steelhead juveniles held in hatcheries through the spring outmigration period pass through a period of elevated ATPase activity which eventually declines to pre-smolt levels. Fish which are released when ATPase levels are declining are capable of rapidly regaining high ATPase levels and may exhibit rates of downstream movement more rapid than the movement of fish released at earlier peak ATPase levels. However, if fish are held too long, the fish may revert to a nonmigratory state (Zaugg 1981).

PREDATION

Chum fry are particularly susceptible to predation during downstream movement. During a 10-year period, an average of 45 percent of the pink and chum fry population in a British Columbia river was consumed by predators, primarily prickly sculpin (*Cottus asper*), coastrange sculpin (*Cottus aleuticus*), and juvenile coho salmon (Hunter 1959).

Approximately 14 percent of juvenile salmonids passing through the John Day Reservoir on the Columbia River between 1983 and 1986 were lost to predation from northern squawfish (*Ptychocheilus oregonenis*) and warm and cool water predators (Rieman et al. 1991). Their estimate is somewhat uncertain because stomach content analysis did not differentiate between consumption of live smolts and smolts which had been killed passing through an upstream dam.

SIZE AT RELEASE

Differential mortality has been observed among hatchery releases of coho smolts; smaller fish exhibit poorer survival (Washington 1981)

Larger sculpin (Cottus spp.) consume a wide range of salmonid juveniles, while smaller sculpin primarily feed on chum and young of year outmigrating chinook fry.

There is a positive relationship between migration speed of active migrants and fish size (Chapman et al. 1994).

CHANGE IN FLOW (Freshets)

A sharp increase in flow can stimulate increased downstream movement. In the upper Snake River, researchers found a 2-fold increase in flow increased the migration rate by 8 to 12 fold for hatchery chinook, 3.5 to 4.6 fold for wild chinook salmon, 1.6 to 2.1 fold for hatchery steelhead trout and 2.4 fold for wild steelhead (Buettner and Brimmer 1996)

"Only the initial rise in river flow appeared to push fish out" (Knapp et al. 1995). Sustained fish movement was not positively correlated with sustained high flows; pulsing water releases appeared to increase the effectiveness of moving fish out of the lower Umatilla River.

Outmigration studies in the Stanislaus River, California, revealed that a pulse in flow from release of stored water stimulated a substantial increase in juvenile chinook outmigration. Increases in fish movement lasted only a few days following an increase in releases of stored water (Demko 1996).

There is increasing evidence that juvenile salmon make use of certain features of flow hydrodynamics in their migration. Rapid increases in flow generate waves which move downstream up to four times faster than the actual water mass (Koski 1974 *in* Williams et al. 1996). Yearling salmon and steelheads migrate in the main river channel near the water surface where the effect of such waves is greatest.

High flows occurring prior to completion of the preparatory phase of smoltification may not be fully utilized (Muir et al. 1992). Flow peaks that occur before fish are physiologically ready to migrate, or flow peaks that occur after most of the available fish have already migrated downstream, may be less important to survival than those peaks that occur when the fish are ready and available to migrate.

Other factors affecting the travel rate and survival of downstream migrants include food supply, channel morphology, presence of woody debris, and concurrent releases of hatchery-reared fish. Identifying the individual and interactive effects of these factors on salmonid outmigrant survival is complex and poorly understood; a common simplifying assumption is to assume a general positive relationship between flow and survival.

b. AWSP Flow : survival Function

The survival of juvenile salmon outmigrants is a common theme to salmon recovery efforts in river reaches dominated by dams, however, there are few studies of flow:outmigrant survival in naturally flowing river reaches. One available study of the relationship between flow and survival was conducted by the Fisheries Research Institute of the University of Washington and reported by J.A. Wetherall (1971), in a doctoral dissertation. During 1966, 1967 and 1969, they released marked lots of hatchery-reared juvenile chinook salmon in the lower Green River at flows ranging from 594 cfs to 3,400 cfs. The release groups of chinook juveniles averaged 128 fish per pound and individual fish averaged 80 mm in length. Wetherall recaptured the fish in the Duwamish estuary using tow nets and developed a flow : survival function using five of seven release lots. Wetherall rejected data on one release group because he believed the observed travel rate of the fish was physically impossible. He rejected data on the group of fish released at 3,400 cfs because he believed the poor survival they observed was due to the poor condition of the fish prior to release. Data on the next highest release flow were collected at 2,518 cfs.

Our analysis of the AWSP focused on a flow : survival function derived from Wetherall's five remaining data points. We derived a positive relationship between flow and survival using a second order polynomial regression of the five data points. This regression provided the equation (Y=-9E-06x2 + 0.0532x + 10.825), where Y equals flow in cfs and x equals percent survival (Figure 3.2). This regression equation was used to estimate survival for Green River salmonid outmigrants for flows at Auburn between 250 and 2,500 cfs. At flows greater than 2,500 cfs, a survival value of approximately 88 percent was assumed for all flows up to 12,000 cfs. Due to the ability to augment natural flows below Howard Hanson Dam, flows in the Green River at Auburn do not drop below 250 cfs. Since 1962, the flood control feature of the dam has also prevented flows greater than 12,000 cfs in the Green River at Auburn.

The decision to hold survival constant at flows between 2,500 cfs and 12,000 cfs was based on the assumption that the downstream movement of juvenile salmonids may be temporarily interrupted at high flows and survival may decrease. Salmonid outmigrants exhibit decreased swimming ability during downstream migration (Houston 1959) and high flow events may decrease survival if fish are exposed to water velocities that exceed their sustained swimming speed for extended periods. High flow events may also inundate side channels and gravel bar pools and may cause increased mortality due to stranding and trapping of outmigrants as the river flow subsequently recedes.

Little information is available to identify the peak of a flow : survival relationship in the Green River. Wetherall (1971) accepted data on chinook outmigrants released at flows up to 2,518 cfs, measured at Auburn. Wetherall rejected data on a group of fish released at a flow of 3,400 cfs. Survival for the release group was calculated at 39 percent; which Wetherall attributed to poor condition of the fish prior to release, rather than a function of instream conditions at 3,400 cfs. Incorporating the 3,400 cfs data point into a regression analysis suggests that flows over 3,000 cfs may have deleterious effects on juvenile survival. Due to the lack of confirming data, the flow : survival function for the AWSP was held constant at flows greater than 2,500 cfs.

Although there are significant differences in their size at outmigration, one flow : survival function was developed and used for all five species of salmon outmigrating in the Green River. The Wetherall (1971) experiments were conducted using hatchery-reared chinook juveniles that averaged 80 mm in length. Many researchers believe that larger outmigrants exhibit increased survival; possibly due to decreased travel time due to faster swimming speeds (Chapman et al. 1994) or lower susceptibility to predation by coho or sculpin (Hunter 1959). Wild chinook fry that exhibit downstream movement shortly after emergence may measure 40-48 mm in length, while chinook smolts that migrate downstream during May and June average 60-90 mm in length. The size of fish used in the Wetherall experiments were within the range of natural-reared chinook smolts outmigrating during May-June.

Coho, steelhead and cutthroat trout outmigrate after spending one or two years rearing in the stream environment and are often 150 mm or more in length during their downstream migration. The larger fish may exhibit increased survival compared to the chinook juveniles used by Wetherall, but there was insufficient data to justify changes specific to the Green River.

Chum salmon outmigrants are smaller than the chinook juveniles used in the Wetherall (1971) experiments and may incur higher rates of mortality. Chum fry that move downstream shortly after emergence are 35 to 40 mm in length; chum fry that migrate after rearing for several weeks or more achieve maximum ATPase levels at lengths of 48-55 mm (Salo 1991). Flow : survival data on chum outmigrants could not be located, but flow : survival data on sockeye salmon fry was collected by Washington Department of Fish and Wildlife (WDFW) researchers (Seiler 1995, Seiler and Kishimoto 1997). They reported that inriver fry survival was largely a function of flow; and their data was cited in an Muckleshoot Indian Tribe assessment of AWSP impacts (Warner and Coccoli 1996).

The WDFW researchers released marked groups of sockeye salmon fry (mean length of 30 mm) and recaptured them before they enter Lake Washington. Their procedure was designed to quantify the number of Cedar River sockeye migrants entering Lake Washington. Warner and Coccoli (1996) analyzed the WDFW data and developed a flow : survival function. Although the slope of the regression line presented by Warner and Coccoli is somewhat steeper than the AWSP flow : survival function (Figure 3.3), the two functions are similar. The sockeye fry are much smaller than the chinook used by Wetherall (1971); and based on size differences alone, a chum flow : survival function might lie somewhere between the two functions. Differences between the AWSP and Cedar River flow : survival functions could be attributed to the small size of the sockeye fry (mean length of 30 mm) but also attributed to potential differences between the two river systems. In the absence of corroborating data, changes to the AWSP function to reflect a change in chum outmigrant survival did not appear justified.

c. AWSP Impact Analysis

The AWSP will change the flow regime in the Green River and may affect survival of juvenile salmonid outmigrants. To assess the effects of expected changes to the flow regime under alternate AWSP scenarios, a spreadsheet model was developed to quantify changes in outmigrant survival.

The daily survival of outmigrating juveniles for flows of 2,500 cfs or less in the Green River below HHD was determined using the following polynomial regression equation:

$$S_i = 10.825 + 0.0532Q_i - 0.000009Q_i^{\,2}$$

where:

S_i = juvenile outmigrant survival for i^{th} day (%);
Q_i = mean daily discharge at Auburn for i^{th} day (cfs).

For flows greater than 2,500 cfs, survival was assumed to be 87.576 percent.
The total change in survival between the Baseline flow regime and Phase I or Phase II flow regime was calculated using the following equation:

$S_y = (Sp_i - Sb_i) \times N_i$

where:

S_y = total change in juvenile outmigrant survival for a given year from Baseline to Phase I or Phase II flow regime (%);

Sp_i = survival of migrating juveniles under Phase I or Phase II flows for i^{th} day (%);

Sb_i = survival of migrating juveniles under Baseline flows for i^{th} day (%);

N_i = portion of total yearly migration of juveniles through the lower Green River for i^{th} day (%).

The total yearly change in survival from Baseline to Phase I or Phase II flow regimes was calculated on a daily basis and totaled separately for each year. Daily flows for the period 1964-1995 were developed for Baseline, Phase I and Phase II conditions by CH2MHill (1997) and available in a spreadsheet format. The proportion of fish outmigrating through the lower Green River was calculated on a daily basis using the distribution identified by species in Figure 2.1. The annual change in outmigrant survival during the period 1964-1995 was calculated and averaged to identify an overall change in survival by species for the 32 year period of record.

Based on these calculations, chum salmon outmigrant survival would decrease (increased mortality) less than one percent between Baseline and Phase I conditions over the period 1964-1995 (Table 3.1 and Figure 3.4). Annual survival would range from an increase of 1.67 percent in 1992 to a loss of 2.89 percent in 1978. Under Phase II conditions, average annual survival over the 32 year period would decrease 4.76 percent. Under Phase II conditions, chum salmon would experience a decrease in 30 out of the 32 years modeled.

Chinook salmon outmigrant survival would increase two percent between Baseline and Phase I conditions over the period 1964-1995 (Table 3.2 and Figure 3.5). Under Phase I conditions, average annual survival would increase slightly during all 32 years. Under Phase II conditions, average annual survival over the 32 year period would increase by less than one percent. Under Phase II conditions, annual chinook survival would range from an increase of 3.12 percent to a decrease of 4.01 percent. Chinook salmon survival would increase in 20 out of the 32 years modeled under Phase II conditions.

Since we did not differentiate between the timing of coho, steelhead and sea-run cutthroat outmigrants, the three stream-type salmonid species were treated in a similar manner. Coho, steelhead and sea-run cutthroat outmigrants would experience a three percent increase in survival between Baseline and Phase I conditions averaged over the period 1964-1995 (Table 3.3 and Figure 3.6). Under Phase I conditions, average annual survival would increase during all 32 years. Under Phase II conditions, average annual survival over the 32 year period would increase by less than two percent. Annual survival under Phase II conditions would range from an increase of 5.63 percent to a decrease of 3.86 percent. Under Phase II conditions, coho, steelhead and sea-run cutthroat survival would increase in 27 out of the 32 years modeled.

Although the same flow : survival function was used for all Green River salmonid species, species-specific differences in predicted survival were caused by differences in the timing of downstream migration. Chinook salmon juveniles migrate downstream later in the year than chum salmon and the majority of chinook migrants avoid the period of greatest storage. Some decreased survival occurs during June when the reservoir is full under Baseline conditions and releases from HHD match inflow. The majority of coho, steelhead and sea-run cutthroat migrate downstream during late April and May and fair better under the AWSP than either chum or chinook outmigrants.

5.3.2 Mitigation

a. Springtime Flow Augmentation

Under Baseline conditions, the reservoir refill and release strategy attempts to satisfy instream baseflows of 900 cfs during 15 March to 1 May (CH2MHill 1997). Without significant storage and release capabilities, a baseflow of 900 cfs cannot be maintained through April and springtime flows in the Green River at Auburn frequently drop well below 900 cfs. Under the AWSP, up to 37,000 acre-feet of additional water is stored which reduces the total volume of water released below HHD during spring months. Increased storage capabilities under Phase I and Phase II provides greater flexibility to meet target instream baseflows which helps offset the impact of the lower volume of springtime releases. Under Phase I and Phase II scenarios, instream baseflow targets were reduced but the frequency of meeting target baseflows increased. A comparison of 95 percent exceedance flows by half-month period indicate that low flow levels in the Green River at Auburn can be increased up to 150 cfs during April through June under Phase I and Phase II conditions (Table 3.4).

A variety of baseflow conditions were examined during AWSP modeling efforts prior to settling on the baseflow targets described in the AWSP model results (CH2MHill 1997). On a real-time basis, baseflow targets would be adjusted depending on whether each spring is considered wet, average or dry based on snow water equivalents measured on 1 March and 1 May. If sufficient runoff appeared likely, baseflows would be adjusted upwards to balance greater instream resource protection and increased reliability of meeting refill targets.

If instream baseflows were not adjusted to ensure they could be met with a high level of certainty, the resultant short-term drop in instream flows could have dramatic impacts on side channel connectivity and steelhead spawning and incubation. Higher baseflow targets during March and early April would reduce the impact of water storage on chum salmon but would increase the risk of later reductions in flow during spring droughts.

The AWSP analysis described in Section 5.3.1 incorporates the results of augmenting instream flows to meet springtime baseflows. The level of impact reflects baseflow targets that can be met with high level of certainty and incorporates mid-season adjustments based on snowpack conditions.

TABLE 3.4 COMPARISON OF 95 PERCENT EXCEEDANCE FLOWS BY HALF-MONTH PERIOD, GREEN RIVER AT AUBURN, WASHINGTON FOR THE PERIOD 1964-1995 (SOURCE: CH2MHILL 1997)

Period	95 % Exceedance Flow		
	BASELINE	PHASE I	PHASE II
02/16 to 02/28	680	680	680
03/01 to 03/15	746	710	704
03/16 to 03/31	758	675	652
04/01 to 04/15	520	575	575
04/16 to 04/30	605	692	655
5/01 to 5/15	570	721	679
5/16 to 5/31	430	532	574
6/01 to 6/15	350	432	492
6/16 to 6/30	416	350	400
7/01 to 7/15	282	283	280
7/16 to 7/31	250	250	250

b. Artificial Freshets

The analysis of AWSP impacts assumed a positive flow : survival function for salmonid outmigrants. While most researchers support a general positive relationship, there is increasing evidence that the timing and duration of flow changes may be as important as flow volume. In the upper Snake River, researchers found a 2-fold increase in flow increased the migration rate by 8 to 12 fold for hatchery chinook and 3.5 to 4.6 fold for wild chinook salmon (Buettner and Brimmer 1996). In the lower Umatilla River (Knapp et al. 1995), sustained fish movement was not positively correlated with sustained high flows; pulsing water releases appeared to increase the effectiveness of initiating fish movement. Release of a pulse of stored water in the Stanislaus River, California, stimulated a substantial increase in juvenile chinook outmigration. Increases in fish movement lasted only a few days following the release (Demko 1996).

The timing of flow releases is also important to stimulating downstream movement. High flows occurring prior to completion of the preparatory phase of smoltification may not be fully utilized by juvenile outmigrants (Muir et al. 1992). Flow peaks that occur before fish are physiologically ready to migrate, or flow peaks that occur after most of the available fish have already migrated downstream, may be less important to survival than those peaks that occur when the fish are ready and available to migrate.

A pulse of water, or freshet, can be the result of precipitation or can be caused by releases of stored water. As partial mitigation for the effects of the AWSP, the release of artificial pulses of water or freshets was incorporated into the Phase I and Phase II operations. The volume of water considered for release was determined through evaluation of water particle travel times and consideration of potential side-effects such as side channel connectivity and steelhead incubation and spawning.

An analysis of water particle travel times in the Green River below HHD was conducted by the Corps of Engineers (Brownell 1996) and showed incremental increases in releases from HHD over about 2,000 cfs resulted in only minor increases in water travel time (Table 3.5). Since the majority of side channel area in the lower Green River is wetted at a flow of 2,500 cfs, the volume of artificial freshets was capped at 2,500 cfs measured at Auburn. Water particle travel times from HHD to Tukwila at flows of this magnitude are approximately 19 hours. If the majority of outmigrants move between the hours of 1800 and 0600 in the Green River (Henrickson 1986), fish would transit the Green River from HHD to Tukwila in two nights. Assuming HHD releases were increased to 2,500 during the afternoon and held for approximately 38 hours, fish could transit the entire reach during one freshet. Maintaining a freshet for only 38 hours allows outmigrants time to exit the freshwater system and minimizes the likelihood of steelhead adults spawning along stream margins or in side channels at the elevated flows. Since a 2,500 cfs freshet held for 38 hours represents a large volume of water, minimizing the duration of freshets also complements water storage objectives.

Under Baseline conditions, flow events of 2,500 cfs or greater occurred 133 times over the 32 year period modeled (Table 3.6). For modeling purposes, additional freshets were assumed to be released on 1 May and 15 May under Phase I conditions. Under real-time operations, the freshets would be released during the last weekend April and the third weekend in May, assuming sufficient water is available. Under Baseline conditions, 24 freshets would be available during March over the 32 year period modeled; due to storage of water early in the spring, the number of freshets during March would be reduced to 17 under Phase I conditions. Over the 32 year period modeled, the number of freshets in April and May increased from 58 under Baseline conditions to 104 under Phase I conditions .

TABLE 3.5 WATER PARTICLE TRAVEL TIMES IN THE GREEN RIVER, WASHINGTON. RELEASES FROM HHD MEASURED AT THE PROJECT TAILWATER, ACCURACY +/- 0.5 HR (SOURCE: BROWNELL 1996).

Flow (cfs)	HHD to Auburn (hr)	Auburn to Tukwila (hr)	Total (hrs)
400	12.00	23.53	35.53
800	8.00	17.92	25.92
1,200	7.50	15.31	22.81
1,600	7.00	13.78	20.78
2,000	7.00	12.47	19.47
2,400	6.50	11.72	18.22
2,800	6.50	11.00	17.50
3,200	6.50	10.53	17.03
3,600	6.50	10.12	16.62
4,000	6.50	9.77	16.27
5,000	6.00	9.11	15.11
6,000	6.00	8.65	14.65
8,000	6.00	8.02	14.02

The effect of releasing artificial freshets has not been fully incorporated into the analysis of AWSP impacts. The change in survival of outmigrants associated with the increase in flow is addressed by the flow : survival function, but the potential increased incidence of fish outmigrating under the higher flow conditions was not addressed in Section 5.3.1.

c. Increased Survival Of Hatchery-Reared Chum Fry

Analysis of AWSP impacts on downstream migration of anadromous salmonids suggests that chum salmon are the primary salmonid species directly impacted by the early storage of water. Assuming the AWSP flow : survival function adequately describes project impacts, chum fry would experience less than 1 percent decrease in survival under Phase I and an estimated 4.76 percent decrease in survival under Phase II. These losses may be partially mitigated by increased survival of hatchery-reared chum fry.

Assuming artificial freshets are released from HHD to maintain a flow of 2,500 cfs at Auburn for a 38 hour period, hatchery managers could increase the survival of hatchery-reared chum fry by releasing the fry during the planned freshets. Between 1992 and 1996, an average of 732,000 chum fry were released into the Green River from hatcheries. During this period, hatchery-reared chum fry have been released into the Green River at an average flow of 1,473 cfs, measured at Auburn. The size of fish and the date of release are dictated by considerations such as growth rate, available hatchery rearing space, general health of the fingerlings and instream conditions during release. Instream survival of chum fry released at 1,473 cfs is 63.45 percent according to the AWSP flow : survival function. Instream survival would increase to 87.79 percent if chum fry were released at flows of 2,500 cfs. The 24.34 percent increase in survival of 732,059 fry yields an increase in survival of 178,000 chum fry each year.

Assuming 4 million wild chum fry are produced in the Green River each year, the 0.35 percent decreased in survival under Phase I conditions would cause a predicted loss of 14,000 wild chum fry. A 4.76 percent decrease in survival of wild fish under Phase II would reduce annual wild chum production by 190,400 fry. The increase in survival of 178,000 hatchery-reared chum fry associated with hatchery releases at 2,500 cfs would offset the loss of wild chum fry under Phase I and partially mitigate for losses under Phase II conditions.

d. Additional Mitigation

The AWSP appears to have no net loss to the outmigration of chinook, coho, steelhead and sea-run cutthroat juveniles in the Green River below HHD. Survival of outmigrating chum fry decreases nearly five percent under Phase II conditions, but may be partially offset if hatchery managers are able to conduct hatchery releases during planned artificial freshets. The need for additional mitigation depends on the level of wild and hatchery-reared chum fry production and the observed behavior of the fish under real-time operations. A proposed monitoring and adaptive management process will help define additional mitigation requirements and several opportunities exist to provide mitigation if required. Chum salmon will benefit from gravel placement and side channel restoration measures proposed for the AWSP and these measures can provide additional mitigation. Hatchery production of additional chum fry can also be considered at a 1997 cost of $66.77 per pound of fish at 400 fish per pound (P. Hickey, pers. comm. 1997).

5.4 DISCUSSION

The impacts of the AWSP on the downstream migration of anadromous salmonids are diffcult to predict with confidence. Our incomplete understanding of the life history of salmonids, our imperfect knowledge of riverine processes and our poor record of predicting all ramifications of bioengineering actions suggest that some of our assumptions may be in error. If some assumptions are incorrect, AWSP impacts may be underestimated, correcting other assumptions may reduce our expected level of impact.

5.4.1 Awsp Impacts May Be Greater Than Expected

- Fish evolved under natural conditions; changing those conditions is inherently risky to our natural resources.
- The AWSP analysis assumes that increased mortality during February and March can be offset by increased survival during April and May (Figure 3.7). This particular assumption could lead to shifts in downstream migration patterns and cause unanticipated effects.
- The AWSP analysis assumes that increased mortality during some years can be offset by increased survival during other years. This assumption could place weak stocks in greater jeopardy than indicated.
- Natural pulses of flow have high levels of turbidity - which reduces the incidence of predation. Artificial freshets don't appreciably increase turbidity levels.
- Wetherall's (1971) data reflects passage through 32 miles of river; fish migrating from HHD must pass through 64 miles of river extending their exposure to agents of mortality. (Chinook and stream-type salmonids show increased survival, most chum spawn in the lower 32 miles of the Green River)
- The AWSP flow : survival function may underestimate losses of chum fry.
- The AWSP flow : survival function assumes no change in survival of juvenile salmonids at flows above 2,500 cfs; the threshold may be higher.
- Early migrating chinook fry are referenced as exhibiting instream movement rather than active migration to saltwater and are not considered in the AWSP analysis. This segment of the population may be important for reasons not well understood.
- Much of the analysis depends on assumptions - which may be wrong - or there may be problems which we aren't identifying because of a lack of knowledge. There are always risks associated with change - by incorporating a learning process and an ability to adapt to meet resource needs, we hope to minimize those risks

5.4.2 Awsp Impacts May Be Less Than Predicted

- Chinook, coho, steelhead and sea-run cutthroat may fare better (MIT 1996) than the AWSP flow : survival function suggests.
- The AWSP will either not affect, or will improve conditions for juveniles outmigrating prior to Feb 16 and after June 30.
- Freshets may initiate greater downstream movement of smolts than indicated by volume of flow alone.
- The Green River is not pristine, some AWSP efforts are designed to restore riverine functions and may indirectly improve salmonid survival.

5.5 MONITORING AND ADAPTIVE MANAGEMENT

The goal of the AWSP is to enhance the production of municipal and industrial water supply while maintaining or enhancing the production of anadromous salmonids, a keystone species in the Pacific Northwest. We cannot restore the Green River to natural conditions. The continued existence of HHD, the City of Tacoma's water supply diversion, timber harvest in the upper watershed, development of the Duwamish estuary and on-going urbanization of the Green River Valley effectively preclude a return to pristine conditions. However, through careful planning, monitoring and incorporation of adaptive management, we can learn to improve existing conditions and partially restore many of the functions a natural river system.

The analysis of AWSP effects on salmonid outmigration through the lower river includes several untested assumptions. For example, the analysis for each species assumes that increased mortality during February and March can be offset by increased survival during April and May. This particular assumption could lead to shifts in downstream migration patterns and cause unanticipated effects. In order to minimize the risk of unforeseen project impacts, a monitoring plan is recommended. The monitoring plan incorporates an adaptive management process to adjust storage and release regimes in response to the observed behavior of target species.
(to be expanded)

5.6 LITERATURE CITED

Achord, S., M.B. Eppard, B.P. Sandford and G.M Mathews. 1996. Monitoring the migrations of wild Snake River spring/summer chinook salmon smolts, 1995. Coastal Zone and estuarine Studies Division, National Marine Fisheries Service and Bonneville Power Administration, Portland, Oregon, Project No. 91-028, Contract Number DE-A179-91BP18800. 179 p.

Adams, B.,W.Zaugg and L. McLain. 1975. Inhibition of saltwater survival and Na-K-AtPase elevation in steelhead trout (Salmo gairdneri) by moderate water temperatures. In: Chapman, D., M. Peven, T. Hillman, A. Giorgi and F. Utter.1994. Status of summer steelhead in the mid-Columbia River. Don Chapman Consultants, Boise, Idaho. 235 p.

Barrett, J.C., G.D. Grossman and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distances of rainbow trout. Tran. Amer. Fish. Soc. 121:437 - 443.

Beeman, J.W. and D.W. Rondorf. 1992. Estimating the effects of river flow, smoltification and other biotic and abiotic variables on the travel time of juvenile salmonids in the Snake and Columbia Rivers. USFWS Report to Bonneville Power Administration, Portland, Oregon.

Berggren,J. and M.J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. N. Amer. J. Fish. Mngmt. 13:48-63.

Bostick, W.E. 1955. Duwamish river seining studies. Puget Sound Stream Studies, Progress Report July-November 1953. Washington Department of Fisheries, Olympia, Washington.

Buettner, E.W. and A.F. Brimmer. 1996. Smolt monitoring at the head of Lower Granite Reservoir and Lower Granite Dam. IDFG 96-18, Project No. 83-323-00B, Idaho Dept.of Fish and Game, Boise, Idaho. 57 p.

CH2MHill. 1997. Howard Hanson Dam Additional Water Storage Project: Modeling results for baseline, Phase I and Phase II reservoir operations. Final report dated March 4, 1997 submitted to US Army Corps of Engineers. CH2MHill, Bellevue, Washington.

Chapman, D., A.Giorgi, T.Hillman, D.Deppert, M.Erho, S. Hays, C. Peven, B. Suzumoto, and R. Klinge. 1994. Status of summer/fall chinook salmon in the mid-Columbia region. Don Chapman consultants inc. Boise, Idaho. 411 p.

Clarke, W.C., J.E. Shelbourn, T.Ogasawara, and T. Hirano, 1989. Effects of initial daylength on growth, seawater adaptability and plasma growth hormone levels in underyearling coho, chinook and chum salmon. Aquaculture 82:51-62.

Demko, D.B. 1996. Effect of pulse flows on outmigration of juvenile chinook in the Stanislaus River. Abstract and talk presented at the Western Division American Fisheries Society Meeting, 14 July-18 July 1996, Eugene, Oregon.

Dilley, S.J., and R.C. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Project, Green River, Washington, 1991. US Fish & Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington. 70 p.

Dilley, S.J., and R.C. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. US Fish & Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington. 72 p.

Dunstan, W. 1955. Green River Downstream Migration. Puget Sound Stream Studies, 1955 Progress Report. Washington Department of Fisheries, Olympia, Washington. 7 p.

Grette, G. and E.O. Salo, 1986. The status of anadromous fishes in the Green/Duwamish River System. Prepared by Evans-Hamilton, Incorporated for the U.S. Army Corps of Engineers, Seattle, Washington. 213 p.

Gregory, R.S. and T.G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salon (Oncorhynchus tshawytscha) in turbid laboratory conditions. Can. J. Fish. Aquat. Sci. 50:233-240.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile chinook salmon (Oncorhynchus tshawytscha). Can. J. Fish. Aquat. Sci. 50: 241 - 246.

Grau, E.G. 1981. Is the lunar cycle a factor timing the onset of salmon migration? Pp. 184-189 In: E.L. Brannon and E.O. Salo [eds.] Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle, Washington.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). *In*:Pacific Salmon Life Histories. Edited by C. Groot and L. Margolis. Univ. of British Columbia, Vancouver, British Columbia. pg. 313-396.

Houston, A.H. 1959. Locomotor performance of chum salmon fry (Oncorhynchus keta) during osmoregulatory adaptation to sea water. Can. J. Zool. 37:591-605.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16(6): 835-887.

Kobayashi, T., and S. Abe. 1997. Studies on the pacific salmon in the Yurappu River and Volcano Bay. 2. On the migration and growth of the fry during seaward migration and the return of marked adults. Sci. Rep. Hokkaido Salmon Hatchery 31:1-11 *cited in:* Hale, S.S., T.E. McMahon, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Chum salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.108). 48 p.

Kobayashi, T., and Y. Ishikawa. 1964. An ecological study on the salmon fry, Oncorhynchus keta (Walbaum) - VIII. The growth and feeding habits of the fry during seaward migration. Sci. Rep. Hokkaido Salmon Hatchery 31:1-11 *cited in:* Hale, S.S., T.E. McMahon, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Chum salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.108). 48 p.

Knapp, S.M., J.C. Kern, W.A. Cameron, S.L. Shapleigh and R.W. Carmichael. 1995. Evaluation of juvenile salmonid outmigration and survival in the lower Umatilla Basin. Annual Report 1995 (October 1994- September 1995), Project No.89-024-01, Oregon Dept. of Fish and Wildlife, Portland, Oregon.133 p.

Lister, D.B., and H.S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Board Can. 27: 1215-1224.

Lister, D.B. and C.E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho and chinook salmon in the Big Qualicum River. Canadian Fish Culturist. 37:3-26.

Mason, J.C. 1975. Seaward movement of juvenile fishes, including lunar periodicity in the movement of coho salmon *(Oncorhynchus kisutch)* fry. J. Fish. Res. Board Can. 32:2542-2547.

McMahon, T.E., and L.B. Holtby. 1992. Behaviour, habitat use, and movements of coho salmon *(Oncorhynchus kisutch)* smolts during seaward migration. Can. J. Fish. Aquat. Sci. 49: 1478-1485.

Meyer, J.H., T.A. Pearce, and S.B. Patlan. 1980. Distribution and food habits of juvenile salmonids in the Duwamish Estuary, Washington, 1980. Report submitted to the U.S. Army Corps of Engineers, Seattle District by Fisheries Assistance Office, U.S. Fish and Wildlife Service, Olympia, Washington. 41 p.

Miller, W.H. 1970. Factors influencing migration of chinook salmon fry (*Oncorhynchus tshawytscha*) in the salmon river. M.S. Thesis, University of Idaho, Moscow, Idaho, 80 p.

Muir, W.D., W.S. Zaugg, S.McCutcheon, and J.G. Williams. 1992. Biological manipulation of migration rate: The use of advanced photoperiod to accelerate smoltification in yearling chinook salmon, 1990. Annual Report to the Bonneville Power Administration by the Coastal Zone and Estuarine Studies Division, National Marine Fisheries Service, Seattle, Washington.

Neave, F. 1955. Notes on the seaward migration of pink and chum salmon fry. J. Fish. Res. Board Can. 12:369-374.

Pautzke, C.F. and R.C. Meigs. 1940. Studies on the life history of the Puget Sound Steelhead (*Salmo gairdneri*). Washington Department of Game Biological Bulletin No. 3. in: Grette, G. and E.O. Salo, 1986. The status of anadromous fishes in the Green/Duwamish River System. Prepared by Evans-Hamilton, Incorporated for the U.S. Army Corps of Engineers, Seattle, Washington. 213 p.

Raymond, H.l. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake river, 1966 to 1975. Tran. Amer. Fish. Soc. 98:513-514.

Regenthal, A. and W. Rees. 1957. The passage of fish through Mud Mountain Dam. Washington Department of Fisheries, Olympia, Washington. 10 p.

Rieman, B.E., R.C. Beamesderfer, S.Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:448-458.

Reimers, P.E. 1971. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Ph.D. Thesis. Oregon State University, Corvallis, Oregon. 99 p.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In*:Pacific Salmon Life Histories. Edited by C. Groot and L. Margolis. Univ. of British Columbia, Vancouver, British Columbia. pg. 233-309.

Salo, E.O., and W.H. Bayliff. 1958. Artificial and natural production of silver salmon (*Oncorhynchus kisutch*) at Minter Creek, Washington. Res. Bull. Washington Department of Fisheries, Olympia, Washington. 4:76 p.

Seiler, D. S. 1995. Estimation of 1994 Cedar River sockeye salmon fry production. Washington Department of Fish & Wildlife, Olympia, Washington. 16 p.

Seiler, D. S., and L. Kishimoto. 1997. 1996 Cedar River sockeye salmon fry production evaluation. Washington Department of Fish & Wildlife, Olympia, Washington. 19 p.

Seiler, D. S., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 & 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia, Washington. 94 p.

Sims, C. and F. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979: A research summary. Final Report to the U.S. Army Corps of Engineers. Contract No. DACW68-78-C-0038, 31 p..

Solomon, D.J. 1978. Some observation on salmon smolt migration in a chalk stream. Journal of fish Biology 12:571 - 574.

Smith, L.S. 1982. Decreased swimming performance as a necessary component of the smolt migration in the Columbia River. N. Amer. J. Fish. Mngmt. 13:48-63.

Tabor, R. and J. Chan. 1996, Predation on sockeye salmon fry by piscivorus fishes in the lower Cedar River and southern Lake Washington. U.S. Fish & Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington, 59 p.

Tabor, R. and J. Chan. 1996b, Predation on sockeye salmon fry by cottids and other predatory fishes in the lower Cedar River, 1996. U.S. Fish & Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington, 48 p.

Thorpe, J.E., L.G. Ross, G. Struthers, and W.Watts. 1981. Tracking Atlantic salmon smolts (*Salmo salar* L.) through Loch Voil, Scotland. J. Fish. Biol. 19:519-537.

Warner, E. 1996. Unpublished data. Muckleshoot Indian Tribe, Fisheries Department, Auburn, Washington.

Warner, E. and H. Coccoli. 1996. Changes to the survival of outmigrating salmon in the Green River as a result of Howard Hanson additional storage. Memo dated 1 January 1996. Muckleshoot Indian Tribe, Fisheries Department, Auburn, Washington, 3 pg.

Washington, P.M. 1981. The influence of the size of juvenile coho salmon (Oncorhynchus kisutch) on seaward migration and survival. Pp. 146-152 In: E.L. Brannon and E.O. Salo [eds.] Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle, Washington.

Weitkamp, D.E. and R.F. Campbell. 1979. Port of Seattle, Terminal 107 Fisheries study. Document No. 79-1120-034FD. Parametrix, Incorporated, Kirkland, Washington.

Wetherall, J. A. 1971. Estimation of survival rates for chinook salmon during their downstream migration in the Green River, Washington. Ph.D. Dissertation submitted to the University of Washington, Seattle, Washington. 170 p.

Williams, R.N., L.D. Calvin, C.C. Coutant, M.W. Erho, J.A. Lichatowich, W.J. Liss, W.E McConnaha, P.R. Mundy, J.A. Stanford, R.R. Whitney, D.L.Bottom, and C.A. Frissell. 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Report by the Independent Scientific Group to the Northwest Power Planning Council. Portland, Oregon. 584 p.

Williams, R.W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization. Volume I. Puget Sound Region. Washington Department of Fisheries, Olympia, Washington.

Wootton, J.T., M.S. Parker, and M.E. Power. 1996. Effects of disturbance on river food webs. Science. 273:1558-1561.

Wydoski, R.S., and R.R. Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle, Washington. 220 P.

Zaugg, W.S. 1981. Relationships between smolt indices and migration in controlled and natural environments. Pp. 173-183 In: E.L. Brannon and E.O. Salo [eds.] Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle, Washington.

Zaugg, W.S., E.F. Prentice, and F.W. Waknitz. 1985. Importance of river migration to the development of seawater tolerance in Columbia River anadromous salmonids. Aquaculture 51:33-47

Figure 2.1 Timing of salmon freshwater life phases in the Green-Duwamish Basin (Source: adapted from Grette and Salo 1986)

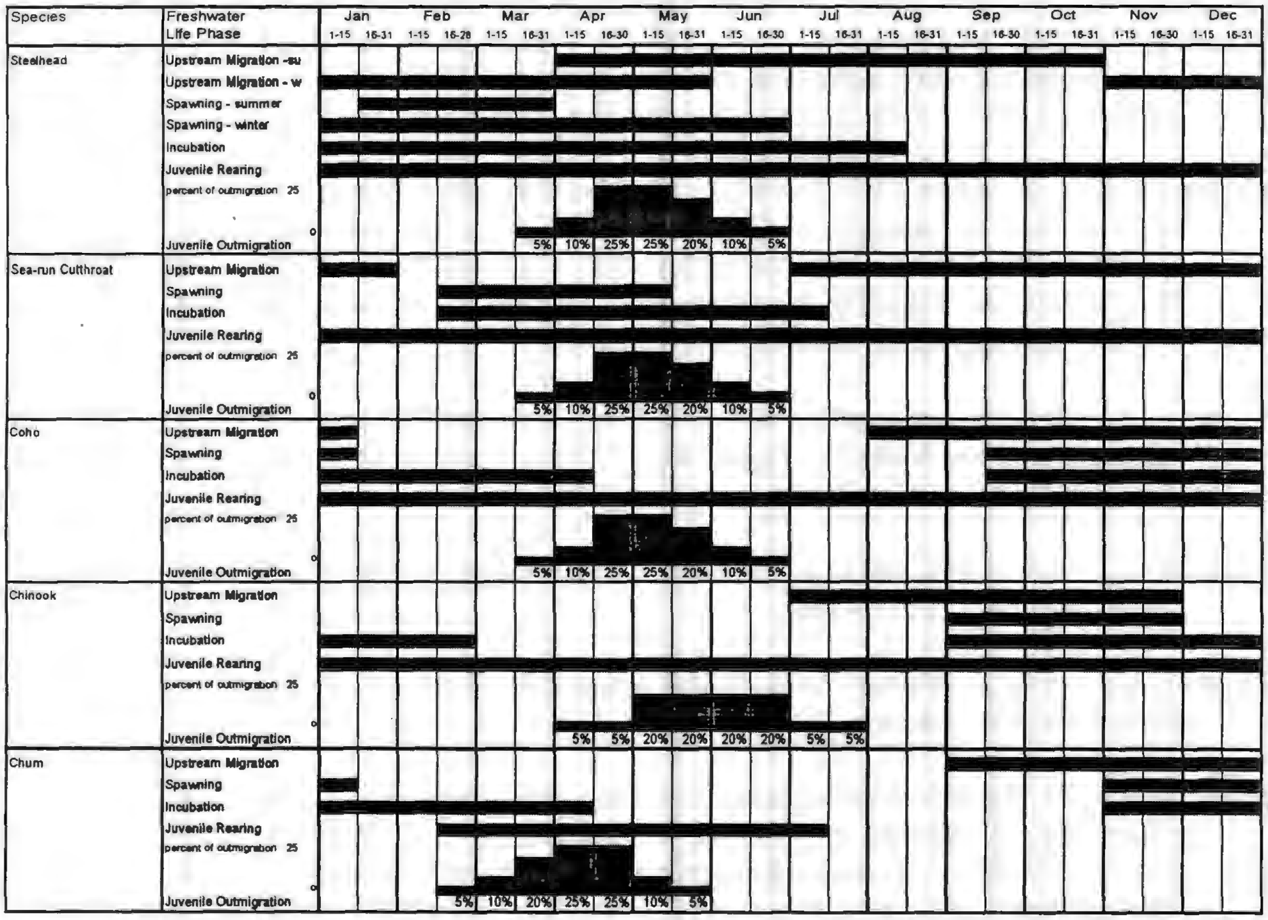


Table 2.1 **Green River hydrological conditions based on season-specific criteria during the period 1964-1995. (Source: CH2MHill 1997)**

Year	Seasonal Flow Condition Set on			
	1-Mar	1-Jul	15-Sep	30-Sep
1964	Average	Average	Wet	Wet
1965	Average	Average	Average	Average
1966	Average	Average	Average	Average
1967	Average	Average	Average	Average
1968	Dry	Average	Wet	Wet
1969	Wet	Average	Wet	Wet
1970	Average	Average	Average	Average
1971	Average	Average	Wet	Wet
1972	Wet	Average	Wet	Wet
1973	Dry	Dry	Average	Average
1974	Wet	Average	Wet	Average
1975	Wet	Average	Wet	Wet
1976	Average	Average	Wet	Wet
1977	Dry	Average	Wet	Wet
1978	Average	Dry	Average	Average
1979	Average	Dry	Average	Average
1980	Average	Average	Wet	Wet
1981	Dry	Average	Wet	Wet
1982	Average	Average	Wet	Wet
1983	Average	Average	Wet	Wet
1984	Average	Average	Wet	Wet
1985	Average	Average	Average	Average
1986	Dry	Average	Average	Average
1987	Average	Dry	Average	Average
1988	Average	Average	Average	Average
1989	Average	Average	Average	Dry
1990	Wet	Average	Wet	Average
1991	Dry	Average	Average	Average
1992	Dry	Dry	Average	Average
1993	Average	Average	Wet	Average
1994	Average	Dry	Average	Average
1995	Average	Dry	Average	Average
Number of years meeting criteria				
Wet	5		16	13
Average	20	25	16	18
Dry	7	7		1

Table 2.2 **Percent exceedence flow by half-month period, Green River at Auburn, Washington (1964 to 1995) (Source: CH2MHill 1997)**

	95 % Exceedence			75 % Exceedence			50 % Exceedence			25 % Exceedence			5 % Exceedence		
CFS	Baseline	Phase 1	Phase 2	Baseline	Phase 1	Phase 2	Baseline	Phase 1	Phase 2	Baseline	Phase 1	Phase 2	Baseline	Phase 1	Phase 2
01/01 to 01/15	530	530	530	810	810	810	1,240	1,240	1,240	2,211	2,211	2,211	5,397	5,397	5,397
01/16 to 01/31	634	634	634	991	991	991	1,561	1,561	1,561	2,941	2,941	2,941	6,612	6,612	6,612
02/01 to 02/15	591	591	591	934	934	931	1,410	1,410	1,410	2,254	2,254	2,235	4,146	4,146	4,143
02/16 to 02/28	680	680	680	972	972	900	1,558	1,558	1,363	2,305	2,305	2,125	7,379	7,379	7,199
03/01 to 03/15	746	710	704	1,039	805	750	1,409	1,098	896	1,889	1,586	1,190	3,744	3,441	2,969
03/16 to 03/31	758	675	652	900	785	750	1,231	1,035	875	1,656	1,478	1,030	2,800	2,620	2,443
04/01 to 04/15	520	575	575	1,070	900	750	1,638	1,436	850	2,206	2,004	1,456	3,253	3,053	2,887
04/16 to 04/30	605	692	655	900	977	1,044	1,256	1,408	1,506	1,681	1,877	2,011	2,461	2,621	2,706
05/01 to 05/15	570	721	679	892	1,227	1,026	1,215	1,601	1,455	1,743	2,312	2,106	2,890	3,335	3,235
05/16 to 05/31	430	532	574	782	900	833	1,204	1,361	1,248	1,745	2,089	1,982	2,899	3,038	2,937
06/01 to 06/15	350	432	492	605	607	561	921	921	920	1,519	1,519	1,480	3,126	3,126	3,126
06/16 to 06/30	416	350	400	531	493	488	757	610	586	1,145	1,012	1,000	2,079	2,046	2,046
07/01 to 07/15	282	283	280	350	350	368	442	442	440	639	639	623	1,070	1,070	1,070
07/16 to 07/31	250	250	250	300	300	300	350	350	350	426	426	420	790	790	790
08/01 to 08/15	250	250	250	300	300	300	300	300	300	391	391	350	474	474	440
08/16 to 08/31	250	250	250	300	300	300	300	300	300	350	350	399	469	469	477
09/01 to 09/15	250	250	250	250	250	300	300	300	350	400	400	423	528	528	700
09/16 to 09/30	250	250	250	250	250	300	300	300	400	397	397	438	972	972	915
10/01 to 10/15	226	229	400	263	263	400	350	350	428	440	440	456	1,029	1,029	1,081
10/16 to 10/31	225	225	400	300	300	400	396	396	450	668	668	677	1,900	1,900	1,981
11/01 to 11/15	264	264	308	476	476	491	827	827	855	1,604	1,604	1,654	4,146	4,146	4,202
11/16 to 11/30	350	350	400	699	699	752	1,157	1,157	1,211	1,911	1,911	1,965	4,688	4,688	4,742
12/01 to 12/15	536	536	569	996	996	1,039	1,583	1,583	1,627	2,586	2,586	2,579	7,648	7,648	7,657
12/16 to 12/31	531	531	551	873	873	929	1,316	1,316	1,372	2,132	2,132	2,188	5,468	5,468	5,524

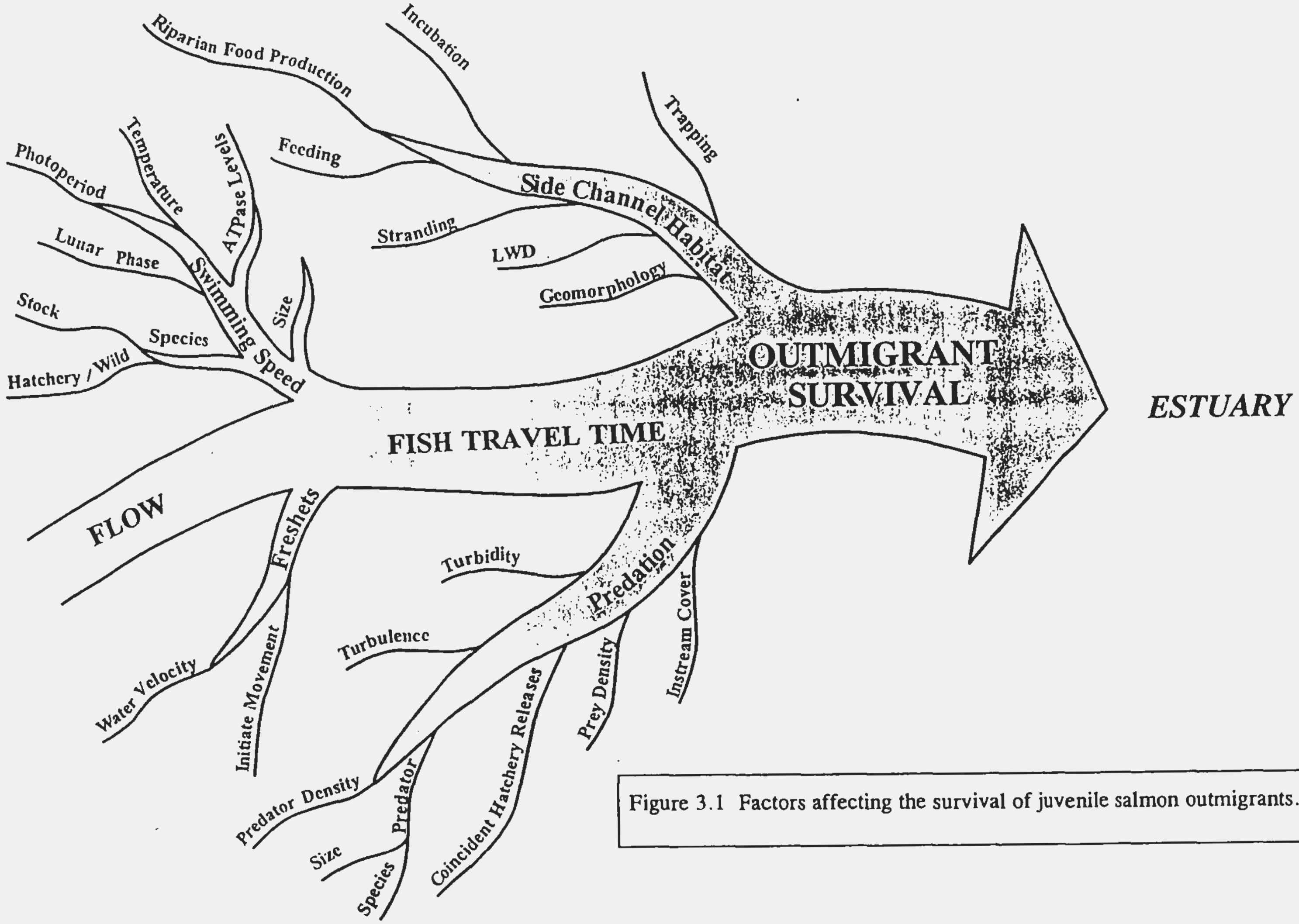


Figure 3.1 Factors affecting the survival of juvenile salmon outmigrants.

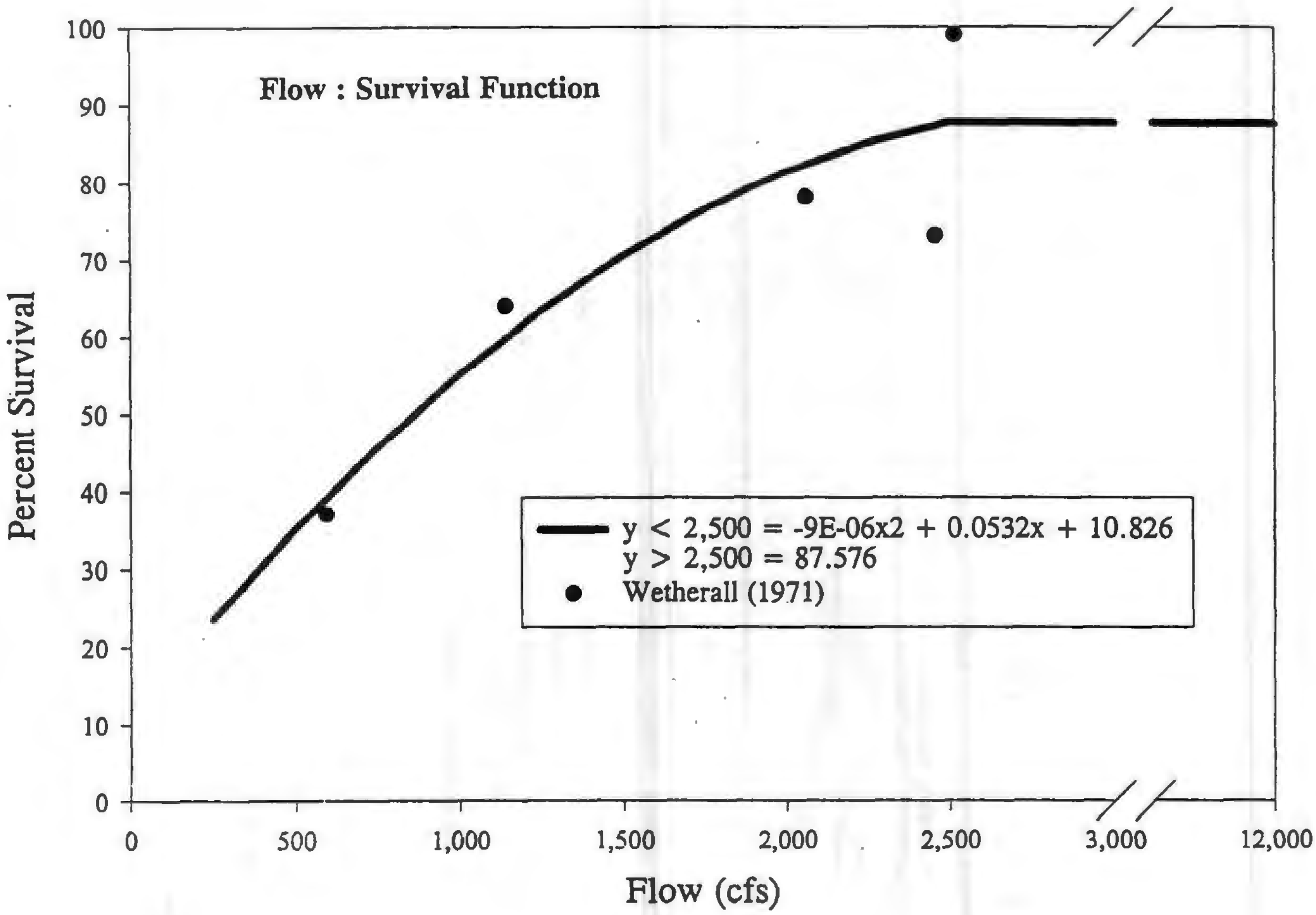


Figure 3.2 Flow:Survival function for juvenile salmonids in the Green River.

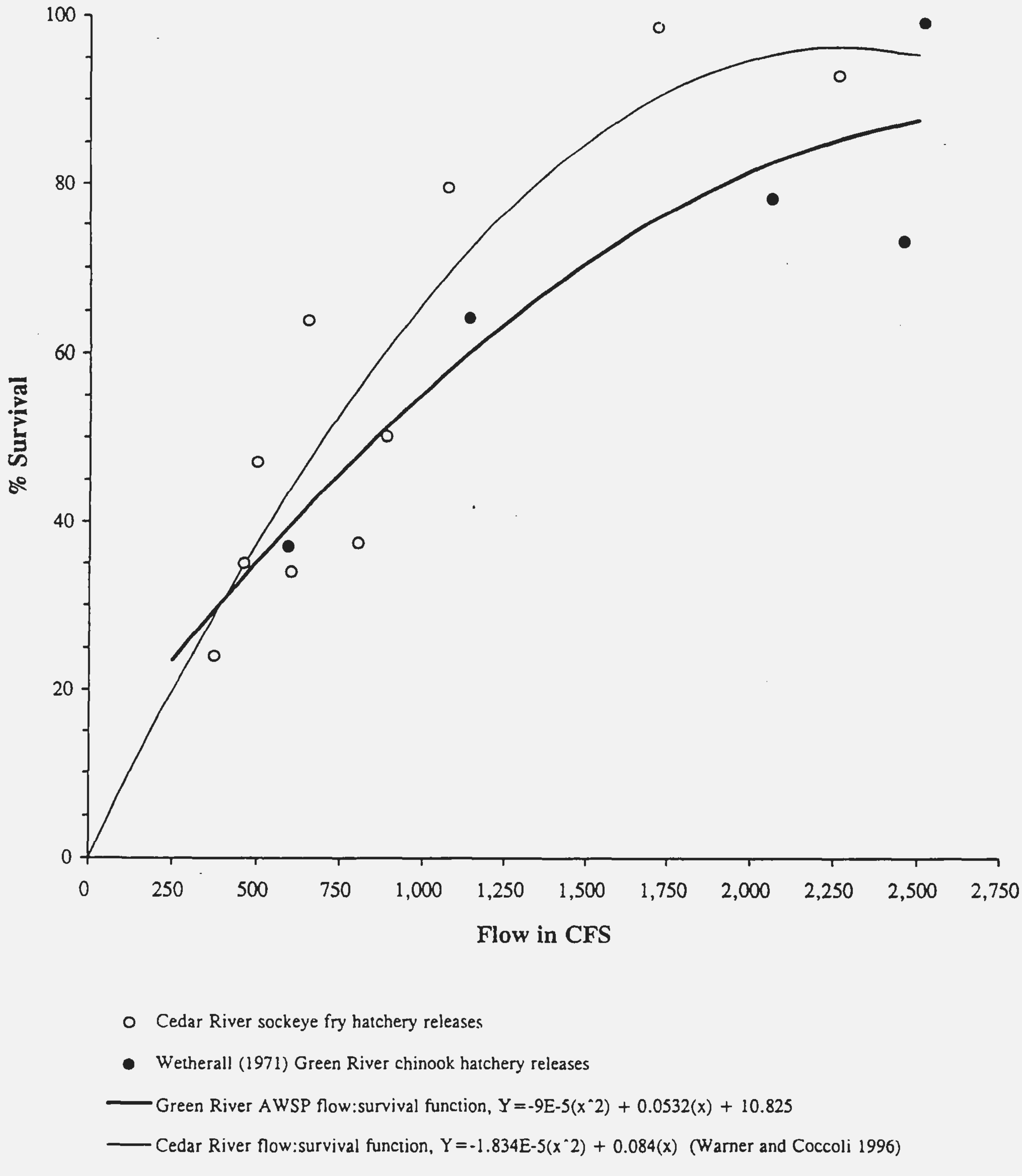


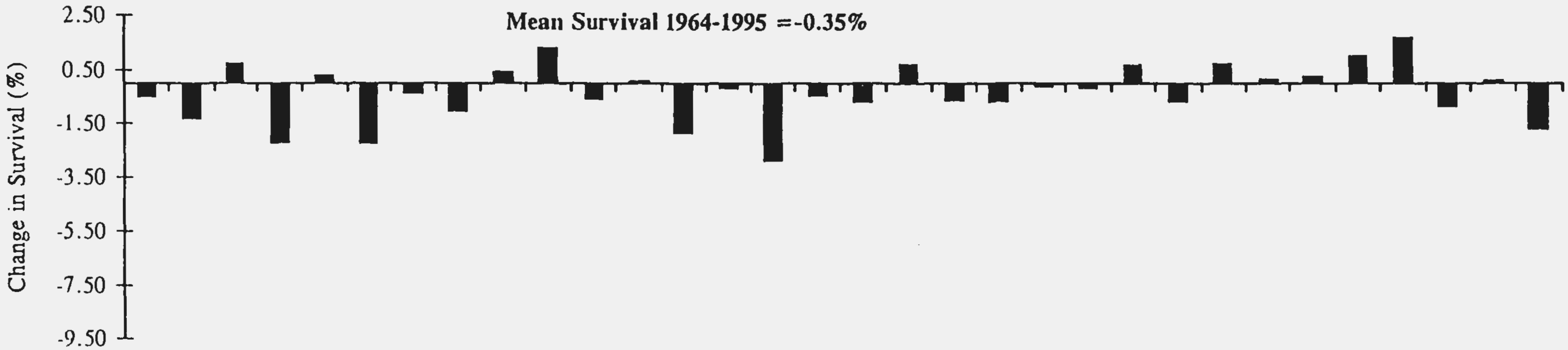
Figure 3.3 Comparison of Cedar River flow:survival function for sockeye fry and Green River Additional Water Storage Project flow:survival function

Table 3.1
Effect of Project Alternatives on Instream Migration of Juvenile Salmonids in the Lower Green River Using Modeled Daily Flows (Years 1964 - 1995)

CHUM SALMON

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Change in Smolt Survival % improvement and (% loss)		
			Base - Ph 1	Base - Ph2/1	Base - Ph-2/2
1964	Average	Average	(0.52)	(6.42)	(6.42)
1965	Average	Average	(1.36)	(4.69)	(4.69)
1966	Average	Average	0.72	(5.21)	(5.21)
1967	Average	Average	(2.25)	(7.12)	(7.12)
1968	Dry	Average	0.28	(4.81)	(4.82)
1969	Wet	Average	(2.27)	(9.20)	(9.20)
1970	Average	Average	(0.36)	(6.44)	(6.44)
1971	Average	Average	(1.05)	(7.17)	(7.17)
1972	Wet	Average	0.42	(0.55)	(0.55)
1973	Dry	Average	1.30	(0.53)	(2.12)
1974	Wet	Average	(0.59)	(4.23)	(4.23)
1975	Wet	Average	0.08	(2.72)	(2.72)
1976	Average	Average	(1.87)	(8.12)	(8.12)
1977	Dry	Dry	(0.18)	(8.13)	(8.48)
1978	Average	Dry	(2.89)	(4.79)	(4.79)
1979	Average	Average	(0.47)	(5.31)	(5.31)
1980	Average	Average	(0.71)	(6.92)	(6.92)
1981	Dry	Dry	0.69	(2.41)	(7.57)
1982	Average	Average	(0.63)	(3.95)	(3.95)
1983	Average	Average	(0.69)	(5.37)	(5.37)
1984	Average	Average	(0.12)	(5.16)	(5.16)
1985	Average	Average	(0.18)	(5.83)	(5.83)
1986	Dry	Average	0.67	(3.26)	(3.26)
1987	Average	Dry	(0.67)	(5.32)	(5.32)
1988	Average	Average	0.72	(2.11)	(2.11)
1989	Average	Dry	0.16	(4.59)	(4.59)
1990	Wet	Average	0.25	(4.24)	(4.24)
1991	Dry	Average	1.02	0.21	0.21
1992	Dry	Dry	1.67	0.02	(1.69)
1993	Average	Average	(0.87)	(5.86)	(5.86)
1994	Average	Average	0.11	(5.80)	(5.80)
1995	Average	Average	(1.72)	(6.35)	(6.35)
Avg.			(0.35)	(4.76)	(5.04)

Figure 3.4 Effect of Project Alternatives on Instream Migration of Juvenile Chum Salmon in the Lower Green River
Using Phase 1 Modeled Daily Flows (1964 - 1995)



Effect of Project Alternatives on Instream Migration of Juvenile Chum Salmon in the Lower Green River
Using Phase 2 Modeled Daily Flows (1964 - 1995)

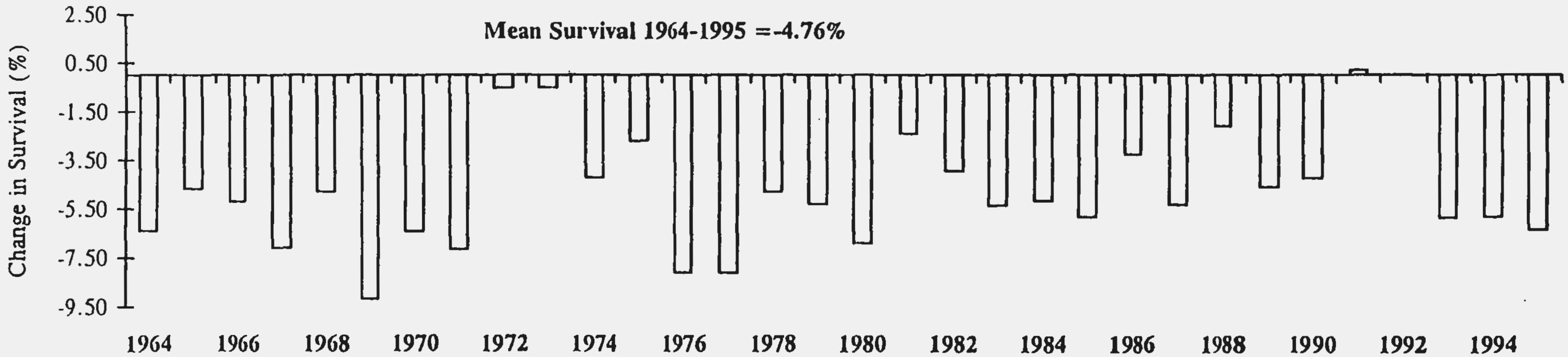
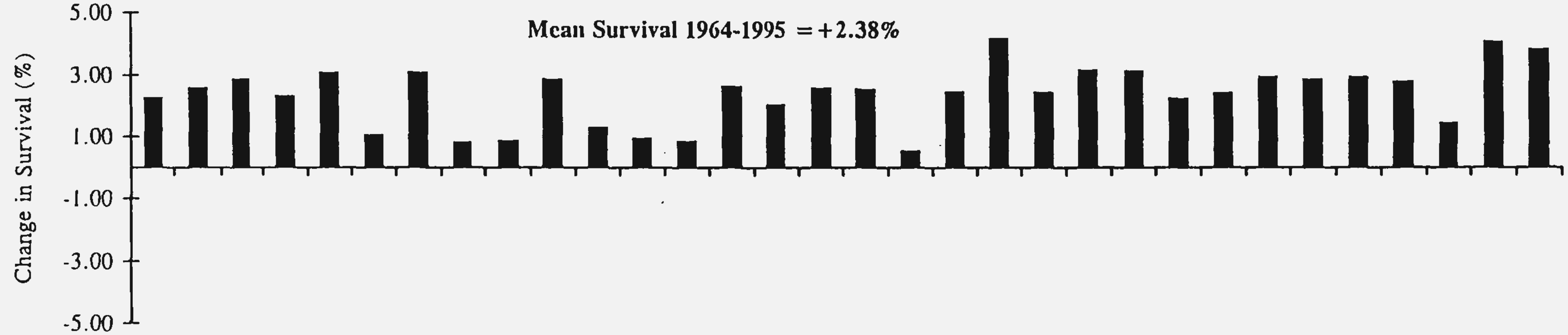


Table 3.2
Effect of Project Alternatives on Instream Migration of Juvenile Salmonids in the Lower Green River Using Modeled Daily Flows (Years 1964 - 1995)

CHINOOK SALMON

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Change in Smolt Survival % improvement and (% loss) Base - Ph 1	Base - Ph2/1	Base - Ph-2/2
1964	Average	Average	2.25	0.72	0.72
1965	Average	Average	2.57	(0.70)	(0.70)
1966	Average	Average	2.87	0.76	0.76
1967	Average	Average	2.30	(1.85)	(1.85)
1968	Dry	Average	3.07	1.63	1.68
1969	Wet	Average	1.05	(2.19)	(2.19)
1970	Average	Average	3.08	0.74	0.74
1971	Average	Average	0.81	(1.29)	(1.29)
1972	Wet	Average	0.84	0.88	0.88
1973	Dry	Average	2.85	(0.76)	(4.13)
1974	Wet	Average	1.28	0.46	0.46
1975	Wet	Average	0.93	(1.09)	(1.09)
1976	Average	Average	0.84	(1.63)	(1.63)
1977	Dry	Dry	2.63	(0.54)	(0.78)
1978	Average	Dry	2.02	(2.12)	(2.12)
1979	Average	Average	2.58	1.35	1.35
1980	Average	Average	2.54	(0.07)	(0.07)
1981	Dry	Dry	0.52	(4.01)	(3.63)
1982	Average	Average	2.46	(0.55)	(0.55)
1983	Average	Average	4.19	1.21	1.21
1984	Average	Average	2.45	1.03	1.03
1985	Average	Average	3.18	0.67	0.67
1986	Dry	Average	3.15	2.32	2.32
1987	Average	Dry	2.24	0.85	0.85
1988	Average	Average	2.43	2.37	2.37
1989	Average	Dry	2.95	1.45	1.45
1990	Wet	Average	2.87	1.75	1.75
1991	Dry	Average	2.94	2.64	2.64
1992	Dry	Dry	2.79	2.87	1.41
1993	Average	Average	1.43	0.49	0.49
1994	Average	Average	4.08	3.12	3.12
1995	Average	Average	3.82	0.33	0.33
Avg.			2.38	0.34	0.19

Figure 3.5 Effect of Project Alternatives on Instream Migration of Juvenile Chinook Salmon in the Lower Green River
Using Phase 1 Modeled Daily Flows (1964 - 1995)



Effect of Project Alternatives on Instream Migration of Juvenile Chinook Salmon in the Lower Green River
Using Phase 2 Modeled Daily Flows (1964 - 1995)

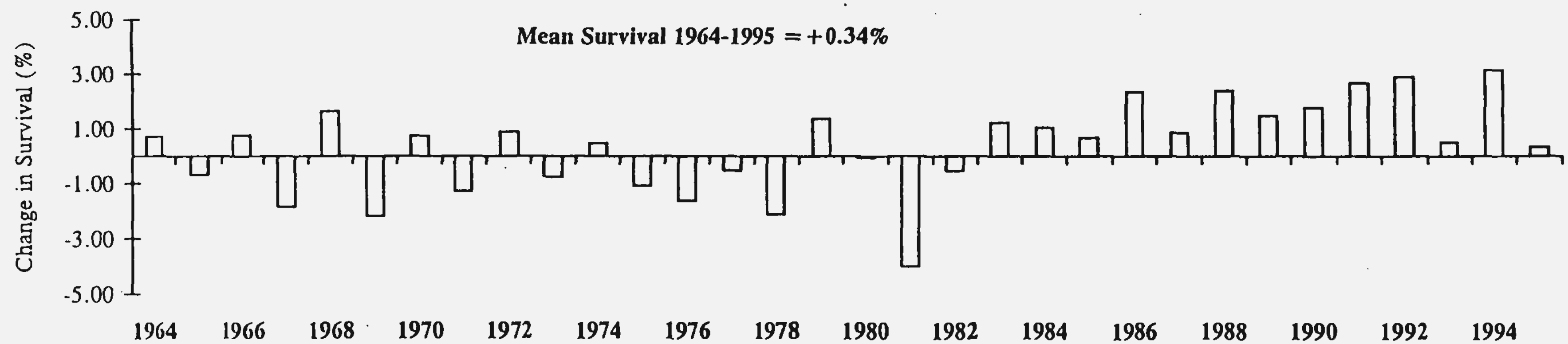
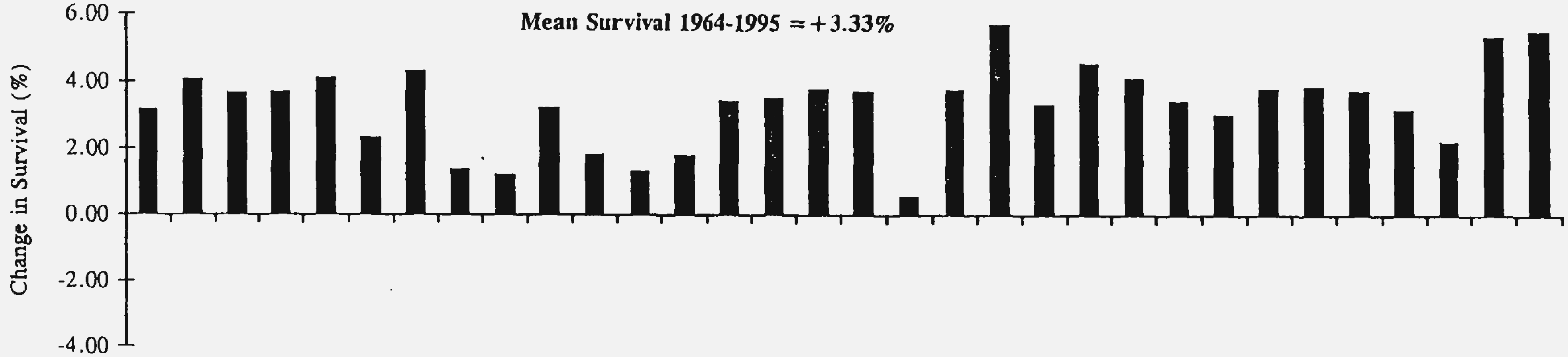


Table 3.3
Effect of Project Alternatives on Instream Migration of Juvenile Salmonids in the Lower Green River Using Modeled Daily Flows (Years 1964 - 1995)

COHO / STEELHEAD / SEA-RUN CUTTHROAT

Year	Seasonal Flow Condition Set 1-Mar	Seasonal Flow Condition Set 1-May	Change in Smolt Survival % improvement and (% loss)		
			Base - Ph 1	Base - Ph2/1	Base - Ph-2/2
1964	Average	Average	3.13	2.71	2.71
1965	Average	Average	4.06	0.08	0.08
1966	Average	Average	3.65	2.65	2.65
1967	Average	Average	3.67	(0.57)	(0.57)
1968	Dry	Average	4.11	3.73	3.81
1969	Wet	Average	2.32	0.41	0.41
1970	Average	Average	4.30	3.03	3.03
1971	Average	Average	1.36	0.51	0.51
1972	Wet	Average	1.20	1.60	1.60
1973	Dry	Average	3.22	(0.93)	(5.10)
1974	Wet	Average	1.82	1.62	1.62
1975	Wet	Average	1.31	(0.79)	(0.79)
1976	Average	Average	1.79	0.53	0.53
1977	Dry	Dry	3.44	1.87	1.66
1978	Average	Dry	3.52	(1.20)	(1.20)
1979	Average	Average	3.80	3.34	3.34
1980	Average	Average	3.72	1.91	1.91
1981	Dry	Dry	0.56	(3.86)	(2.77)
1982	Average	Average	3.77	0.39	0.39
1983	Average	Average	5.72	2.65	2.65
1984	Average	Average	3.33	2.92	2.92
1985	Average	Average	4.56	3.02	3.02
1986	Dry	Average	4.12	4.00	4.00
1987	Average	Dry	3.44	2.85	2.85
1988	Average	Average	3.03	3.37	3.37
1989	Average	Dry	3.82	3.31	3.31
1990	Wet	Average	3.88	3.46	3.46
1991	Dry	Average	3.73	3.42	3.42
1992	Dry	Dry	3.17	3.21	1.73
1993	Average	Average	2.22	2.34	2.34
1994	Average	Average	5.35	5.63	5.63
1995	Average	Average	5.50	1.73	1.73
Avg.			3.33	1.84	1.69

Figure 3.6 **Effect of Project Alternatives on Instream Migration of Juvenile Coho / Steelhead / Sea-run Cuthroat in the Lower Green River Using Phase 1 Modeled Daily Flows (1964 - 1995)**



Effect of Project Alternatives on Instream Migration of Juvenile Coho / Steelhead / Sea-run Cutthroat in the Lower Green River Using Phase 2 Modeled Daily Flows (1964 - 1995)

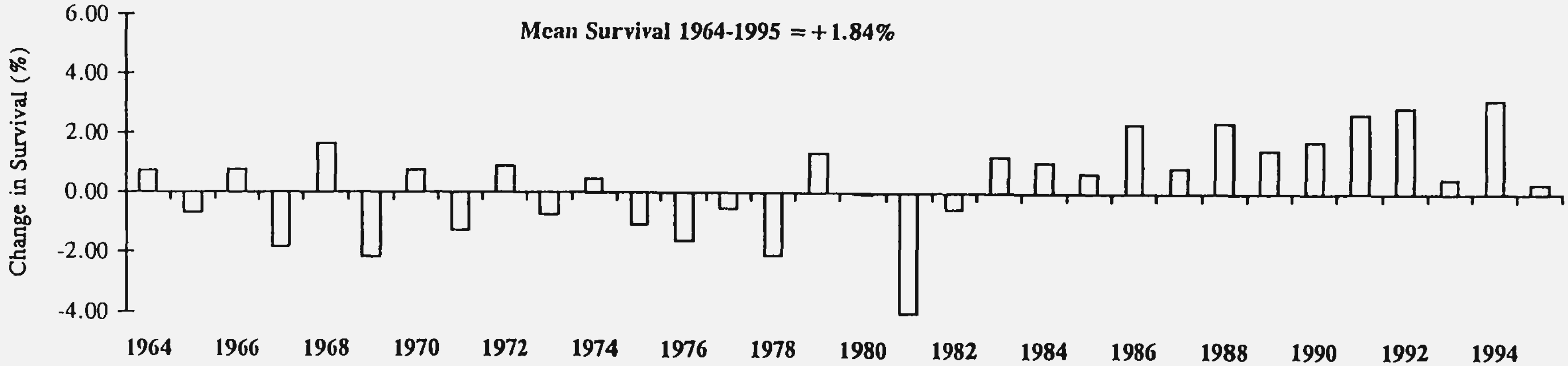
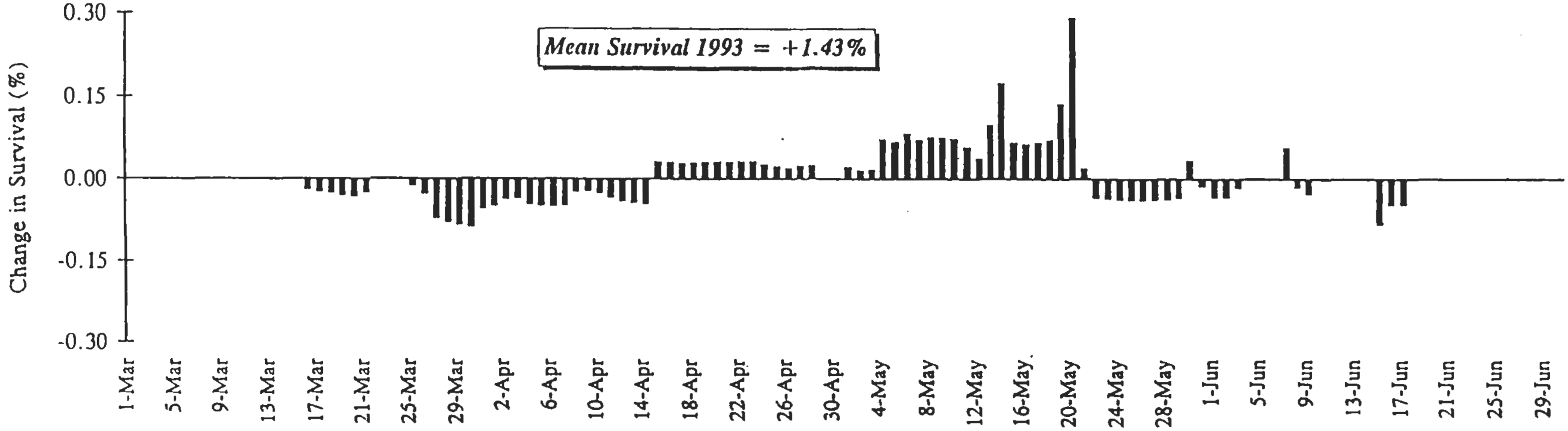


Figure 3.7

Effect of Project Alternatives on Instream Migration of Juvenile Chinook in the Lower Green River Using Phase 1 Modeled Daily Flows (1993 Water Year)



Effect of Project Alternatives on Instream Migration of Juvenile Chinook in the Lower Green River Using Phase 2 Modeled Daily Flows (1993 Water Year)

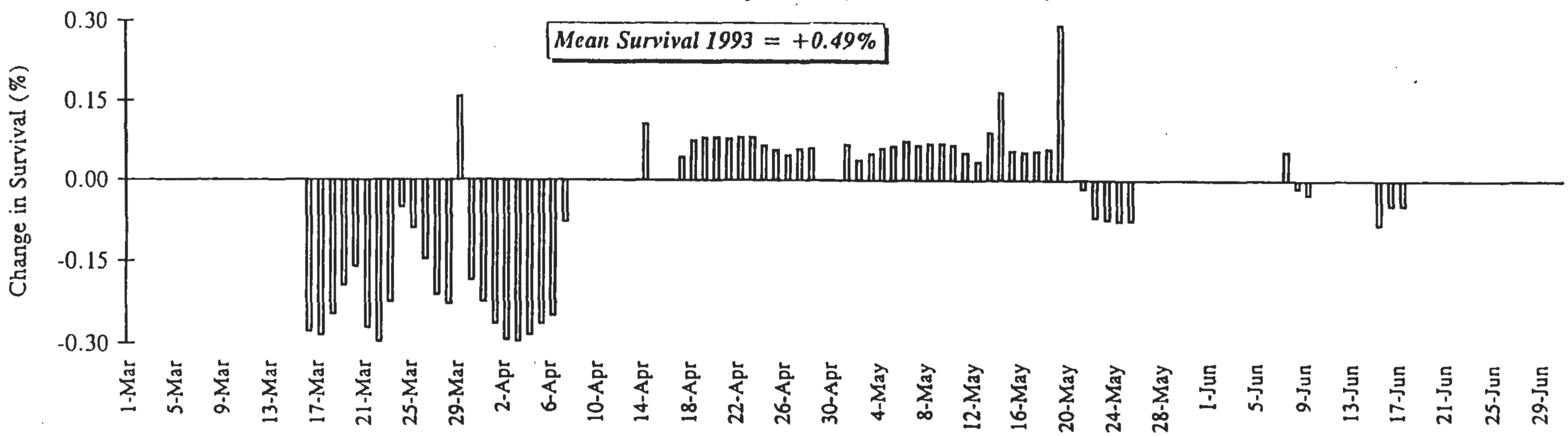


Table 3.6 **Number of flow events in the Green River greater than or equal to 2,500 cfs at Auburn**
One flow event defined as single continuous flow exceeding specified value regardless of duration.
(Source: CH2MHill 1997)

Year	BASELINE						PHASE 1						PHASE 2					
	Feb	Mar	Apr	May	Jun	Total	Feb	Mar	Apr	May	Jun	Total	Feb	Mar	Apr	May	Jun	Total
1964	1	1	2	2	2	**8**	1	1	1	4	2	**9**	1	1	2	3	2	**9**
1965	3	0	1	0	0	**4**	3	0	2	2	0	**7**	3	1	2	1	0	**7**
1966	0	1	2	2	0	**5**	0	1	2	3	0	**6**	0	0	3	2	0	**5**
1967	4	0	0	2	0	**6**	4	0	0	3	0	**7**	4	0	0	2	0	**6**
1968	2	1	0	0	1	**4**	2	1	0	0	1	**4**	2	0	0	0	1	**3**
1969	0	1	4	3	0	**8**	0	0	3	4	0	**7**	0	0	4	4	0	**8**
1970	1	0	1	0	0	**2**	1	0	1	2	0	**4**	1	0	2	1	0	**4**
1971	2	0	0	4	0	**6**	2	0	0	4	0	**6**	2	0	2	3	0	**7**
1972	2	1	2	4	3	**12**	2	1	1	4	2	**10**	2	2	3	3	2	**12**
1973	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	0	0	0	**0**
1974	2	3	2	2	1	**10**	2	1	3	3	1	**10**	1	1	4	4	1	**11**
1975	2	1	0	3	1	**7**	2	1	0	4	1	**8**	2	1	0	3	1	**7**
1976	1	0	1	2	0	**4**	1	0	2	3	0	**6**	0	0	2	2	0	**4**
1977	0	0	1	0	0	**1**	0	0	1	0	0	**1**	0	0	0	0	0	**0**
1978	0	0	0	0	0	**0**	0	0	0	2	0	**2**	0	0	0	0	0	**0**
1979	1	1	0	0	0	**2**	1	1	1	2	0	**5**	1	2	2	1	0	**6**
1980	2	1	2	0	0	**5**	2	0	3	1	0	**6**	2	1	5	1	0	**9**
1981	1	0	1	0	0	**2**	1	0	1	0	0	**2**	1	0	1	0	0	**2**
1982	2	1	0	0	0	**3**	2	1	0	2	0	**5**	2	2	1	1	0	**6**
1983	1	2	0	0	0	**3**	1	1	0	2	0	**4**	0	1	2	1	0	**4**
1984	2	2	0	0	0	**4**	2	1	0	5	0	**8**	1	1	2	2	0	**6**
1985	0	0	3	0	1	**4**	0	0	5	2	1	**8**	0	0	3	1	1	**5**
1986	1	1	0	1	0	**3**	1	0	0	1	0	**2**	1	0	0	1	0	**2**
1987	1	3	0	0	0	**4**	1	3	0	2	0	**6**	1	2	2	1	0	**6**
1988	1	1	2	2	0	**6**	1	2	2	4	0	**9**	1	1	4	3	0	**9**
1989	1	0	2	0	0	**3**	1	0	2	2	0	**5**	1	0	2	1	0	**4**
1990	3	1	1	0	1	**6**	3	0	1	2	1	**7**	2	1	2	1	1	**7**
1991	2	0	1	0	0	**3**	2	0	1	1	0	**4**	2	0	1	1	0	**4**
1992	1	0	1	0	0	**2**	1	0	1	0	0	**2**	1	0	1	0	0	**2**
1993	0	1	1	1	0	**3**	0	1	1	3	0	**5**	0	1	2	4	0	**7**
1994	0	1	0	0	0	**1**	0	1	0	1	0	**2**	0	2	2	1	0	**5**
1995	2	0	0	0	0	**2**	2	0	0	2	0	**4**	2	0	1	1	0	**4**
Total	41	24	30	28	10	**133**	41	17	34	70	9	**171**	36	20	57	49	9	**171**
Average	1.3	0.8	0.9	0.9	0.3	**4.2**	1.3	0.5	1.1	2.2	0.3	**5.3**	1.1	0.6	1.8	1.5	0.3	**5.3**

SECTION 6 GREEN RIVER STEELHEAD SPAWNING AND INCUBATION

Executive Summary

Tacoma Public Utilities and the US Army Corps of Engineers propose to increase water storage behind Howard Hanson Dam in the Green River basin located in King County, Washington for municipal water supply and instream flow enhancement. A major objective of the project is to develop and operate it with no net loss to wild Green River steelhead. A flow model was developed to predict how the proposed project would operate using 1996 reservoir refill rules applied to the historic flow records from 1964 through 1995. The effects of the proposed project on wild winter steelhead spawning and incubation in the mainstem Green River were evaluated using a daily flow model to quantify how frequently potential steelhead spawning area would be dewatered under Baseline and proposed conditions.

The analysis compared the relative amount of mainstem channel width at the study site subject to a reduction in river stage of one foot and greater for a period of 48-hours or more during the 50-days following spawning (dewatered spawnable channel width) for the Baseline, Phase I and Phase II conditions. Data for the model were developed using the Washington Department of Ecology's Instream Flow Incremental Methodology Nealy Bridge Site Transect 6 at River Mile 35.4 as the reference point. Spawning was considered to take place from March 1 through June 30 for each year in the period of record, based on Washington Department of Fish & Wildlife steelhead redd counts from 1994 - 1996. Embryonic development was assumed to last 50 days. Mean daily flows for the Nealy Site were calculated by subtracting the mean daily flows measured at the US Geological Survey (USGS) Gage No. 12112600 (Big Soos Creek Above Hatchery, Near Auburn) from the modeled mean daily flows at USGS Gage No. 12113000 (Green River Near Auburn).

The results of the analysis indicated that for the period of record 1964 through 1995, the mean daily spawnable channel width subject to dewatering during incubation was 0.780 ft/day (9.4 in/day) for Baseline conditions, 0.884 ft/day (10.6 in/day) for Phase I, and 0.798 ft/day (9.6 in/day) for Phase II. Spawnable channel width that remained wetted during the 50-day incubation period ranged from 158.5 ft/day for Baseline conditions to 157.8 ft/day for Phase II conditions.

In the Baseline condition, the largest amount of dewatered spawnable channel width was found to affect redds constructed during the June 1 - 15 time period. In Phases I and II, the largest dewatered spawnable channel width was found to affect redds constructed during the May 16 - 31 time period.

One approach to reducing the amount of channel width subject to stage reductions of one foot and greater for a period of 48 hours or more was examined. The 2,500 cfs artificial freshet programmed in the flow model for May 15 during wet and average springs was reduced by

500 cfs, making an additional 1,570 acre feet of water available for instream flow augmentation at a rate of 53 cfs for a 15-day period. Using this water to supplement instream flows in July reduced the difference in dewatered spawnable channel width between Phase I and Baseline conditions by half, and reduced the total amount of dewatered spawnable channel width in Phase II to less than Baseline conditions.

The results of the flow and steelhead spawning and incubation models provide an indication of probable impacts of the Additional Storage Project on steelhead spawning and incubation. Model results should be verified by a rigorous program of monitoring the actual impacts of project operations. Information gained through the monitoring program can be used to modify project operations to minimize impacts on steelhead; however, allocating water to protect or enhance one species and life stage will affect other species and life stages, and is therefore a defacto decision to prioritize species and life stages. Federal and State resource agencies and the Muckleshoot Indian Tribe will be able to use the information gained from the Howard Hanson Dam Additional Water Storage studies to better understand the impacts of water allocation decisions, and consequently to make more enlightened choices to maximize Green River fish resources.

Existing Resources

Three steelhead stocks utilize the Green River during the freshwater phases of their life cycle. These include summer and winter stocks of hatchery origin, and natural-spawning (wild) winter steelhead. The two hatchery stocks are managed by the Washington Department of Fish & Wildlife (WDFW) and the Muckleshoot Indian Tribe (MIT) for harvest in the sports, commercial and tribal fisheries. The natural spawning stock is managed for a spawning escapement of 2,000 fish, with the excess available to the sport and tribal fisheries. Although there is evidence that some hatchery steelhead spawn naturally in the Green River, natural spawning of hatchery fish is not desirable from a resource management standpoint because it increases the likelihood of interbreeding between hatchery and natural spawning stocks with consequent degradation of genetic integrity of the natural spawning stock. This report examines the impacts of the Howard Hanson Dam Additional Water Storage Project on spawning and incubation of wild winter steelhead in the mainstem Green River downstream of the proposed project.

Wild winter steelhead adults return to the Green River from the ocean during December through May. Spawning occurs in the mainstem river from approximately River Mile (RM) 26.4 (Kent) to RM 61.0 (Tacoma Headworks) (Figure 1), and takes place from March through June, with peak spawning occurring in April and May (Table 1). On average, about 2 percent of spawning occurs during the first two weeks in March and the last two weeks of June.

Operations

Howard Hanson Dam began operations in December 1961. The project was authorized by Congress to provide flood control protection to the Green River valley during the winter, and instream flow enhancement to the river during the summer. Project management has evolved over the years in response to new information pertaining to flood control and natural resource management needs.

The original operational storage strategy, generally followed from 1962 to 1983, delayed the start of refill until June to enhance municipal water quality. Once refill was initiated, all inflow was stored and only water required to satisfy instream flow requirements was released. Storing water quickly dramatically reduced flows in the mainstem river downstream of the project during the period when steelhead were spawning and eggs were incubating in the gravel.

During the period 1983 to 1991, the reservoir storage and release strategy was modified to initiate refill earlier than the 1962 to 1983 practice, but delay refill as late as possible to facilitate downstream passage of outmigrating juveniles through the reservoir. Juvenile steelhead began to be planted in the watershed upstream of Howard Hanson Dam in October 1982 by the then Washington Department of Game and the MIT. In March 1983, the then Washington Department of Fisheries began planting coho in the watershed upstream of Howard Hanson Dam. The change in strategy to delay refill was made partly in response to these new planting programs. Refill was initiated as early as April 19 and as late as June 4, whereas refill completion was accomplished as early as May 3 and as late as July 10. The shortest refill duration was 9 days in 1989, and the longest was 53 days in 1987. This strategy continued to produce conflicts between fisheries resources upstream and downstream of the project. Outmigrating smolts pass easily through the project at low pool, but as the reservoir fills, outmigrating fish find it increasingly difficult to find the reservoir outlet and exit the project. Delaying refill as late as possible improved conditions for juveniles outmigrating through the project, but refilling the reservoir after outmigrant needs were considered met required a short but intense reduction in discharge to the river downstream of the project which continued to result in steelhead redd dewatering.

Since 1992, the refill and discharge strategy has involved periodic adjustments to meet a variety of resource needs. Releases from the project are adjusted in response to changing inflow and weather conditions to provide additional flows to protect fisheries resources, to provide white water recreation opportunities and for community activities. Refill generally begins in mid-April in response to input provided by WDFW, MIT, the City of Tacoma, the US Fish and Wildlife Service, Washington Department of Ecology, Trout Unlimited and other interested groups. The timing and rate of spring refill is meant to be a compromise between providing passage for juvenile outmigrants through the project and downstream flows adequate to protect steelhead spawning and incubation.

Instream Flow Model

In order to identify the potential impacts of the Howard Hanson Dam Additional Water Storage Project on fisheries resources, and to use impact information to shape project operations to meet a broad range of fisheries needs, a model describing the timing and rate of reservoir refill and discharge was developed by water resource staff from the firm CH2MHill in conjunction with water managers and fisheries biologists from the Army Corps of Engineers, Tacoma City Water, and R2 Resources, Inc. The model employed mean daily flow measurements from US Geological Survey gages in the basin from the period 1964 through 1995. A thorough discussion of the model can be found in Section 9 of Appendix F, Part 1. Highlights of the model are presented here to facilitate the reader's understanding of the steelhead spawning and incubation analysis.

Storage behind Howard Hanson Dam was hypothetically divided into three modeled storage allocations, each with different rules for use. Fish Dam 1 is the existing storage which strictly follows the Corps of Engineers' 98 percent rule curve and meets a 110 cfs base flow at the USGS Gage No. 12106700, Green River At Purification Plant Near Palmer (Palmer gage) during the summer for instream flow protection. Fish Dam 2 represents the storage volume available to protect and improve instream flow conditions, and Diversion Dam represents the storage volume available to Tacoma for Municipal and Industrial uses.

Baseline

In the Baseline condition, up to 5,100 acre feet of water can be stored for reservoir debris removal and early summer instream flow enhancement in Fish Dam 2 between March 15 and June 15. Water allocated to those purposes that is not used by June 15 is discharged from the reservoir by June 15 or shortly after during wet and average years, and by July 15 during dry years.

The model established a target instream flow level of 900 cfs from March 15 to May 1 at USGS Gage No. 12113000, Green River Near Auburn (Auburn gage) for refill of Fish Dam 2. Water can be stored in Fish Dam 2 when flows exceeded 900 cfs at Auburn during the March 15 - May 1 time period. Water was released from Fish Dam 2 when flows at Auburn dropped below 900 cfs up to the volume stored in Fish Dam 2. Instream flows at Auburn were decreased from 900 cfs on May 1 to 400 cfs on July 1.

From July 1 through the end of reservoir operations (generally around December 8), Fish Dam 1 was managed to meet baseflow levels at Auburn in accordance with the 1995 *Agreement between the Muckleshoot Indian Tribe and the City of Tacoma Regarding the Green/Duwamish River System*. Summer months conditions stated in the Agreement are *"For Wet Years, the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years, the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought."*

There were no freshets or shaving of peak flows programmed for the Baseline condition.

Phase I

In Phase I, instream flow targets for refill of Fish Dam 2 were 900 cfs in February for all hydrologic conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions respectively. Instream flow targets decreased from 900 cfs and 750 cfs on May 1 to 400 cfs on July 1, and in dry conditions from 575 cfs on May 1 to 250 cfs on July 1.

Hydrologic conditions were evaluated in the late winter to determine whether or not the spring season was to be considered wet, average or dry. This was done by measuring the snow water equivalent at Stampede Pass on March 1. If greater than or equal to 50 inches, the spring was considered wet. If between 24 and 50 inches, the spring was considered average, and if less than or equal to 24 inches, the spring was considered dry. In addition, the snow water equivalent was measured again on May 1. If it exceeded 12 inches, the summer was considered to be average or better; if 12 inches or less, drought conditions were implemented in accordance with the Muckleshoot Agreement.

Freshets of 38 hours duration and 2,500 cfs magnitude, measured at the Auburn gage, were delivered on May 1 and May 15 under wet and average conditions, and at a level of 1,250 cfs on May 1 under dry conditions.

Fish Dam 1 was filled following the Corps of Engineers' 98 percent rule curve with a base flow of 110 cfs measured at the Palmer gage. The dam met the 350, 300, 250, and 225 cfs requirements at the Auburn gage in an average year, and 250 cfs and 225 cfs in a dry year, in accordance with the Muckleshoot Agreement. In dry springs, the refill period for Fish Dam 1 began 15 days earlier on April 1.

<u>Phase II</u>

In Phase II, the level of snow water equivalent at Stampede Pass and the level of water stored in the Fish Dams were evaluated four times between March and September to set the conditions for the particular season. The snow water equivalent on March 1 set the condition for the spring in the same manner as for Phase I. Conditions were reevaluated again on July 1, September 15, and September 30.

Refill began on February 15. Instream flow targets for the refill of Fish Dam 2 and the Diversion Dam were established at 900 cfs in February for all hydrologic conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions respectively. Instream flow targets decreased from 900 cfs and 750 cfs on May 1 to 400 cfs on July 1, and in dry conditions from 575 cfs on May 1 to 250 cfs on July 1.

During the summer, Fish Dam 1 supported 350, 300, 250, and 225 cfs at Auburn in an average summer, and 250 and 225 cfs during a dry summer. Fish Dam 2 supported 300 cfs in an average summer and 250 cfs in a dry summer. In Phase II, no condition anticipated a flow at Auburn less than 250 cfs.

Freshets, at a duration of 38 hours and a level of 2,500 cfs measured at the Auburn gage, were delivered on April 1, April 15, May 1, and May 15 under wet and average conditions, and at a level of 1,250 cfs on the same four days under dry conditions. Whenever Fish Dam 2 was below 65 percent of full on any of the four days where freshets were to be provided, the freshet for that day was skipped.

Fish Dam 1 was filled following the Corps' 98 percent rule curve, with a base flow of 110 cfs at Palmer. The dam met the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 and 225 cfs in a dry year, in accordance with the agreement between the

Muckleshoot Tribe and City of Tacoma. In dry springs, the refill period for Fish Dam 1 began 15 days earlier on April 1.

Steelhead Spawning and Incubation Model

The reservoir operations model described above was useful to the analysis of impacts of the project on steelhead spawning and incubation because it predicted the flow regime for the Baseline, Phase I and Phase II operating conditions measured at the Auburn gage. The modeled flow regime by itself, however, did not describe potential impacts on steelhead spawning and incubation. In order to understand the nature of potential impacts, modeled flows were converted to river stage and channel width values for the winter steelhead were spawning and incubation period.

Several assumptions were made for development of the model. They included 1) wild steelhead spawn in the mainstem Green River from about March 1 to about June 30 (WDFW redd surveys); 2) Green River steelhead exhibit a preference for spawning in river depths of one foot and greater (Appendix H4, Caldwell and Hirschey, 1989); 3) eggs can withstand dewatering for 48-hours without significant adverse impact (Becker et al, 1983); 4) egg development to fry emergence takes, on average, about 50 days (Burton and Little, 1997; Green River temperature data). Although these assumptions may not be totally accurate, they were employed in the model because it was felt that they served as indices of effects with which to evaluate impact alternatives.

The Washington Department of Ecology's *Green River Fish Habitat Analysis Using the Instream Flow Incremental Methodology, IFIM Technical Bulletin No. 89-35 (July 1989)* provided five reference sites in the Green River for establishing relationships between river flow, stage and width (Figure 2). The five sites were selected in 1986 by federal and state fisheries resource agencies, the MIT, Corps of Engineers, City of Tacoma and Trout Unlimited as the sites from which to collect information needed to predict how fish habitat in the mainstem Green River is affected by incremental changes in streamflow. Of the five sites used in the IFIM study, three were located in heavily-used steelhead spawning reaches (Nealy Bridge, Car Body, Flaming Geyser). One transect from each site was chosen for comparison with the others to understand how the sites were related. The transects selected were those used by Jean Caldwell in her report for the Muckleshoot Indian Tribe entitled "Green River IFIM Study Further Analysis" (Caldwell and Associates, January 1992). They were chosen to provide an estimate, based on a measured stage-discharge relationship in steelhead spawning reaches of the Green River, of the change in stage associated with a reduction in river flows caused by the operation of Howard Hanson Dam.

A comparison of Transect 6 of the Nealy IFIM site (RM 35.4), Transect 4 of the Car Body IFIM site (RM 39.6), and Transect 1 of the Flaming Geyser IFIM site (RM 40.6) showed that a reduction in flow from 1200 cfs to 400 cfs would result in a reduction in stage of 12 inches at Nealy Transect 6, about 14.4 inches at Car Body Transect 4 (located 1.6 river miles upstream from the Nealy site), and about 10 inches at Flaming Geyser Transect 1 (located 5.6 river miles upstream of Nealy) (Table 3). Because the stage-discharge relationship for the Nealy Transect 6 site was found to be intermediate between the stage-discharge relationships at Car Body

Transect 4 and Flaming Geyser Transect 1, the analysis was conducted using the Nealy Transect 6 site (Figure 3) as the reference point.

Mean daily flows for the Nealy Bridge site were calculated by subtracting the mean daily flows at USGS Gage No. 12112600, Big Soos Creek Above Hatchery, Near Auburn, from the mean daily flows measured at the Auburn gage.

The steelhead analysis model assumed that reductions in stage of 1 foot and greater following spawning can subject redds to the risk of dewatering. The analysis estimated the amount of channel width (ft/day) subject to dewatering of one foot and more for 48-hours during the 50-day incubation period corresponding to each day during the March 1 - June 30 spawning period. Estimates of Dewatered Spawnable Channel Width (DSW) were made for the Baseline, Phase I and Phase II conditions, and the values for Phases I and II were compared to the Baseline values to obtain an estimate of impact (Figure 4).

Dewatered Spawnable Channel Width was calculated by subtracting the spawnable channel width (SW) from the wetted channel width at the 48 hour low flow during incubation (LFWW) (Figure 4). The daily SW was estimated to be the channel width corresponding to the wetted channel width (WWD) flow (mean daily flow) minus one foot of stage. The LFWW was estimated as the channel width corresponding to the higher of the lowest two consecutive mean daily flows occurring at the Nealy site during the 50 days following each spawning day between March 1 and June 30. The stage corresponding to the higher of the two low flows was calculated from the stage-discharge relationship for Transect 6 of the Nealy IFIM site (page 70, Appendix C2, Green River IFIM Technical Bulletin), described by the following equation:

$$\text{Stage} = A * Q^B + SZF$$

		Nealy Transect 6
where:	A = alpha regression constant	A = 0.2778
	Q = Flow	
	B = exponential constant	B = 0.3437
	SZF = Stage (ft) at Zero Flow	SZF = 86.5

The difference between WWD and SW was labeled Unspawnable Channel Width (USWD). This value describes the width of channel not available to steelhead for spawning because it is located in the upper one foot of the water column. The Wetted Spawnable Width (WSW) was calculated by comparing SW with LFWW. When SW was less than LFWW, WSW equaled SW. When SW was greater than LFWW, WSW equaled LFWW.

Spreadsheets were created for each year in the period of record for the Baseline, Phase I and Phase II conditions. Each spreadsheet contains a date (March 1 - June 30 for spawning; March 1 - August 19 for incubation), flow at Nealy Transect 6 (cfs), the 48-hour low flow (cfs) observed during each 50-day incubation period associated with each spawning day, WWD (ft/day), SW (ft/day), LFWW (ft/day), WSW (ft/day), DSW (ft/day), and USWD (ft/day). The sums of the WWD, USWD, DSW, WSW and SW for each two week period between March 1 and June 30 for the proposed Baseline, Phase I and Phase II conditions were then calculated, and the values displayed in Table 4.

Results

Results from the modeling exercise predict that operating the Howard Hanson Dam Additional Water Storage Project using the 1996 refill strategy during the 32-year period of record 1964 - 1995 would result in an average increase of about 0.1 ft/day (1.2 in/day) of DSW during the steelhead spawning and incubation period (March 1 - August 19) in Phase I compared to Baseline. Phase II of the project would result in 0.02 ft/day (0.24 in/day) additional DSW on an average per day basis compared to Baseline.

The analysis predicted that while there is little change in the total amount of DSW between Baseline, Phase I and Phase II conditions, the Additional Storage Project would result in within-season timing differences in DSW. Project effects were found to be greater during certain time periods and less in others (Table 5). In Phases I and II, DSW will decrease for redds constructed during the March 1 through April 15 and June 16 through June 30 time periods. It will decrease in Phase II during the June 1 through June 15 time period, and will increase in Phases I and II for redds constructed during the April 16 through May 31 time period. The average annual peak impact in the Baseline condition is predicted to occur for redds constructed during the June 1 through 15 time period, whereas in Phases I and II, the average annual peak impact is predicted to occur for redds constructed during the May 16 through 31 time period.

The mean annual DSW exposed to 48-hour dewatering at the Nealy Transect 6 site during the incubation period March 1 - August 19 for the Baseline condition was estimated to be 0.780 ft/day (9.4 in/day) compared to an average WWD of 158.61 ft/day. In Phase I, the mean annual DSW was estimated to be 0.884 ft/day (10.61 in/day) compared to an average WWD of 158.53 ft/day. In Phase II, the mean annual DSW was estimated to be 0.798 ft/day (9.6 in/day) compared to an average WWD of 157.8 ft/day.

The results of the analysis for the 32 year period of record were ordered by total DSW per year from the greatest to the least (Table 6). Associated with each year are hydrologic conditions for the spring, determined on March 1, and for the summer, determined on May 1 for Phase I and on July 1 for Phase II. In general, "wet" hydrologic conditions in the spring were found to be associated with larger amounts of DSW during the incubation period, whereas "dry" hydrologic conditions in the spring tend to be associated with lesser amounts of DSW. With a few exceptions, the years with the least amount of unprotected channel width were associated with dry or average hydrologic conditions in the summer combined with either dry or average conditions in the spring.

The total DSW for the 32-year period of record was skewed by a few years with very large DSW values. For example, the year 1972, the wettest in the period of record with 115.59 inches of precipitation measured at Howard Hanson Dam, had the largest amount of DSW in each of the three development conditions. It exceeded the next closest year (1964) by 0.5 ft/day in the Baseline condition, 0.4 ft/day in Phase I, and 0.8 ft/day in Phase II. To put the magnitude of 1972's impact into perspective, consider that 9 of 32 years (28.1 %) in the Baseline condition experienced less than 0.5 ft/day of impact; 7 out of 32 years (21.9 %) in

Phase I experienced less than 0.4 ft/day of impact, and 14 out of 32 years (43.8 %) in Phase II experienced less than 0.8 ft/day of impact.

Sample years from each combination of hydrologic conditions and their associated levels of DSW are presented. The wet spring / average summer condition is represented by the year 1974 (Table 7). For this year, the model's results for the Baseline condition provided an average of 1.78 ft/day (21.4 in/day) of DSW for the 122 day spawning period March 1 - June 30. In Phase I, this decreased by 3.9 % to 1.71 ft/day (20.6 in/day), and in the Phase II condition, it decreased by 1.1% to 1.76 ft/day (21.13 in/day) compared to Baseline. The greatest modeled impact during 1974 occurred for the redds constructed during the June 1 through 15 time period.

The average spring / average summer combination is represented by the year 1985 (Table 8). Baseline results for this year were 1.27 ft/day (15.2 in/day) of DSW during the 122 day spawning period. In Phase I, this increased by 1.6 % to 1.29 ft/day (15.4 in/day), and in Phase II it decreased to 0.84 ft/day (10.1 in/day), a reduction of 33.9 % compared to Baseline. In 1985, the greatest impact occurred to redds constructed during the April 1 through 15 time period in the Baseline condition, whereas in Phases I and II the impact is shifted to redds constructed during the May 16 through 31 time period.

The average spring / dry summer condition is represented by the year 1987 (Table 9). In the Baseline condition, an average of 0.53 ft/day (6.3 in/day) of DSW was estimated by the model. In Phase I, an average of 1.00 ft/day (12.06 in/day), an increase of 88.7 %, was estimated; and in Phase II, an average of 0.79 ft/day (9.5 in/day) was estimated, an increase of 49.1 % compared to Baseline. During 1987, the greatest impact affects redds constructed during the March 1 through 15 time period in the Baseline condition, whereas in Phases I and II, the largest impact shifts to the May 1 through 15 time period.

The dry spring / average summer condition is represented by the year 1991 (Table 10). In the Baseline condition, an average of 0.37 ft/day (4.5 in/day) of DSW was projected by the model. In Phase I, this was reduced by 10.8 % to an average of 0.33 ft/day (3.9 in/day). In Phase II, it was reduced even more to 0.20 ft/day (2.4 in/day), or a reduction of 46.0 % compared to Baseline. During 1991, the greatest impact is seen for those redds constructed during the April 1 through 15 time period in the Baseline and Phase I conditions. In Phase II, the impact shifts to the May 16 through 31 time period.

The dry spring / dry summer condition is represented by the year 1992 (Table 11). In the Baseline condition, an average of 0.20 ft/day (2.37 in/day) of DSW was estimated. In Phase I, this was reduced by 15.0 % to an average of 0.17 ft/day (1.99 in/day), and in Phase II it was reduced even more to 0.08 ft/day (0.94 in/day), or a reduction of 60.0 % compared to Baseline. In 1992, the greatest impact was found to affect redds constructed during the April 16 through 30 time period for all three development conditions.

The results presented so far do not consider the relationship between DSW and the percentage of the steelhead population that spawns at different times during the March 1 through June 30 spawning period. In order to understand this relationship, the WDFW steelhead redd survey data for 1994 through 1996 was examined. On average, less than 2 % of steelhead spawning was found to occur during the first two weeks in March, and similarly, during the last two weeks in June. The majority of spawning was found to take place during the months of April and May, with the peak generally occurring during the second week in April.

Weighting the DSW values for each year in the period of record by the percentage of redds constructed during the eight two-week intervals in the March 1 - June 30 spawning period reduced the average daily DSW over the period of record to 0.09 ft/day (1.09 in/day) for the Baseline condition (compared to 0.78 ft/day (9.35 in/day) for the unweighted), 0.12 ft/day (1.45 in/day) for the Phase I condition (compared to 0.88 ft/day (10.61 in/day) for unweighted), and 0.11 ft/day (1.29 in/day) for the Phase II condition (compared to 0.80 ft/day (9.58 in/day) for unweighted) (Table 12).

Discussion

The Howard Hanson Dam Additional Water Storage Project steelhead spawning and incubation impact analysis integrated a daily reservoir operations model with a model that examined the effect of reservoir operations on river stage and channel width at a transect located in a known steelhead spawning reach. Both models utilized stream flow data obtained from the US Geological Survey as well as a number of assumptions about how the project would operate, and how steelhead would behave.

The assumption that steelhead spawn from March 1 through June 30 may overestimate the period of time that wild winter steelhead actually spawn in the mainstem Green River. The WDFW assumes that wild fish spawning begins around March 15, and ends around June 15. Since it is commonly accepted that outliers exist in most salmonid populations for most life history parameters, it is reasonable to assume that in some years wild steelhead will spawn as early as March 1, and as late as the last week in June.

The assumption that steelhead exhibit a preference for spawning in river depths of one foot and greater is substantiated by observations conducted during the instream flow study conducted by the Washington Department of Ecology.

The simplifying assumption that eggs can withstand dewatering for 48-hours without significant adverse impact is a source of potential error. Tolerance to dewatering varies under different gravel and environmental conditions. In general, eggs are more resistant to dewatering early in their development, and become more susceptible as they develop. Yolk-sac fry can withstand dewatering for one or two hours under certain conditions, but susceptibility of pre-emergent alevins to dewatering can be measured in minutes.

The assumption that embryonic development from fertilization to emergence lasts 50-days is a simplification. The time required for egg incubation and alevin development to the emergent fry stage is dependent upon the accumulation of Fahrenheit Temperature Units (FTUs), which in turn is a function of water temperature. Burton and Little (1997) found that winter steelhead fry emerge from the gravel in the Cedar River after accumulating between 1045 and 1284 mean Fahrenheit Temperature Units (FTUs), with mean emergence at about 1165 FTUs. Green River water temperatures during the incubation period range from about 45 degrees

Fahrenheit in early March to about 62 degrees Fahrenheit in mid August. In the Green River, the number of days required to accumulate 1165 FTUs from March through June varies between from 40 to 45 days for eggs fertilized near the end of June to from 75 to 80 days for eggs fertilized in early March. For this analysis, 50 days was selected as the time between fertilization to emergence for modeling purposes. Based on the 50-day assumption, the steelhead spawning and incubation model developed for this analysis projected that fry would emerge from the gravel between April 20 (early March spawn) and August 19 (late June spawn) (Table 2). In reality, fifty days underestimates development time for eggs fertilized in March through the first two weeks in May, and overestimates development time for eggs fertilized during the last two weeks in June. Fifty days is a good estimate for eggs fertilized during the last two weeks in May through the first two weeks in June.

The model predicted that the project would change the timing of peak DSW. In the Baseline condition, the greatest impact was predicted to occur for redds constructed during the June 1 through June 15 time period, whereas in Phases I and II it was predicted for redds constructed during the May 16 through May 31 time period. This change in timing is due to the differences in the way the project would be operated during the Baseline condition and Phases I and II.

In the Baseline condition, up to 5,100 acre feet of water is stored in Fish Dam 2 for reservoir debris removal and early summer instream flow enhancement. Water allocated to those purposes that is not used by June 15 is discharged from the reservoir by June 15 or shortly thereafter during wet and average years, and by July 15 during dry years. The peak DSW associated with the June 1 - 15 spawning period is primarily a reflection of the reduction in flows during the second half of July combined with augmented flows early in June from the discharge of stored water.

The 50 percent exceedence flow during June 1 through 15 in the Baseline condition was estimated to be 921 cfs. Redds constructed during that time period were modeled to produce fry emerging from the gravel between July 21 and August 4. The 48-hour low flow associated with redds constructed between June 1 - 15 was predicted by the model to occur primarily between July 16 - 31, and occasionally during the first week in July or early August. The fifty percent exceedence flow for July 16 - 31 was calculated to be 350 cfs, whereas the 95 percent exceedence flow was calculated to be 250 cfs. The stage reduction from 921 cfs to 350 cfs is 0.8ft. The reduction from 921 cfs to 250 cfs is 1.1 ft. From this it can be inferred that release of the stored water early in June serves to hold instream flows at stage levels greater than the model's one foot threshold in relation to flows during the second half of July. The 48-hour low flow events affecting redds constructed during the first two weeks in June tend to occur about the time the fry from that spawning period are predicted to emerge from the gravel.

In Phases I and II, municipal water is stored along with water for instream flow enhancement and debris removal. In Phase I, stored water is used to augment instream flows and to provide flushing flows in the form of freshets during the spring outmigration. Water stored for these purposes is released by June 1 during wet and average years, and by July 1 in dry years whenever possible. In Phase II, stored water is used to augment instream flows throughout the summer into the fall as well as provide spring freshets to assist outmigrating smolts. The peak DSW associated with spawning that occurs during the May 16 through 31 time period is a reflection of the tapering off of inflow to the river primarily during the first two weeks in July, and to some extent during the third week in July, as well as the result of increasing river stage during artificial freshets.

In Phase I, the 50 percent exceedence flow during May 16 through 31 was calculated to be 1361 cfs. Redds constructed during that time period were modeled to produce fry emerging between July 5 and July 20. The 48-hour low flows associated with redds constructed between May 16 - 31 were predicted to occur primarily during the first two weeks in July, and in some years during the third week in July. The fifty percent exceedence flows for those time periods were calculated to be 442 cfs and 350 cfs respectively, whereas the 95 percent exceedence flows were calculated to be 283 and 250 cfs. The stage-discharge relationship established at Nealy Transect 6 indicates that a reduction in flow from 1361 cfs to 442 cfs creates a stage reduction of about 1.1 foot. As with the Baseline condition, the 48-hour low-flow events tend to occur toward the end of the incubation period.

In Phase II, the 50 percent exceedence flow during May 16 through 31 was calculated to be 1248 cfs. The fifty percent exceedence flow for the first two weeks in July was calculated to be 440 cfs, and during the third and fourth weeks it was estimated to be 350 cfs. The 95 percent exceedence flows for those time periods were calculated to be 280 and 250 cfs respectively. The stage reduction corresponding to the reduction in flow from 1248 cfs to 440 cfs was estimated to be one foot.

The artificial freshets programmed in Phases I and II to help flush smolts through the reservoir and the river downstream of the project were found to exacerbate the magnitude of the stage reductions between spawning and incubation. The planned release of freshets increases flows and stage during the spawning period. During the 50-days following an artificial freshet, a greater reduction in stage occurs than would have had the freshet not occurred. In reality, artificial freshets may not have as much impact as the model predicts since the initiation of spawning is influenced by a variety of factors, such as barometric pressure and weather, in addition to rapid increases in flows. It is uncertain whether an artificial freshet of 38-hour duration would induce spawning to occur (Gary Engman, personal communication).

Weighting the DSW values by redd timing has the effect of emphasizing the impact during the time periods that experience proportionately more spawning, and de-emphasizing the impact for the time periods that experience proportionately less spawning. Although this would seem to be a pragmatic approach to project operations, it emphasizes maximum production from the peak of the run at the expense of the rest of the spawning population. The project should be operated to protect redds throughout the spawning period, including the early and late portions of the run.

Mitigation

The model results discussed above give an indication of the relative impacts of Phases I and II of the project on steelhead spawning and incubation in the mainstem Green River compared to the Baseline condition. The model has limitations, and could in time be refined to more accurately describe project impacts; but even with its limitations, it serves as a useful tool to examine project impacts on steelhead.

One of the project objectives is no net loss of fish habitat and fish. This includes no net loss of steelhead redds. The analysis found that the threat of dewatering, expressed as DSW, occurs at some time between early March and mid August during most years when steelhead embryos and alevins are in the gravel, but doesn't occur every year, and doesn't occur at the same time during the incubation period each year. In general, large amounts of DSW were found to be associated with wet spring years, and lower amounts of DSW were associated with dry or average spring years.

One approach to mitigating the impacts would be to reduce the magnitude of the spring freshets. During Phase I, freshets of 38-hours duration and 2500 cfs magnitude measured at the Auburn gage are programmed for May 1 and 15 during wet and average springs. During dry springs, one freshet of 1250 cfs magnitude is programmed for May 1. In Phase II, freshets of 38-hours duration and 2500 cfs magnitude measured at the Auburn gage are programmed for April 1, April 15, May 1 and May 15 under wet and average spring conditions, and at a magnitude of 1250 cfs on the same four days during dry springs. In addition, whenever Fish Dam 2 is below 65 percent of full on any of the four days when freshets are to be delivered, the freshet for that day is skipped.

If one 38-hour freshet was reduced by 500 cfs, an additional 1570 acre feet would be available for flow enhancement during incubation. Allocated over a two-week period, this amount of water would allow for an increase of about 53 cfs to enhance flows downstream of the project to protect incubating eggs.

One alternative would be to use this freshet water to enhance flows to protect redds that experience the greatest amount of impact. The largest amount of DSW in both Phases I and II was found to be associated with redds constructed during the May 16 - 31 time period. The model was programmed to consider eggs fertilized on May 16 to be in the gravel through July 5, and eggs fertilized on May 31 to be in the gravel through July 20. The impact on redds constructed during the May 16 - 31 time period was found to occur throughout the month of July, but primarily between July 1 - 15.

The model was re-run to examine the effect of reducing the May 15 freshet in Phase I by 500 cfs, and distributing the 1570 acre feet of water at a rate of 53 cfs during the July 1 - 15 or July 16 - 31 time periods. In Phase I, water stored for instream augmentation beyond that provided by the existing project is used up by the end of June. Reducing the May 15 artificial freshet by 500 cfs and storing the water for release during July at a rate of 53 cfs resulted in an annual average DSW of 0.832 ft/day (9.99 in/day), effectively reducing the difference between Phase I and Baseline DSW by half (Table 13). Water allocated during the second two weeks in July resulted in an annual average of 0.828 ft/day (9.94 in/day), which reduces the difference between Phase I and Baseline DSW by more than half.

This approach was also applied to Phase II. Allocating the 53 cfs during the first two weeks of July resulted in a mean annual DSW of 0.752 ft/day (9.02 in/day), a reduction of 0.05 ft/day (0.6 in/day) compared to the original Phase II DSW of 0.798 ft/day (9.58 in/day) (Table 13). Allocating the 1570 acre feet of water to the second two weeks in July resulted in a mean annual DSW of 0.750 ft/day (9.00 in/day), a reduction of 0.05 ft/day (0.60 in/day) compared to the original Phase II DSW. The conclusion from this exercise is that in Phase II, supplementing instream flows in July combined with reducing the May 15 artificial freshet by 500 cfs will reduce the annual average DSW to a level 3.4 % less than the Baseline condition. Supplementing flows during the second two weeks in July may provide even more benefits than supplementing during the first two weeks in July.

Conclusion

Phases I and II of the proposed Howard Hanson Dam Additional Water Storage Project were modeled to compare the relative impacts of the project compared to Baseline conditions on wild winter steelhead spawning and incubation in the mainstem Green River downstream of the project. Modeling results indicated that Phases I and II operations are predicted to impact naturally-spawning Green River winter steelhead by altering the flow regime in the mainstem Green River during spawning and incubation. The impact will occur in the form of increasing the amount of channel width subject to a reduction in stage of one foot and greater measured at the Nealy IFIM Transect 6 for a period of 48 hours or more during the incubation period (dewatered spawnable channel width) by approximately 0.1 ft/day in Phase I compared to Baseline, and by approximately 0.02 ft/day in Phase II compared to Baseline.

Phases I and II operations were predicted to change the timing of the peak impact on redds. In the Baseline condition, the peak impact was found to impact redds constructed during the June 1 - 15 time period. In Phases I and II, the peak impact was found to impact redds constructed during the May 16 - 31 time period. WDFW redd counts from 1994 through 1996 indicate that, on average, steelhead redds constructed during the May 16 - 31 time period comprise about 17.5 % of the total, while redds constructed during the June 1 - 15 time period comprise about 5.0 % of the total. Peak steelhead spawning was found to occur between April 1 and May 15 with the average peak occurring during the second two weeks in April.

The impact of the project on steelhead spawning and incubation can be lessened by reducing the artificial freshets programmed for May in Phases I and II and supplementing July flows with the stored water. The May 15 freshet was reduced by 500 cfs and the stored water allocated to the river at a rate of 53 cfs during the month of July in Phases I and II. The effect of this modification was to reduce the amount of average annual DSW in both Phases I and II. In Phase II, DSW was reduced below the Baseline level indicating that the project objective of no net loss in steelhead habitat or fish could be achieved. Supplementing flows during the second two weeks in July provided a slightly greater benefit to steelhead redds than supplementing during the first two weeks in July.

The risk of dewatering steelhead redds was found to be greater during years with wet spring conditions than during years of average or dry spring conditions. Maximum protection to steelhead redds is afforded by supplementing instream flows through July, and into early August in those years when steelhead are known to have spawned in late June. A rigorous monitoring program should be established and adhered to during project operations, and information obtained on redd timing and location of should be used to modify project operations to protect steelhead redds throughout the incubation period.

The fisheries studies conducted to assess the impacts of the proposed Howard Hanson Dam Additional Water Storage Project have provided detailed information about the Green River not heretofore available to fisheries managers. Tools have been developed that can be used to better understand how water management decisions affect various instream resources. One example of this is quantitative, albeit modeled, information about how managing the project to maximize protection to steelhead spawning and incubation will likely impact other species and life stages. Additional options for allocating water from storage to protect steelhead redds downstream of the project should be explored by project proponents, federal and state resource managers and the Muckleshoot Indian Tribe. Ultimately, decisions to allocate stored water to instream flows during different time periods becomes an exercise in prioritizing species and life stages.

Table 1. Winter steelhead redd count estimate in the mainstem Green River by timing, 1994 - 1996. Data adapted from Washington Department of Fish & Wildlife

	1994		1995		1996		Average 1994 - 1996	
Time Period	**No. Redds**	**Percent**	**No. Redds**	**Percent**	**No. Redds**	**Percent**	**No. Redds**	**Percent**
March 1 - 15	18.40	2.25%	37.00	3.40%	0.00	0.00%	18.47	1.67%
March 16 - 31	109.60	13.42%	17.02	1.57%	93.81	6.60%	73.48	6.64%
April 1 - 15	218.50	26.75%	166.43	15.31%	309.50	21.79%	231.48	20.91%
April 16 - 30	217.86	26.67%	298.00	27.41%	362.50	25.52%	292.79	26.45%
May 1 - 15	171.82	21.04%	311.05	28.61%	182.63	12.86%	220.78	19.94%
May 16 - 31	60.16	7.37%	188.53	17.34%	333.00	23.44%	193.90	17.51%
June 1 - 15	20.48	2.51%	52.05	4.79%	94.11	6.62%	55.55	5.02%
June 16 - 30	0.00	0.00%	17.00	1.56%	45.00	3.17%	20.67	1.87%
Totals	816.82	100.00%	1087.08	100.00%	1420.55	100.00%	1107.10	100.00%

Table 2. Relationship between timing of winter steelhead spawning and incubation in two week intervals for the Green River, King County, Washington, based on modeled 50-day incubation period, and on 1165 Fahrenheit Temperature Units to 50 % Emergence.

Spawning Periods	End 50-day incubation periods	Approximate time of 50 % Emergence (1165 FTUs)
March 1 - 15	April 20 - May 4	May 18 - May 28
March 16 - 31	May 5 - May 20	May 29 - June 8
April 1 - 15	May 21 - June 4	June 8 - June 18
April 16 - 30	June 5 - June 19	June 19 - June 28
May 1 - 15	June 20 - July 4	June 28 - July 7
May 16 - 31	July 5 - July 20	July 8 - July 18
June 1 - 15	July 21 - August 4	July 19 - July 29
June 16 - 30	August 5 - August 19	July 30 - August 10

trapped in side channels or isolated from the main channel in individual pools.

The following report describes the results of a preliminary study conducted to quantify the impacts expected to result from implementation of the AWSP. Section 7.2 describes existing conditions and the results of other recent or ongoing investigations of side channels within the study reach. Section 7.3 contains a description of the methods used to identify and measure side channel habitats, and develop a relationship between mainstem discharge and wetted side channel area for this report. The results of the investigation and impact analysis are provided in Section 7.4. Section 7.5 summarizes the results and discusses the limitations of this preliminary study. References cited in the text are listed in Section 7.6. Recommendations for monitoring and other additional investigations will be provided as a separate supplement to this report.

7.2 BACKGROUND AND EXISTING CONDITIONS

Side channels habitats form when a river moves from its original bed to a new location, either through catastrophic avulsion, meander cutoff or gradual lateral migration. Such shifts are common in unconfined rivers where accumulations of sediment or large woody debris (LWD) build up in the channel. The Green River has historically traveled widely over its floodplain, as evidenced by the numerous side channels of various ages (Perkins 1993).

Levees and revetments currently impede lateral migration of the Green River in many locations. Early maps and engineering documents reveal few structures downstream of the Green River Gorge (RM 45.7) in the early 1900's. Today, 95 percent of the shoreline downstream of RM 17 is leveed on both banks, to protect businesses and residences in Kent, Auburn and Seattle (Fuerstenberg et al. 1996). Levees also line one, and less frequently both, banks between Flaming Geyser Park and Metzler O'Grady Park (RM 44 to RM 40.3), and from RM 38.3 to RM 33.7 (Perkins 1993). These levees have cut off at least eight large, historically active side channels (Fuerstenberg et al. 1996), and have reduced channel migration rates by over 60 percent in some reaches (Perkins 1993). The construction of Howard Hanson Dam also influenced downstream side channel habitat. The dam acts as an efficient sediment trap, intercepting an estimated 14,100 tons of bedload per year (Madsen and Beck 1997). Historically, most of the bedload supplied to the Green River below the gorge was believed to originate upstream of the dam, as there are few major sediment inputs within the gorge. Material that does enter the system in the gorge is easily abraded sandstone which breaks down quickly (Dunne and Dietrich 1978). Bedload from upstream is therefore the primarily source of spawning gravel.

Clear water released from the dam has an increased ability to carry sediment (Kondolf and Matthews 1993), eroding smaller substrates from the bed until an "armor" layer forms. Over time, the zone of armoring extends downstream. In the Green River, the zone of armoring was estimated to be moving downstream at approximately 700-900 feet per year (Perkins 1993). This suggests that the impact of reduced sediment supply from Howard

Table 3. Stage/Discharge Relationships for Selected Transects at Nealy, Car Body and Flaming Geyser IFIM Study Sites.

Study Site	RM	Transect No	A	B	SZF	S(400)[1] (ft)	S(1200)[2] (ft)	S(1200) - S(400) (ft)
Nealy	35.0	6	0.2778	0.3437	86.5	88.68	89.68	1.0
Car Body	39.6	4	0.3870	0.3270	89.5	92.25	93.43	1.18
Flaming Geyser	40.6	1	0.3321	0.3049	93.2	95.26	96.09	0.83

[1] S(400) = Stage (ft) at 400 cfs
[2] S(1200) = Stage (ft) at 1200 cfs

Table 4. Summary of average Steelhead Spawning Channel Widths (ft) modeled at Nealy Bridge IFIM Site, Transect 6, Green River, King County, Washington, for 32 year period of record (1964 - 1995) for Howard Hanson Dam Additional Water Storage Project Baseline, Phase I, Phase II Conditions

Baseline

Spawning Interval	WWD	USWD	DSW	WSW	SW
3/1 - 3/15	159.71	7.74	0.62	151.35	151.97
3/16 - 3/31	158.77	7.57	0.26	150.94	151.20
4/1 - 4/15	160.19	10.64	0.81	148.74	149.55
4/16 - 4/30	158.77	9.51	0.46	148.80	149.26
5/1 - 5/15	158.95	10.17	0.50	148.28	148.78
5/16 - 5/31	158.65	13.82	1.24	143.60	144.84
6/1 - 6/15	157.51	21.08	1.52	134.91	136.44
6/16 - 6/30	156.37	23.32	0.83	132.22	133.05
Average	158.61	12.98	0.78	144.86	145.64

Phase I

Spawning Interval	WWD	USWD	DSW	WSW	SW
3/1 - 3/15	158.25	9.65	0.49	148.11	148.60
3/16 - 3/31	157.77	9.57	0.12	148.08	148.20
4/1 - 4/15	159.38	8.93	0.40	150.06	150.46
4/16 - 4/30	159.36	8.04	0.61	150.71	151.32
5/1 - 5/15	160.79	7.13	1.47	152.20	153.66
5/16 - 5/31	159.57	10.73	1.83	147.01	148.84
6/1 - 6/15	157.63	19.36	1.54	136.72	138.27
6/16 - 6/30	155.48	31.77	0.60	123.12	123.72
Average	158.53	13.15	0.88	144.50	145.38

Phase II

Spawning Interval	WWD	USWD	DSW	WSW	SW
3/1 - 3/15	156.98	10.87	0.41	145.70	146.10
3/16 - 3/31	156.29	11.46	0.17	144.65	144.83
4/1 - 4/15	157.26	11.80	0.29	145.16	145.46
4/16 - 4/30	159.68	8.37	0.78	150.53	151.31
5/1 - 5/15	160.06	8.16	1.10	150.80	151.90
5/16 - 5/31	159.18	10.49	1.52	147.16	148.68
6/1 - 6/15	157.61	18.48	1.44	137.69	139.13
6/16 - 6/30	155.46	32.00	0.66	122.80	123.46
Average	157.81	13.96	0.80	143.06	143.86

WWD = Wetted Channel Width
USWD = Unspawnable Channel Width
DSW = Dewatered Spawnable Channel Width
WSW = Wetted Spawnable Channel Width
SW = Spawnable Channel Width

Table 5. Comparison of DSW (Dewatered Spawnable Channel Width) between Baseline, Phase I, and Phase II conditions of the Howard Hanson Dam Additional Water Storage Project for each two week spawning interval (March 1 - June 30) for the period 1964 - 1995, modeled at the Nealy IFIM Transect 6, Green River, King County, Washington

	DSW (ft/day)		
Spawning Interval	**Baseline**	**Phase I**	**Phase II**
3/1 - 3/15	0.62	0.49	0.41
3/16 - 3/31	0.26	0.12	0.17
4/1 - 4/15	0.81	0.40	0.29
4/16 - 4/30	0.46	0.61	0.78
5/1 - 5/15	0.50	1.47	1.10
5/16 - 5/31	1.24	1.83	1.52
6/1 - 6/15	1.52	1.54	1.44
6/16 - 6/30	0.83	0.60	0.66
Average	0.78	0.88	0.80

Table 6. Annual dewatered spawnable channel widths (DSW) at 1 ft. stage reduction associated with the winter steelhead spawning period (March 1 - June 30) and Green River hydrologic conditions. Data modeled at Transect 6, Nealy IFIM site, Green River, King County, Washington, for the period of record 1964 - 1995 for the Howard Hanson Dam Additional Water Storage Project

	Baseline	Season Flow Condition Set			**Phase I**	Season Flow Condition Set			**Phase II**	Season Flow Condition Set	
Year	**Dewatered Spawnable Channel Width (ft)**	**1-Mar**	**1-May**	**Year**	**Dewatered Spawnable Channel Width (ft)**	**1-Mar**	**1-May**	**Year**	**Dewatered Spawnabl e Channel Width (ft)**	**1-Mar**	**1-Jul**
1972	300.45	Wet	Average	1972	273.70	Wet	Average	1972	317.97	Wet	Average
1964	235.22	Average	Average	1975	226.61	Wet	Average	1964	219.40	Average	Average
1974	217.74	Wet	Average	1964	218.22	Average	Average	1974	214.81	Wet	Average
1975	214.50	Wet	Average	1974	209.05	Wet	Average	1975	198.58	Wet	Average
1985	154.64	Average	Average	1969	181.72	Wet	Average	1969	165.77	Wet	Average
1969	135.51	Wet	Average	1979	168.14	Average	Average	1989	149.23	Average	Average
1989	131.29	Average	Dry	1985	156.93	Average	Average	1979	144.50	Average	Dry
1990	127.68	Wet	Average	1967	151.20	Average	Average	1990	144.35	Wet	Average
1984	123.37	Average	Average	1989	150.62	Average	Dry	1967	116.55	Average	Average
1967	113.20	Average	Average	1982	133.56	Average	Average	1980	113.48	Average	Average
1970	104.17	Average	Average	1990	132.69	Wet	Average	1984	104.29	Average	Average
1994	101.91	Average	Average	1970	129.59	Average	Average	1970	103.42	Average	Average
1971	97.12	Average	Average	1987	122.60	Average	Dry	1985	103.05	Average	Average
1982	95.29	Average	Average	1980	114.97	Average	Average	1971	101.10	Average	Average
1979	91.85	Average	Average	1976	107.66	Average	Average	1976	100.76	Average	Average
1986	91.59	Dry	Average	1984	107.24	Average	Average	1987	96.35	Average	Dry
1988	86.28	Average	Average	1965	97.64	Average	Average	1982	94.76	Average	Average
1980	74.09	Average	Average	1971	96.85	Average	Average	1965	91.16	Average	Average
1966	71.32	Average	Average	1986	94.46	Dry	Average	1988	89.11	Average	Average
1976	70.69	Average	Average	1988	90.90	Average	Average	1981	74.80	Dry	Average
1965	67.65	Average	Average	1994	81.24	Average	Average	1966	69.71	Average	Average
1981	64.74	Dry	Dry	1981	70.15	Dry	Dry	1986	66.87	Dry	Average
1987	64.05	Average	Dry	1966	66.61	Average	Average	1993	66.07	Average	Average
1991	45.74	Dry	Average	1968	43.39	Dry	Average	1994	49.37	Average	Dry

1968	43.61	Dry	Average	1993	43.30	Average	Average	1968	32.55	Dry	Average
1977	33.21	Dry	Dry	1991	39.66	Dry	Average	1991	24.36	Dry	Average
1983	30.87	Average	Average	1995	34.66	Average	Average	1983	20.52	Average	Average
1992	24.07	Dry	Dry	1983	31.23	Average	Average	1995	14.35	Average	Dry
1993	21.81	Average	Average	1978	31.18	Average	Dry	1978	11.53	Average	Dry
1978	6.88	Average	Dry	1977	24.39	Dry	Dry	1992	9.52	Dry	Dry
1973	0.75	Dry	Dry	1992	20.28	Dry	Dry	1977	9.21	Dry	Average
1995	0.00	Average	Dry	1973	0.04	Dry	Average	1973	0.00	Dry	Dry
Total	3041.31			Total	3450.46			Total	3117.51		
Mean Annual	95.04			Mean Annual	107.83			Mean Annual	97.42		
Mean Daily	0.779			Mean Daily	0.884			Mean Daily	0.798		

Table 9. Comparison of DSW (Dewatered Spawnable Channel Width) for the Baseline, Phase I and Phase II conditions using 1987 hydrologic data

1987
Average Spring / Dry Summer

Spawning Intervals	Baseline	Phase1	Phase II
3/1-3/15	23.81	26.81	9.99
3/16-3/31	-	0.97	3.72
4/1-4/15	5.06	3.91	4.90
4/16-4/30	14.58	27.65	32.06
5/1-5/15	20.00	42.16	34.72
5/16-5/31	0.60	21.09	10.96
6/1-6/15	-	-	-
6/16-6/30	-	-	-
Total	64.05	122.60	96.35
Daily Av (ft)	0.53	1.00	0.79
Daily Av (in)	6.30	12.06	9.48

Table 10. Comparison of DSW (Dewatered Spawnable Channel Width) for the Baseline, Phase I and Phase II conditions using 1991 hydrologic data

1991
Dry Spring / Average Summer

Spawning Intervals	Baseline	Phase I	Phase II
3/1-3/15	0.07	-	-
3/16-3/31	-	-	-
4/1-4/15	30.84	18.74	3.29
4/16-4/30	-	0.19	5.69
5/1-5/15	5.67	8.66	7.20
5/16-5/31	6.29	12.08	8.17
6/1-6/15	-	-	-
6/16-6/30	2.88	-	-
Total	45.74	39.66	24.36
Daily Av (ft)	0.37	0.33	0.20
Daily Av (in)	4.50	3.90	2.40

Table 11. Comparison of DSW (Dewatered Spawnable Channel Width) for the Baseline, Phase I and Phase II conditions using 1992 hydrologic data

1992
Dry Spring / Dry Summer

Spawning Intervals	Baseline	Phase I	Phase II
3/1-3/15	8.43	-	-
3/16-3/31	0.33	-	-
4/1-4/15	-	-	-
4/16-4/30	15.31	17.84	9.52
5/1-5/15	-	2.44	-
5/16-5/31	-	-	-
6/1-6/15	-	-	-
6/16-6/30	-	-	-
Total	24.07	20.28	9.52
Daily Av (ft)	0.20	0.17	0.08
Daily Av (in)	2.37	1.99	0.94

Table 12. Comparison of unweighted dewatered spawnable widths with dewatered spawnable widths weighted by steelhead redd timing in the mainstem Green River, based on WDFW redd counts from 1994 - 1995. Values are in ft/day.

	% Redds	Baseline		Phase I		Phase II	
	by Timing	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
March 1 - 15	1.67%	298.20	4.98	235.96	3.94	195.23	3.26
March 16 - 31	6.64%	134.54	8.93	62.54	4.15	88.27	5.86
April 1 - 15	20.91%	388.90	81.32	191.34	40.01	140.59	29.40
April 16 - 30	26.45%	220.37	58.29	292.07	77.25	374.71	99.11
May 1 - 15	19.94%	238.12	47.48	703.81	140.34	529.33	105.55
May 16 - 31	17.51%	633.84	110.98	938.13	164.27	780.42	136.65
June 1 - 15	5.02%	730.97	36.69	739.79	37.14	692.88	34.78
June 16 - 30	1.87%	396.37	7.41	286.86	5.36	316.09	5.91
Totals	100.00%	3041.31	356.09	3450.49	472.46	3117.51	420.52
Ft per Day		0.78	0.09	0.88	0.12	0.80	0.11
In per Day		9.35	1.09	10.61	1.45	9.58	1.29

Table 13. Comparison of original Baseline, Phase I and Phase II DSW (ft/day) with Phases I and II DSW after reducing the 38-hour freshet on May 15 by 500 cfs and supplementing instream flows at the rate of 53 cfs for two week periods in July

Spawning Time Period	Baseline	Phase I			Phase II		
		Original	Augmented Flows		Original	Augmented Flows	
			July 1 - 15	July 16 - 30		July 1 - 15	July 16 - 30
March 1 - 15	0.621	0.492	0.492	0.492	0.407	0.407	0.407
March 16 - 31	0.263	0.122	0.122	0.122	0.172	0.174	0.174
April 1 - 15	0.810	0.399	0.399	0.399	0.293	0.294	0.294
April 16 - 30	0.459	0.608	0.608	0.608	0.781	0.781	0.781
May 1 - 15	0.496	1.466	1.448	1.466	1.103	1.082	1.103
May 16 - 31	1.238	1.832	1.458	1.631	1.524	1.184	1.342
June 1 - 15	1.523	1.541	1.535	1.329	1.443	1.440	1.248
June 16 - 30	0.826	0.598	0.598	0.576	0.659	0.659	0.655
Ft per Day	**0.780**	**0.884**	**0.832**	**0.828**	**0.798**	**0.752**	**0.750**
In per Day	**9.360**	**10.606**	**9.988**	**9.935**	**9.576**	**9.029**	**9.004**

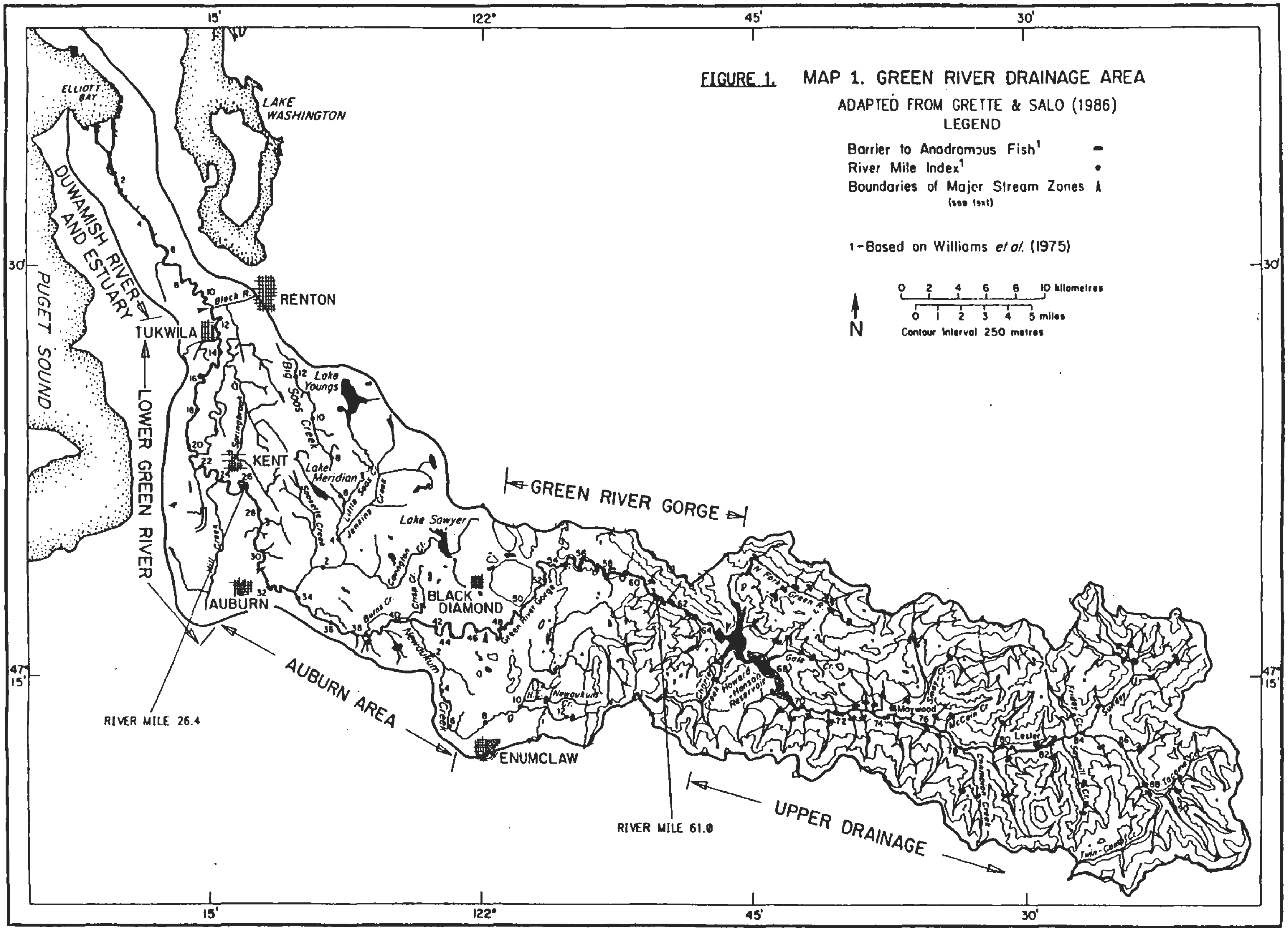
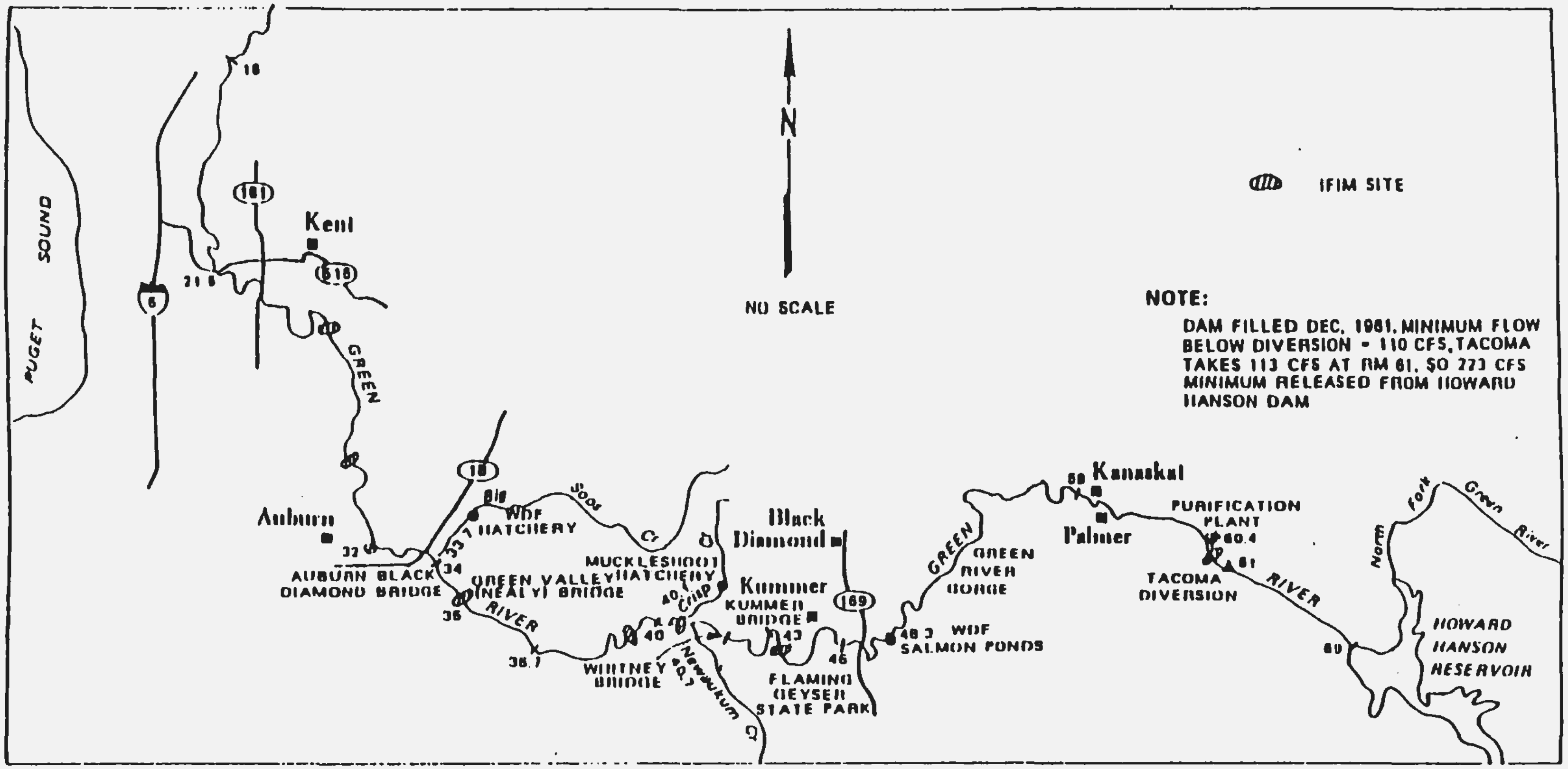


FIGURE 1. MAP 1. GREEN RIVER DRAINAGE AREA
ADAPTED FROM GRETTE & SALO (1986)
LEGEND
Barrier to Anadromous Fish[1]
River Mile Index[1]
Boundaries of Major Stream Zones
(see text)
1-Based on Williams et al. (1975)
0 2 4 6 8 10 kilometres
0 1 2 3 4 5 miles
Contour interval 250 metres
N
ELLIOTT BAY
LAKE WASHINGTON
PUGET SOUND
DUWAMISH RIVER AND ESTUARY
RENTON
TUKWILA
KENT
LOWER GREEN RIVER
AUBURN
BLACK DIAMOND
ENUMCLAW
Lake Youngs
Lake Meridian
Lake Sawyer
GREEN RIVER GORGE
AUBURN AREA
UPPER DRAINAGE
RIVER MILE 26.4
RIVER MILE 61.0
Howard Hanson Reservoir
122°
45'
30'
15'
47° 15'



RIVER REACH	% GRADIENT	SITE NAME	RIVER MILE	NO. OF TRANSECTS	HABITAT
12-32	0.08	KENT	27.2, 30.5	6	WIDE, SLOW, DIKED, SILTED BOTTOM, SOME SPAWNING IN RIFFLES, MOSTLY POOL-GLIDE.
32-36.7	0.1	NEALY BRIDGE	35	7	WIDE, MEDIUM VELOCITES, OFTEN ONE SIDE DIKED, GRAVEL BOTTOM, EXCELLENT SPAWNING, LONG GLIDES.
36.7-40	0.2	CAR BODY	39.8	7	WIDER, MEDIUM VELOCITES, UNDIKED, LARGE COBBLE BARS, GRAVEL BOTTOM, EXCELLENT SPAWNING, POOL-RIFFLE.
40-46	0.3	FLAMING GEYSER	40.6, 43.6	6	WIDE-FAST VELOCITIES IN COBBLE GLIDES, NARROW-FAST RIFFLES, MEDIUM VELOCITY GLIDES/POOLS WITH GOOD SPAWNING, GRAVEL/COBBLE.
46-58	1.5	NO SITE			GREEN RIVER GORGE
58-64	0.7	HOSEY	60.6	6	NARROW CANYON, DEEP POOLS, COBBLE BOTTOM, SOME FAST RIFFLES/CASCADES, SOME GOOD SPAWNING.

Figure 2. GREEN RIVER IFIM SITES LISTING RIVER MILES REPRESENTED, GRADIENT, SITE NAME, RIVER MILE LOCATION OF SITES, NUMBER OF TRANSECTS, AND HABITAT DESCRIPTION.
Adapted from Caldwell and Hirschey (1989)

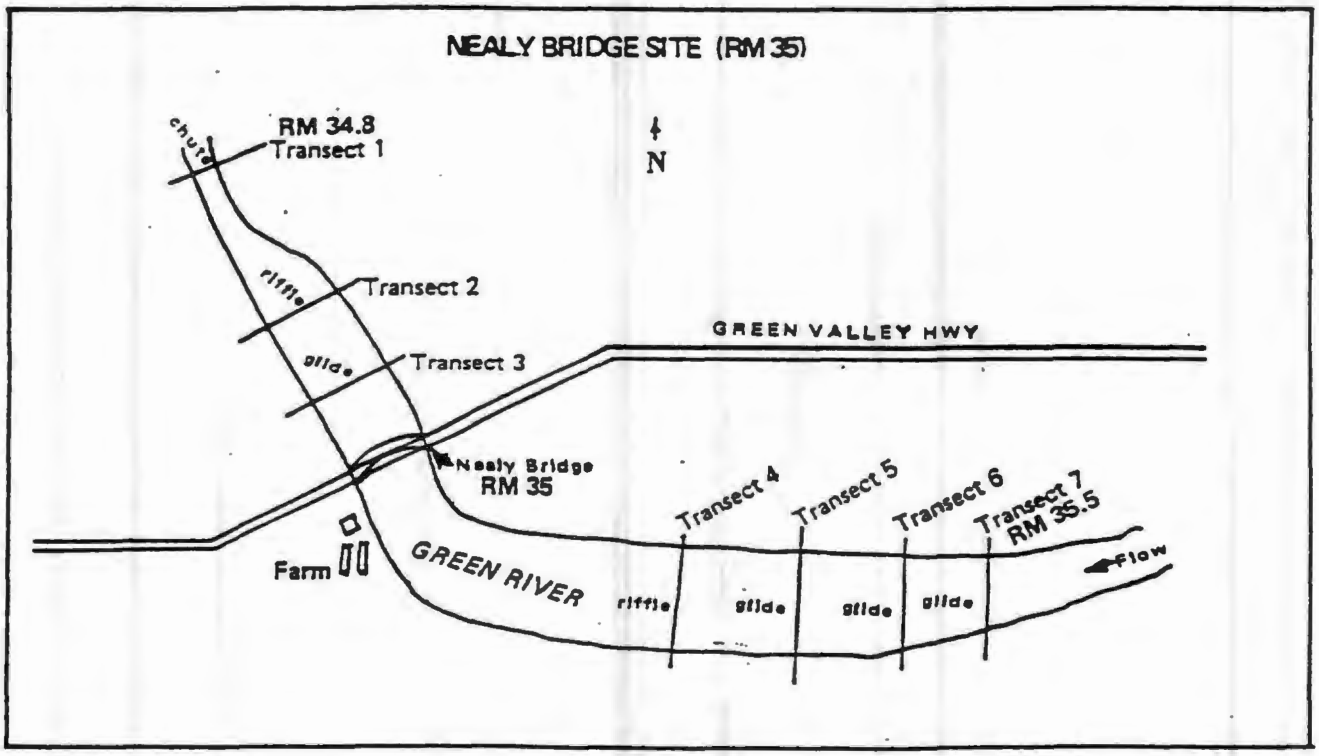
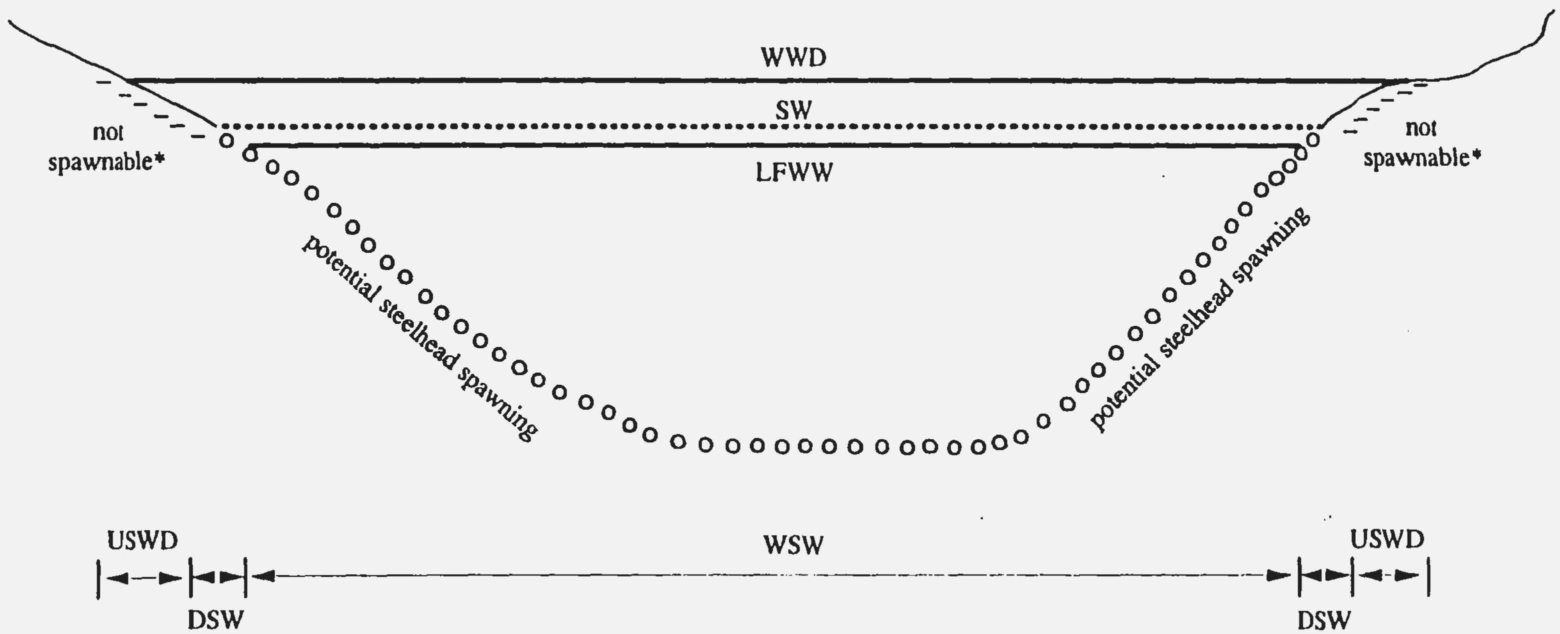


Figure 3. SITE AND TRANSECT MAP OF NEALY BRIDGE SITE.
Adapted from Caldwell and Hirschey (1989)

Figure 4. River channel cross section depicting wetted widths used in the analysis of the effects of the Howard Hanson Dam Additional Water Storage Project on steelhead spawning and incubation in the Green River, King County, Washington.



WWD = Wetted Width
SW = Spawnable Width
LFWW = Low Flow Wetted Width
USWD = Unspawnable Width
DSW = Dewatered Spawnable Width
WSW = Wetted Spawnable Width

SECTION 7 SIDE CHANNEL HABITATS IN THE GREEN RIVER, WASHINGTON

7.0 EXECUTIVE SUMMARY

The Additional Water Storage Project (AWSP) is a proposal by the City of Tacoma and Corps of Engineers to store additional water behind Howard Hanson Dam for municipal and industrial purposes and to supplement instream flows in the Green River. Phase I of the proposal involves storage of up to 20,000 acre-feet of additional water and Phase II involves storage of up to 37,000 acre-feet of water. Under Phase I and II operating regimes, water is primarily stored in the early spring while maintaining increased baseflow conditions. Storing additional water alters the springtime flow regime and affects the timing, magnitude, frequency and duration of the connectivity of side channel habitats with the mainstem Green River.

Side channel habitats are used by all species of Green River salmonids at some point in their life cycle. Adult salmon will spawn in side channels if appropriate substrates or flow conditions are available and side channels provide productive rearing habitat for juvenile fish. Side channels may serve as overwintering habitat for juvenile salmon and temporary refuge habitat for juveniles and adults. In order to assess the influence of alternate operating scenarios on side channel habitats, a survey of the Green River was conducted in the fall of 1997. Using data collected during two field trips, models of 59 Green River side channel areas were developed. These models allowed us to quantify the amount of wetted side channel surface area available under Baseline, Phase I and Phase II conditions on a daily basis.

Under both Phase I and II, the availability of wetted side channel area decreases during February, March and early April and increases during late April and May compared to Baseline conditions. The net effect is that under Phase I, the average amount of wetted side channel area increases by 45,000 ft^2, while side channel area wetted under Phase II conditions decreases by approximately 367,000 ft^2. The change in availability of wetted side channel area is primarily restricted to those areas that are alternately wetted and dewatered during rising and dropping flows. There is negligible difference in the amount of side channel area continuously wetted between 1 January and 30 April under Phase I and Phase II conditions.

The overall number of times side channels were wetted by flows greater than or equal to 2,500 cfs increased under Phase I and II conditions due to the release of artificial freshets. The number of times flow events equaled or exceeded 2,500 cfs decreased 12 percent during February and March, but were offset by an 81 percent increase in the number of high flow events during April and May.

7.1 INTRODUCTION

Side channel habitats are essential to many species of salmon at some point in their life cycle. Adult salmon may seek refuge from high flows in side channels, and frequently spawn there if appropriate substrates or flow conditions are available. Side channels may provide productive rearing habitat for juvenile fish and may serve as overwintering and refuge habitat for juveniles and adults.

Prior to Euro-American settlement, the lower reaches of the Green River were characterized by a network of sloughs and islands, often without a distinct main channel (Fuerstenberg et al. 1996). Settlement of the Green River valley began in 1850, and the river channel was cleared to facilitate navigation. As farms and residences were established, levees were constructed along portions of the river to prevent flooding. Levees and revetments currently line at least one bank for over 50 percent of the length of the river below RM 45.6 (Perkins 1993), and as a result, much of the formerly highly productive off-channel habitat has been lost. The abandoned channels, braided areas and backwater sloughs (collectively referred to as side channels for the remainder of this paper) which remain connected to main channel flows for some portion of the year continue to provide significant salmonid habitat.

In 1913, the City of Tacoma completed a diversion dam at RM 61.5 near the town of Palmer, and began diverting approximately 110 cfs from the Green River. In 1962, the Army Corps of Engineers constructed Howard Hanson Dam at RM 64.5. Howard Hanson Dam is operated primarily for flood control, limiting peak flows to 12,000 cfs at Auburn. In 1986, Tacoma obtained an additional water right for 100 cfs; however, the ability to divert water is limited in some months by instream flow requirements. A feasibility study was initiated to evaluate a proposed increase in reservoir storage from 25,000 acre feet to 63,000 acre feet. The increase in storage would allow flow augmentation for regional water supply and instream natural resources. This proposed increase in storage is hereafter referred to as the AWSP.

The proposed AWSP would be implemented in two stages. In Phase I, a fish passage facility would be constructed at the dam, and storage would increase by 20,000 acre feet. In Phase II, an additional 37,000 acre feet of storage are added to the Phase I conditions. 14,600 acre-feet of water would be available for fisheries and 22,400 for Tacoma's second supply pipeline.

Storing an increased amount of spring runoff behind Howard Hanson Dam may alter the timing, frequency, duration and magnitude of side-channel connectivity, resulting in potential detrimental impacts to juvenile salmonids in the Green River below Howard Hanson Dam. Salmonid redds constructed in side channels may become dewatered, while juvenile salmonids utilizing side channel habitats for rearing could be stranded or trapped. Fish trapped in disconnected side channel habitats may suffer increased rates of predation, impaired water quality and loss of rearing space. Juvenile salmonids which migrate downstream shortly after emergence are particularly vulnerable to high mortalities if

Hanson Dam should be starting to affect the Green River below RM 40.2 in this decade.

Howard Hanson Dam has also reduced the magnitude of flood flows. Prior to construction of the dam, the bankfull flow at Auburn (with a return interval of 1.8 years) was about 12,000 cfs. Since construction of the dam, flows greater higher than 12,000 cfs are prevented, and the 1.8 year return interval flood has been reduced to approximately 8,800 cfs. However, flows ranging from 3,000 to 9,000 cfs have occurred more frequently (Madsen and Beck 1997). Dunne and Dietrich (1978) estimated that the altered flow regime downstream of the dam had increased the annual sediment transport capacity by up to 30 percent. The increase in sediment transport capacity resulting from more frequent moderate flows, and from the downstream migration of armoring is expected to result in downcutting and may isolate side channels which were previously active.

Increased awareness of the importance of side channel habitat to salmonids, and the potential impacts to such habitats by human activities such as levee construction or flow regulation has resulted in the instigation of several recent studies. A study of the effects of springtime flow alterations on four side channels in the Middle Green River found that the frequency of habitat connectivity had declined by an average of 28 percent since construction of Howard Hanson Dam (Coccoli 1996). The KCSWM Division quantified historic changes in channel migration (Perkins 1993) and is currently studying salmonid use of four side channels (Fuerstenberg pers. comm. 1996). The Green River Basin Restoration Committee, including members from the Corps and KCSWM has identified a number of side channels which are no longer accessible or have been cutoff by levee construction as possible habitat restoration projects (Noel Gilbrough, pers comm.). Restoration plans are being developed for these side channels.

Implementation of the AWSP is expected to change the frequency, duration and timing of side channel connectivity in the Green River below Howard Hanson Dam. In order to fill the larger storage pool, more water will be stored during the spring, beginning 15 February, reducing flows downstream. To determine the potential impacts of the AWSP on side channel habitat, a preliminary study was conducted in the fall of 1996. Active side channels were identified, and a field survey was conducted to determine the amount of potential habitat provided by each side channel and the flow at which individual channels became connected to the mainstem. Hydrologic modeling was conducted in order to quantify changes in the amount of wetted side channel area resulting from the planned Phase I and Phase II flow regimes.

7.3 METHODS

The goal of the 1996 study was to estimate the change in the magnitude, frequency, timing and duration of wetted side channel habitat after implementation of Phase I and Phase II of the AWSP. A combination of literature review, remote sensing analysis, site specific field investigations and modeling was used to accomplish this goal. Specific objectives of the preliminary study were to:

1) Locate and describe existing side channel habitat below Howard Hanson Dam which periodically becomes accessible to salmon under the current flow regime;
2) Determine the flow at which each side channel became connected to the mainstem Green River;
3) Develop a relationship between wetted side channel surface area and mainstem flow for each side channel and for the entire project reach.
4) Estimate the importance of intragravel flow in maintaining side channel connectivity.
5) Quantify the magnitude, frequency, timing and duration of side channel connectivity under Baseline, Phase I and Phase II operating conditions.

Existing reports, topographic maps and aerial photographs were reviewed to determine the general location of side channel habitat below Howard Hanson Dam. Two study segments were identified (Figure 7-1). Immediately below Howard Hanson Dam, the channel is confined by steep sideslopes; thus side channel formation is limited. Between the Tacoma Purification Plant (RM 60.3) and Kanasket State Park (RM 57.0), the valley opens up and the channel becomes less confined, and both active and inactive side channels were observed on air photos. This segment was chosen for further study, and is hereafter referred to as the "Palmer Segment".

Figure 7-1. Green River Drainage Area.

Downstream of Kanasket Park, the Green River flows through a deep, confined canyon known as the Green River gorge. A review of air photos and a reconnaissance float trip revealed few side channels in this segment, thus it was excluded from the current investigation.

At RM 45.5, the river exits the gorge and flows across a wide alluvial valley. From RM 45.5 to RM 33.8, numerous side channels were identified, both active and inactive. This reach, hereafter referred to as the "Middle Green Segment", was chosen as the second study site. Below RM 33.8, the Green River previously included numerous side channels, however the channel is now diked for over 95 percent of its length; thus few active side channel habitats remain.

Two USGS gaging stations are located near the study segments (Figure 7-1). The Auburn gage is located at RM 32.0 and was used to reference all measured and modeled flows in the Middle Green Segment. The Palmer gage, located at RM 60.3 was used to reference all measured and modeled flows in the Palmer Segment. Measurements of side channels were collected from 2 to 9 October 1996 at approximately 200 cfs at Auburn and 140 cfs at Palmer. A second set of measurements were collected from 28 October to 6 November at approximately 1,800 cfs at Auburn and 1,350 cfs at Palmer. Each study reach was floated by two teams of surveyors, who identified, flagged and collected data at side channel inlets and outlets on either the left or right bank of the river.

Data collected at each side channel inlet during low flow surveys included the stage of zero (SZF) flow relative to the mainstem stage; the minimum, wetted, toe and bankfull width; the wetted, toe and bankfull stage relative to the SZF; and the wetted channel length (if flow was not continuous throughout the channel). The maximum flow depth, and discharge if sufficient flow was available were measured at both inlet and outlet. The temperature of the mainstem, and side channel inflow and outflow if present were recorded. The general type of adjacent vegetation (grass, shrub, hardwood or conifer), and the percent canopy cover (0, 1-25,26-50,51-75,76-100) were described. Qualitative comments were made regarding measurement uncertainty, habitat type (spawning or rearing) and quality, and potential restoration opportunities. The SZF and mainstem water surface elevations, wetted width, inflow and outflow depth, discharge and temperature measurements were repeated during the high flow surveys. Photos were taken during both surveys of each inlet and outlet from the mainstem, and from the inlet or outlet looking into the side channel. Specific data collection procedures are described in more detail in the following sections.

7.3.1 Locate and Describe Existing Active Side Channel Habitat

After identifying the two general study segments, available maps and air photos were reviewed to develop a preliminary map of the location of all side channels. Obvious side channels as well as locations conducive to the development of side channels were identified. Side channels were classified according to the geomorphic process responsible for their formation as follows:

Active secondary	channels separated from the mainstem by well established islands supporting upland vegetation, which may become dewatered at low flows (Figure 7-2a). Secondary channels which remain active below 200 cfs were generally considered part of the mainstem.
Backbar	channels located along lateral or point bar margins, bordered by well established upland vegetation on at least one bank (Figure 7-2b). Channels crossing unvegetated bar tops which may frequently shift position during high flows were not inventoried as backbar channels.
Abandoned	historic mainstem channels which were cut off by channel avulsions or human activity, but which become connected to the mainstem during high flows (Figure 7-2c).
Wallbase	a type of abandoned channel located along the base of a steep slope, and fed by sideslope seepage (Figure 7-2d).

After preparing the preliminary maps, each study reach was floated to confirm the location of all side channels and collect data on physical characteristics.

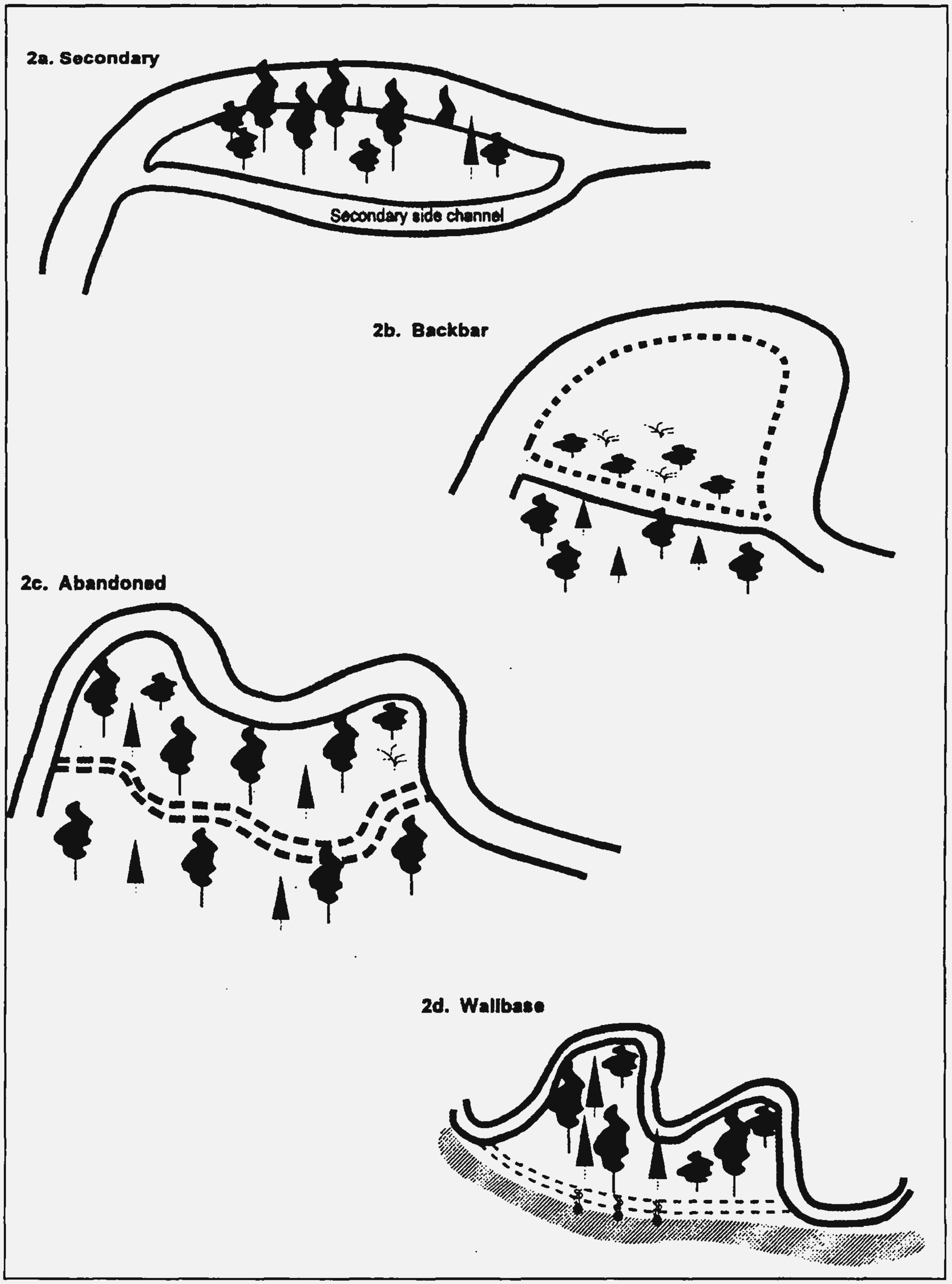


Figure 7-2. Types of side channels identified in Green River study segments, 1996.

During the float surveys, all locations identified as having known or potential side channels were investigated. Side channels observed during the survey but not included on the preliminary maps were added. Side channels were identified as being on either the left or right bank, named according to river mile and described as being either an inlet or outlet (eg. R45.1I). A metal tag bearing the date and side channel identification code was attached to nearby trees or shrubs which would remain visible from the mainstem at higher flows. Blue flagging was hung near each tag to further facilitate relocation of survey sites.

Active side channels were identified as those side channels which frequently become wetted under the existing flow regime. A number of side channels were identified on the maps or photos which were cut off from the channel by levees or roads. Several other side channels were identified in the field as perched above the current flow levels. These channels were classified inactive side channels. The location of inactive side channels was noted on the base maps to guide potential habitat restoration activities, however no data was collected from these channels.

In some cases, side channels were complex, with multiple inlets or outlets. The primary inlet of such side channels was identified as the point at which flow first entered the side channel, or the largest inlet if one inlet contributed the majority of inflow. The primary outlet was identified in a similar fashion. Measurements were taken only at the primary inlet or outlet; secondary inlets or outlets were noted and described qualitatively.

7.3.2 Determine Flows at Which Active Side Channel Habitat Becomes Connected

In most cases, flow in the mainstem channel must exceed the level of the side channel inlet before flow through the side channel is initiated. The rate at which the river level, or stage, changes with a change in discharge is a function of channel morphology and local flow hydraulics. The mainstem stage at which water just begins to flow through the side channel was designated the stage of zero flow (SZF) (Figure 7-3). The mainstem flow at which a side channel becomes wetted may be identified by measuring the difference between the side channel SZF and mainstem stage at several flows, then applying or developing a stage:discharge relationship for the mainstem.

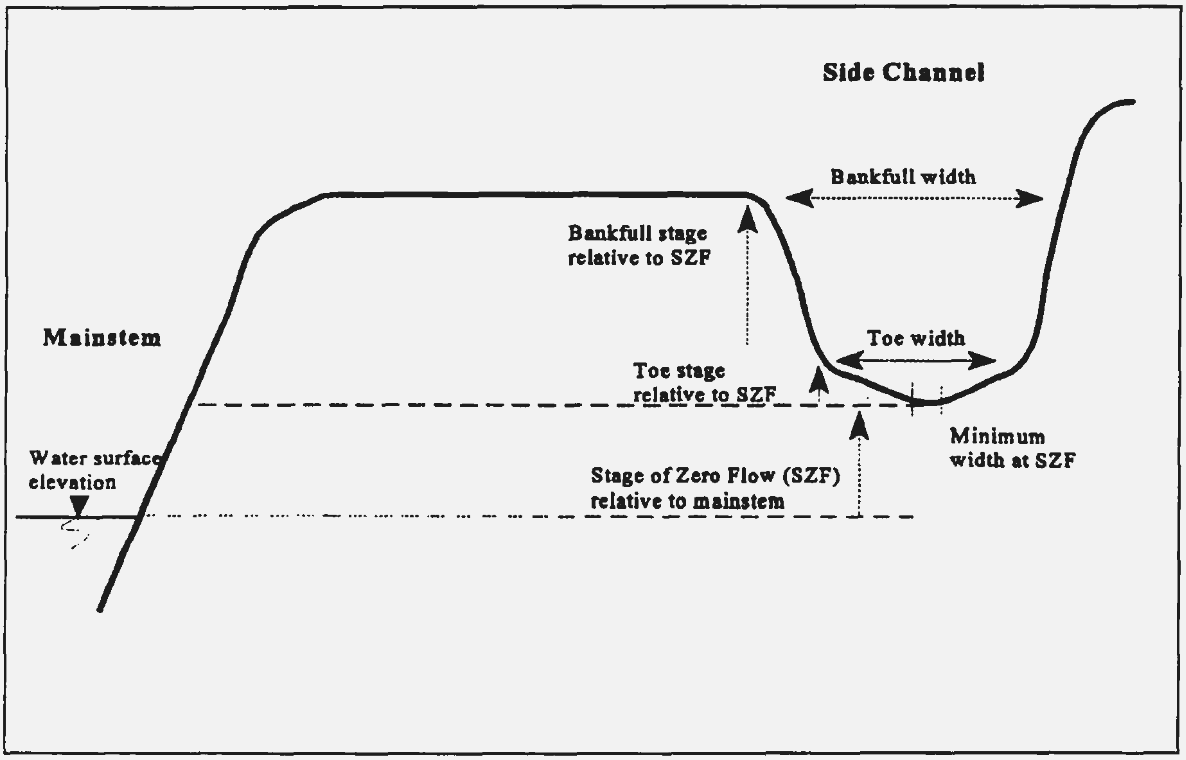


Figure 7-3. Schematic diagram of stage of zero flow, toe stage, bankfull stage and corresponding widths in a side channel.

The stage of zero flow was identified in the field by an experienced geomorphologist or biologist. The crest of the inlet was located, then the elevation of one or more low spots was checked using a handlevel and survey rod. The lowest point on the inlet crest, representing the SZF, was measured relative to the mainstem stage. For the purpose of this study we assumed side channels were wetted once the mainstem stage equaled or exceeded the SZF.

If water was flowing through the side channel at the time of the survey, the SZF equaled the mainstem stage minus the depth of water passing over the lowest point of the inlet crest. Unless evidence to the contrary was observed at the inlet, flow was assumed to be continuous throughout the side channel. If flow was obstructed by vegetation, large woody debris or gravel berms, the extent of flow blockage were described in the notes. Local hydraulic conditions (e.g. turbulence, super-elevation on meander bends, or back eddies) were also noted to help assess measurement accuracy.

Once the mainstem stage increase required to connect the inlet has been quantified, a stage:discharge relationship was applied to estimate the corresponding increase in mainstem flow. Several options for specifying appropriate mainstem stage:discharge relationships were investigated. One alternative was simply to use the rating curve for either the Palmer or Auburn gaging stations. Large variations in channel morphology were apparent on aerial photos, particularly between the Middle Green segment and the Auburn gage site; thus simply using the USGS gage station rating curve was believed to introduce error.

Modeled rating curves developed for a series of cross sections spaced at approximately 500 foot intervals from RM 45.06 to RM 33.7 were developed as part of a floodplain mapping project conducted by the KCSWM division (Cardinal pers. comm. 1997). The HEC-RAS model was used to develop predicted rating curves for each cross-section. The stage change corresponding to the increase in discharge from 270 to 1,800 cfs may be estimated using the rating curve for the cross-section nearest each side channel inlet.

The actual relative stage changes observed within the study reach between the low flow and high flow surveys provided a third means of empirical evaluating the mainstem stage:discharge relationship at each side channel inlet, and were used to assess the applicability of both the USGS rating curves and the KCSWM rating curves.

The accuracy of SZF estimates was checked by comparing data from the current study to detailed data collected in a study of four side channels within the Middle Green Reach in early 1996. In that study, the side channel stage relative to the mainstem stage was measured at 6 to 8 flows ranging from 320 to 1,701 cfs (Coccoli 1996). The flow required to establish direct surface connection was determined from a stage:discharge relationship developed for each side channel.

7.3.3 Estimate the Importance of Subsurface Flow in Maintaining Side Channel Connectivity

Some side channels are fed by subsurface flow, and therefore remain hydraulically connected to the mainstem channel below the predicted stage of zero flow. Such channels provide particularly valuable spawning and rearing habitats. Temperatures fluctuate less in groundwater fed channels thus they tend to be warmer than normal during the winter, and remain cooler through the summer. Channels fed by subsurface flow also provide upwelling groundwater conditions preferred for spawning by many salmonid species, particularly chum (*Onchorhynchus keta*).

Investigating the role of subsurface flow during October and November allows an assessment of the potential "worst case" scenario. In the fall, flows are just beginning to rise after having been near base level for several months. Floodplain soils contain little available moisture, and groundwater and bank storage have been depleted. Identifying side channels where subsurface sources contribute flow even when groundwater contributions are limited helps to identify those channels that will likely remain wetted for extended periods after mainstem flows decline in the spring.

The contribution of subsurface flow was estimated by measuring the side channel discharge at both the inlet and outlet. Velocity was measured using a Swoffer model 2100 current meter, taking ten to twenty measurements across a transect oriented perpendicular to flow. If no evidence of secondary side channel inlets or outlets was observed while floating past the side channel, increases in the discharge observed at the outlet was assumed to come from the contribution of subsurface flow. In backbar, abandoned and secondary side channels, subsurface flows were assumed to be fed by intragravel flow. Groundwater was assumed to be the main source of subsurface flow only in wallbase channels where seepage from sideslopes was observed.

7.3.4 Develop a Relationship Between Wetted Side Channel Area and Mainstem Flow

For this preliminary study, wetted side channel area was assumed to represent available habitat. While qualitative data was gathered on the nature of habitat (i.e. spawning, rearing) provided by each side channel to help develop a more specific monitoring and management plan, for the purpose of impact analysis, all wetted side channels were assumed to provide equal habitat at all flows. No attempt was made to adjust for wetted areas that were unsuitable as salmonid habitat at certain flows (e.g. high velocity, inadequate depth), thus the estimate of wetted side channel area at any given flow likely represents a liberal estimate of the amount of available habitat.

Channel lengths were estimated from the basemaps and air photos after both inlet and outlet had been identified. During the field surveys, if the channel was dry at both the inlet and outlet, the entire length of the side channel was assumed to be dry. If the inlet was wetted and a flow velocity greater than zero was observed, then flow was assumed to be continuous throughout the length of the side channel. If the inlet was dry, but measurable flow was observed at the outlet then the survey team walked up the channel to the point at which flow originated, measuring the wetted length using a rangefinder. If either the inlet or outlet was wetted, but flow was ponded with no measurable velocity, then flow was assumed to be discontinuous, and the survey team walked up or down the channel to the point at which it became dry, measuring the wetted length using a rangefinder.

The average side channel width was calculated based on field data collected at the side channel inlet and outlet. The wetted, minimum, toe and bankfull widths were measured just downstream of the primary inlet, and just upstream of the primary outlet. The minimum width was assumed to correspond to the area that would be wetted when the mainstem stage just equaled the SZF (Figure 7-3). The toe width, (width at the base of the channel) and stage above SZF corresponding to complete wetting of the toe width were measured using a handlevel, survey rod and 100 m fiberglass tape for small channels, or a rangefinder for larger channels. The bankfull width, and stage above SZF at which the flow equaled bankfull were also measured (Figure 7-3).

The wetted area of the channel was calculated for both survey dates, and estimated for SZF, toe stage and bankfull stage. Wetted area equaled the wetted width multiplied by the measured wetted length if the side channel was partially connected, or by the estimated side channel length if totally connected. The wetted area when the mainstem flow was equal to the SZF, toe stage and bankfull stage was estimated by multiplying the estimated side channel length by the measured minimum, toe and bankfull widths respectively. The average of the inlet and outlet widths were used for all calculations.

The flows corresponding to the SZF were estimated as described in Section 7.3.2. Flows corresponding to the toe stage and bankfull stage for each side channel were estimated in a similar manner; the elevation difference between the SZF and toe stage, or SZF and bankfull stage were added to the measured difference in elevation between the SZF and mainstem elevation at the time of the low flow survey. The total stage change required to fill the side channel to toe width or bankfull was then determined using the appropriate stage discharge relationship.

The measured and estimated wetted side channel area versus flow was plotted for each channel. If a channel was wetted and completely connected at both the low flow and high flow surveys, a straight line relationship between the two known data points was assumed. A straight line relationship was also assumed between the measured surface area at high flow and the estimated measured surface area at bankfull (Figure 7-4a).

If the channel was completely dry at the low flow survey, but completely wetted at the high flow survey, then the channel was assumed to go from zero surface area to the minimum surface area when the mainstem flow equaled the predicted SZF. A straight line relationship was assumed between the estimated stage of zero flow, and the measured area at high flow, and from the measured area at high flow to the estimated area at bankfull (Figure 7-4b).

If the channel was partially wetted at one or both surveys, either from backwater effects or by subsurface outflow, a straight line relationship was assumed from the predicted SZF through the partial wetted area and down to the point of zero flow. Above the predicted SZF, the relationship was assumed to follow the pattern described above (Figure 7-4c).

If the channel was completely dry both the high and low flow surveys, the channel was assumed to go from zero surface area to the minimum surface area when the mainstem flow equaled the predicted SZF. A linear regression equation was calculated using the predicted minimum, toe and bankfull area and used to predict wetted area relative to flow between the predicted SZF and bankfull (Figure 7-4d).

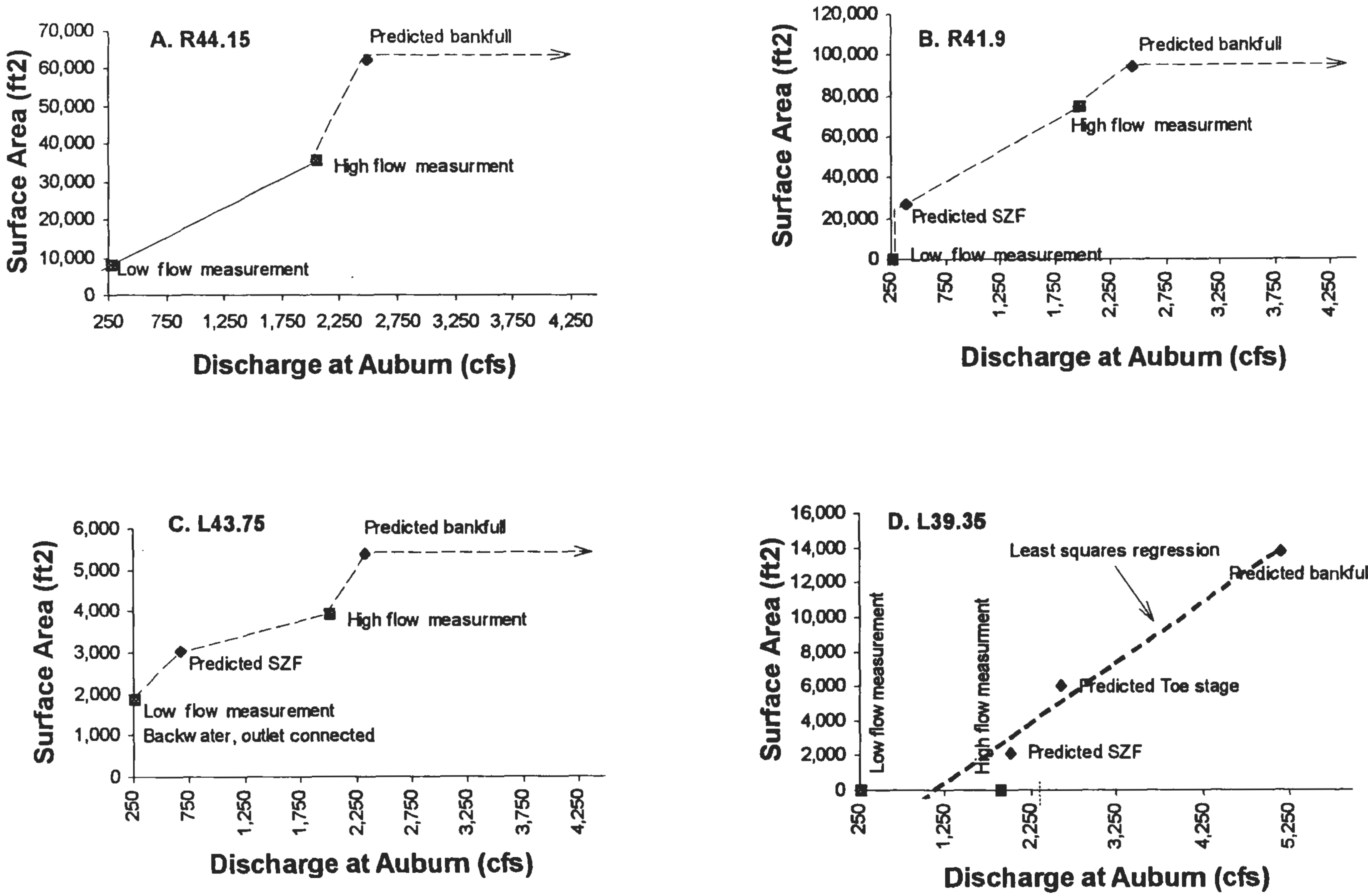


Figure 7-4. *Relationship between wetted side channel area and mainstem flow: A.. wetted at both high and low flow survey; B. dry at low flow survey, wet at high flow survey; C. partially connected at low flow survey, wet at high flow survey; D. dry at both low and high flow surveys.*

Once plots of wetted surface area versus mainstem discharge had been constructed for each side channel, a relationship between total wetted side channel area and mainstem flow was constructed for each study segment. The wetted area in each individual side channel was calculated at a series of 8 flows: flow at the low flow survey, flow at the high flow survey, 500 cfs, 1,000 cfs, 1,500 cfs, 2,500 cfs and 4,500 cfs, and the flow at which each side channel was bankfull. The wetted area of individual side channels at each flow of interest were summed to produce a relationship between wetted side channel area and mainstem discharge for each study segment. A relationship between the total number of wetted side channels versus flow was developed for each segment by assuming that each side channel became wetted only when the mainstem flow exceeded the predicted SZF.

The accuracy of wetted side channel area estimates was checked by comparing data from the current study to data collected during a detailed study of four side channels in the Middle Green Reach (Coccoli 1996). In that study, side channel length was measured directly using a string box, and the average side channel width was determined by measuring the wetted width at al least 10 sites using a fiberglass tape (Coccoli pers. comm. 1997).

7.3.5 Quantify Changes in the Amount of Wetted Side Channel Area, and the Frequency and Duration of Side Channel Connectivity Resulting From Increased Storage Between February 15 and May 30.

The AWSP involves storing additional water between 15 February and 31 May. Phase I involves increasing the total storage by 20,000 acre feet by storing Tacoma's pipeline 5 water right. In Phase II, an additional 37,000 acre feet of water are stored (14,600 for fisheries and 22,400 for M&I use).

During the period of active reservoir refill, instream flow below Howard Hanson Dam will be reduced. The change in downstream flows which could be expected to result from implementation of the AWSP was determined by using the existing 32 year hydrologic record (1964-1995) to model flows which would occur under the baseline, Phase I and Phase II operating scenarios. Flow modeling was conducted by CH2MHill, and is not discussed in detail in this report.

a. Magnitude

The side channel area versus flow relationship developed for each segment was used to calculate the amount of side channel habitat available on a daily basis between 15 February to 31 May for each year of record under each operating scenario. Daily values of wetted side channel habitat were averaged over half-month intervals throughout the period of interest.

b. Duration

Two types of wetted side channel area were identified; area that remains continuously wetted, and area that is temporarily connected by high flow events, but dewatered at lower flows (Figure 7-5). Side channel area which is not de-watered for more than 48 hours at any time throughout the chum salmon incubation period (1 January through 30 April) is assumed to represent viable spawning and incubation habitat. The continuously wetted side channel area was estimated using the flow versus wetted area relationship (Section 7.3.4). The highest discharge of the two-day period with the lowest recorded flows between 1 January and 30 April was identified for each year of record under each operating scenario. Side channel area wetted only at flows greater than that discharge are assumed to be dewatered for the entire two day low-flow, killing incubating eggs and alevins.

Side channel area which is connected only temporarily by high flows or freshets was classified as temporarily wetted. Flow exceedance curves were used to identify the discharge exceeded 95, 75, 50, 25 and 5 percent of the time. These flows were used to estimate the duration of temporary wetted side channel area. Changes in the flow exceedance curves associated with implementation of each project alternative illustrate the change in duration of temporarily wetted side channel area.

c. Timing and Frequency

The timing and frequency of flows that temporarily connect side channel habitat, expediting egress of juvenile salmonids was also assessed. Plots were prepared of the daily wetted side channel area versus time for each year for the period during which the AWSP is expected to change flows (15 February to 31 May). Freshets were defined as flows greater than or equal to 2,500 cfs. The number and date of freshets that occurred under baseline, Phase I and Phase II operating scenarios were identified for each of the 32 years of record. The average number of freshets by month was compared to the number under baseline conditions to identify changes resulting from implementation of each operating scenario

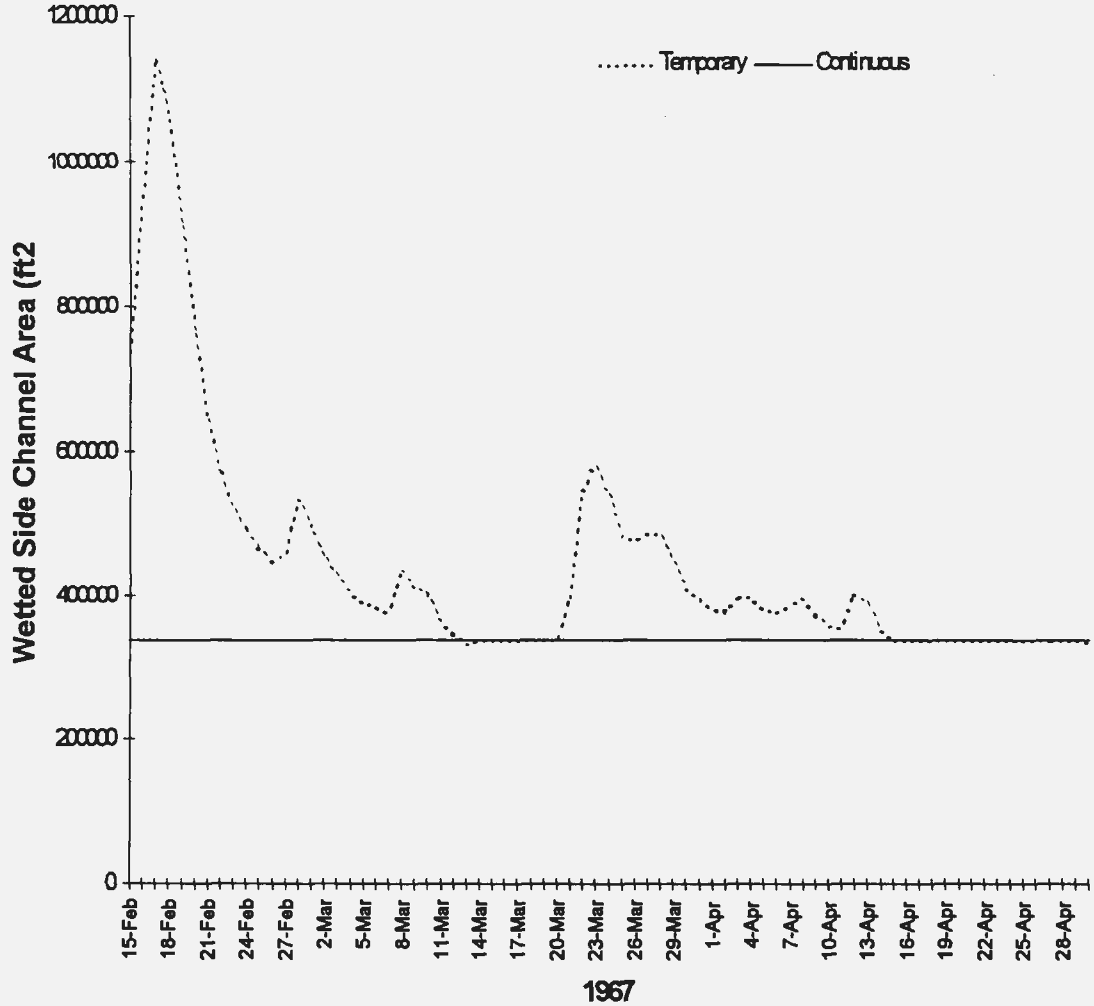


Figure 7-5. Wetted side channel area.

7.4 RESULTS

7.4.1 Locate and Describe Existing Active Side Channel Habitat

Preliminary maps of existing side channels were prepared for each study segment. Floodplain maps scaled at 1 inch to 200 feet with a 2-foot contour interval were obtained from the King County Surface Water Management Division (Harper Righellis Inc. 1996), and provided an excellent basemap of the Middle Green Segment. A set of 1 inch to 600-foot aerial photographs of this study segment, flown in 1994, were also provided by King County. The location of all potential side channels were plotted on the base maps.

Middle Green Segment

A total of 48 active side channels were identified between Flaming Geyser State Park and Neely Bridge in the Middle Green study segment (Figure 7-6). A few additional side channels were mapped downstream of Neely bridge, however time limitations prevented data collection on that part of the river. Twenty-two of the side channels identified in the Middle Green segment were backbar channels, 15 were abandoned channels, four were wallbase channels and seven were secondary channels.

Flooding in 1996 is believed to have altered the configuration of many active side channels. Major changes in channel morphology were noted between RM 39.5 and RM 37.5. At approximately RM 39.15, a large new backwater slough had been eroded, modifying the outlets of three backbar channels and one wallbase channel. At RM 38.48, a large new log jam blocked the entrance of a former large secondary channel. This log jam appears stable, thus it is likely that the former secondary channel will evolve into an abandoned side channel. At RM 37.5, the main channel cut through a former large mid-channel bar, forming a new backbar channel on the south bank of the river.

Palmer Segment

Detailed floodplain maps were not available for the Palmer segment, however a set of one inch to 400 foot photographs flown in 1987 was provided by the Corps. Potential side channels were plotted on an acetate overlay of these photos to develop a preliminary field map. Eleven side channels were identified in the Palmer study segment (Figures 7-7a and 7-7b). Six were backbar channels, four were secondary channels, and one was a wallbase channel. No active abandoned side channels were encountered, although a large former meander now cut off by the road and railroad was noted on the air photos (Figure 7-7a).

Figure 7-6. Location of side channels in the Middle Green River study segment, Green River, Washington.

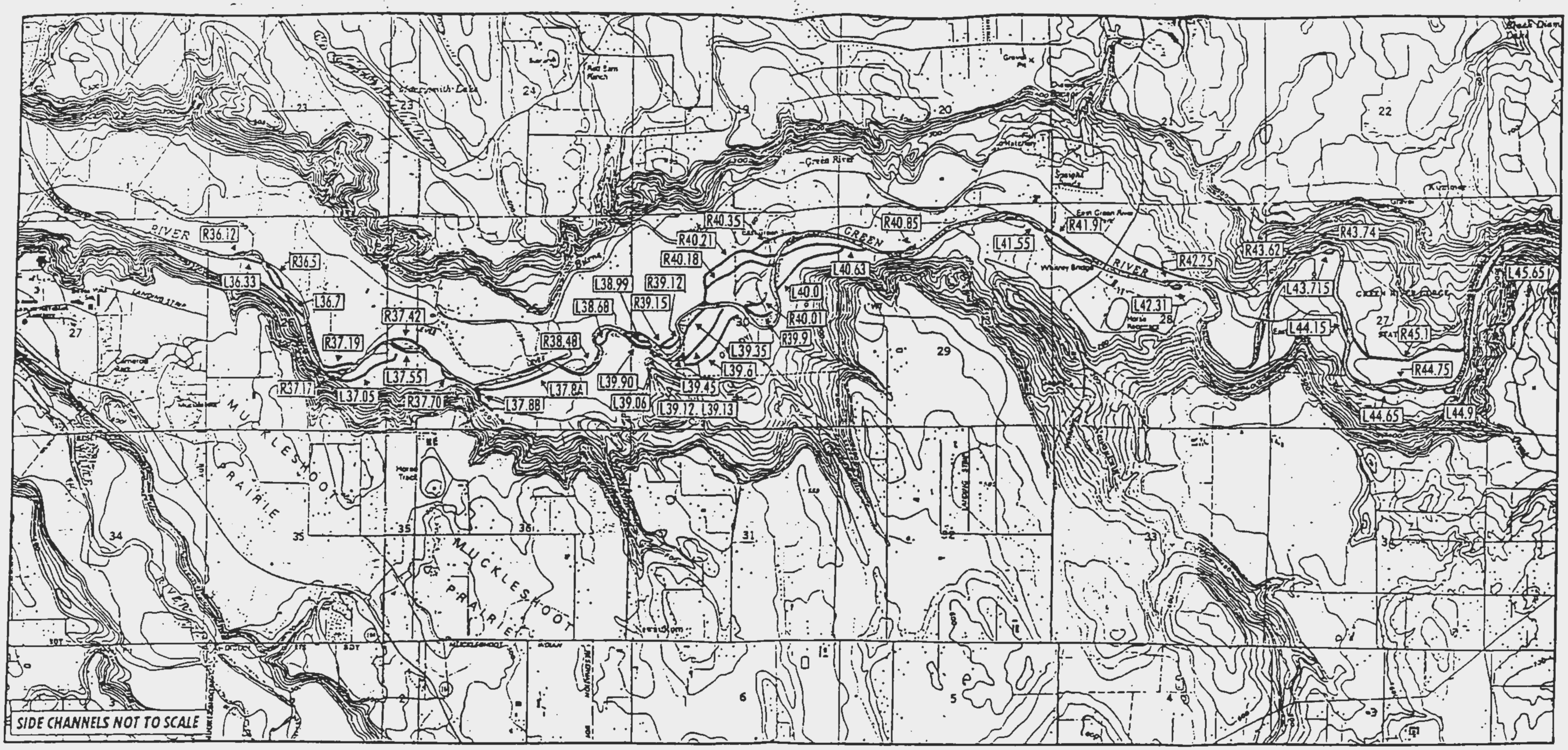


Figure 7-7a. Location of side channels in the Palmer segment (RM 60.3-57.1), Green River, Washington. Note: photo scale is not the same as listed in the Legend.

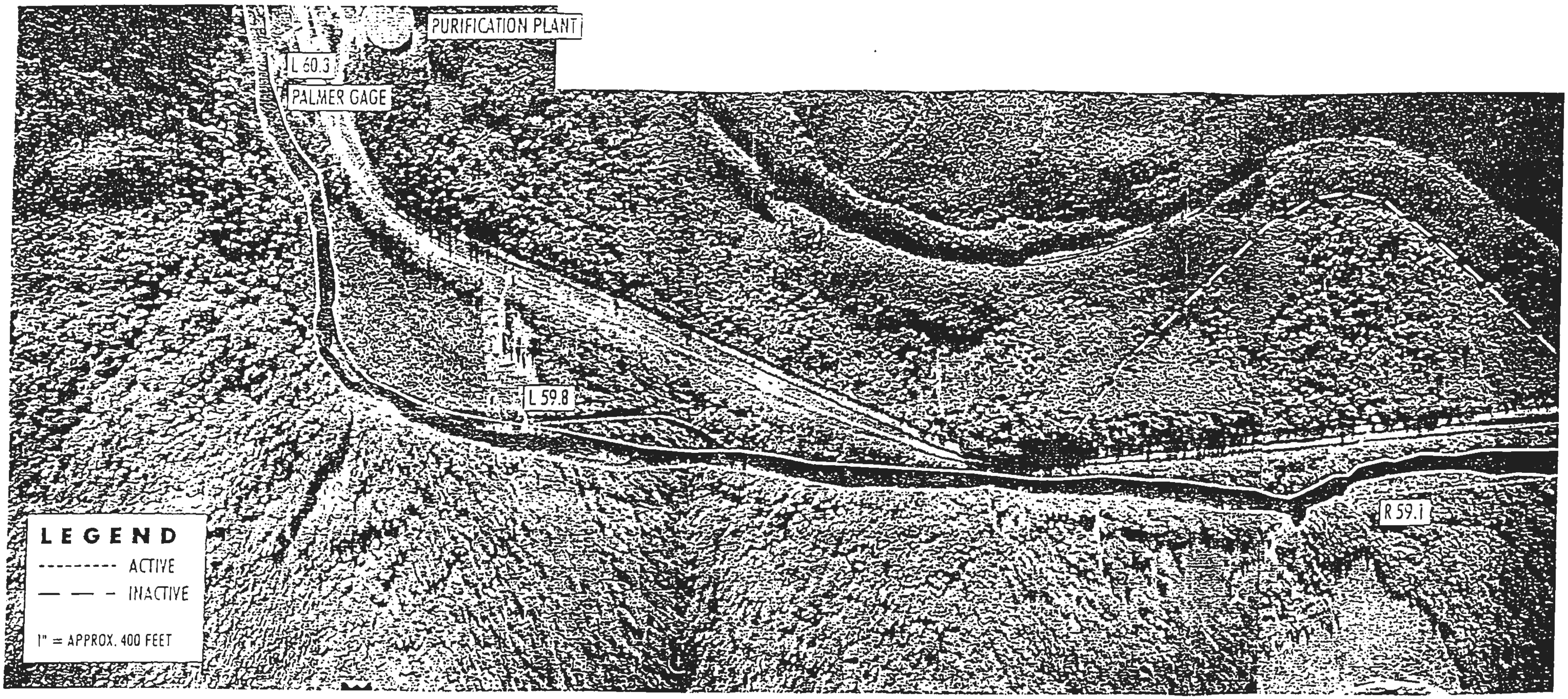
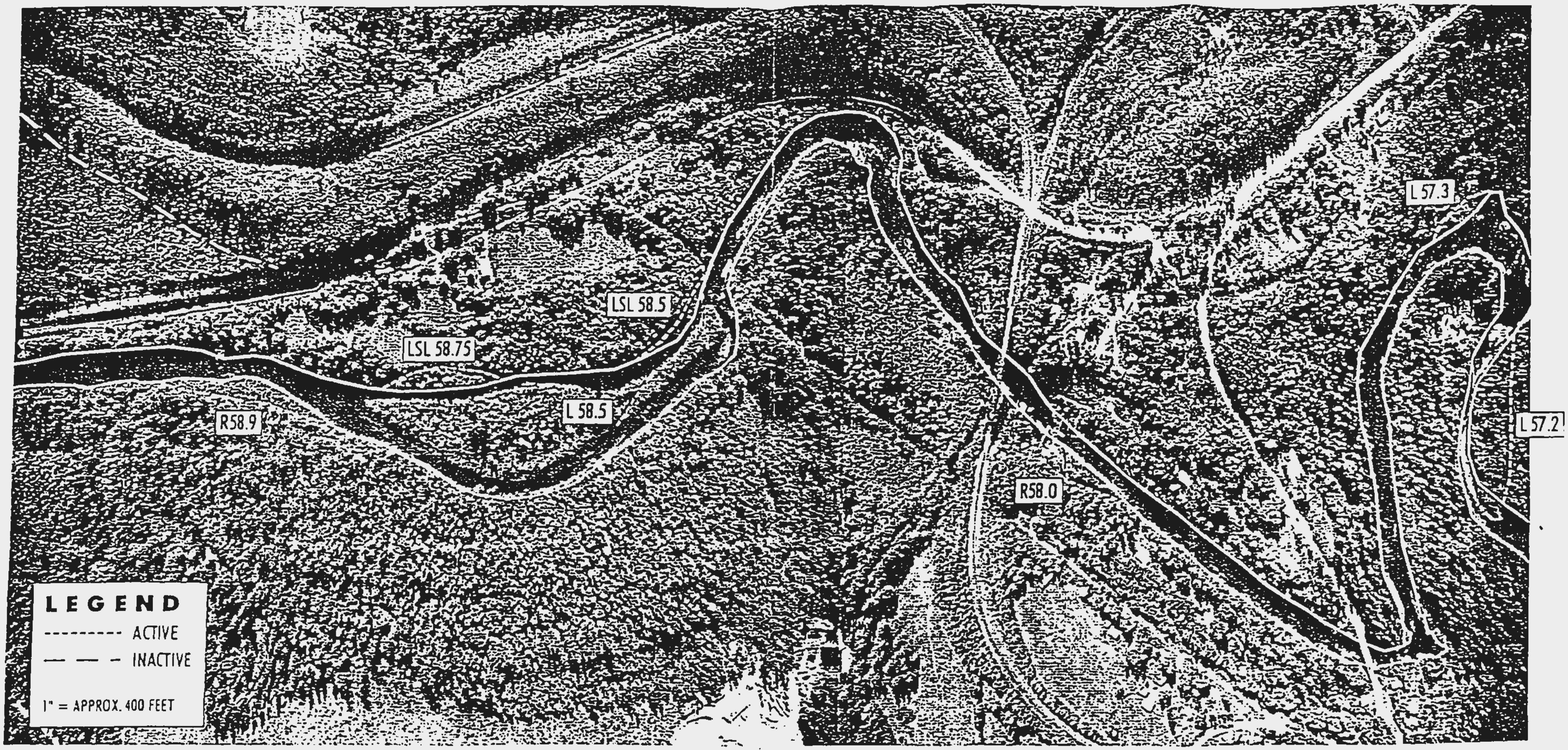


Figure 7-7b. Location of side channels in the Palmer segment (RM 60.3-57.1), Green River, Washington. Note: photo scale is not the same as listed in the Legend.



7.4.2 Determine Flows at Which Active Side Channel Habitat Becomes Connected

The change in stage resulting from a given change in discharge depends on channel morphology. For a given change in flow, the stage change is much greater in a narrow, highly confined channel than in a wide, shallow channel. Because channel morphology varies dramatically within the Green River study segments, stage changes were also expected to vary throughout the study reach.

Because of the lack of available on stage:discharge relations in the Green River, it was initially assumed that rating curves from the Palmer and Auburn USGS gage stations would have to be used to predict stage changes in the Palmer and Middle Green study segments. Gage sites are generally located in straight, single-thread channels as such sites are ideal for developing accurate rating curves. By their nature however, side channels often branch off the mainstem at channel bends, or are formed in areas where wide, shifting bars are common. Such sites give rise to complex stage:discharge relationships that are difficult to develop and require a great deal of data. It was therefore expected that there would be some error between the USGS rating curves and site specific conditions at individual channel inlets.

<u>Middle Green River Study Segment</u>
During subsequent meetings with the Corps, we learned that the Corps and King County had worked together to model flood flows in the Middle Green Reach, and in so doing developed model rating curves for a series of cross-sections between RM 33.8 and RM 45.1. The cross sections were spaced at about 500-foot intervals, and thus were initially believed to better represent conditions within the Middle Green River study segment. Cross-sections and model rating curves were obtained in the hope that site specific data would provide improved stage:discharge relationships at individual side channels.

Stage changes between high and low flow surveys observed at individual side channels in the Middle Green study segment varied widely as a result of both local hydraulics and the difficulty of accurately repeating individual measurements. Flow patterns at side channel inlets were frequently influenced by the presence of LWD, which blocked inflow and resulted in super-elevation of the water surface. Other hydraulic factors affecting the accuracy of stage measurements included back-eddies and the presence of herbaceous or shrub vegetation. In a few cases, swift velocities at side channel inlets prevented the survey crew from remeasuring the difference between the SZF and the mainstem water surface during the high flow survey; at other sites, markers left to facilitate relocation of the SZF could not be found. A final problem occurred at side channels where the SZF had been incorrectly identified at low flow. At these sites, the difference between the SZF and water surface were measured both at the old, incorrect location and at the new, correctly identified SZF.

Neither the USGS rating curves or King County/Corps model rating curves closely matched the stage changes observed at side channel inlets and outlets in the Middle Green study segment. As noted before, USGS gages are purposely located in straight, single thread channels and thus are inherently different from the types of sites where side channels develop. The stage change between high and low flow surveys at the Auburn gage ranged from 2.7 to 2.3 feet. Observed stage changes within the Middle Green Reach were highly variable, but averaged 0.6 feet less than those observed at Auburn.

Rating curves developed by the Corps were based on cross-sections surveyed in the study segment, and thus were expected to be more representative of channel morphology than the USGS gage. However, the HEC-II flow modeling was specifically designed to predict water surface elevations for flows greater than 8,000 cfs, and was considered inaccurate for lower flows (Clint Loper, KCSWM pers comm. 1996). As a result, the modeled rating curves tended to overpredict the actual stage change between flows of approximately 250 and 1,800 cfs. The average difference between the observed stage change and model stage change at the nearest cross-section was 0.9 ft.

Since both the USGS rating curve and the model rating curves substantially overpredicted the observed stage change at side channels within the Middle Green study segment, we concluded that actual data was preferable for predicting flows at which side channels become connected. To overcome data inadequacies at sites with complex hydraulics, we developed a reach average estimate of the stage:discharge relationship using only high quality data. The study segment was subdivided into three reaches (RM 45.6 to RM 40.25; RM 40.24 to RM 38.8 and RM 38.7 to RM 34.8) with similar geomorphic characteristics. Notes and photos were reviewed to identify side channels for which stage change data was considered good. The average stage change for all sites rated good in each subsegment was used to generate a linear equation of stage versus discharge. This equation was then applied to all side channels within the sub-segment to estimate the discharge at which inflow from the mainstem began. Table 7-1 lists the estimated SZF for each side channel in the Middle Green Reach.

Table 7-1.
Summary of SZF, bankfull stage and maximum estimated side channel area, Middle Green Segment, Green River, Washington

Side Channel I.D.	Type	Estimated Inlet SZF (mainstem cfs)	Estimated Bankfull Flow (mainstem cfs)	Side Channel Length (ft)	Side Channel Bankfull Width (ft)	Estimated Side Channel Bankfull Area (ft2)
L45.65	WALLBASE	2,563	4,380	1,931	18	35,241
R45.10	ABANDONED	841	2,579	2,800	38	106,120
L44.9	ABANDONED	2,004	3,426	980	24	23,275
R44.75	BACKBAR	114	2,484	780	80	62,400
L44.65	ABANDONED	0	2,879	600	27	16,200
L44.15	BACKBAR	2,054	3,634	800	36	28,800
R43.74	BACKBAR	513	1,896	720	16	11,448
L43.715	SECONDARY	667	2,326	180	30	5,400
R43.62	BACKBAR	588	3,116	420	63	26,376
L42.31A	ABANDONED	1,299	3,037	290	27	7,830
L42.31B	ABANDONED	509	2,326	70	51	3,570
R42.25	BACKBAR	0	2,089	460	56	25,576
R41.9	SECONDARY	391	2,445	1,600	59	94,880
L41.55	BACKBAR	1,295	2,875	400	23	9,300
R40.85	SECONDARY	0	1,211	114	32	3,648
L40.63	BACKBAR	2,001	2,910	1,880	62	116,560
R40.35	ABANDONED	784	3,233	1,440	15	21,600
R40.21	ABANDONED	710	3,447	2,740	34	92,886
R40.18	ABANDONED	4,607	6,749	2,120	25	53,848
R40.01	ABANDONED	NA	7,046	500	21	10,450
L40.00	BACKBAR	2,643	3,238	3,160	32	101,120
R39.90	BACKBAR	NA	5,742	1,060	13	13,462
L39.60	ABANDONED	5,028	6,273	2,200	46	101,200
L39.45	BACKBAR	4,909	8,360	1,500	35	52,500
L39.35	BACKBAR	2,009	5,163	860	16	13,760
L39.12	BACKBAR	NA	ND	300	47	20,640
L39.13A	BACKBAR	NA	ND	81	23	1,296
L39.13B	BACKBAR	NA	ND	60	18	300
R39.38	BACKBAR	506	3,481	200	31	6,220
R39.15	ABANDONED	4,433	7,111	400	24	9,520
R39.12	BACKBAR	1,541	5,980	420	23	12,176
L39.06	WALLBASE	1,339	3,600	400	26	10,400
L39.00	BACKBAR	506	2,886	860	28	24,080
L38.99	BACKBAR	0	3,600	500	46	23,000
L38.68	BACKBAR	2,088	5,182	660	25	16,170
R38.48	ABANDONED	25	1,929	700	32	22,120
L37.80A	ABANDONED	NA	2,524	2,200	20	44,000
L37.80B	WALLBASE	1,643	ND	1,700	100	10,000
L37.7	ABANDONED	1,550	3,349	900	23	20,700
L37.55	BACKBAR	799	2,539	900	43	38,700
R37.42	BACKBAR	1,159	2,899	1,200	36	43,680
L37.4	WALLBASE	1,310	3,290	1,800	24	42,300
R37.19	ABANDONED	1,910	2,510	900	21	19,170
R37.17	ABANDONED	1,730	2,479	820	19	15,580
L36.7	BACKBAR	410	2,630	1,000	48	48,000
R36.5	BACKBAR	2,419	3,199	900	19	16,650
L36.33	BACKBAR	191	2,111	600	40	23,700
R36.12	BACKBAR	2,120	3,371	460	25	11,684
					Total:	1,517,536

Seven of the 48 side channels identified in the Middle Green study segment were wetted at both ends during the low flow survey (Figure 7-8). All the channels wetted at low flow were classified as secondary channels, defined as channels which are currently part of the active channel but which may become de-watered at very low flows. These seven secondary channels were classified as side channels because the habitat provided at higher flows was expected to differ from that provided by the mainstem (eg. finer substrate, slower flows). Large, exposed secondary channels that appeared to provide habitat similar to that in the mainstem were not considered side channels for the purpose of this investigation.

The number of side channels connected to the mainstem increased steadily from seven to 43 between 270 and 2,500 cfs (Figure 7-8). Five additional side channels which appeared to consistently become wetted under the existing flow regime had SZF's greater than 2,500 cfs. In this case, our definition of connectivity required the mainstem flow to be greater than the SZF. As will be discussed in Section 7.4.3, there was evidence that some side channels became connected to the mainstem via subsurface flow at mainstem flows less than that required to establish direct surface connection.

The estimated SZF for the current study differed by less than 100 cfs from the stage of zero flow identified by Coccoli (1996) for the side channels with unobstructed inlets (R39.12 and L40.63, Table 7-2). The correlation between our estimated SZF and the SZF identified by Coccoli (1996) differed by approximately 200 cfs at the inlet of R40.21, however the inlet at this site was blocked by a logjam which created complex hydraulic conditions and reduced the accuracy of stage measurements. The final side channel measured in both studies (L39.45) was blocked by a high gravel berm at the upstream end. Coccoli (1996) reported that this channel became connected to the mainstem when flows at Auburn were approximately 943 cfs in April 1996. However, connectivity was established by subsurface flow, and no direct connection by surface flow was noted over the range of study flows (350-1,701 cfs). Our data indicate that the SZF exceeds 4,500 cfs for this side channel. Only a trickle of subsurface flow was observed during the survey conducted at 1,850 cfs in late October 1996.

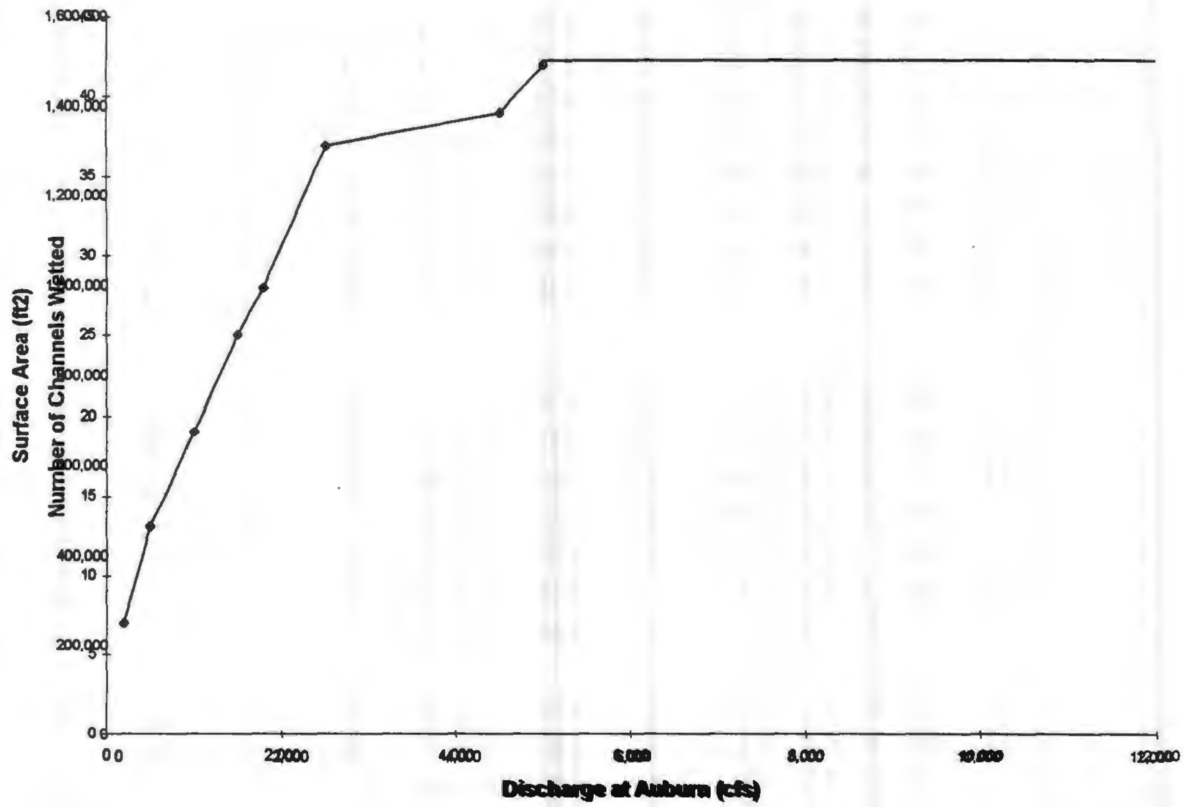


Figure 7-8.

Table 7-2.
Comparison of estimated side channel SZFs for selected side channels.

Side Channel I.D.		Estimated SZF (cfs)		
Beak (1996)	Coccoli (1996)	Beak (1996)	Coccoli (1996) Q on site	Coccoli (1996) Q at Auburn
L40.63	Upper O'Grady back bar	1,541	1,318	1,449
R40.21	Metzler Main (MOAS)	710	458	503
L39.45	Big Chum	4,909	858	943
R39.12	Private Property	2,001	1,842	2,026

<u>Palmer Study Segment</u>
Stage changes observed within the Palmer Reach were also quite variable. The quality of

stage change data was assessed using the procedures previously described for the Middle Green study segment. The average stage change for side channels with "good" data was 1.9 ft. The stage change observed at the Palmer gage was 1.8 ft, suggesting that the gage rating curve provided an adequate representation of the stage change within the study segment. Because of the close agreement between observed stage changes and the Palmer rating curve, the rating curve was used to predict the discharge at which inflow from the mainstem began for side channels in the Palmer study segment. Table 7-3 lists the predicted SZF for all side channels in the Palmer segment. The close agreement between the USGS rating curve and measured side channel stage changes is not surprising, as the channel is more uniform and confined within the Palmer segment than in the Middle Green segment.

Table 7-3.
Summary of SZF, bankfull stage and maximum estimated side channel area, Palmer Segment, Green River Washington.

Side Channel I.D.	Type	Estimated Inlet SZF (mainstem cfs)	Estimated Bankfull Flow (mainstem cfs)	Side Channel Length (ft)	Side Channel Bankfull Width (ft)	Estimated Side Channel Bankfull Area (ft2)
L60.30	Backbar	72	690	70	28	1,999
L59.82	Secondary	85	2,763	1,056	64	67,584
R59.10	Backbar	1,231	2,827	330	33	10,890
R58.89	Backbar	487	1,917	620	25	15,500
LSL58.75	Secondary	0	1,762	528	40	21,094
L58.5	Secondary	137	2,867	172	34	5,848
LSL58.5	Secondary	137	1,502	360	64	23,040
R58.0	Backbar	0	787	396	21	8,316
L57.3	Wallbase	1,177	2,867	450	18	8,010
L57.2	Backbar	1,340	4,265	524	27	13,886
R57.1	Backbar	690	2,380	420	35	14,490
					TOTAL:	**190,657**

Four of the 11 side channels identified in the Palmer study segment were wetted at the time of the low flow survey, conducted at a mainstem flow of approximately 137 cfs (Figure 7-9). All of the side channels in the Palmer reach were wetted during the high flow survey, conducted at approximately 1,350 cfs.

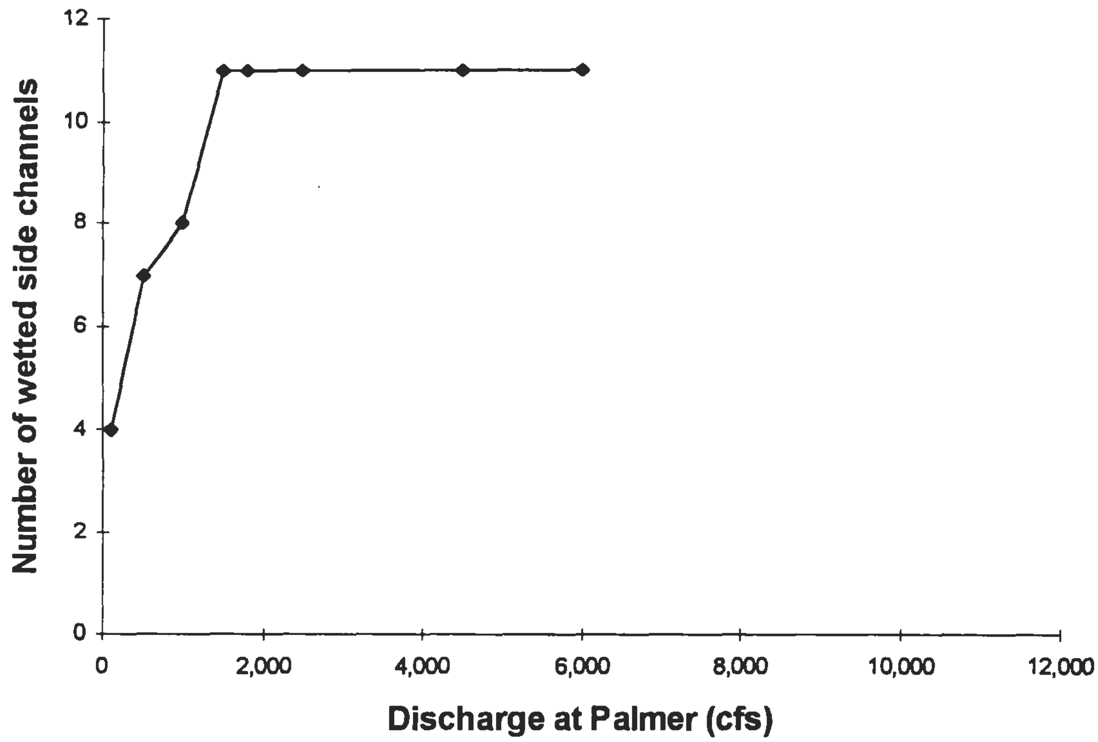


Figure 7-9.

7.4.3 Estimate the Importance of Subsurface Flow in Maintaining Side Channel Connectivity

Intragravel flows and floodplain return flows are known to maintain side channel connectivity below the stage of zero flow for some side channels on the Green River (Coccoli 1996). One of the goals of this investigation was to identify channels where subsurface flow maintains connectivity after inflow from the mainstem ceases, and to develop a preliminary estimate of the magnitude of subsurface flow contributions. Outflow from channels where no inflow was observed was assumed to be fed by subsurface flow. In channels that had both inflow and outflow at the time of the survey, discharge measurements were taken at both ends. If no secondary inlets or outlets were observed, the difference between the inflow discharge and outflow discharge was assumed to be contributed by subsurface flow. Differences in temperature between the inlet and outlet were also used to qualitatively estimate the proportion of surface and subsurface flow contributions.

Middle Green Study Segment

During the low flow survey, 24 of the 48 side channels identified in the Middle Green Reach were connected at one or both ends, frequently by only a trickle of flow. Inflow from the mainstem provided direct surface flow to only seven of the 24 wetted side channels. Discharges were estimated for side channels where site conditions prevented use of the current meter at extremely low flows. Subsurface flow contributions accounted for 100 percent of the outflow in 17 of the 24 wetted side channels (Table 7-4). Side channel R45.10 received the greatest contribution of subsurface flow, estimated at 1.2 cfs. Subsurface flow contributions for the remaining side channels were less than 0.5 cfs.

Not surprisingly, 75 percent of the wallbase channels (three of four) were wetted by subsurface flow. By definition these are channels which receive inflows from sideslope seeps. These channels also received the greatest amount of subsurface flow, with an average outflow of 1.1 cfs. Side channel L37.80b was a beaver pond which received inflow from sideslope seeps, but was disconnected from the mainstem by a porous beaver dam. Exchange of water occurs through this dam, however the channel was considered disconnected below the SZF because fish passage is prevented.

Six of the 22 backbar channels were wetted by subsurface flows, however in most cases the contributions were extremely low (mean <0.1 cfs). Subsurface flows in backbar and secondary channels are believed to be supplied by intragravel throughflow from the mainstem. Water temperatures were substantially cooler in backbar and secondary channels fed by subsurface flow, averaging 2.3 °C less than mainstem temperatures. Side channels fed by surface flow from the mainstem were either the same temperature, or warmer than the mainstem.

Table 7-4.
Summary of subsurface flow contributions for side channels in the Middle Green Segment, Green River, Washington, October-November 1996.

Side Channel I.D.	Type	Lowflow Qss (cfs)	Low flow (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)	Highflow Qss (cfs)	Q Outlet (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)
L45.65	BACKBAR	0.0	0.0	0	-	-	0.0	0.0	0	-	-
R45.10	ABANDONED	1.2*	1.2*	100	13.5	15.0	1.0	3.0	33	10.0	9.5
L44.9	ABANDONED	0.0	4.5	0	15.0	15.0	0.0	3.1	0	9.5	8.0
R44.75	SECONDARY	0.0	2.2	0	15.0	14.0	ND	ND	ND	9.5	9.5
L44.65	ABANDONED	0.0	1.3	0	13.0	13.0	0.0	21.3	0	9.0	9.0
L44.15	BACKBAR	0.0	Ponded	0	14.5	14.0	0.0	0.0	0	9.0	9.0
R43.74	WALLBASE	0.5*	<0.5*	100	13.0	14.5	0.3	10.3	3	9.5	10.0
L43.715	SECONDARY	<0.1*	<0.1*	100	14.0	14.5	0.0	143.0	0	9.0	9.0
R43.62	SECONDARY	0.0	<0.1*	100	13.5	14.5	ND	ND	0	9.0	10.5
L42.31A	ABANDONED	0.0	<0.1*	100	14.5	15.0	0.0	<0.5*	0	9.0	9.0
L42.31B	ABANDONED	0.0	<0.1	100	14.5	15.0	0.0	74.4	0	9.5	9.5
R42.25	BACKBAR	0.0	1.5*	0	12.0	13.0	ND	78.6	0	10.0	9.5
R41.9	SECONDARY	<0.5*	<0.5*	100	12.0	15.5	0.0	198.0	0	9.0	9.0
L41.55	BACKBAR	0.0	0.0	0	-	15.5	0.0	1.6	0	-	8.0
R40.85	SECONDARY	0.0	6.1	0	11.0	11.0	0.0	92.9	0	8.0	8.0
L40.63	BACKBAR	0.0	0.0	0	-	13.0	0.0	0.0	0	-	8.0
R40.35	ABANDONED	ND	ND	ND	-	-	0.0	0.7	0	8.0	8.0
R40.21	ABANDONED	0.2*	0.2*	100	11.5	16.0	5.4	44.1	12	9.0	9.0
R40.18	ABANDONED	0.0	PONDED	0	11.5	16.0	0.8	0.8	100	9.0	9.0
R40.01	ABANDONED	<0.1*	<0.1*	100	-	-	1.7	1.7	100	12.0	9.0
L40.00	BACKBAR	0.0	0.0	0	-	-	0.0	0.0	0		8.0
R39.90	BACKBAR	0.3	0.3	100	12.0	16.0	0.3	0.3*	100	9.0	9.0
L39.60	ABANDONED	ND	ND	ND			<1*	<1*	100	9.0	9.0
L39.45	BACKBAR	0.0	0.0	0	-	-	ND	ND	ND	-	8.5
L39.35	BACKBAR	0.0	0.0	0		-	0.0	0.0	0	-	8.5
L39.12	BACKBAR	<0.1*	<0.1*	100	13.5	17.0	0.0	PONDED	ND	-	-
L39.13A	BACKBAR	<0.1*	<0.1*	100	14.5	17.0	<1*	<1*	100	-	-
L39.13B	BACKBAR	<0.1*	<0.1*	100	14.5	17.0	<1*	<1*	100	-	-
R39.38	SECONDARY	0.0	PONDED	0	15.0	16.0	0.0	132.2	0	9.0	9.0
R39.15	ABANDONED	0.0	0.0	0	-	-	<0.5*	<0.5*	100	13.0	9.0
R39.12	BACKBAR	<0.1*	PONDED	100	15.0	17.0	2.1	2.8	75	12.0	9.0
L39.06	WALLBASE	ND	ND	ND	-	-	ND	ND	ND	-	9.0

Side Channel I.D.	Type	Lowflow Qss (cfs)	Low flow (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)	Highflow Qss (cfs)	Q Outlet (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)
L39.00	BACKBAR	0.0	0.0	0	-	13.0	0.0	16.3	0	-	-
L38.99	BACKBAR	0.0	0.0	0	-	-	0.0	141.3	0	-	-
L38.68	BACKBAR	0.0	0.0	0	-	13.5	0.0	0.0	0	-	7.0
R38.48	SECONDARY	0.0	0.5*	0	15.0	13.0	0.0	389.5	0	7.5	7.5
L37.80A	ABANDONED	<0.5*	<0.5*	100	11.0	13.5	<0.5*	<0.5*	100	7.0	7.0
L37.80B	WALLBASE	0.0	<0.5*	100	13.5	13.5	0.0	<0.5*	100	7.0	7.0
L37.7	ABANDONED	0.0	0.0	0	-	14.0	0.0	0.0	0	-	7.5
L37.55	BACKBAR	0.0	0.0	0	15.0	14.0	0.0	95.6	0	-	8.0
R37.42	BACKBAR	0.0	0.0	0	17.0	14.5	0.0	0.5	0	8.5	8.0
L37.4	WALLBASE	0.0	2.5	100	-	-	2.4	19.6	12	-	8.0
R37.19	ABANDONED	0.5*	0.5*	100	11.0	14.5	0.7	0.7	100	12.5	8.5
R37.17	ABANDONED	0.0	0.0	0	-	-	<0.5*	<0.5*	0	11.0	8.5
L36.7	BACKBAR	0.0	0.0	0	13.5	15.0	0.0	28.5	0	8.0	8.0
R36.5	BACKBAR	0.0	0.0	0	17.0	15.0	0.0	0.0	0	-	-
L36.33	BACKBAR	0.0	0.5*	0	15.0	15.0	0.0	158.9	0	-	8.0
R36.12	BACKBAR	0.0	0.0	0	17.0	15.0	0.0	0.0	0	-	-

Almost half of the abandoned side channels were fed by subsurface flows. The average discharge of these channels was only 0.3 cfs, however standing water and deep pools were common. The source of subsurface contributions to these side channels likely represents a combination of subsurface throughflow from the mainstem, and groundwater inflow. Side channel water temperatures averaged 2.0 °C less than the mainstem.

During the high flow survey, 35 of the 48 side channels were connected at one or both ends (Table 7-4). Measurable subsurface flow contributed from 3 to 100 percent of the total flow. Subsurface flow was believed to supply all of the flow observed in nine of the 35 wetted side channels.

The volume of subsurface flow contributed by groundwater sources was not expected to change substantially between October and November 1996. Precipitation during the fall of 1996 was not unusually high, and field data confirmed our expectation. The amount of flow contributed by groundwater remained unchanged in the three wallbase side channels where discharge data was collected.

In contrast, intragravel flows appeared to increase with increasing mainstem discharge. Detectable subsurface flow contributions in backbar channels, assumed to be supplied exclusively by intragravel flow, ranged from 0.1 to 2.1 cfs, accounting for 75 to 100 percent of the total side channel outflow. Intragravel flow accounted for the majority of outflow in four of the twelve wetted backbar channels. Temperatures in backbar channels receiving intragravel flow were up to 4 °C warmer than the mainstem temperature, illustrating the moderating influence of subsurface flow on water temperature.

Mainstem inflows to secondary channels during the high flow survey had increased substantially, ranging from 93 to 389 cfs (5 to 22 percent of the mainstem discharge). Because of the high flow volumes in secondary channels, no evidence of subsurface flow was detected by either comparisons of discharge or temperature.

Abandoned side channels are believed to receive subsurface flow from both groundwater and intragravel sources. Measurable subsurface flow contributions ranging from approximately 0.5 to 5.4 cfs were observed in abandoned side channels. Subsurface flow contributions accounted for 12 to 100 percent of the total outflow in these channels during the high flow surveys, and temperatures were generally 3 to 4 °C warmer than in the mainstem. In side channels receiving subsurface flow where no temperature differences were observed, ponding and backwater effects were frequently noted. No temperature differences were noted in abandoned side channels supplied exclusively by direct mainstem surface flows.

Palmer Study Segment

During the low flow survey, six of the 11 active side channels identified in the Palmer study segment were connected at one or both ends. Discharge measurements indicated that subsurface flow was contributing 38 and 100 percent of the flow in two of the six wetted side channels (Table 7-5). Measurable temperature differences were observed only in the wallbase channel (L57.3) where all outflow originated from groundwater sources.

During the high flow surveys, both inlets and outlets were wetted for all side channels within the Palmer study segment. Subsurface flow contributions were positively identified in only one of the six side channels for which discharge could be safely measured. The wallbase side channel (L57.3) described previously was just wetted at the inlet, however a 2-foot-wide gravel berm at mid-channel prevented flow from fully connecting the side channel. A small amount of outflow was again noted, fed by sideslope seepage. The water temperature in this side channel was slightly warmer than that of the mainstem.

7.4.4 Develop a Relationship Between Wetted Side Channel Area and Mainstem Flow

The amount of wetted side channel area in each side channel was measured or estimated at five stages (surveyed low flow, SZF, toe, surveyed high flow and bankfull) by multiplying the average side channel width at that stage by the wetted length. The wetted area at these five stages was used to develop an area versus flow relationship for each side channel. Next, a relationship of wetted side channel area versus flow was constructed for the entire study segment by calculating and summing the wetted area of individual side channels at a series of eight flows: surveyed low flow, 500 cfs, 1,000 cfs, 1,500 cfs, surveyed high flow, 2,500 cfs, 4,500 cfs, and the flow at which all channels were bankfull.

Table 7-5.
Summary of Subsurface Flow Contributions for Side Channels in the Palmer Segment
Green River, Washington, October-November 1996

Side Channel I.D.	Type	Lowflow Qss (cfs)	Low flow (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)	Highflow Qss (cfs)	Q Outlet (cfs)	Subsurface contribution (%)	SC Temp (C)	Mainstem Temp (C)
L60.30	BACKBAR	0.0	0.0	0	13.0	13.0	ND	ND	0	8.0	8.0
L59.82	SECONDARY	3*	8.0	38	12.5	13.0	ND	ND	ND	8.0	8.0
R59.10	BACKBAR	0.0	0.0	0	-	-	0.0	2.1	0	8.0	8.0
R58.89	BACKBAR	0.0	0.0	0	-	-	0.0	52.4	0	8.0	8.0
LSL58.75	SECONDARY	0.0	0.8	0	13.5	13.0	0.0	92	0	8.0	8.0
L58.5	SECONDARY	0.0	<0.5*	0	14.0	14.0	ND	ND	ND	-	-
LSL58.5	SECONDARY	0.0	<0.5*	0	14.0	15.0	0.0	145	0	8.0	8.0
R58.0	BACKBAR	0.0	12*	0	14.0	14.0	ND	ND	0	-	-
L57.3	WALLBASE	<0.5*	<0.5*	100	11.0	14.0	<0.5*	<0.5*	100	9.0	8.0
L57.2	BACKBAR	0.0	0.0	0	-	-	0.0	0.3	0	8.0	8.0
R57.1	BACKBAR	0.0	0.0	0	-	-	0.0	ND	ND	8.5	8.5

Middle Green Study Segment
The maximum wetted side channel area in the Middle Green study segment was estimated to be just over 1.5 million ft^2 when flows exceeded approximately 8,000 cfs (Figure 7-10). At 250 cfs, less than 200,000 ft^2 of side channel area was wetted and connected to the mainstem at one or both ends. The wetted area increased rapidly between 250 and 2,500 cfs. Above 2,500 cfs the rate of increase dropped off, as most side channels were already at bankfull.

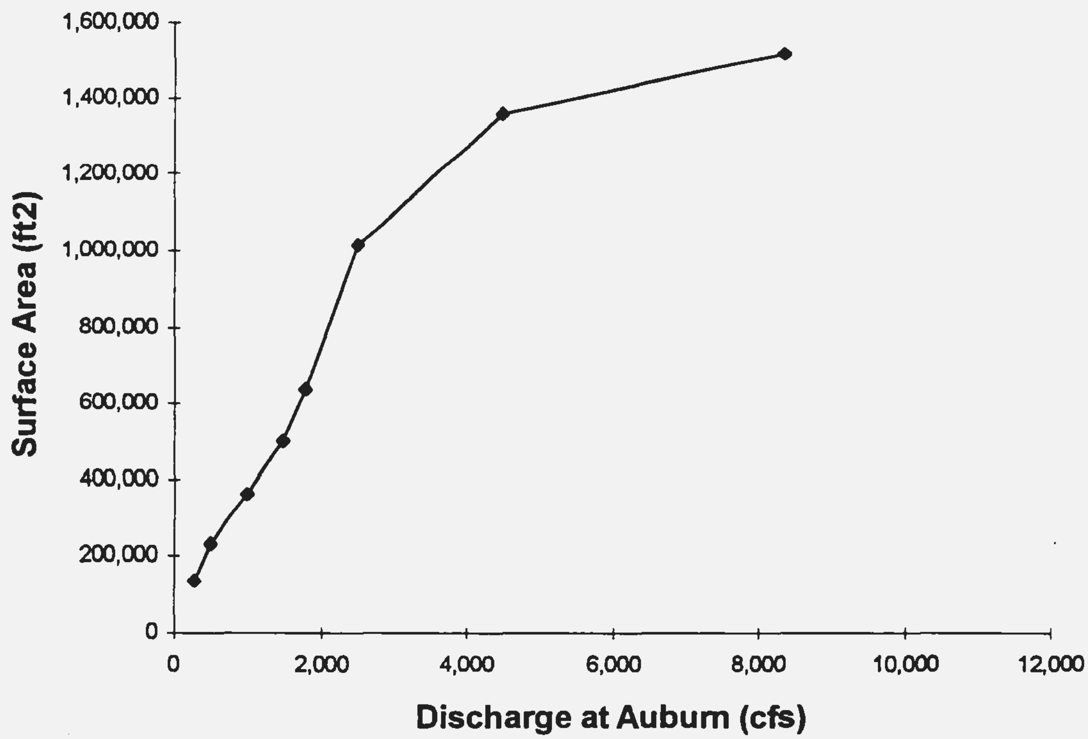


Figure 7-10.

Compared to Coccoli (1996), the present study tended to underpredict side channel area by as much as 63 percent (Table 7-6). Estimated side channel lengths were similar in both studies, therefore the difference in side channel area results from differences in estimates of average side channel widths. There are several possible explanations for the discrepancy.

Table 7-6.
Comparison of estimated side channel area and length for selected side channels.

Side Channel I.D.			(ft^2)		Side Channel Area (ft^2)	
Beak (1996)	Coccoli (1996	Flow at Auburn (cfs)	Beak (1996)	Coccoli (1996)	Beak (1996)	Coccoli (1996)
R40.21	Metzler Main (MOAS)	1,229	39,344	76,463	2,740	2,875
L39.45	Big Chum	1,050	<924	30,026	1,500	1,580
R39.12	Private property	1,730	1,836	4,934	420	416
		2,580	3,554[1]	6,827	420	416

[1]*Area calculated without backwater to be comparable with Coccoli 1996.*

Coccoli's surveys were conducted in the spring of 1996. Her data from L39.45 indicate that up to 30,026 feet of side channel area were wetted during the spring as a result of subsurface flow. Only 924 feet of wetted area were noted during surveys conducted in October 1996. The apparent change in subsurface flow between spring and fall measurements could account for some or all of the difference in wetted side channel widths. Subsurface flow contributions were also noted in R 40.21 and R39.12 during the October high flow surveys; changes in subsurface flow contributions between spring and fall may also account for differences in average wetted channel widths in these areas.

Channel widths were measured only at the inlet and outlet for the current study, thus it is also possible that estimates of average width were the source of some of the difference between the two sets of measurements. The wetted side channel width was observed to be quite variable in R39.12, and may have been even more so in long side channels such as R40.21. Different procedures used to estimate average channel width may account for some discrepancies between side channel area measurements.

Palmer Study Segment

Approximately 191,000 ft^2 of wetted side channel habitat is available in the Palmer study segment during high flows (Figure 7-11). All but three of the side channels were at or near bankfull during the high flow survey, conducted at 1,350 cfs. At approximately 4,300 cfs all side channels are bankfull.

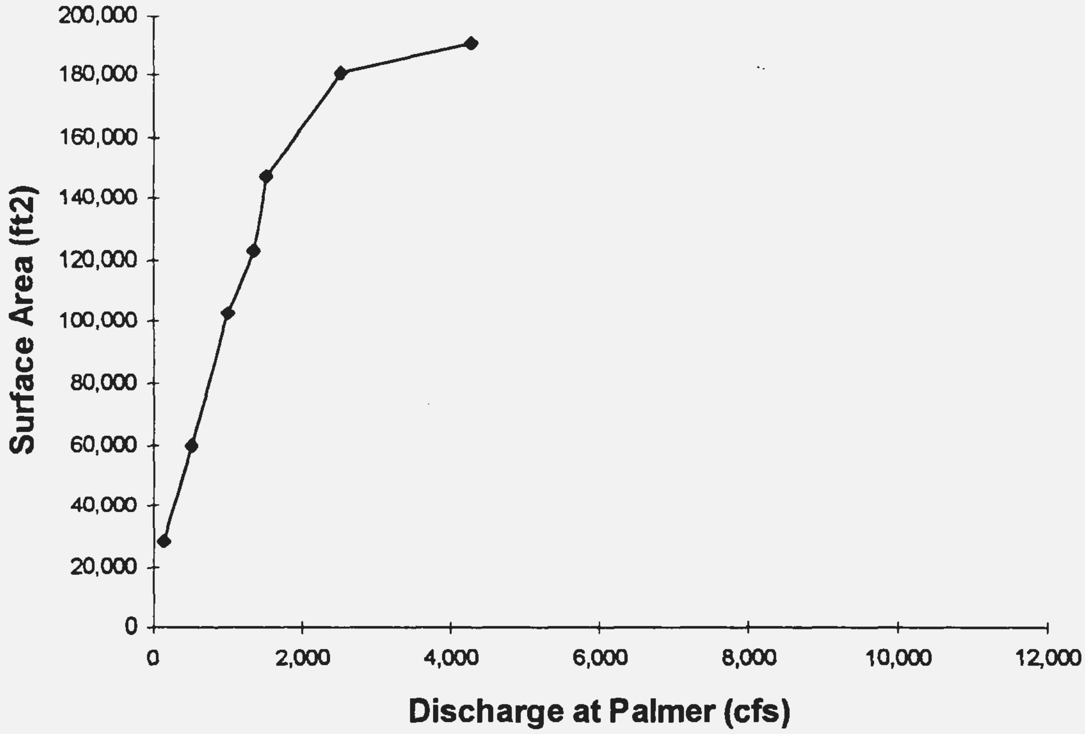


Figure 7-11.

7.4.5 Quantify Changes in the Amount Wetted Side Channel Area, and the Frequency and Duration of Side Channel Connectivity Resulting From Increased Storage Between February 15 and May 30.

The amount of wetted side channel area and the duration and frequency of events which connected side channels to the mainstem via surface flows was estimated using the flow versus area relationships developed in 7.4.4 and the results of hydrologic modeling conducted by CH2MHill (1997). The impact of the proposed AWSP was assessed by comparing each operating scenario with baseline conditions.

a. Magnitude

<u>Middle Green Study Segment</u>
Under Phase I the average daily wetted side channel area experienced a net increase of approximately 39,000 ft^2 for the period of 15 February to 31 May (Figure 7-12a). The amount of wetted side channel area under Phase I ranges from 7,000 to 76,000 ft^2 less than the wetted side channel area under baseline conditions from 15 February to 15 April (Table 7-7, Figure 7-12a). From 15 April to 31 May the wetted side channel area under Phase I is up to 113,000 ft^2 greater than under baseline as a result of both increased baseflows and periodic artificial freshets (Table 7-7, Figure 7-12a).

Under Phase II the average daily wetted side channel area experienced a decrease of approximately 282,000 ft^2 for the period of 15 February to 31 May (Table 7-7, Figure 7-12b). During the early spring (15 February to 15 April) both natural freshets and baseflows may be substantially reduced, particularly during dry years. If water supply conditions allow it, up to four artificial freshets are released in April and May. Baseflows during the late spring (15 April to 30 May) generally equal or exceed those of baseline conditions, prolonging the connectivity of some side channels.

Table 7-7.
Effect of AWSP alternatives on wetted side channel area, 15 February to 31 May, Middle Green River, based on modeled daily flows (1964-1995)

	Baseline	Phase I	Change from Baseline		Phase II	Change from Baseline	
Period	**ft2**	**ft2**	**ft2**	**percent**	**ft2**	**ft2**	**percent**
2/15-2/28	658,000	651,000	(7,000)	-1	604,000	(54,000)	-8
3/1-3/15	571,000	495,000	(76,000)	-14	419,000	(152,000)	-26
3/16-3/31	514,000	460,000	(54,000)	-11	381,000	(133,000)	-24
4/1-4/15	619,000	550,000	(69,000)	-8	477,000	(142,000)	-19
4/16-4/30	495,000	567,000	72,000	+15	579,000	84,000	+17
5/1-5/15	510,000	623,000	113,000	+24	588,000	78,000	+19
5/16-5/31	495,000	555,000	60,000	+16	531,000	37,000	+12
Net change:			39,000	21		(282,000)	-29

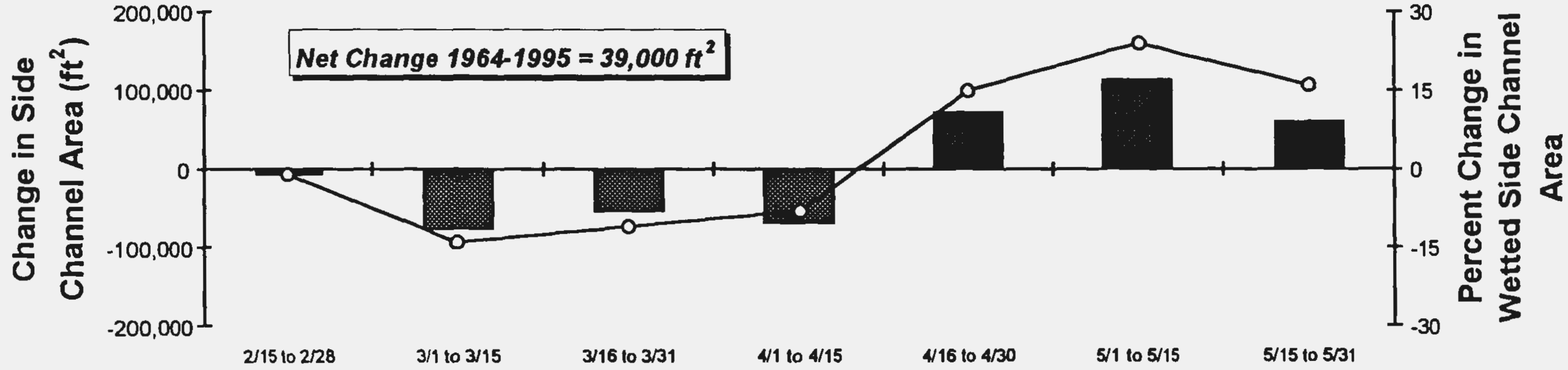


Figure 7-12a. Phase I.

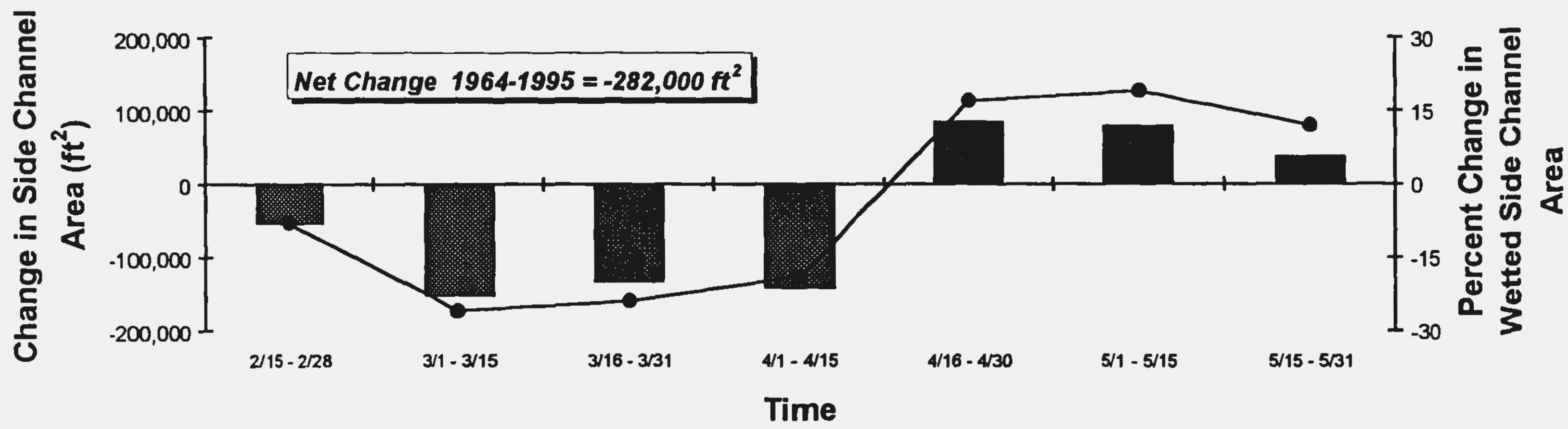


Figure 7-12b. Phase II.

Palmer Study Segment

The proposed Phase I operating scenario results in a net increase of approximately 6,000 ft^2 in the average daily wetted side channel area between 15 February and 31 May (Figure 7-13a). As noted for the Middle Green Reach, the average daily wetted side channel area decreases from mid-February through mid-April, then increases through the end of May as a result of increased baseflows and artificial freshets (Table 7-8, Figure 7-13a).

Under Phase II, the average daily wetted side channel area in the Palmer segment decreases by approximately 85,000 ft^2 from baseline (Figure 7-13b). During the early spring, both baseflows and natural freshets may be substantially reduced, particularly during dry years (Table 7-8, Figure 7-13b). If water supply is sufficient, up to four artificial freshets are released in late April and May. Baseflows during the late spring generally equal or exceed those of baseline conditions, prolonging the connectivity of some side channels.

Table 7-8.
Effect of AWSP alternatives on wetted side channel area, 15 February to 31 May, Palmer Segment, based on modeled daily flows (1964-1995)

	Baseline	Phase I	Change from Baseline		Phase I	Change from Baseline	
Period	ft2	ft2	ft	percent	ft2	ft	percent
2/15-2/28	91,000	90,000	(2,000)	-2	78,000	(13,000)	-15
3/1-3/15	82,000	67,000	(19,000)	-27	43,000	(39,000)	-47
3/16-3/31	76,000	61,000	(15,000)	-21	41,000	(35,000)	-44
4/1-4/15	101,000	90,000	(11,000)	-8	63,000	(38,000)	-32
4/16-4/30	82,000	96,000	14,000	+22	99,000	17,000	+23
5/1-5/15	87,000	113,000	26,000	+36	104,000	17,000	+21
5/16-5/31	83,000	96,000	13,000	+26	89,000	6,000	+17
Net change:			**6,000**	**26**		**(85,000)**	**-77**

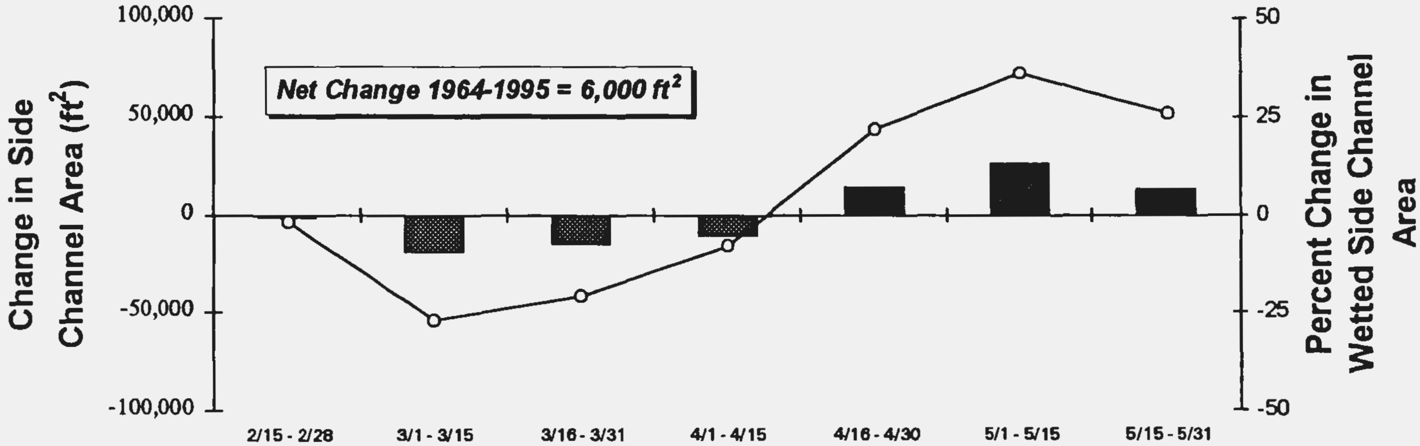


Figure 13a. Phase I.

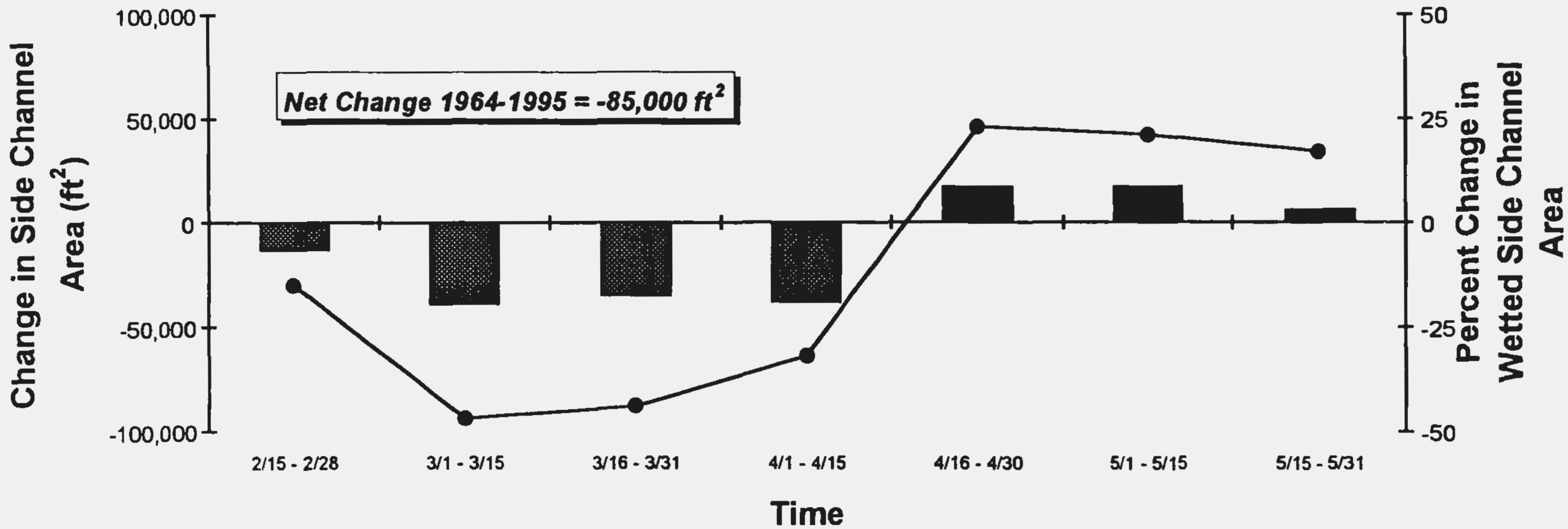


Figure 13b. Phase II.

b. Duration

Middle Green Study Segment
Chum salmon are a major species of concern in the lower Green River. The fish utilize side channels for spawning and rearing, and may suffer decreased survival if redds are dewatered or if outmigration of young fish is delayed because they are trapped in disconnected side channels. The impact of the AWSP on chum incubation was assessed by quantifying the amount of side channel habitat that remains continuously wetted throughout the chum incubation season, 1 January to 30 April.

Under baseline conditions, the two days of lowest flow during the chum incubation season was highly variable, ranging from 246 to 1,030 cfs. The amount of continuously wetted side channel area associated with these flows ranged from 96,000 to 372,000 ft^2, averaging approximately 275,000 (Table 7-9). The two-day low flow occurred in January and February in 18 out of the 32 years of record.

The average amount of continuously wetted side channel area increased slightly under Phase I, to approximately 278,000 ft^2 (Table 7-9). As under baseline, inter-annual variation was high, ranging from 96,000 to 400,000 ft^2. In general, flows decreased slightly during late February and March, but increased in April and May. Because of the late season flow increases, low flows in January and February determined the amount of continuously wetted side channel habitat in 21 out of the 32 years. The two-day low flow increased slightly in eight years, and decreased slightly in six years (Table 7-9).

Palmer Study Segment
While chum salmon do not spawn and rear upstream of the Green River Gorge, other species likely utilize side channels in the Palmer Segment for rearing and refuge during the late winter and early spring. Variation in the amount of continuously wetted side channel habitat in the Palmer segment increased slightly over baseline under the proposed Phase I operating rules, and decreased slightly under Phase II.

Table 7-9.
Side channel area that remains continously wetted throughout the chum salmon incubation period (1 January to 30 April) Middle Green Segment Green River Washington, 1964-1995

Year	BASELINE High of 2-day Low flow, Auburn gage, Jan-April	BASELINE Month of Low flow	BASELINE Continuosly wetted side channel area	PHASE I High of 2-day Low flow, Auburn gage, Jan-April	PHASE I Month of Low flow	PHASE I Continuosly wetted side channel area	PHASE II High of 2-day Low flow, Auburn gage, Jan-April	PHASE II Month of Low flow	PHASE II Continuosly wetted side channel area
1964	1,019	Mar	369,521	841	Mar	321,355	750	Mar/Apr	296,730
1965	897	Jan	336,508	750	Mar/Apr	296,730	750	Mar/Apr	296,730
1966	687	Feb	279,682	687	Feb	279,682	687	Feb	279,682
1967	900	Mar/Apr	337,320	750	Mar/Apr	296,730	750	Mar/Apr	296,730
1968	696	Apr	282,118	730	Mar	291,318	730	Mar/Apr	291,318
1969	680	Mar	277,788	680	Mar	277,788	680	Mar	277,788
1970	689	Jan	280,223	689	Jan	280,223	689	Jan	280,223
1971	792	Jan	308,095	792	Jan	308,095	750	Apr	296,730
1972	1,030	Apr	372,498	1,131	Apr	399,829	900	Apr	337,320
1973	443	Apr	173,080	575	Apr	249,375	575	Apr	249,375
1974	838	Jan	320,543	838	Jan	320,543	838	Jan	320,543
1975	900	Apr	337,320	900	Mar/Apr	337,320	900	Mar/Apr	337,320
1976	900	Mar	337,320	750	Mar	296,730	750	Mar/Apr	296,730
1977	492	Jan	192,224	492	Jan	192,224	492	Jan	192,224
1978	696	Mar	282,118	720	Jan	288,612	720	Jan	288,612
1979	517	Jan	233,680	517	Jan	233,680	517	Jan	233,680
1980	778	Jan	304,307	778	Jan	304,307	778	Jan	304,307
1981	554	Feb	243,692	554	Feb	243,692	554	Feb	243,692
1982	720	Jan	288,612	720	Jan	288,612	720	Jan	288,612
1983	566	Apr	246,940	640	Jan	266,964	640	Jan	266,964
1984	900	Apr	337,320	863	Mar	327,308	863	Mar	327,308
1985	526	Feb	236,116	526	Feb	236,116	526	Feb	236,116
1986	573	Apr	248,834	641	Jan	267,235	640	Mar	266,964
1987	693	Jan	281,306	693	Jan	281,306	693	Jan	281,306
1988	246	Jan	96,112	246	Jan	96,112	246	Jan	96,112
1989	809	Feb	312,695	809	Feb	312,695	809	Feb	312,695
1990	767	Jan	301,330	767	Jan	301,330	767	Jan	301,330
1991	842	Jan	321,625	842	Jan/Mar	321,625	800	Apr	310,260
1992	373	Apr	145,731	573	Jan	248,834	573	Jan	248,834
1993	471	Jan	184,020	471	Jan	184,020	471	Jan	184,020
1994	577	Feb	249,916	577	Feb	249,916	577	Feb	249,916

1995	726	Apr	290,236	750	Apr	296,730	750	Apr	296,730
Average	697		275,276	697		278,032	684		274,591

c. Frequency

Side channel area that is wetted only temporarily still provides salmonids with rearing and refuge habitat during high flows. Overwintering fish and emerging chum fry may be trapped in side channels as the mainstem flow level drops. Periodic freshets temporarily re-connect such side channels, allowing young fish egress. Flow exceedance values calculated for each half-month period were used to assess changes in the general frequency of side channel connectivity (Table 7-10). The 95 percent exceedance flow, that flow which is exceeded 95 percent of the time during the half-month period (14 of the 15 days), decreased by approximately 5 to 15 percent during March and early April under both Phase I and Phase II, then increased by up to 30 percent during late April and May. Changes in the 95 percent exceedance flow are representative of changes in baseflow conditions which maintain continuously wetted side channel areas, and follow the patterns described in Section 5.3.2.

The largest changes generally occurred in the 50 percent exceedance flow (the flow exceeded for approximately 7 days during the half-month period) (Table 7-10). Under the Phase I operating scenario, the 50 percent exceedance flow decreased by almost 25 percent during March. The impact of Phase II was even greater, resulting in a decrease of almost 50 percent. In late April and May, the 50 percent exceedance flow increased, by 12 to 30 percent under Phase I, and by approximately 20 percent under Phase II.

The largest flows for each half-month period (that flow exceeded only 5 percent of the time, or 1 of the 15 days) did not change as dramatically as moderately high flows (Table 7-10). In the early spring, the 5 percent exceedance flow decreased by less than 10 percent under Phase I, and by only 10 to 20 percent under Phase II. During the late spring, the average highest daily flow for each half month period increased by approximately 10 percent under both Phase I and Phase II.

Another way of quantifying changes in the amount of temporary wetted side channel area is to identify the number of days a give flow occurs under each operating scenario (Table 7-11). Using 1,800 cfs (approximately equivalent to the 25 percent exceedance flow in the spring under baseline conditions) as an example, the number of days side channels wetted at flows less than or equal to 1,800 cfs were connected to the mainstem was essentially unchanged in February under either operating scenario. In March, under Phase I, the amount of time those side channels are wetted drops from 7 to 5 days.

Table 7-10.
Percent exceedance flow by half-month period, Green River at Auburn, Washington (1964 to 1995)
(Source: CH2MHill, 1997)

CFS	95 % Exceedance			75 % Exceedance			50 % Exceedance			25 % Exceedance			5 % Exceedance		
	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II
01/01 to 01/15	530	530	530	810	810	810	1,240	1,240	1,240	2,211	2,211	2,211	5,397	5,397	5,397
01/16 to 01/31	634	634	634	991	991	991	1,561	1,561	1,561	2,941	2,941	2,941	6,612	6,612	6,612
02/01 to 02/15	591	591	591	934	934	931	1,410	1,410	1,410	2,254	2,254	2,235	4,146	4,146	4,143
02/16 to 02/28	680	680	680	972	972	900	1,558	1,558	1,363	2,305	2,305	2,125	7,379	7,379	7,199
03/01 to 03/15	746	710	704	1,039	805	750	1,409	1,098	896	1,889	1,586	1,190	3,744	3,441	2,969
03/16 to 03/31	758	675	652	900	785	750	1,231	1,035	875	1,656	1,478	1,030	2,800	2,620	2,443
04/01 to 04/15	520	575	575	1,070	900	750	1,638	1,436	850	2,206	2,004	1,456	3,253	3,053	2,887
04/16 to 04/30	605	692	655	900	977	1,044	1,256	1,408	1,506	1,681	1,877	2,011	2,461	2,621	2,706
05/01 to 05/15	570	721	679	892	1,227	1,026	1,215	1,601	1,455	1,743	2,312	2,106	2,890	3,335	3,235
05/16 to 05/31	430	532	574	782	900	833	1,204	1,361	1,248	1,745	2,089	1,982	2,899	3,038	2,937
06/01 to 06/15	350	432	492	605	607	561	921	921	920	1,519	1,519	1,480	3,126	3,126	3,126
06/16 to 06/30	416	350	400	531	493	488	757	610	586	1,145	1,012	1,000	2,079	2,046	2,046
07/01 to 07/15	282	283	280	350	350	368	442	442	440	639	639	623	1,070	1,070	1,070
07/16 to 07/31	250	250	250	300	300	300	350	350	350	426	426	420	790	790	790
08/01 to 08/15	250	250	250	300	300	300	300	300	300	391	391	350	474	474	440

CFS	95 % Exceedance			75 % Exceedance			50 % Exceedance			25 % Exceedance			5 % Exceedance		
	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II	Base-line	Phase I	Phase II
08/16 to 08/31	250	250	250	300	300	300	300	300	300	350	350	399	469	469	477
09/01 to 09/15	250	250	250	250	250	300	300	300	350	400	400	423	528	528	700
09/16 to 09/30	250	250	250	250	250	300	300	300	400	397	397	438	972	972	915
10/01 to 10/15	226	229	400	263	263	400	350	350	428	440	440	456	1,029	1,029	1,081
10/16 to 10/31	225	225	400	300	300	400	396	396	450	668	668	677	1,900	1,900	1,981
11/01 to 11/15	264	264	308	476	476	491	827	827	855	1,604	1,604	1,654	4,146	4,146	4,202
11/16 to 11/30	350	350	400	699	699	752	1,157	1,157	1,211	1,911	1,911	1,965	4,688	4,688	4,742
12/01 to 12/15	536	536	569	996	996	1,039	1,583	1,583	1,627	2,586	2,586	2,579	7,648	7,648	7,657
12/16 to 12/31	531	531	551	873	873	929	1,316	1,316	1,372	2,132	2,132	2,188	5,468	5,468	5,524

Table 7-11.
Number of days flow exceeds 1800 cfs at Auburn, March-May, based on modeled flows (Source: CH2MHill 1997)

Year	March			April			May		
	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II	Baseline	Phase I	Phase II
1964	5	2	1	12	12	4	20	23	19
1965	7	2	1	11	11	7	0	2	1
1966	5	2	0	15	13	8	7	10	8
1967	0	0	0	0	0	0	6	16	6
1968	5	3	0	0	0	0	0	0	0
1969	4	1	0	22	19	10	21	23	20
1970	0	0	0	5	5	2	5	10	5
1971	5	3	0	9	8	2	26	30	23
1972	29	27	26	15	12	5	26	28	25
1973	0	0	0	0	0	0	0	0	0
1974	15	14	3	28	29	11	23	31	19
1975	10	7	5	0	1	0	23	24	16
1976	0	0	0	11	12	2	16	19	16
1977	0	0	0	5	3	0	0	0	0
1978	0	0	0	0	0	0	0	5	0
1979	13	12	6	7	5	4	5	11	6
1980	8	6	3	20	18	10	0	5	1
1981	0	0	0	7	8	4	0	1	0
1982	13	8	7	0	1	1	7	19	4
1983	8	7	2	3	1	2	0	2	1
1984	10	9	3	6	5	2	16	25	10
1985	0	0	0	19	18	9	4	9	6
1986	13	5	1	0	1	0	2	5	2
1987	15	12	7	7	7	4	1	3	2
1988	10	9	5	22	23	17	5	11	5
1989	9	3	0	24	26	17	1	5	2
1990	23	11	4	19	17	7	2	7	4
1991	10	3	0	10	13	2	2	4	2
1992	0	0	0	1	1	1	0	0	0
1993	8	6	2	10	10	1	12	15	8
1994	8	6	5	7	3	2	0	1	1
1995	1	0	0	0	0	1	0	2	1
Avg	**7.3**	**4.9**	**2.5**	**9.2**	**8.8**	**4.2**	**7.2**	**10.8**	**6.7**

Table 7-12.
Number of flow events in the Green River greater than or equal to 2,500 cfs at Auburn. One flow event is defined as a single continuous flow exceeding the specified value without regard to duration.

	Baseline					Phase I					Phase II				
Year	Feb	Mar	Apr	May	Total	Feb	Mar	Apr	May	Total	Feb	Mar	Apr	May	Total
1964	1	1	2	2	6	1	1	1	4	7	1	1	2	3	7
1965	3	0	1	0	4	3	0	2	2	7	3	1	2	1	7
1966	0	1	2	2	5	0	1	2	3	6	0	0	3	2	5
1967	4	0	0	2	6	4	0	0	3	7	4	0	0	2	6
1968	2	1	0	0	3	2	1	0	0	3	2	0	0	0	2
1969	0	1	4	3	8	0	0	3	4	7	0	0	4	4	8
1970	1	0	1	0	2	1	0	1	2	4	1	0	2	1	4
1971	2	0	0	4	6	2	0	0	4	6	2	0	2	3	7
1972	2	1	2	4	9	2	1	1	4	8	2	2	3	3	10
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	2	3	2	2	9	2	1	3	3	9	1	1	4	4	10
1975	2	1	0	3	6	2	1	0	4	7	2	1	0	3	6
1976	1	0	1	2	4	1	0	2	3	6	0	0	2	2	4
1977	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
1979	1	1	0	0	2	1	1	1	2	5	1	2	2	1	6
1980	2	1	2	0	5	2	0	3	1	6	2	1	5	1	9
1981	1	0	1	0	2	1	0	1	0	2	1	0	1	0	2
1982	2	1	0	0	3	2	1	0	2	5	2	2	1	1	6
1983	1	2	0	0	3	1	1	0	2	4	0	1	2	1	4
1984	2	2	0	0	4	2	1	0	5	8	1	1	2	2	6
1985	0	0	3	0	3	0	0	5	2	7	0	0	3	1	4
1986	1	1	0	1	3	1	0	0	1	2	1	0	0	1	2
1987	1	3	0	0	4	1	3	0	2	6	1	2	2	1	6
1988	1	1	2	2	6	1	2	2	4	9	1	1	4	3	9
1989	1	0	2	0	3	1	0	2	2	5	1	0	2	1	4
1990	3	1	1	0	5	3	0	1	2	6	2	1	2	1	6
1991	2	0	1	0	3	2	0	1	1	4	2	0	1	1	4
1992	1	0	1	0	2	1	0	1	0	2	1	0	1	0	2
1993	0	1	1	1	3	0	1	1	3	5	0	1	2	4	7
1994	0	1	0	0	1	0	1	0	1	2	0	2	2	1	5
1995	2	0	0	0	2	2	0	0	2	4	2	0	1	1	4
Total	**41**	**24**	**30**	**28**	**123**	**41**	**17**	**34**	**70**	**162**	**36**	**20**	**57**	**49**	**162**
Avg.	**1.3**	**0.8**	**0.9**	**0.9**	**4**	**1.3**	**0.5**	**1.1**	**2.2**	**5**	**1**	**1**	**2**	**2**	**5**

The Phase II decrease is even more pronounced, from 7 to less than 3 days. In May, the number of days side channels with an SZF greater than 1,800 cfs are wetted increases by more than 3 days under Phase I, and is essentially unchanged under Phase II. The interannual variability is high under all operating scenarios. In general, early season decreases were greater in wet than dry years because few flows exceeded 1,800 cfs in dry years even under baseline conditions. Late season increases were largest in moderate and wet years when sufficient water was available to supplement baseflows and release freshets.

The number of freshets (defined as flows greater than or equal to 2,500 cfs) increased under both Phase I and Phase II (Table 7-12). Natural freshets in the early spring (February and March) were generally allowed to pass, but the magnitudes were reduced slightly, resulting in a decrease in the number of freshets in eight of the 32 modeled years. Artificial freshets were released in April and June in all but the driest years, resulting in an average total increase of approximately two freshets per year.

7.5 DISCUSSION

7.5.1 Locate and Describe Existing Active Side Channel Habitat

This study focused on locating and surveying active side channels, defined as those side channels which frequently become connected to the mainstem under the current flow regime. A total of 59 side channels were identified; 48 in the Middle Green study segment and 11 in the Palmer study segment. King County had previously identified 28 side channels in the Middle Green segment (RM 33.8 to RM 47.4), eight of which were cut off from the river by levees, roads and farms (Fuerstenberg et al. 1996). The KCSWM reconnaissance generally did not include active secondary or backbar channels, although such sites are known to function as side channels and provide important salmonid habitat (Coccoli 1996).

7.5.2 Determine Flows at Which Active Side Channel Habitat Becomes Connected

The flow at which side channels in the Green River became connected to the mainstem was estimated by identifying the stage of zero flow at the inlet crest. Ideally, a mainstem stage: discharge relationship would be developed at each individual side channel inlet, however this requires numerous visits to each side channel inlet at a variety of flows. Reliable stage:discharge relationships developed for portions of the mainstem should provide a reasonable surrogate for individual relationships.

The stage of zero flow in individual side channels may also vary quite dramatically over time due to transient blockages. Log jams, herbaceous vegetation and gravel berms were all observed to influence the mainstem discharge at which side channels actually became wetted in our study segments. The influence of these features varies by flow stage, complicating the already complex relationship between mainstem and side channel flow. Large flows may periodically alter such blockages, by washing out log jams and vegetation or by depositing additional sediment and forming new jams. Because of the dynamic nature of the Green River system, site-specific data collected for the current study may only be valid until the next flood event. However, because numerous side channels were included in the data set, the accuracy of general conclusions and relationships between mainstem flow and wetted side channel area are expected to remain representative over the short term.

Over the long-term, changes in the sediment supply regime initiated by construction of Howard Hanson Dam could result in the advancement of armor layer formation and downcutting. If that occurs, stage:discharge relationships throughout the study reach could be affected, dramatically changing the relationship between mainstem flow and wetted side channel area. The implications of the altered sediment supply are discussed in detail in Madsen and Beck (1997).

A major assumption of the current study is that side channels become fully wetted and accessible to fish when flow in the mainstem exceeds the side channel SZF. Data was collected only at the inlet and outlet of each side channel, thus blockages that prevent continuous flow throughout the side channel may have been missed. In addition, the depth of water required to allow access is expected to vary by the species and age of fish attempting to enter or leave the side channel. For example, Coccoli (1997) noted that at a depth of at least one inch was required between deeper pools for chum salmon fry to leave side channel L39.45. In addition, a number of the channels appear to receive subsurface inflows, which may alter the stage at which they become disconnected from the mainstem.

7.5.3 Estimate the Importance of Subsurface Flow in Maintaining Side Channel Connectivity

Data collected during the fall 1996 surveys indicate that a number of channels receive subsurface inflow. The contribution of subsurface flow is expected to be lowest during the fall, and highest during the spring, when soil moisture is high, and bank and groundwater storage has been replenished. Data collected at four side channels in early 1996 confirms the expectation of higher springtime subsurface flow contributions. In that study, side channel L39.45 was connected to the mainstem by subsurface outflow at 858 cfs (Coccoli 1996). Just a trickle of subsurface outflow was observed in the same channel at approximately 1,800 cfs in late October 1996. Quantifying the amount of mainstem flow required to maintain a given subsurface discharge the contribution of subsurface flow is difficult. The rate of intragravel flow is expected to have a longer lag time than surface flows in the mainstem, but will decline over time. The lag time likely varies seasonally as well.

Different types of side channel receive subsurface flows from different sources. Wallbase channels, defined as abandoned channel located along the base of a steep slope, receive flow from groundwater seeps, when subsurface moving laterally along the hillslope emerges at the base. Abandoned channels located on the floodplain likely receive subsurface flow from both groundwater and intragravel sources. The proportion of flow attributable to each source probably varies seasonally. Backbar and secondary channel receive subsurface flow primarily from intragravel flow, and thus should exhibit the strongest correlation with mainstem flow.

7.5.4 Develop a Relationship Between Wetted Side Channel Area and Mainstem Flow

Significant differences were noted between detailed data collected at four side channels in the spring of 1996 (Coccoli 1996) and the estimates of wetted area at comparable flows derived from the current study. While there are several potential explanations for these differences (Section 4.4) the implication is that the current study may underestimate the amount of wetted side channel area in the Green River during the spring.

One of the primary assumptions of the current study was that wetted area was representative of available habitat. Observations made during the survey suggest that this is not always the case however. The quality and type of habitat varied widely between the side channels. In some cases, side channels supported dense stands of herbaceous vegetation growing on very fine substrate. Such side channels would provide valuable rearing and refuge habitat, but are unsuitable for spawning. Other side channels provided excellent spawning habitat, but little cover and few pools. In addition, the amount of available habitat depends a great deal on the mainstem flow levels. Velocities in several of the side channels were greater than 2.0 feet per second at 1,800 cfs, and habitat for juvenile fish was limited to the channel margins. Future monitoring work should identify the type of habitat provided by each side channel at various flows in order to improve understanding of the true impacts of the AWSP.

7.5.5 Quantify Changes in the Amount Wetted Side Channel Area, and the Frequency and Duration of Side Channel Connectivity Resulting From Increased Storage Between February 15 and May 30.

The purpose of the impact analysis was to determine how implementation of Phases I and II of the AWSP would affect side channel habitat relative to baseline conditions (defined as 1996 operating scenario with second supply pipeline in place), rather than to determine how the flow regime under each alternative differs from pre-Howard Hanson dam conditions.

The total amount of continuously wetted habitat does not change significantly under either Phase I or Phase II. This area is believed to represent habitat capable of sustaining chum salmon redds throughout the incubation and emergence period. The amount of continuously wetted side channel habitat identified by this study likely underestimates the actual amount, as springtime subsurface flows, known to sustain water levels in some side channels, were not accounted for in data collected during the fall of 1997. Future monitoring efforts should focus on refining the estimate of continuously wetted habitat and clarifying the relationship between subsurface outflows and mainstem discharge.

Phase I of the AWSP results in an overall increase in the average amount of wetted side channel habitat between 15 February and 31 May. Naturally occurring high flows are reduced slightly in the early spring, resulting in a loss of rearing habitat. Periodic freshets are released in April and May when sufficient water is available, and it is believed that these freshets will facilitate egress and downstream migration of juvenile salmonids that might otherwise remain trapped in side channels as flows decline. Predictable flood pulses have been shown to be beneficial to aquatic communities (Bayley 1991) and would also benefit recreational users of the Green River.

The amount of temporarily wetted habitat decreases significantly in the early spring, under Phase II. This could result in a sizable decline in the amount of rearing habitat available to juvenile salmonids in March and early April. Monitoring to identify those areas actually used by juvenile fish is recommended to better define the impacts of implementing Phase II.

7.6 LITERATURE CITED

Cardinal, Patty. U.S. Army Corps of Engineers. Personal communication, meeting with Susan Madsen (Beak) on 24 September 1996.

Coccoli, H.A. 1996. Effects of springtime flow alteration on side channel habitat in the Green River. MS Thesis, University of Washington, Seattle WA. 78 p.

Coccoli, H.A., 1997. Fisheries biologist, Muckleshoot Indian Tribe. Personal communication, telephone conversation with Susan Madsen (Beak) on 9 January 1997.

Dunne, T., and W.E. Dietrich, 1978. Geomorphology and hydrology of the Green River. Appendix A in: Jones and Jones, 1978. A river of Green. Report to King County.

Fuerstenberg, R.F., Surface Water Management Division, King County Department of Natural Resources. Personal communication, meeting with Susan Madsen, Phil Hilgert (Beak) 12 August 1996.

Fuerstenberg, R.F., K. Nelson and R. Blomquist, 1996. Ecological conditions and limitations to salmonid diversity in the Green River, Washington, U.S.A. Structure, functiona and process in river ecology. Draft report, Surface Water Management Division, King County Department of Natural Resources, Seattle, WA. 31 p.

Gilbrough, Noel. U.S. Army Corps of Engineers. Personal communication, field trip with Susan Madsen, 29 October, 1996.

Harper Righellis, Inc. 1996. King County Flood Boundary Work Map, Green River Sheets 1-9. Prepared for King County Surface Water Management Division.

Kondolf, G.M. and W.V.G. Matthews, 1993. Management of coarse sediment on regulated rivers. Report No. 80, ISSN 0575-4968. California Water Resources Center, University of California, Berkeley, CA. 128 p.

Loper, Clint, 1996. Hydrologist, King County Surface Water Management Division. Personal communication with Susan Madsen (Beak), 25 November 1996.

Madsen, S.W. and S.M. Beck. 1997. Howard Hanson Dam Additional Water Storage Project: gravel nourishment opportunities in the lower Green River. Draft Consultant Report prepared for Tacoma Public Utilities and the U.S. Army Corps of Engineers. Beak Consultants Inc., Seattle WA. 10 p.

Perkins, S.J., 1993. Green River Channel Migration Study. King County Department of Public Works, Surface Water Management Division, Seattle, WA. 46 p.

Table 7. Comparison of DSW (Dewatered Spawnable Channel Width) for the Baseline, Phase I and Phase II conditions using 1974 hydrologic data

1974
Wet Spring, Average Summer

Spawning Intervals	Baseline	Phase I	Phase II
3/1-3/15	-	-	-
3/16-3/31	0.14	0.29	0.29
4/1-4/15	0.49	-	-
4/16-4/30	-	-	-
5/1-5/15	-	0.55	0.27
5/16-5/31	20.99	21.72	21.29
6/1-6/15	121.32	121.32	122.21
6/16-6/30	74.79	65.18	70.74
Total	217.74	209.05	214.81
Daily Av (ft)	1.78	1.71	1.76
Daily Av (in)	21.42	20.56	21.13

Table 8. Comparison of DSW (Dewatered Spawnable Channel Width) for the Baseline, Phase I and Phase II conditions using 1985 hydrologic data

1985
Average Spring / Average Summer

Spawning Intervals	Baseline	Phase I	Phase II
3/1-3/15	-	-	-
3/16-3/31	-	-	-
4/1-4/15	49.83	22.47	1.85
4/16-4/30	6.80	5.85	7.97
5/1-5/15	-	15.77	8.20
5/16-5/31	44.97	63.44	48.29
6/1-6/15	49.39	49.39	36.75
6/16-6/30	3.65	0.01	-
Total	154.64	156.93	103.05
Daily Av (ft)	1.27	1.29	0.84
Daily Av (in)	15.21	15.44	10.14

SECTION 8 FISH MITIGATION AND RESTORATION PLAN SUMMARY

NOTE TO READERS: *At the original writing of this Appendix F, Part 1, the discussion reflected the HHD AWS Project, and potential impacts, at mid-1997. During the fall of 1997, negotiations with resource agencies and tribal representatives resulted in a change in the project. The project now includes storage under Section 1135 of 5,000 ac-ft on a yearly basis beginning in Phase I of the project: previously, the 5,000 ac-ft was considered a 1-in-5 year event until initiation of Phase II when it would become yearly. Part F1 has been revised to reflect this change; however, there may be some omissions. These omissions, if any, will be corrected in the final edition.*

An exception to this is modeling. Modeling was conducted with Phase I only having drought year storage of the 5,000 ac-ft, and re-modeling will not be conducted for this change.

8.0 EXECUTIVE SUMMARY

The purpose of this report is to summarize impacts related to storing 32,000 ac-ft of water for low-flow augmentation and municipal and industrial water supply, and to identify mitigation projects that address these impacts and restoration projects that address effects from original dam construction. Aspects of the basin ecosystem, Duwamish-Green River, will be discussed to identify selected opportunities that the AWSP can address as restoration projects. The goals of the AWSP for aquatic resources are:

1. to have no net loss of lower watershed habitat while maintaining existing anadromous salmonid populations,
2. restore selected aquatic habitat limiting factors of the lower watershed, and
3. restore natural, self-sustaining runs of anadromous salmonids in the Headwaters watershed.

As related to goal no. 1 and no. 3, five unavoidable adverse impacts requiring mitigation were identified under the AWSP feasibility study resulting from storing an additional 32,000 ac-ft during the winter and spring. These impacts are found in two distinct areas: 1) within the HHD project boundary, at the dam and within the reservoir; and 2) in the lower watershed, from HHD to the estuary. The impacts within the project boundary requiring mitigation are: 1) decreased survival of a proportion of juvenile salmon and steelhead migrating through the larger pool, and 2) stream and riparian habitat inundated by the pool raise. The impacts requiring mitigation in the lower watershed from spring refill are: 1) dewatering of steelhead eggs, 2) reduced survival of outmigrating juvenile salmon and steelhead, and 3) disconnection of side-channel habitat from the mainstem river.

Mitigation projects or sites considered were specific for each project impact. Restoration projects or sites considered addressed specific aquatic habitat limiting factors identified through AWSP scoping or were identified under the Green-Duwamish Ecosystem Restoration General Investigation Study. Table 1 lists all selected habitat mitigation and restoration projects. Table 1-A lists total project construction costs for habitat mitigation and restoration projects. Table I-B lists mitigation and restoration project construction costs by AWSP phases, Phase I and Phase II. Annualized construction and maintenance costs vary by project. A list of all of habitat projects considered under incremental analysis is provided in Appendix Table D-1.

Total construction cost for all habitat projects under mitigation is $2,860,000, restoration cost is $1,461,000. Most mitigation construction costs occur under Phase II as the greater level of impacts occurs during this period: Phase I costs are $935,000, Phase II costs are $1,925,000. All habitat restoration projects occur under Phase I. Phase I mitigation is limited to impacts from inundation of riparian and stream habitat by the pool raise. Phase II mitigation includes additional impact from the pool raise and impacts during spring refill to lower watershed side-channel habitat and instream survival of juvenile salmon.

Reservoir and dam passage mitigation includes a component of restoration through selection of the fish passage facility. The fish passage facility outflow capacity was increased to the maximum volume technically feasible, this increased outflow capacity will greatly improve surface attraction of the facility and should decrease smolt mortality. A combination of flow management and monitoring is also suggested to "optimize" operation of the project so survival of smolts through the project can be maximized. Flow management strategies include: minimizing the storage of water during the peak outmigration period, mid-April to end of May; and releasing periodic artificial freshets or mimicking natural freshets. Monitoring of smolt outmigration and predator distribution is recommended so adaptive measures can be employed to maintain or improve smolt survival.

Four riparian projects were selected to mitigate for 121 acres of riparian habitat area inundated by the AWSP pool raise. These projects include maintenance of stream-corridor habitat within the inundation pool (13.3 acres) and management of riparian forests to accelerate succession on major streams above the project (108.3 acres) for a total of 121.6 acres. Mitigation by phases include 79.2 acres in Phase I and 42.4 acres in Phase II. Project types include: leave of trees in the inundation pool rather than clearing (not counted as a listed project); planting of water-tolerant vegetation; reserve of riparian forests at 5 acres to 1 acre impacted; and intensified forest management – thinning and planting. The mitigation impact amount was dependent on defining the riparian area, the definition was provided from the Tacoma Forest Land Management Plan.

Nine tributary or stream projects were selected to mitigate for 17.4 acres of stream habitat area inundated by the AWSP pool raise. These projects include maintenance of in-stream habitat within the inundation pool (8.1 acres) and improvement of habitat in streams above the project (8.8 acres) for a total of 16.9 acres. Mitigation by phases includes 11.2 acres in Phase I and 5.7 acres in Phase II. These projects do not equal the total 17.4 acre mitigation requirement, but additional compensation can be found through leave of trees in the inundation zone or under the two habitat restoration projects above and below the project. Stream habitat mitigation project types include: placement of large structures (boulders or logs) to increase habitat complexity; replacement of culverts reconnecting tributary habitat; creation of side-channel or pond habitat through excavation.

Four side-channel projects were selected to mitigate for 8.4 acres of wetted side-channel habitat impacted under Phase II. There was no identified loss of wetted side-channel habitat area under Phase I. Middle Green River side-channel impact area was 6.4 acres, Upper Green River area was 2.0 acres. Three of the projects are in the Middle Green River and one project is in the Upper Green River. A portion of the benefits of gravel nourishment, a restoration measure, was included to fully compensate for the side-channel impact. These projects also compensate for the estimated 5% mortality of juvenile chum salmon.

Spring refill baseflow targets,, reduction in artificial freshet volume, additional augmentation of baseflows in June, and lowflow augmentation are several options that can compensate for Phase I impacts to steelhead redd and egg desiccation. Under Phase I, there is an increase in the amount of channel width that is dewatered for 48 hours or more over the 50 day egg incubation period. Under Phase II there is no loss in the amount of wetted channel width. Hydrologic modeling identified maximum winter and spring baseflow targets that could be maintained during the steelhead spawning and egg incubation period under one refill and flow release strategy. These baseflows appear to avoid most of the potential impacts from flow reduction. Additional protection and/or compensation can be provided in Phase I by 1) reducing freshet volume, and 2) increasing instream flows at the end of the spring refill period during June. In Phase II, flow augmentation during the summer and fall low flow period provides additional benefits that can improve steelhead production. Lastly, unaccounted for benefits will accrue to steelhead spawning habitat during Phase I and II from maintenance of Middle Green River habitat through gravel nourishment.

Fish passage, summer and fall low flows, sediment transport, and limited stream habitat improvements were identified as restoration opportunities to address aquatic limiting features in the Middle, Upper, and Headwaters watershed. Construction of HHD disconnected the Headwaters from the lower Green River basin by creating a near-complete downstream passage barrier. In association with improvements at the Tacoma Diversion Dam, fish passage improvements at HHD will provide for reconnection of the Headwaters watershed to the lower basin. Water quantity and water quality in the lower river can limit anadromous salmonid production in most years. The storage of late winter and spring flows for flow augmentation during the summer and fall will increase available habitat for rearing and spawning and can improve water quality as well. Sediment transport of gravel sized materials was altered by the construction of HHD and operation of the project to reduce peak flows during flood season. Sediment augmentation (a.k.a. gravel nourishment) in limited areas of the lower watershed will maintain spawning habitat for salmon and steelhead. The construction of HHD resulted in the degradation of Upper

Green River side-channel habitat and inundation of several miles of stream habitat above HHD. Specific habitat improvement projects can improve or restore a portion of this original dam impact.

Nine downstream fish passage alternatives were evaluated for the restoration facility. A unique design, a combined modular incline screen (MIS) and fish lock, was selected as the preferred alternative. This facility has the second greatest outflow capacity of any dam passage facility (400-1250 cfs) and is more technically feasible than the most expensive and greatest capacity alternative, a dual lock/MIS facility. If this facility can be realized, it should provide dam passage survival of over 95% and in combination with the Tacoma Diversion Dam fish ladder will essentially re-connect the Headwaters watershed to the rest of the Green-Duwamish basin: the Headwaters watershed represents almost 45% of the entire Green River Basin area and stream miles available for use by salmon and steelhead. Without HHD passage improvements, self-sustaining runs of salmon and steelhead cannot be achieved. Smolt production and adult escapement estimates were developed and used as outputs for evaluation of the alternatives.

As originally conceived, Phase II of the project would provide storage of 14,600 ac ft of (during late winter and spring) to augment downstream releases later in the year: since Fall 1997, this storage volume has been reduced to 9,600 ac ft. Effects of storing additional water in the spring are discussed under unavoidable adverse impacts.. Augmenting flows during the summer and early fall alters the flow regime from HHD (RM 64) to the estuary (RM 7) during the period when 1) juvenile salmonids are rearing in the river; 2) steelhead eggs are incubating and fry are emerging, 3) adult chinook and coho salmon are migrating upstream; and 4) chinook salmon are spawning in the river. AWSP flow augmentation can be used to increase summer and fall flows for meeting or exceeding -- 1) minimum flow volumes and depths for adult upstream migration; 2) increasing adult holding habitat; 3) creation of late-summer freshets to draw salmon to preferred upstream spawning areas; 4) meeting preferred fall spawning flows; and 5) potential reduction in stream temperatures that can stress or kill adults, delay spawning, and kill incubating eggs. AWSP flow augmentation can also be used to increase summer baseflows and fall flows which will increase available rearing habitat for juvenile salmon and steelhead with potential improvements in water temperature from increased stream velocities, pool depths, and wetting of side-channel areas (cool-water refugia).

The disruption of sediment transport from the Headwaters watershed due to the interception of almost all course sediment (including gravel) by the original construction of HHD may be causing fundamental changes in the mainstem channel and associated habitats of the Upper to Lower Green River. Gravel nourishment could be used to replenish areas presently deficient of salmon and steelhead spawning-sized sediments and slow or stop the downstream extent of streambed armoring. Three levels of gravel nourishment (3900, 7800, and 11,700 yd^3) were evaluated for the placement in the Middle Green River (RM 46-40.2) under incremental analysis. The smallest amount, 3900 yd^3, was selected based on cost and flood protection impact concerns. To implement this measure, monitoring or sediment transport modeling will be required to evaluate the long-term impacts of this restoration measure. This lowest level of gravel nourishment should maintain 400,00 ft^2 of spawning habitat in the Middle Green River.

In addition to gravel nourishment, two habitat restoration projects were selected to address original impacts of dam construction and pool inundation that impacted over 8 miles of stream and side-channel habitat. A third project was considered but rejected based on cost and limited benefits. One project is a side-channel reconnection in the Upper Green River (below HHD) that will restore up to 3.2 acres of off-channel habitat and the other is 3.5 miles of river and stream habitat improvement in tributaries above the AWSP inundation pool (from 1177 to 1240 ft elevation). These projects will interact with the fish passage restoration facility and should help accelerate re-establishment of Headwaters and Upper Green River salmon and steelhead populations.

TABLE 1. SUMMARY TABLE OF ALL AQUATIC RESTORATION AND MITIGATION MANAGEMENT MEASURES FOR THE HOWARD HANSON DAM ECOSYSTEM RESTORATION AND ADDITIONAL WATER STORAGE FEASIBILITY STUDY.

Project Package Name	Activity Name	Project Number	Mitigation/ Restoration	Location
Howard Hanson Dam Fish Passage	Dam Fish Passage Alternative 4	FP-04	M/R	Howard Hanson Dam, Right Bank, Intake Tower, 1070-1177 ft Elevation
Headwaters Green River Habitat Mitigation	Mainstem and Sunday Creek Habitat Restoration	MS-04	M	Headwaters Mainstem below Sunday Creek Confluence
Headwaters Green River Habitat Mitigation	Tacoma Wildlands Set-asides in Conservation and Natural Forest Zones	MS-08, TR-09	M	Headwaters Floodplain, RM 71.3-80.1, Gale Creek 1240-1280 ft el., N. Fork 1240-1320 ft el.
Howard Hanson Reservoir Mitigation Zone	Mainstem and North Fork Channel Maintenance	MS-02, TR-04	M	Headwaters and North Fork in New Inundation, 1146-1177 ft Elevation
Howard Hanson Reservoir Mitigation Zone	Tributary Stream Channel Maintenance	TR-05	M	Tributaries to Reservoir in New Inundation, 1146-1177 ft Elevation
Page Mill Pond Mitigation	Page Mill Pond and Page Creek Maintenance	VF-05	M	North Fork Green Floodplain, Left Bank, 1147-1185 ft Elevation
Bear Creek Channel Improvement	Lower Bear Creek Stream Restoration	TR-01	M	Lower Bear Creek, Below HHD at RM 64
Headwaters Green River Habitat Mitigation	Headwaters Culvert Replacement	TR-10	M	Three tributaries in Headwaters Watershed, two small tribs and one large tributary
Middle Green River Side Channel Mitigation	Loans Levee Removal and Burns Creek Reconnection	LVF-03	M	Middle Green River Floodplain, Right Bank, RM 37.9-38.1
Middle Green River Side Channel Mitigation	Metzler and O-grady Connector Side Channel Improvement	LVF-04	M	Middle Green River Floodplain, Left and Right, RM 39-40.2
Middle Green River Side Channel Mitigation	Flaming Geyser North: Cutoff Channel Reconnection	LVF-06	M	Middle Green River Floodplain, Right Bank, RM 44.3
Upper Green River Side Channel Mitigation	Brunner Side-Channel Restoration	VF-03	M	Upper Green River Floodplain, Right Bank, RM 58
Howard Hanson Reservoir Restoration Zone	Mainstem, North Fork and Tributary Restoration	MS-03, TR-06, TR-07	R	Headwaters, North Fork, Reservoir Tributaries, 1177-1240 ft Elevation
Upper Green River Side Channel Restoration	Signani Side-channel Reconnection and Restoration	VF-04	R	Upper Green River Floodplain, Left Bank, RM 58.6-59.6.
Mainstem Green River Gravel Nourishment	Middle Green River Gravel Bar Nourishment	LMS-01, LMS-02, LMS-03, LMS-04	R	Middle Green Mainstem, 4 Alternate Locations, RM 40-45
Truck and Haul of Large Woody Debris	Collection and Transport or Reservoir Woody Debr.	MS-09	R	Upper Green River, Left Bank, RM 59-60.3

TABLE 1-A. TOTAL PROJECT CONSTRUCTION COSTS BY HABITAT MITIGATION AND RESTORATION PROJECTS INCLUDING CONTINGENCY BUT NOT EDS&A COST: FISH PASSAGE COST IN COST-ENGINEERING APPENDIX.

Activity Name	Project Number	Mitigation/ Restoration	Estimated Construction Cost
FISH PASSAGE MITIGATION AND RESTORATION			
Dam Fish Passage Altemative 4	FP-04	M/R	See MCACES Estimate
HABITAT MITIGATION PROJECTS AND COST			
Mainstem and Sunday Creek Habitat Restoration	MS-04	M	82,000
Tacoma Wildlands Set-asides in Conservation and Natural Forest Zones	MS-08	M	179,000
	TR-09	M	28,000
Mainstem and North Fork Channel Maintenance	MS-02, TR-04	M	495,000
Tributary Stream Channel Maintenance	TR-05	M	122,000
Page Mill Pond and Page Creek Maintenance	VF-05	M	208,000
Lower Bear Creek Stream Restoration	TR-01	M	64,000
Headwaters Culvert Replacement	TR-10	M	216,000
Loans Levee Removal and Bums Creek Reconnection	LVF-03	M	732,000
Metzler and O-grady Connector Side Channel Improvement	LVF-04	M	167,000
Flaming Geyser North: Cutoff Channel Reconnection	LVF-06	M	359,000
Brunner Side-Channel Restoration	VF-03	M	208,000
HABITAT MITIGATION COST			**2,860,000**
HABITAT RESTORATION PROJECTS AND COST			
Mainstem, North Fork and Tributary Restoration	MS-03, TR-06, TR-07	R	341,000
Signani Side-channel Reconnection and Restoration	VF-04	R	947,000
Middle Green River Gravel Bar Nourishment	LMS-01, LMS-02, LMS-03, LMS-04	R	173,000
Truck and Haul of Collected large Woody Debris	MS-09	R	No Cost[a]
HABITAT RESTORATION COST			**1,461,000**
TOTAL HABITAT MITIGATION AND RESTORATION COST			**4,321,000**

a. There are no costs associated with this project, it is assumed that this will be part of the adaptive management operation plan for the project.

TABLE 1-B. HABITAT MITIGATION AND RESTORATION PROJECT CONSTRUCTION COSTS BY PHASES OF THE AWSP: PHASE I, PHASE II, AND TOTAL COST (INCLUDING CONTINGENCY BUT NOT EDS&A).

PHASE I AND PHASE II COSTS FOR MITIGATION AND RESTORATION				
Project Number	**Mitigation/ Restoration**	**Phase I Cost**	**Phase II Cost**	**Total Project Cost**
FP-04	M/R			
MS-04	M	82,000[a]		82,000
MS-08	M	116350	62,650	179,000
TR-09	M	18200	9,800	28,000
MS-02, TR-04	M	321750	173,250	495,000
TR-05	M	79300	42,700	122,000
VF-05	M	135200	72,800	208,000
TR-01	M	41600	22,400	64,000
TR-10	M	140400	75,600	216,000
LVF-03	M	0	732,000	732,000
LVF-04	M	0	167,000	167,000
LVF-06	M	0	359,000	359,000
VF-03	M	0	208,000	208,000
	HABITAT MITIGATION COST	**934800**	**1,925,200**	**2860000**
MS-03, TR-06, TR-07	R	341,000	0	341,000
VF-04	R	947,000	0	947,000
LMS-01, LMS-02, LMS-03, LMS-04	R	173,000	0	173,000
MS-09	R	**No Cost[b]**	**No Cost**	**XX**
	HABITAT RESTORATION COST	**1,461,000**	**0**	**1,461,000**
	TOTAL HABITAT MITIGATION AND RESTORATION COST	**2,395,800**	**1,925,200**	**4,321,000**

a. Project MS-04 cannot be completed in increments for Phase I and Phase II as most other riparian and stream habitat mitigation projects. As such, all costs are included under Phase I.
b. There are no costs associated with this project, it is assumed that this will be part of the adaptive management operation plan for the project.

8.1 PURPOSE AND SCOPE

8.1.1 Purpose

The purpose of the feasibility phase of planning is to determine if the Howard Hanson Dam Additional Water Storage Project (AWSP) ecosystem restoration study should proceed to the plans and specification phase (PED). This report identifies specific sites required to mitigate for impacts to fish habitat of the AWSP pool raise and storage of 32,000 ac-ft of additional water as well as restoration alternatives and sites required to restore or partially restore selected aquatic habitat functions or habitat areas affected by original construction of HHD. This report addresses the following unavoidable adverse impacts, mitigation, and selected restoration opportunities:

Unavoidable Impacts and Mitigation

- Reservoir Survival of Outmigrating Juvenile Salmon and Steelhead
- Dam Passage of Outmigrating Juvenile Salmon and Steelhead
- Riparian and Tributary Inundation
- Connection of Side-Channel Habitat to the Mainstem River
- Downstream Survival of Outmigrating Juvenile Salmonids
- Steelhead Spawning and Egg Incubation

Restoration Opportunities

- Dam Passage of Juvenile Outmigrant Salmon and Steelhead
- Flow Augmentation for Improved Water Quantity and Water Quality
- Sediment Transport of Gravel-sized Material (Gravel Nourishment)
- Stream Habitat Impacted by Original Dam Construction or Operation

8.1.2 Scope

Mitigation projects are specific to each unavoidable adverse impact. Whenever possible impacts were avoided or minimized to the greatest extent possible. Where impacts were unavoidable, in-kind and in-place mitigation projects were developed and evaluated if possible. If compensation could not be completed in-kind and/or in-place, additional mitigation sites were developed and evaluated to the level necessary for each impact. Restoration projects that were developed and evaluated are specific to impacts resulting from original construction of the dam or its operation. The Green-Duwamish River Ecosystem Restoration General Investigation (Basin Analysis) provided an overview of basin limiting factors including impacts of operation of HHD. The Basin Analysis was used to assist in development of restoration projects.

8.2 INTRODUCTION

Historical Changes to the Duwamish-Green River Ecosystem. The ability of the Duwamish-Green River Basin to sustain significant populations of fish and wildlife has been affected by a series of major actions. In the late 1850s, a steady increase in agricultural practices started to modify and destroy ecosystem components of the lower valley. The Duwamish delta at one time had over 4,000 acres of tidal and intertidal habitat critical to a number of fish and wildlife species. Only 5 percent of the estuary is left today, because the estuary was filled for industrial and shipping purposes with dredge materials from the Corps who constructed and maintained the navigation channels. In the early 1900s, two major actions occurred: the diversion of the White River from the Green River in 1906, and the 1916 diversion of the Black and Cedar rivers from the Duwamish. The Black and Cedar diversions were caused by the Corps project that lowered Lake Washington 9 feet. These two actions reduced the basin of the Duwamish/Green by 70 percent, with a subsequent adverse effect on the anadromous fishery. In 1913 the city of Tacoma completed their water diversion at RM 61 which blocked over 265 miles of mainstream and tributary spawning and rearing areas in the upper river.

The early to mid-1900s saw a steady increase in agricultural development of the basin causing a decline in ecosystem habitats throughout the basin. After a devastating flood in 1958 there was extensive levee construction by the local and federal governments. In 1962 Howard Hanson Dam was completed by the Corps of Engineers. Flood protection provided by the Dam has caused unprecedented growth from Auburn to Tukwila. Billions of dollars of development was brought into the basin. King County began to purchase development rights upstream of Auburn to help save some of the remaining green space. This urban growth caused a continued destruction of tributary streams in the basin and a continuation of destruction of shade, habitat and diversity in the mainstream river. During this period the population of the basin tripled and caused a subsequent degradation of air and water quality.

Construction of Howard Hanson Dam created a second passage barrier to the Headwaters watershed above the Tacoma Diversion Dam and also eliminated the major source of spawning gravel for the spawning habitat left in the mainstem river. Since construction of HHD, reducing high river flows and eliminating a source of sediment, the river now cuts down within its existing banks and affects the river's ability to recruit woody debris, to move in to new gravel rich channels, and isolates side-channel habitat from the mainstem. This affects spawning and rearing habitats for fish and the ecosystem diversity that is present in free flowing rivers.

Historically, the Green-Duwamish River system support large runs of anadromous fish including summer-fall chinook, coho, chum and pink salmon, steelhead trout, small run of spring chinook salmon, and sea-run cutthroat trout and charr, Dolly Varden and bull trout. All of the stocks in the river have seen tremendous declines while Dolly Varden, bull trout, spring chinook, and pink salmon may have been extirpated. Salmon and steelhead escapements o the Green River declined 60% or more between the late 1930's and 1991 (Fuerstenberg et al. 1996). These declines in run-size and escapement can be directly attributed to large habitat loss and degradation within the basin as well as from overfishing.

Besides their importance to the tribal, commercial and recreational fisheries, anadromous fish have been recognized as a critical link in aquatic foodwebs in the Pacific Northwest. They are considered a "keystone" species upon which producers and consumers from the bottom to the top of the food chain depend. Rearing in the rich-ocean waters, adult salmon return to nutrient poor streams with a wealth of ocean nutrients, enriching the food-web from primary producers to top carnivores. At the top of the food web, at least 22 species of wildlife, including black bear, mink, river otter, and bald eagle, feed on salmon carcasses (Cedarholm 1989). At the base of the food web, salmon carcasses provide a significant, if not major amount of nitrogen to streamside vegetation as well as large amounts of carbon and nitrogen to aquatic insects and other macroinvertebrates (Bilby et al. 1996).

AWSP and Ecosystem Restoration. The AWSP presents unique challenges and opportunities to the maintenance and restoration of aquatic habitat within the Duwamish-Green River ecosystem. The AWSP is a multi-objective water-resource development project seeking to improve ecosystem functions within the basin while providing a regional water supply. When it comes to fish and wildlife habitat, these objectives can run counter to each other. As such, the AWSP has two aspects: a mitigation component addressing future impacts of storing 32,000 ac-ft of additional water, and a restoration component addressing existing ecosystem impacts. The mitigation component is linked to the first two goals of the AWSP, to have no net loss of lower watershed habitat while maintaining existing anadromous salmonid populations, and to restore self-sustaining runs of anadromous salmonids in the Headwaters watershed. Mitigation projects will be selected to meet these goals. The restoration component has linked all three goals, the two described above, and a third, restore selected aquatic habitat limiting factors of the lower watershed.

Despite the innumerable problems to restoring the basin ecosystem, the AWSP presents significant opportunities to restore or maintain much of the affected fish and wildlife habitat in this basin. Environmental mitigation and restoration measures include: improvement of downstream fish passage through HHD, augmentation of summer and fall mainstem river flows, side-channel reconnection to the mainstem river, maintenance and creation of wetlands, removal of culverts that block fish passage in tributaries, planting aquatic buffer zones, accelerating succession of wooded uplands (riparian zone) around tributaries and wetlands, installation of large woody debris in the main river channel and tributaries, excavating meanders and pools in tributaries which were artificially straightened, setting back levees from the bank area, importing gravel to the upper mainstem, and managing Headwaters forestland for fish and wildlife habitat. Tacoma, the Corps of Engineers, and cooperating resource agencies have the unique ability under the Corps Ecosystem Restoration Authority to implement a near-basin wide approach to solving the numerous ecosystem restoration challenges that are presented in this report. Figure 1 provides an overview of problems affecting salmon and steelhead populations in the basin, goals and objectives of the AWSP, and the federal interest for mitigation and restoration alternatives.

This feasibility study involved evaluating over 26 ecosystem mitigation and restoration sites throughout the basin. The implementation cost of the preferred habitat sites is estimated to be $2.9 million for mitigation and $1.4 million for restoration. The AWSP feasibility study shows that these sites meet mitigation requirements for in-reservoir and lower watershed impacts and will restore connection of the Headwaters and Lower watersheds with the fish passage facility, and partially restore gravel sediment transport, and stream habitat lost during original dam construction.

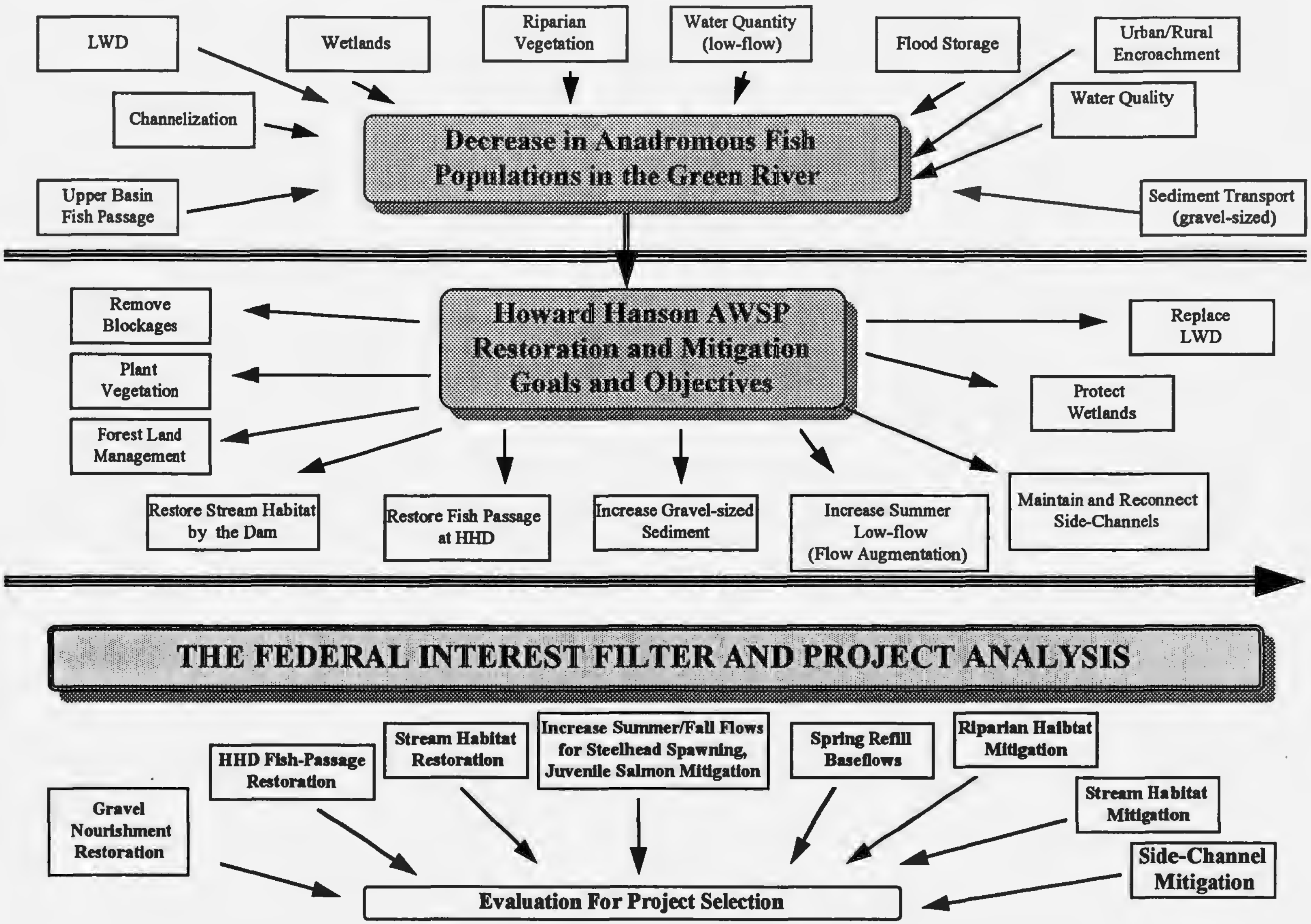


FIGURE 1. OVERVIEW OF THE AWSP FISH MITIGATION AND RESTORATION PLAN.

8.3 PROBLEM IDENTIFICATION, MITIGATION AND RESTORATION STRATEGY AND OPPORTUNITIES

8.3.1 Problem Identification

A significant amount of the feasibility study effort was devoted to the identification of project impacts and ecosystem problems. The following outlines the various endeavors pursued to identify the variety of functions and process that could be degraded by the project (mitigation) and have been degraded (restoration). The studies and reviews described below tend to adopt two complementary perspectives in defining the basic problems affecting ecosystem integrity and function in the basin.

The first identifies problems that relate to changes in the processes that form and maintain habitat within and adjacent to streams affected by the AWSP and is the focus of the Mitigation Plan. This analysis is site-specific to impacts of the project on riparian, stream, and side-channel habitat, and anadromous salmonid survival. The second identifies problems that relate to changes in the processes that form and maintain habitat within and adjacent to streams affected within the basin and is the focus of the Limiting Factors Analysis of the Green-Duwamish River Ecosystem Restoration Report General Investigation (Basin Analysis). This analysis relates the dynamics of the river system to its interactions with the surrounding landscape and describes how habitat functions derive directly and indirectly from that interaction. This is a process-oriented problem identification approach that is aimed at identifying site-specific problems, broader land-use problems, and/or fundamental conflicts between system functions and particular uses, such as the operation of water-control structures within the basin.

Problem identification for both perspectives has proceeded on various levels in the AWSP feasibility study and the Basin Analysis and include:

<u>AWSP</u>

- Scoping of and execution of baseline studies with resource agencies, U.S. Fish and Wildlife Service, National Marine Fisheries Service, Washington Department of Ecology, Washington Department of Fish and Wildlife, and Muckleshoot Indian Tribe, over a period of 4 years, 1990-1994. These studies were to identify problems associated with anadromous fish passage at the dam (see Section 2), and stream and riparian forest habitat affected by inundation with the larger reservoir pool (see Section3), and outflow temperature releases (see Water Quality appendix). In addition, water storage for low-flow augmentation was identified as a key project feature to improve instream habitat in the lower watershed and to protect steelhead redds and incubating eggs.
- Scoping of additional downstream impacts not identified during earlier coordination through a technical-policy level process, Agency Resolution

Process, in late 1995 and 1996. Technical staff and Directors of each agency and tribe met with Tacoma and the Corps to finalize any outstanding issues and concerns. Two additional issues related to spring refill impacting lower watershed habitat were identified and analyzed, connection of side-channel habitat to the mainstem (see Section 7), and survival of outmigrating juvenile anadromous salmonids, (see Section 6).

- Culmination of the scoping and study efforts in hydrologic modeling of spring refill conditions and summer/fall flow release for 32 years, 1964-1995, by a team integrated team of Corps and Tacoma hydrologists, hydraulic engineers, water managers, and biologists. Results from this modeling effort were used in impact analyses related to smolt passage through the project, Section 2, tributary and riparian inundation, Section 3, steelhead spawning and egg incubation, Section 5, downstream juvenile survival, Section 6, and side-channel connectivity, Section 7.

BASIN ANALYSIS

- A Basin Analysis was developed that recounts the history of human development in the basin, compares historic and current physical and biological conditions, and summarizes the significance of those changes with respect to fish and wildlife resources. Specific problems associated with sub-basins are described. A similar approach was used for the upper watershed analysis completed by the USFS (1996). If the reader is interested, the more detailed (than the reconnaissance report) Basin Analysis may be acquired from the Seattle District Corps by contacting Patrick Cagney of the Environmental Resources Section at (206) 764-3624.
- King County Department of Natural Resources, Water and Land Resources Division, developed a Limiting Factors Analysis to identify and describe the fundamental impediments to ecosystem function within the Green/Duwamish River and its associated floodplain (Fuerstenberg et al., 1996).

- Technical workshops were held to solicit input from representatives of various governmental entities, natural resource agencies, and tribes. These workshops clarified certain problems, illuminated the applicability of the existing databases, and produced recommendations for potential restoration projects.
- The reconnaissance study team assembled a variety of existing spatial databases into a single coordinated Geographic Information System (GIS). These include topographic and physical feature coverages; databases that pinpoint particular areas of concern such as tributary blockages and priority species habitats ([WDW] Washington Rivers Information System [WARIS] and Priority Habitat and Species [PHS] databases); King County databases relating to habitat features within the river and adjacent riparian zones; and a land use classification coverage developed specifically for this project.
- Forest Service Basin Analysis of the Headwaters Green River.

Major specific problem areas identified by the analyses include the following:

8.3.2 Impacts of Awsp

a. **Reservoir Survival of Juvenile Outmigrant Salmon and Steelhead.** Two aspects of the AWSP may affect the survival of salmon and steelhead juveniles migrating through the reservoir: the larger pool size and the rate at which the pool is filled (refill rate). These two features can increase the travel time it takes juveniles to migrate through the reservoir. Increased travel times can result in two general negative outcomes: 1) if smolts are "delayed" beyond the normal outmigration period, "biological window," this can result in residualism, smolts stay in the reservoir and don't migrate to the ocean; and 2) increased travel times can provide more opportunities (increased exposure of prey to predators) for predation by opportunistic birds, mammals or large fish. Overall, total project survival, (dam passage and reservoir survival) will greater exceed any impacts from decreased reservoir survival.

b. Dam Passage of Juvenile Outmigrant Salmon and Steelhead. Restoration aspects are discussed below. There are two uncertainties associated with the preferred fish passage facility, MIS/Fish Lock, outside of the actual technical feasibility of the facility. The first, juveniles may hold for a period of time if flows exceed the maximum outlet capacity of the facility, or may dive to the deepwater outlets. The second, any period of time juveniles congregate above the facility or are held in the lock chamber provides opportunity for predation. Resident trout or large steelhead or coho smolts could prey on smaller juvenile fish at these times.

c. **Riparian and Tributary Inundation from the AWSP Pool Raise.** As more water is stored in the reservoir, stream (tributary) and riparian habitat (streamside forest) becomes covered (inundated) by the larger reservoir pool. This inundation of forest and stream habitat will decrease the total amount of quality habitat found near the reservoir.

d. **Connection of Side-Channel Habitat to the Mainstem River.** During spring refill, storage of water in the reservoir will reduce flows in the lower river. There is over 1.5 million ft^2 of side-channel habitat below HHD. As flows decline during refill, side-channel inlets can become disconnected from the river for periods of time. This disconnection reduces habitat area and can affect the survival of incubating eggs (dewatering) and rearing juvenile fish (stranding).

e. **Downstream Survival of Outmigrating Juvenile Salmonids.** During the spring, there are millions of juvenile salmon and steelhead that migrate from freshwater rearing areas through the mainstem river to the ocean. Storing more water during the spring can reduce total river flow and the natural freshets that these juveniles use to "assist" them in their migration to the ocean. This reduction in flow and freshets could result in lower survival of the smallest outmigrating juveniles.

f. **Steelhead Spawning and Egg Incubation.** The majority of Green River steelhead spawn in the mainstem Green River from March 15 to mid-June with peak spawning in April and May. The laid eggs can remain in the gravel for 50 or more days, and fry may emerge through mid August. Reservoir refill can reduce mainstem flow to a point where eggs and near-emergent fry are dewatered. Under existing reservoir operation, in 1987, a drought year, one-half or more of all steelhead redds were dewatered as reservoir refill decreased flows.

8.3.3 Basin Analysis And AWSP

a. **Lack of Habitat in the Lower Green/Duwamish Estuary**. The lower river has been dramatically altered in historic times, resulting in a loss of more than 97 percent of the original wetland area (Blomberg et al., 1988). This has had adverse effects on most of the species that once used the estuary system, but current concerns particularly focus on the lack of refuge and salinity adaptation habitat for salmonids.

b. **Changes in Sediment Loads and Transport**. The disruption of sediment transport from the upper watershed due to the interception of almost all course sediment and gravel by HHD may be causing fundamental changes in the mainstem channel and associated habitats. One concern is the elimination of spawning gravels downstream of HHD. Reduction in peak flows and increases in moderate flows appear to be causing this condition to continue farther down stream. In some areas there are problems related to excessive fine sediment inputs resulting from mass wasting from land sides. Overall the channel is down-cutting, causing a resultant channel instability which is aggravated by losses of riparian vegetation.

c. **Changes In Flows**. Flood control operations are generally effective and have therefore disconnected the mainstem channel from its floodplain. Similarly, changes in flow regimes have reduced the channel-forming effects of high flows, and largely curtailed side-channel formation and similar dynamic patterns in the mainstem. At the same time, extensive logging has had significant effects on water storage and infiltration, reducing low flows, and runoff patterns.

d. **Loss of Channel Complexity and In-Channel Structure**. In addition to the effects of hydrologic change and sediment trapping, channel complexity in the lower river, middle river, and many tributaries has been affected by reduced loading with LWD. Complexity has also been directly reduced by channelization and construction of levees and revetments intended specifically to create and maintain a single, deep channel.

e. **Water Quality Degradation**. Increased water temperatures are a problem in various locations where there are critically low summer flows and lack of shading.

f. **Barriers to Fish Passage**. The two major dams and many impassable flapgates, culverts, and weirs in the basin effectively block salmonid passage to more than half of the potential habitat in the watershed. This has implications beyond the direct effects on fish because of the complex nutrient transport interactions that are dependent on fish migration. Salmonids' role in the nutrient transformation cycle is essential to many other elements of the ecosystem, including riparian as well as aquatic communities.

g. **Floodplain Disconnection**. Levees, channel degradation, and controlled flows have reduced the interaction between floodplains and stream channels in the basin. Many areas of the floodplain have been converted to other uses. This has dramatically reduced the interchange of water and materials between the aquatic and terrestrial systems and has isolated floodplain wetlands.

h. **Habitat Fragmentation**. The formerly extensive estuarine system has been reduced to a few scattered functional habitats. Many tributaries and wetlands have been cut off from the mainstem river because of development. Extensive logging for more than a century has broken the forests of the basin into disconnected patches. In some instances reduction in forest patch size and breaks in continuity among systems effectively prevent movement and use by some animal species.

i. **Degradation of Wetlands and Rare Species Habitats**. Wetlands have undergone extensive degradation from filling, sediment inputs, and changes in hydrology. These and similar impacts have increased threats to rare plant species and promoted establishment of non-native species.

j. **Changes in Forest Structure and Composition**. Extensive development in the lower watershed has eliminated much of the original forest habitat. In the upper watershed, where forests are still extensive, their character has been changed considerably. Remaining old-growth habitat is highly fragmented, log and snag habitat is insufficient in many areas, and corridors between habitats are non-existent or unsuitable for use by some wildlife species.

8.4 MITIGATION AND RESTORATION STRATEGIES

8.4.1 Mitigation Strategies

The potential approaches to achieve compensation for estimated impacts of the AWSP are dictated by the nature and location of the impacts. Some impacts can be addressed directly in-kind and in-place. For example, side-channel disconnection can be compensated for by improving the quantity (area) and quality (gravel, cover, etc.) of side-channels in the impacted areas. This increase in quantity can be accomplished by creating new side-channels, re-connecting relic side-channels, or by constructing additional habitat within existing side-channels.

Other impacts are related to seasonal maintenance of habitat-supporting instream flows. Reducing flows in the spring has specific impacts to habitat types and to particular lifestages of fish. Addressing these impacts requires a multi-pronged approach requiring: avoidance, minimizing flow reductions, and redistributing the seasonal delivery of water. These impacts can be avoided to a degree by reducing flows during periods non-critical to fish survival or by maintaining a minimum baseflow during the critical period. Compensation for unavoidable impacts from flow reduction is in-place but not necessarily in-kind. Flow augmentation, redistributing flow, during the summer/fall low flow period can improve conditions during a limiting season for particular species but may not provide compensation for all fish.

Some project or management changes that are called mitigation strategies are also discussed under restoration strategies (discussed below). Mitigation strategies addressing some AWSP impacts may also provide partial restoration for basin aquatic habitat problems (discussed below). Flow augmentation is a mitigation strategy that also addresses a critical limiting factor throughout the basin.

The following is a list of mitigation strategies linked to the impacts identified under the AWSP. These strategies have been proposed by participating agencies; by Corps and Tacoma staff. or have been addressed in other studies within the basin.

- **Reservoir and Dam Passage Survival of Juvenile Outmigrant Salmon and Steelhead.** Maximize outflow capacity of the fish passage facility. Minimize the reservoir refill rate during the main smolt outmigration periods. Make use of periodic artificial freshets and mimic natural freshets (through minimizing refill rates). Establish a long-term monitoring program to provide information necessary to evaluate and adapt the AWSP to maximize survival. After establishing the need, consider potential removal of predatory fish. Include habitat improvements above and below the reservoir to provide adequate or additional capacity for rearing and spawning.

- **Riparian and Tributary Inundation from the AWSP Pool Raise.** Two strategies are required, within the reservoir to maintain limited habitat quantity and quality, and above the reservoir to compensate for habitat in-reservoir projects can't address. In the new inundation zone several strategies are considered: 1) retain existing standing timber to partially maintain wildlife, riparian and instream habitat; 2) maintain existing instream and riparian habitat through placement of large structural elements and planting of water tolerant riparian zone vegetation, respectively; 3) maintain reservoir perimeter vegetation by planting of water tolerant vegetation; and 4) enhance reservoir habitat by creation of sub-impoundments and addition of floating debris. Above the proposed inundation zone: 1) protect important mainstem and large tributary drainages through riparian reserve and management of riparian forests for late-successional characteristics (this management type is more fully described in the Wildlife Mitigation Plan); 2) improve fish passage to one or more tributaries by replacing impassable culverts; and 3) improve selected areas of mainstem and large tributary instream habitat through placement of large woody debris or boulders.

- **Connection of Side-Channel Habitat to the Mainstem River.** As side-channel impacts are dispersed throughout the Middle and Upper Green River, strategies for compensation must be dispersed or distributed in a like manner. Side-channel strategies can include: improving the quantity (area) and quality (gravel, cover, etc.) of side-channels in the impacted areas. This increase in quantity can be accomplished by creating new side-channels, re-connecting relic side-channels, or by constructing additional habitat within existing side-channels. In addition, flow management can be used to minimize overall impacts. Two options are considered, maintenance of a minimum baseflow to keep selected areas wetted, and periodic "flushing flows" or artificial freshets timed and of adequate magnitude to connect side-channels for the desired duration and frequency necessary to minimize impacts.

- **Downstream Survival of Outmigrating Juvenile Salmonids.** Strategies for compensation for mortality of juvenile salmonids involves flow management of spring, summer, and fall flows. Specific actions that can be implemented include: maintaining a baseflow target during the spring refill period, augmentation of fall spawning flows, and release of periodic artificial freshets during the peak outmigration period. At least one habitat restoration measure could be an acceptable strategy. Gravel nourishment, while partially maintaining an aquatic habitat limiting factor, lack of gravel-sized sediments, can be considered a means for compensation in place by maintaining adequate spawning habitat.

- **Steelhead Spawning and Egg Incubation.** The majority of steelhead spawning in the Green River occurs from March 15-June 15 in the mainstem, from RM 28-60.6. Egg incubation continues until late July. Strategies for compensation must be flow-dependent and occur during the impact period. Three flow management strategies that can address these impacts include: 1) maintaining the maximum baseflow during the spawning and incubation period, 2) follow a slow decline in flow reduction (stage/discharge relationship) during the latter part of the incubation period, and 3) increase baseflows during later life-cycles, fry and juvenile rearing during lowflow periods. A non-flow dependent restoration strategy, gravel nourishment, could also be considered as a mitigation strategy if the flow strategies are insufficient.

8.4.2 Restoration Strategies

The potential approaches to achieve some level of restoration are suggested by the nature of the problems defined. Some problems can be addressed relatively directly and with permanent effect. For example, strategically placed plantings of floodplain vegetation would reduce forest fragmentation and improve shading of stream channels. Decommissioning of specific roads in the upper watershed would reduce excessive point-source sediment inputs. Other problems are related to maintenance of habitat-forming processes in the system. Addressing these problems may require an indirect approach, such as restoration of channel migration to assure periodic creation of side-channel habitats and recruitment of LWD to the stream system.

Some of the restoration strategies that have been identified would require fundamental changes in resource management, including water releases from the HHD, or changes in forest practices on the upper watershed. Still other strategies imply changes in land uses, such as reforestation of cleared lands. It is likely that an effective overall restoration strategy will involve a combination of various elements, and will include protection or preservation of certain key areas that already function as essential components of the system (e.g., refugia, per Sedell at al., 1990).

The following is a list of generic potential restoration strategies, keyed to the problem areas defined in this study. They have been proposed by the various participating agencies, in the technical workshops, or have been addressed in other studies of the Green/Duwamish River Basin.

Aspects of these restoration strategies that the AWSP can address under restoration <u>or</u> mitigation are underlined:

- **Lack of Habitat in the Lower Green/Duwamish Estuary:** Restore connections to off-channel habitats. Restore intertidal habitats along the mainstem. Improve shading through riparian plantings. Preserve existing refugia.
- **Changes in Sediment Loads and Transport:** Improve forest practices. Logging road improvements, closures, or decommissioning. Reforest riparian zones. Install woody debris to moderate in-channel sediment storage. <u>Relocate or import sediments to sediment-deficient reaches.</u> Pass sediment through mainstem dams.
- **Changes in Flows:** <u>Alter withdrawals and release schedules from dams</u>. Improve infiltration and storage in the watershed through reforestation and runoff control. Improve floodplain connectivity and reforest to improve storage and groundwater recharge.
- **Loss of Channel Complexity and In-Channel Structure:** Retrofit existing levees to provide in-channel bankline diversity. Reconfigure some channel reaches. <u>Introduce LWD</u>. <u>Improve connections to side channels and floodplain habitats</u>. Remove impediments to channel migration in appropriate reaches.
- **Increased Water Temperatures:** Improve infiltration and subsurface storage of water to maintain baseflow in summer<u>. Alter discharge and withdrawal schedules.</u> Alter channel configuration. Increase shading through riparian plantings.
- **Barriers to Fish Passage**<u>: Provide fish passage facilities at Tacoma Diversion Dam and HHD. Remove barriers to passage and retrofit non-functional structures to allow passage.</u>
- **Floodplain Disconnection**: <u>Remove or set back unnecessary levees.</u> Modify flow operation of HHD to allow periodic floodplain inundation. Restore native floodplain habitats.
- **Habitat Fragmentation:** Improve continuity of intertidal habitats. Improve continuity of riparian corridors. Increase size of forest patches.

- **Degradation of Wetlands and Rare Species Habitats:** Identify, protect, and preserve unique and highly functional habitats. Remove roads and improve buffers. Control invasive exotic species. Encompass special habitats within larger natural communities to assure continuity and accessibility.
- **Changes in Forest Composition and Structure:** Maintain native communities, including detrital components. Increase proportion of old-growth forest and preserve existing old-growth. Increase conifer component of riparian forests.

SECTION 8A SUMMARY OF UNAVOIDABLE ADVERSE IMPACTS

Each impact area or issue is discussed below: 1) Reservoir Survival; 2) Dam Passage; 3) Riparian and Tributary Inundation; 4) Side-Channel Connection; 5) Downstream Outmigrant Survival; and 6) Steelhead Spawning and Incubation. Mitigation measures for unavoidable adverse impacts are discussed in 8B and 8D.

Unavoidable Adverse Impact No. 1. Reservoir Survival of Juvenile Outmigrant Salmon and Steelhead. There is one measure of the change in reservoir performance for outmigrating juveniles, increase in reservoir travel time. This measure is based on an empirical relationship between reservoir refill rate and travel rate of coho, steelhead, and chinook salmon smolts. The effect of 1996 Baseline refill and the AWSP were modeled for 32 years, utilizing semi-months with percent of outmigrants, refill rate, size of pool (volume and length), and travel rate to predict travel times by species. The objective of the AWSP is to have no net loss of juvenile salmonids migrating through Howard Hanson Reservoir.

Beyond the actual change in travel times, the results of this model are open to interpretation -- there is no accepted travel rate and the implications of increased travel rate for application to small reservoirs. The Corps spent 2 years in coordination with resource agencies (HHD Technical Workgroup) to develop a level of acceptable and unacceptable travel time. In 1995 and 1996, the Corps presented a request -- that if the Workgroup did not define acceptable and unacceptable travel times, -- the Corps would provide definitions for the AWSP impact analysis. The Corps has provided definitions. Final definitions included that acceptable travel times would be within the "biological window" of outmigrating fish. Travel rates of greater than 10 days are considered significant for coho and steelhead as these stocks have a more defined biological window while 20 days was selected for chinook which can spend a considerable period rearing prior to migrating.

For coho and steelhead, if the time required to traverse the reservoir was greater than 10 days, this was considered an adverse impact requiring additional monitoring and potential mitigation. For chinook, if the time required to traverse the reservoir was greater than 20 days, this was considered an adverse impact requiring additional monitoring and potential mitigation. The discussion below covers the percent of time each species exceeded a maximum travel rate, 10 or 20 days.

Under Baseline, there were no periods of time when travel times exceeded 10 days for coho and steelhead. Under Phase I, there was a slight but negligible increase in the percent of time (1.0%<), for 32 years, coho and steelhead exceeded 10 days. For chinook, there was an overall decline in travel rate from Baseline to Phase I for periods exceeding 10 days but less than 20 days (-7.2%) and a slight increase for periods greater than 20 days (0.2%). From Baseline to Phase I, performance of smolts is expected to equal or improve based on. In comparison to total project travel time at other water control projects (dam + reservoir), the overall expected travel times through HHD under Phase I are not exceptional: coho 4.5 days, steelhead 3.7 days, chinook 6.7. Three years of outmigrant trapping at Wynoochee Reservoir, a shorter length but greater volume reservoir, showed a range of total project travel times of 18-44 days for coho, 11.4-20.6 days for steelhead, and over 30 days for chinook. Phase I has the potential for major improvements (even with greater reservoir volume and length) over Baseline -- 1) a reduced refill rate during the major outmigration period; 2) greater outflow in May, with 2 artificial freshets; and 3) unaccounted improvements in attraction to the dam from the selected fish passage facility.

Unlike Phase I, there is an obvious change from Baseline to Phase II for all species. For coho, maximum travel times increase by 3.9% for 10-20 days, and by 6.0% for 20-30 days. This equals a total increase in maximum travel rate (percent of travel exceeding 10 days) of 9.9% over Baseline. For steelhead, the total increase was 2.3 % for periods of 10-15 days, and 7% for 15-20 days, a total maximum travel rate increase of 9.3% over Baseline. For chinook, there was a decline in maximum travel time from Baseline to Phase II for periods between 10-20 days (9.8%). There was an increase in travel rate for periods greater than 20 days (4.7%). In addition, Phase II proportional (overall) travel times are greater than Phase I, coho 5.8 vs. 4.5 days, steelhead 4.8 vs. 3.7 days, chinook 8.6 vs. 6.7 days.

For chinook, even with the decrease in travel rate for 10-20 days and low increase for over 20 days, we have the greatest uncertainty in predicting potential survival for this stock: we only have travel rates for a small release group of smolts that were undersized for the radio-tags used. This stock is also the latest outmigrant at the smallest size migrating through the largest pool at lowest inflow and outflow. So, although percent change is less for chinook than steelhead or coho, greater precautions are recommended to increase certainty for successful reservoir migration. Based on assumptions and definitions applied above, monitoring and mitigation management measures are required under Phase II for coho and steelhead requiring greater than 10 days of travel and for chinook greater than 20 days.

Unavoidable Adverse Impact No. 2. Dam Passage of Juvenile Outmigrants. The objective of AWSP is to have 95% or greater dam passage survival and to maximize surface outflow from the fish passage facility. As discussed in the Hydraulics and Hydrology Appendix and Section 2, the fish passage facility will address all recommended criteria for successful passage of juvenile salmon and steelhead. Estimated survival of smolts using the facility is greater than 95%. The fish passage facility has gone through 3 years of design refinement and meets all specified design criteria (Hydraulics and Hydrology Appendix).

However, there are two uncertainties associated with the preferred fish passage facility, MIS/Fish Lock, outside of the actual technical feasibility of the facility. The first, the maximum capacity of the facility, 1250 cfs (maximum flow within screening criteria, total capacity is 1650 cfs), may be exceeded for periods of time during the spring outmigration period, specifically late April and May. The facility could not be designed to fully provide for one requested feature, ability to screen all or most outflow from the project. The FPTC wanted the facility to screen the maximum volume of flow encountered during the peak normal outmigration period for smolts. The design has been altered to the point where the facility can safely screen (within criteria) up to 1250 cfs, near the 50% exceedance value for HHD Baseline outflows in late April and early May: no design alternative was technically feasible to handle a greater capacity.

However, that means for wet periods, a portion of flow must exit through the lower level outlets. The effect of this dual release of flow is unknown, conceivably it could result in smolts holding for a period of time or more likely, smolts attempting to dive (sound) and exit through the lower outlets: the radial gates will be between 100-135 ft below the surface by late April to early May. Most literature references and monitoring at HHD confirm that smolts are surface oriented, 5-20 ft, and we presume few smolts will attempt to dive to the deep-water exit given the preferred design elevation and attraction flows of the fish passage facility. If smolts do dive to the radial gates, HHD outmigrant studies have been shown smolts to have greater than 98% survival rates exiting under existing pool elevations. Survival at greater depths with greater head and greater pressure is unknown but is presumed to be greater than 95%.

A second uncertainty was raised by NMFS during the agency resolution process -- any period of time juveniles congregate above the facility or are held in the lock chamber provides opportunity for predation. Resident trout or large steelhead or coho smolts could prey on smaller juvenile fish at these times. Resident trout may not be a problem in the lower reservoir. Studies by the WDFW and USFWS has shown no outmigration of resident trout during three years of monitoring nor any congregation of larger fish in the lower 0.5 miles of the reservoir (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992 and 1993; Dilley 1994). In addition, the spawn time for at least part of the resident trout population is during the peak in smolt outmigration, April and May. Smolt predation within the facility is a possibility. A fry trap was incorporated into the wetwell and can provide refuge for smaller juveniles.

Unavoidable Adverse Impact No. 3. Riparian and Tributary Inundation. The objective of the AWSP is no net loss of riparian and tributary habitat functional value resulting from inundation of riparian and tributary areas from the AWSP pool raise. Under Phase I, raising the pool from 1147 ft drought year elevation to 1167 ft drought year elevation will seasonally inundate 1.9 lineal miles of tributary (stream) and riparian habitat. Under Phase II, raising the pool from 1167-1177 ft will seasonally inundate an additional 1.0 mile of stream and riparian habitat. Stream and riparian habitat area affected by the pool raise is a function of 1) period of inundation, and 2) expected decline in habitat quality through time. Under the AWSP, Baseline habitat from the 1070-1147 ft pool will be inundated for a greater period of time and will further degrade. Currently uninundated areas from 1147-1167, Phase I, and 1167-1177 ft, Phase II, will experience the first inundation and degradation. Total stream habitat unit loss, acres of quality and quantity, from Baseline to Phase I is 11.5 acres and from Phase I to Phase II is 5.9 acres for a total of 17.4 acres.

Riparian habitat loss is represented by length of stream habitat loss, 10,110 ft Phase I, and 5356 ft in Phase II and the horizontal width of riparian zones bordering the streams. Based on regulatory definition, a riparian area habitat loss could be considered a measurement dependent on the authority used to define an acceptable riparian buffer. Riparian buffer widths can range from 25 ft for small streams to 300 ft on large streams or rivers on federal lands (Forest Service of Bureau of Land Management). The Tacoma Forest Land Management Plan (Forest Plan) has more restrictive requirements than the Washington FPA, with riparian areas defined as natural zones (Table 10, Section 3). All lands within the AWSP pool raise are City of Tacoma Forest Lands.

The Corps would consider the interim riparian buffers recommended by the Forest Plan to be adequate in consideration of functional area necessary to maintain instream habitat. These buffer widths were applied to each of the streams found within the AWSP pool raise to estimate the potential loss of riparian area. Total affected riparian area, using Tacoma Forest Land required buffer widths, is 78.2 acres in Phase I, and 42.1 acres in Phase II for a total of 120.3 acres for the entire AWSP. **Mitigation is therefore required for the loss of 17.4 acres of stream habitat and 120.3 acres of riparian habitat resulting from the AWSP pool raise.**

Unavoidable Adverse Impact No. 4. Connection of Side-Channel Habitat to the Mainstem River. There are three elements of Middle Green River, RM 34.9 to 45.6, and Upper Green River, RM 57.0-60.3, side-channel habitat quantity and quality discussed in *Section 7. Green River Side Channel Inventory* -- magnitude of wetted side-channel area, duration of continuously wetted side-channel area, and frequency of side-channel connection to the mainstem, that the AWSP may adversely affect. The objective of the AWSP is to have no net loss of Middle or Upper Green River side-channel habitat.

Magnitude. Under Phase I the average daily wetted side channel area increases by 45,000 ft^2 over Baseline for the spring refill period, February 15 to May 31. From February 15 to April 15 (early spring) Phase I average daily wetted area ranges from 9,000 to 94,000 ft^2 less than Baseline but from April 15 to May 31 is up to 139,000 ft^2 greater. Under Phase II, average daily wetted side channel area decreases by 367,000 ft^2 for the spring refill period. Both natural freshets and baseflows may be substantially reduced during early spring. The net effect during the spring refill period is that under Phase I, the average amount of wetted side channel area increases by 45,000 ft^2 over Baseline, while the side channel area wetted under Phase II decreases by approximately 367,000 ft^2. The change in availability of wetted side channel area is primarily restricted to those areas that are alternately wetted and dewatered during rising and dropping flows. **Mitigation is**

required for the loss of 367,000 ft^2 wetted side channel area under Phase II: 282,000 ft^2 in the Middle Green River, 85,000 ft^2 in the Upper Green River.

Duration. The average amount of continuously wetted side channel habitat was estimated for the Middle Green River during the period of January 1 to April 30, the chum salmon egg and alevin incubation season. Chum salmon were chosen as an indicator of AWSP impacts as they are the Green River anadromous stock most dependent on side-channel habitat. Under Baseline, the amount of continuously wetted channel area averaged 275,000 ft^2 (range 96,000-372,000 ft^2). Under Phase I, there is a negligible increase to 278,000 ft^2 and the interannual variation increases slightly, range 96,000-400,000 ft^2. Under Phase II, the average amount decreases slightly (<800 ft^2), but interannual variation decreases more, 96,000 to 337,000 ft^2. **Although there appears to be no discernible impact, there is a degree of uncertainty associated with these estimates, as such, a minor increment of mitigation is recommended, to be included under side-channel mitigation and gravel nourishment restoration.**

Frequency. Periodic freshets (flows >2500 cfs) temporarily reconnect side channels allowing young salmon an avenue of escape. Under Baseline, freshets occur sporadically with most occurring in February (1.3/month), with fewer in March through May (≥ 1 per month). Phase I and II replace natural freshets with artificial freshets timed to critical periods of juvenile salmonid rearing or outmigration. Phase I reduces freshets in late winter (February to March 31) but increases spring freshets (May 1 and 15). Overall changes from Baseline to Phase I there were 1) decrease of average monthly freshets in February (1.3 to __) and March (1._ to 0.5); and 2) an increase in April (1.0 to 1.1) and May 0.9 to 2.2). Phase II replaces most natural freshets in later spring refill April and May) with up to four artificial freshets. Under this release scenario, freshets are approximately equal in February and March but are more common in April and May over Baseline and Phase I. The net effect is an increase in the number of times side channels are wetted during Phase I and II because of artificial freshets. The number of times flow events equaled or exceed 2,500 cfs decreased 12% during early refill (February and March), but were offset by an 81% increase in the number of events during late refill (April and May). **If the proposed release scenario is acceptable, no additional mitigation is required for frequency although additional benefits are presumed to occur from side channel mitigation and gravel nourishment restoration.**

Unavoidable Adverse Impact No. 5. Downstream Survival of Outmigrating Juvenile Salmonids. Researchers in the Green River identified a general trend of increased survival of juvenile chinook with increased flow in the lower river. Using this data, a flow-survival hypothesis was developed and used to assess Phase I and Phase II of the AWSP. An analysis using daily flow records for a 32 year period suggests chum salmon would incur up to 5% increased mortality under the AWSP. Unlike chum salmon, chinook salmon survival would increase up to 2% and coho and steelhead juveniles would exhibit up to a 3% increase in survival. The chum mortality increase is a result of timing of major flow reductions. The primary refill period for Phase II, with no-refill limits, is from March 1 to April 15. This time period coincides with the peak period of chum outmigration. The other juveniles, salmon and steelhead, outmigrate later in the spring when most storage has already occurred and coincide with increased baseflows and release of artificial freshets. Mitigation is required for the loss of 5% of all naturally reared chum juveniles.

Unavoidable Adverse Impact No. 6. Steelhead Spawning and Incubation. The objective of the AWSP is to have no net loss of steelhead egg production through minimizing the desiccation (drying) of steelhead egg nests (redds). If steelhead spawn on the margins of the mainstem Green River at higher flows, some of the areas along the margins may go dry during the incubation period. An analysis of wetted stream area that is protected or unprotected within mainstem channel reaches was conducted. "Protected" is defined as channel area that remains wetted during incubation of eggs. Unprotected areas, or areas "at risk" are those which become dry for two consecutive days during the 50 day period following redd construction.

A summation of unprotected area for a one-foot stage drop shows: 1) from Baseline to Phase I an increase of 0.07 ft of channel width/day would be unprotected; and 2) Baseline to to Phase II a decrease of 0.02 ft of unprotected width/day occurs. Under Phase I, this results in an impact with an increase in the amount of channel width that is dewatered for 48 hours or more over the 50-day egg incubation period. Under Phase II, there is no impact or a slight improvement in conditions, with a decrease in the channel width that is dewatered.

The reason Phase II has an improvement or is almost equal to Baseline (is compensation has already been provided under the AWSP flow modeling. Hydrologic modeling identified maximum winter and spring baseflow targets that could be maintained during the steelhead spawning and egg incubation period under one refill and flow release strategy. Under Phase II, these baseflows appear to avoid potential impacts from flow reduction.

SECTION 8B SELECTED MITIGATION PROJECTS

8B.1 RESERVOIR MORTALITY AND DAM PASSAGE OF OUTMIGRATING JUVENILE SALMONIDS

The objective of the AWSP is to have no net loss of juvenile salmonids migrating through Howard Hanson Reservoir and maximize survival of outmigrants through the dam. Dam passage survival has been maximized by the expansion of the preferred fish passage facility to handle a normal capacity of 400-1250 cfs. This fish passage facility capacity expansion will also mitigate for many aspects related to the uncertainty of survival of smolts migrating through the enlarged AWSP reservoir (discussed below).

Impacts from increased travel time are unquantified beyond the percent change in maximum travel rates. There is no formula, empirical relationship, or accepted concept that can equate an increase in travel time to a measured decrease in survival. However, there is a general understanding that delaying fish beyond a period of time can decrease the chance that they will successfully migrate to the ocean. In Howard Hanson Reservoir, this delay can lead to increased residualism and predation risk for coho, steelhead, and chinook. The greatest predation risk occurs for chinook, as they migrate later and are the smallest smolt. For smolts that do outmigrate, the delays we have estimated should not result in lowered ocean survival as estimated times for all stocks will fall within their "biological window" of opportunity to reach the ocean. Mitigation is required for all stocks under Phase II for increased travel times, and potential for decreased survival, and will be compensated for by: 1) expansion of the fish passage facility outflow volume; 2) minimizing refill rate during main outmigration periods; 3) use of periodic artificial freshets; 4) a long-term monitoring program, 15 years; 5) potential removal of predatory fish; and 6) habitat improvements above and below the reservoir, restoration and mitigation projects. Mitigation projects are:

<u>Expansion of the Fish Passage Facility.</u> After the initial selection of fish passage facility alternative 4, the FPTC felt there was enough concern about passing smolts through the reservoir and collection at the dam that they requested maximizing the outflow capacity of facility. Following this, the fish passage facility was increased in size from a maximum 400-550 cfs outflow volume at surface withdrawal (5-20 ft) to 400-1250 cfs: the original design was constrained by the size of the existing bypass pipe and head of the reservoir. The new screened outflow (within criteria) represents up to 300% increase in total flow volume. The FPTC recommended the maximum expansion of the facility to provide for capacity to pass surface flows to assist in reservoir outmigration of smolts.

Outmigrant Monitoring and Evaluation. For coho, steelhead, and chinook, a 15 year outmigrant monitoring and evaluation plan is required (discussed in Section 10), cost is shared under restoration. A sampling station, hydroacoustic monitoring, and pit-tag release and evaluation are proposed. First year construction costs are estimated at $625,000 with a 20% contingency (total $750,000) and are included in the cost of the fish passage facility. Annual monitoring and evaluation costs are estimated and broken down by separate monitoring functions and are described in Section 10.

Predator Monitoring, Evaluation, and Selective Removal. Beginning in 1999, PED Phase, 2 years of Baseline monitoring of predator abundance is proposed. This is a preventive measure to insure successful outmigration of chinook outmigrants (the smallest outmigrants). In combination with PIT-tag and hydroacoustic monitoring and evaluation, monitoring of predators would continue during Phase I with four additional years of monitoring. If there is an increase in overall abundance in response to outmigrant presence a selective predator removal program can be initiated. The predator removal program must be coordinated through the City of Tacoma, and cooperating resource agencies. Annual Baseline and Phase I monitoring costs are estimated at $45,000.

Maximum Refill Rate. A maximum refill rate (rate the reservoir is filled or the difference of inflow-outflow) is proposed for each phase of the AWSP. A fill rate limit was already implemented under the AWSP hydrologic modeling (Section 9). The fill rates varied by phase: Phase I had maximum rates in March of 400 cfs per day, in April of 300 cfs per day, and in May of 200 cfs per day; Phase II had maximum rates only in late April at 300 cfs per day, and in May of 200 cfs per day. Even with the maximum fill rates, there are less protected times when smolts outmigrate, especially any early migrants in March or early April in Phase II. Our empirical data has only looked at travel times when fill was up to 400 cfs per day. We are uncertain if additional travel times well beyond the 11 days observed for coho salmon could occur. Monitoring during the first years of the AWSP project operation are essential to identify the range of fill rates affecting smolt travel times and ultimately survival. This monitoring should provide the needed information to adapt the AWSP to maximize smolt survival through the project.

Artificial Freshets. Another project operation or management tool for mitigation of potential reservoir mortality is the use of increased outflows or artificial freshets. In the past few years under existing operation, the Corps has "captured" natural freshets to guarantee the 98% reliability of filling the pool. This capture was necessary as the existing pool has a limited storage capacity, it cannot be raised above 1141 ft (until the Section 1135 project is formally approved) with the river has almost dewatered during some drought years. The capture of freshets results in a flat or constant outflow rate with an associated high refill rate that is presumed to have a very negative effect on outmigration success.

Outmigration study results (Dilley and Wunderlich 1992 and 1993) are unequivacable that increased outflow will increase the number of smolts that can safely exit the project. As such, periodic freshets should be considered as an important management tool to improve survival of smolts migrating through the AWSP. This measure will require careful integration of information gained from monitoring of smolts migrating through the reservoir as well as from monitoring of downstream areas to minimize salmonid fry stranding and impacts to steelhead spawning. These freshets were modeled under the AWSP hydrologic modeling exercise (Section 9) and incorporated the best available information on juvenile salmonid behavior downstream as well has side-channel/mainstem channel dynamics.

These freshets are necessary to decrease the travel-time of outmigrating smolts through HHD reservoir and for smolts transiting the lower river to the estuary and to maintain connections between floodplain and mainstem habitats. Phase I targets are for Auburn are: 1) normal years -- two 2500 cfs, 38 hour freshets, and 2) dry years -- two 1250 cfs, 38 hour freshets. Phase II targets are for: 1) normal years -- four 2500 cfs freshets, and 2) dry years -- four 1250 cfs freshets, with modeled average frequency for 32 years of 2.91/year.

Habitat Improvement. Additional habitat improvement and increased production capacity is planned as part restoration and mitigation measures for original and AWSP riparian and tributary inundation: all habitat projects selected are planned as improvements for anadromous salmonid rearing and spawning habitat (discussed below).

Habitat Mitigation for fish and wildlife. This management measure has two components, stream channel and riparian habitat maintenance, and stream channel and riparian habitat improvements. Several components of stream channel and riparian habitat maintenance and habitat improvement and have been identified and organized by impact issue and watershed area. Impact issues and watershed location are 1) reservoir survival of outmigrating juvenile salmonids and riparian and tributary habitat inundation in the reservoir, in-reservoir areas in the Headwaters watershed; 2) Middle and Upper Green River side-channel connection and downstream outmigrant survival, lower watershed below the dam; and 3) Middle and Upper Green River steelhead spawning and egg incubation, lower watershed below the dam. Habitat projects for reservoir survival and tributary inundation are combined as are Middle Green River side-channel connection and lower watershed downstream outmigrant survival. Management measures to mitigate for these unavoidable adverse impacts are discussed by issue/area.

8B.2 RIPARIAN AND TRIBUTARY HABITAT INUNDATION AND RESERVOIR SURVIVAL

NOTE: Project descriptions do not reflect the phased nature of the AWS project with descriptions encompassing the full project impact of Phase II (to 1177 ft).

The primary objective of this mitigation measure is no net loss of riparian and tributary habitat functional value resulting from inundation of riparian and tributary areas from the

AWSP pool raise. A secondary objective of this mitigation measure is to provide for protection of instream and reservoir habitat required as cover for juvenile salmon and steelhead migrating through the reservoir. Specific recommendations to meet these objectives are broken into in-reservoir areas, 1147-1177 ft, and above-reservoir areas, 1240 ft elevation and above.

In-reservoir. In the new inundation zone (1147 to 1167 ft Phase I and 1167 to 1177 ft Phase II elevation): 1) retain existing standing timber to partially maintain wildlife, riparian and instream habitat; 2) maintain existing instream and riparian habitat through placement of large structural elements and planting of water tolerant riparian zone vegetation, respectively; 3) maintain reservoir perimeter vegetation by planting of water tolerant vegetation; and 4) enhance reservoir habitat by creation of sub-impoundments and addition of floating debris.

Above-reservoir. Above the proposed inundation zone and restoration zone (above 1240 ft elevation): 1) protect important mainstem and large tributary drainages through riparian reserve and management of riparian forests for late-successional characteristics (this management type is more fully described in the Wildlife Mitigation Plan); 2) improve fish passage to one or more tributaries by replacing impassable culverts; and 3) improve selected areas of mainstem and large tributary instream habitat through placement of large woody debris or boulders.

Mitigation is required to compensate for impacts of the Phase I and Phase II pool raise: Phase I – 79 acres of riparian habitat, 11.5 acres of stream habitat; Phase II – 42 acres of riparian habitat, 5.9 acres of stream habitat. There are two tasks for mitigation from the above recommendations: 1) maintenance of existing habitat within the new inundation zone; and 2) replacement of lost habitat in areas above the new inundation zone.

Riparian Habitat Maintenance and Replacement Mitigation. To maintain and replace riparian habitat within and above the new inundation zone, respectively, two measures are selected -- 1) placement of water-tolerant plants along stream banks and the shoreline perimeter in the AWSP inundation zone, and 2) protect important mainstem and large tributary drainages through riparian reserve and management of riparian forests for late-successional characteristics (Headwaters Wildland Set-aside).

Project Package Name: **Howard Hanson Reservoir Mitigation Zone/Riparian**
Activity Name: **Mainstem, North Fork, and Tributary Riparian Maintenance**
Project Number MS-02, TR-04, TR-05

Project Location:: Headwaters Green River, North Fork Green River, and major tributaries from Baseline full pool (elev. 1147 ft) to full additional pool elevation (1177 ft).

Project Description: Partial maintenance of up to 2.9 miles of riparian habitat affected by the inundation of the Green River, North Fork Green River, and up to 10 additional tributaries (1147 to 1177 ft elevation). The inundated riparian and stream habitat will deteriorate in habitat quality and complexity through time. Partial mitigation for riparian area affected would be accomplished by 1) retention of existing trees along stream corridors; 2) placement of large structural elements to contain the existing stream channel (discussed in Maintenance of Stream Habitat); and 3) plantings in bare areas in/and along stream channels with inundation tolerant grasses, forbs, trees and aquatic: up to 15 acres of plantings of diverse wetland and riparian species including tree species such as ash and bald cypress, manual application.

Wildlife related riparian and wetland projects are described in greater detail in the wildlife mitigation/restoration summary (Appendix F, Part Two; and in the DFR/EIS Sections 3 and 4). A locator map showing the selected projects by site number is shown in Section 4 of the DFR (Figure 4.8). Following is a brief list of these projects:

- Create sub-impoundments (wetlands) along the reservoir shore. Create wetlands and/or ponds along the reservoir shore for wildlife utilization (and possibly fish).
- Terrestrial habitat manipulation above the reservoir riparian zone. Manipulate habitat by fertilizing, thinning, tree topping, placement of woody debris, etc. in areas above elevation 1177 ft.
- Reservoir perimeter plantings of water tolerant species. Plant water-tolerant tree, shrub, and forbs along the reservoir shoreline (non-stream corridors).

Project Package Name: **Headwaters Green River Habitat Mitigation**
Activity Name: **Tacoma Wildlands Set-asides in Conservation and Natural Forest Zones**
Project Number: MS-08, TR-09

Project Location: Mainstem Green River valley floor RM 71.3-80.1, Gale Creek from elevation 1240 to 1280 ft, North Fork Green from elevation 1240 to 1320 ft elevation.

Project Description: This partial mitigation measure is a set-aside or riparian forest reserve (managed solely for fish and wildlife habitat) of riparian and stream area over 3 times greater than the inundated riparian and stream length around Howard Hanson in lands owned and managed by Tacoma Water Department in the upper Green: including stream buffer areas on both sides of the stream or river. This project implements portions of the Natural Zone prescriptions described in the City of Tacoma Green River Watershed Forest Management Plan. The multiplier for replacement value, 5 times the area of inundated riparian areas, is an intermediate value, recent reviews of wetland mitigation suggest up to a 10:1 ratio if using the replacement value of protecting existing wetlands or special wetlands (pool/riffle complexes and riparian areas) to compensate for impacted area.

Applied riparian buffers are the required buffer widths in the interim Tacoma Forest Plan. For the mainstem Green, including stream buffers of 200 ft on either side, total linear length is 46,500 ft, riparian area is 427 acres, beginning at RM 71.3 (elevation 1240 ft) and extending to RM 80.1. For the North Fork Green, including stream buffers of 150 ft on either side, total linear length is 4600 ft, riparian area is 31.7 acres, beginning at elevation 1240 ft and extending to 1320 ft. For Gale Creek, including stream buffers of 150 ft on either side, total linear length is 1200 ft, riparian area is 8.3 acres, beginning at elevation 1240 ft and extending to 1280 ft. In mitigation compensation, the equivalent reserve, 210 mainstem acres=42 inundated acres (5:1 ratio), 95 acres thinned=28.5 acres inundated (3:1 ratio), 126 acres planted=37.8 inundated acres (3:1 ratio). Within the set-aside areas are two hot-spots of biodiversity, the only remaining old-growth area along the mainstem Green, approximately 20 acres of Sitka spruce, and a large unsurveyed wetland area (recently identified).

Management prescriptions within the protected area to improve fish and wildlife habitat include: 1) addition of large keystone trees (60 ft or greater, 4 ft diameter, rootwad attached) at one 2-3 trees cluster/half-mile of mainstem to act as collection points for additional debris and to improve channel diversity -- pools, gravel collection, side channels; 2) selective thinning (20%, 95 total acres total) of riparian zones to open forest canopy, improve tree growth, and to drop habitat logs for aquatic and terrestrial habitat; and 3) planting of evergreen species, cedar, hemlock and spruce (50/acre for 126 total acres).

Additional Riparian and Stream Habitat Project Descriptions to be provided later.

8B.3 SIDE-CHANNEL CONNECTION AND IMPROVEMENT/DOWNSTREAM OUTMIGRANT SURVIVAL MITIGATION PROJECTS

Two primary objectives of AWSP mitigation for the lower watershed is to have no net loss of Middle Green River and Upper Green River habitat or no decline in juvenile outmigrant survival. Under Phase II, an average of 282,000 ft^2 of wetted side-channel habitat will be lost during the spring refill period, February 15-May 31. For the Upper Green River, there is an additional 85,000 ft^2 annual average loss of wetted side-channel area. Therefore, replacement of 367,000 ft^2 of wetted side-channel area is required, or 8.4 acres. In addition, there is an estimated loss of 5% of all naturally produced chum smolts from reduced spring outflows. This reduced smolt survival is combined with mitigation for the loss of wetted side-channel area.

In addition to habitat improvements to mitigate for side-channel wetted area loss and the decreased survival of chum juveniles a number of flow management techniques were employed to minimize or avoid impacts: 1) minimum baseflows were established for the spring refill period (see 8B.4 below); and 2) period artificial freshets (flushing flows) were modeled for release in April and May to connect habitat at regular intervals and to flush juveniles to the estuary (number and periodicity discussed under 8B.1 and Section 9).

Under incremental analysis, the projects with the highest combined habitat score (area and quality, discussed in Section 5) were selected for 1) the Middle Green River, LVF-03, Loans Levee Removal and Burns Creek Reconnection, LVF-04, Metzler and O'Grady Park Side-channel Improvements, and LVF-06, Flaming Geyser North Side-Channel Reconnection; and 2) the Upper Green River, VF-03 Brunner Side-Channel Reconnection.

The selected Middle Green River projects are spaced between Neely Bridge and the upper end of the Middle Green Reach, Flaming Geyser. Two of these projects LVF-04, Metzler and O-Grady Parks, and LVF-06, Flaming Geyser North, incorporate 3 of the 6 largest side-channels found in the Middle Green River. LVF-03, Loans Levee Removal, would re-create a relic side-channel that would be equivalent to the 7th largest side-channel in the Middle Green. For new side-channel area alone, these three projects do not equal the habitat area necessary for Middle Green River side-channel mitigation, 6.4 acres or 280,000 ft^2. However, this area measure does not incorporate improvements in quality, which is why the three highest total habitat scores were selected for the mitigation measures. Improvements in quality not accounted for in the areal comparison are considered a buffer for losses in chum smolt survival (5%). To equal the total side-channel area required for mitigation, gravel nourishment is assumed to annually contribute 0.92 acres of side-channel habitat (back-bar) and is added to the area of the 3 side-channel projects, 5.43 acres (Table 2).

The selected Upper Green River project, VF-03 Brunner Side-Channel Reconnection, is located on the rightbank between RM 58.7 and RM 58.2. It is one of only two areas in the Upper Green River where major improvements to side-channel habitat could be realized. The second area, the leftbank facing VF-03, RM 59.4-58.8, is being improved as a habitat restoration project related to original dam construction, VF-04, described in Section 5.

TABLE 2. INCREASE IN NEW HABITAT AREA FROM FOUR SELECTED SIDE-CHANNEL MITIGATION PROJECTS AND FROM GRAVEL NOURISHMENT: INCREASE IN TOTAL ACREAGE MUST EQUAL 8.4 ACRES -- 6.4 ACRES MIDDLE GREEN, 2.0 ACRES UPPER GREEN.

	With Project/Without Mitigation Habitat (acres)	With Project/With Mitigation Habitat (acres)	Additional Area (acres)
Middle Green			
LVF-03	0	2.01	2.01
LVF-04	4.81	6.92	2.11
LVF-06	2.44	3.75	1.31
LMS-01 to 04	0	0.92	0.92
	Middle Green River Subtotal		6.35
Upper Green			
VF-03	0.55	2.96	2.40
	Upper Green River Subtotal		2.40
	Total Habitat Increase		8.75

Project Package Name: **Middle Green River Side Channel Mitigation**
Activity Name: **Flaming Geyser North: Cutoff Channel Reconnection**
Project Number: LVF-06 (location shown in Figure 4.5 of the DFR/EIS)

Project Location: Lower Middle Green River valley floor at RM 44.3-45.1, Right Bank, in Flaming Geyser State Park

Current Conditions: Flaming Geyser Park contains a 2800' side channel, which is currently connected to the river. Slightly downstream of the channel is the mouth of an existing spring-fed stream. The side channel has been connected to the stream in the past but has abandoned the connection and created a new direct channel to the mainstem. There is little large woody debris, gravels are scarce and pools are small and few in number.

Project Description: This project is in state park land and should be considered for conservation easement. This project was conceived under the Green-Duwamish Basin Restoration Reconnaissance Study. Under the concept plan for the Basin Study, an existing side channel and an existing spring-fed stream would be reconnected through excavation of an old cutoff channel. The existing and new channels would be enhanced through addition of large woody debris and providing stable water source (spring-fed stream).

Proposed Project: Reconnect and improve up to 3.75 acres of side-channel habitat: 2.4 acres baseline and 2.35 additional acres with mitigation. Divert the downstream end of the side channel to join the stream through the relic, perched side channel. This will create 1500 feet of new channel and improve flows through the lower portion of the side channel. Excavate 150 ft of inlet 1-2 ft deeper, RM 45.1, and place a debris jam just downstream of inlet to improve connection of side channel at lower flows. Install large woody debris throughout all channels to improve rearing habitat, create pools, and capture gravels.

Project Package Name: **Middle Green River Side Channel Mitigation**
Activity Name: **Metzler and O-grady Side Channel Improvement**
Project Number: LVF-04 (location shown in Figure 4.5 of the DFR/EIS)

Project Location: Lower Middle Green River valley floor at RM 39-40.6, Left and Right Banks, O-Grady and Metzler Parks, and short segment of Mainstem Green River at RM 40.15, Left Bank

Project Description: Reconnect and improve up to 6.92 acres of Middle Green River side-channel habitat: 4.81 acres baseline, 2.1 additional acres with mitigation. This project would increase the complexity and connectivity of two major side channels located on the right bank (Metzler Park) and left bank (O-Grady Park) and rebuild one tributary. As this is County park land, this project may require easements over acquisition. Large woody debris would be added at specific points along existing side channels to increase channel complexity. To provide a more permanent connection from the river to two major side channels -- debris jams would be added to the mainstem Green just downstream of the inlets to raise the mainstem channel. Rebuild run-off that now flows into a ground-water stream channel in O-grady Park upstream of side-channel.

Side Channel RM 40.21L: At RM 40.21, Right Bank. This Side Channel is known as the Metzler (Metzler Park) or MOAS (mother of all side channels). It is the second longest side channel, 3,000 ft currently accessible at moderate flows in the Middle Green River. This project would improve connectivity of side channel at moderate flows 800-2000 cfs and improve habitat quality throughout the length of channel. A debris jam would be placed at a secondary inlet at RM 40.2 to raise the water surface elevation and partially block this secondary inlet. Throughout the length of the actual channel debris would be added to improve habitat quality for pool formation, gravel collection, and available cover.

Side Channel RM 40.63L: At RM 40.63, Left Bank. This is a back-bar channel -- channel on a gravel bar. A debris jam would be placed at the inlet of the side channel near RM 40.2 to trap gravels and divert more flow into the channel.

Side Channel RM 40.01R: At RM 40.01, Right Bank. Improve connectivity to an 500 ft long side channel by excavating the upper 250-300 ft of the channel and adding a debris jam just below the improved inlet. Add woody debris throughout channel length.

Side Channel RM 39.45L: At RM 39.45, Left Bank. This side channel is known as O'grady (O'grady Park) has a perched inlet, is approximately 1600 ft long with a secondary channel flowing into it near the outlet. The outlet empties into a backwater slough. A debris jam would be placed near the inlet and 300 ft of the channel would be excavated to improve connectivity at low to moderate flows. Large woody debris would be added throughout channel 39.45, secondary channel and the backwater slough to improve habitat quality.

Two streams flowing into the Side Channel 39.45L, backwater slough. The first stream, a run-off stream now empties into a shorter groundwater fed stream. The project would reconnect the run-off stream to its historic channel by rebuilding about 400 ft of stream channel. By splitting the two streams, overall stream length would be increased by 1500 ft, and the groundwater fed stream water quality would be improved. Woody debris would be added to improve habitat quality in both streams.

Project Package Name: **Middle Green River Side Channel Mitigation**
Activity Name: **Loans Levee Removal and Burns Creek Reconnection**
Project Number: LVF-03 (location shown in Figure 4.5 of the DFR/EIS)

Project Location: Lower Middle Green River valley floor at RM 37.9-38.2, Right Bank, and Lower Burns Creek

Current Conditions: Loans levee is a 1200 ft levee on the right bank of the Green River. Burns Creek was rerouted around the upstream end of the levee. The levee is about 10 feet high. There is a wetland and a perched channel behind the levee. There is a farm protected by the levee which is outside the 100 year floodplain.

Project Description: Reconnect and improve up to 2.8 acres of side-channel habitat. Removal of an isolated levee along mainstem at RM 37.9-38.2 allowing river to reclaim historic floodplain. Re-alignment of Burns Creek to its historic connection with the floodplain. The outlet to Burns Creek is partially blocked by gravel berm during selected years. Build a set-back levee to provide protection at edge of 100 year floodplain. Rehabilitate an existing, abandoned, 2500 ft long side-channel through excavation, placement of woody debris and plantings. Divert Burns Creek to connect with new side-channel by excavating new channel and filling old channel.

Project Package Name: **Upper Green River Side Channel Mitigation**
Activity Name: **Brunner Side-Channel Reconnection**
Project Number: VF-03 (location shown in Figure 4.5 of the DFR/EIS)

Project Description: Reconnect and improve up to 2.8 acres of side-channel habitat to quality fish habitat which was permanently lost due to reduced peak flows from HHD and isolation of upstream meander on south side of river from construction of railroad and pipeline berm. This would be accomplished in the inner threaded channel by 1) excavating the upper channel area to the existing level of the Green River; 2) diverting flow from the mainstem Green to allow natural scour and excavation of the old channel; and 3) addition of LWD for habitat complexity. In the outer threaded channel - 1) the lower channel would be deepened; 2) the upper channel would be excavated and private road crossings breached; 3) redirect a small tributary that formerly flowed into this channel (but now enters the mainstem Green downstream of this side-channel); and 4) add LWD for habitat complexity.

Besides diversion of a small tributary stream, all work would occur within the historic Green River floodplain and would be below the elevation of the King County road paralleling the area to the north. There is an existing large beaver pond at the downstream end of the slough without fish access to the Green River. There are also several old overflow channels throughout the floodplain. Flow would be diverted into one (30-40 cfs) of the existing overflow channels to create additional off-channel spawning habitat. This would require a diversion structure in the river, cutting down to river level for the upper few hundred few of new channel, adding structural elements and gravels to the new channel. The outer thread channel would require excavating the upper end of the channel above the existing beaver pond to create more smaller ponds that would be connected to the beaver pond and new overflow channel. The small tributary stream at one time flowed into the slough, it appears to have been diverted to the west when the railroad was re-aligned. A sand and gravel company now lies in the course of the old channel and a 500-700 ft culvert would be required to traverse the gravel company land.

8B.4 FLOW AUGMENTATION AS MITIGATION FOR STEELHEAD REDD DESICCATION

Under Phase I, spring refill baseflow targets, reduction in artificial freshet volume, and additional augmentation of baseflows in June are recommended mitigation features to compensate for impacts to steelhead redd and egg desiccation. Minimum baseflow targets were established through the AWSP hydrologic modeling process (Section 9). Spring refill baseflow targets were determined by manipulating the historic database to find the maximum flow volume that could be determined under seasonal hydrologic conditions, wet, average and dry years. An additional target was to have a linear decline in the stage-discharge over a 2 month period, from May 1 to June 30. The modeled instream flow levels for Phase I and Phase II are: 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

Phase I baseflow targets for May 1 to June 30 do not adequately protect incubating eggs. There is an increase of 0.07 ft per day of channel width that is dewatered for 48 hours over the 50 day egg incubation period. One option to compensate for this impact is to reduce artificial freshet volumes in May and augment spring refill flows in June. A reduction in the volume from 2,500 cfs to 2,000 cfs can decrease the amount of unprotected channel width in May from 0.07 to 0.05 ft and provides for an additional 33 cfs per day in June. This augmentation of June flows would provide an additional __0.03 ft of protected channel width. The combination of reduced unprotected area in May and increased protected area in June reduces the daily dewatered width from 0.07 ft to 0.02 ft.

The option of reducing freshets for protection of steelhead eggs will have associated impacts on other species and lifestages throughout the basin.

Selecting a particular dam release schedule provides benefits to specific downstream resources but limits the opportunity to address other instream needs. Timing of instream releases (as baseflow targets, freshets, or for flow augmentation) may entail trade-off between species. Selecting between competing release schedules requires knowledge of the effects of releases which may not be known until after several years of project operation and monitoring. Under the AWSP adaptive management process, the release scenario can be modified for Phase I and Phase II. As such, the option of reducing freshets for steelhead egg protection is one potential option for avoiding or minimizing impacts of spring refill.

The use of baseflow targets may greatly reduce expected impacts to steelhead. If there are additional impacts unaccounted for in Phase II, flow augmentation is another accepted compensation method. While flow augmentation is considered a restoration feature to address Green River low-flow water quantity and quality limiting factors, here it is also a mitigation feature to compensate for downstream impacts.

In a 1975 report, the Washington State Department of Fisheries stated that low summer flows and poor water quality are principal limiting factors for salmon (and steelhead) production in the Green River. They indicated that although operation of HHD has augmented summer flows, releases from HHD were often too low to completely alleviate poor water quality conditions in August and September, and are too low to provide adequate adult salmon transportation water (Williams et al. 1975).

Production of steelhead and coho has been consistently identified as being limited by the availability of summer rearing habitat throughout their range (Bisson 1987; Reeves et al. 1991) Many researchers agree that quantity of water during critical summer low flow periods is a key factor limiting freshwater production of coho and steelhead (Reiser and Bjornn 1979; Marshall and Britton 1980; Bottom et al. 1985; Everest et al. 1985; Bisson 1987; Jenks 1989; McEwan and Nelson 1991; Reeves et al. 1991; Healey 1991; and Sandercock 1991). The augmentation of summer and early fall flows should provide major improvements to steelhead rearing habitat quantity and quality and will compensate for all expected impacts under Phase II.

SECTION 8C SELECTED HABITAT RESTORATION MEASURES

The Howard Hanson Dam Ecosystem Restoration Goal has been defined as:

> Restore and maintain healthy, naturally reproducing, self-sustaining runs of the historical anadromous runs found in the headwaters above Howard Hanson Dam through improved downstream fish passage, increased flows during the main juvenile outmigration period and low-flow period, outflow temperature control, and by mimicking natural inflow fluctuations. Maintain riparian zone functions within the reservoir inundation zone (and in nearby stream channels) to provide bank stabilization and fish and wildlife habitat, and management of upland and upper river project areas for increased diversity of fish and wildlife habitat.
>
> In the Middle to Upper Green River, below Howard Hanson Dam, maintain (and where possible) improve the existing natural self-sustaining runs of resident and anadromous fish through increased flows during the low-flow period, replenishment of gravel-sized sediments, outlet temperature control, mimicking natural flow fluctuations, and by improving selected side-channel areas.

The three major components (or management measures) of the ecosystem restoration are **1) improved downstream fish passage and salmon restoration; 2) hydrology and flow augmentation;** and **3) habitat restoration**. A description of the three management measures, their components, and project descriptions are listed below.

SECTION 8D HABITAT RESTORATION AND MITIGATION PROJECT DESCRIPTIONS

8D.1 IMPROVED FISH PASSAGE AND SALMON RESTORATION

This management measure is designed to improve fish passage and survival of juvenile coho, fall and spring chinook, and juvenile and adult steelhead through the HHD project (dam and reservoir).

Improved fish passage. Objective, to maximize survival of juvenile salmon and steelhead migrating through the dam (95% or greater survival). Ten downstream fish passage alternatives were identified, the first eight are screen and bypass designs at the existing dam structure, a ninth and tenth alternative, an upstream collector above HHD project, is included as a means to screen fish before they enter the reservoir. The selected alternative is a combination floating modular incline screen, fish bypass, and single lock facility. The facility will "fish" from 6-20 ft in the water column at all pool elevations (1070-1177 ft), and is designed to handle 1250 cfs while meeting all biological screening criteria. Under full capacity, the facility can pass up to 1650 cfs, equal or exceeding the 50% exceedance flow for the expected peak in juvenile outmigration, in April and May. Up to 15 years of downstream outmigrant monitoring is proposed using a combination of passive integrated transponders and hydroacoustics. A sampling station is planned near the bypass outfall. Discussion of facility design is presented in the Hydraulics and Hydrology Appendix, and Incremental Analysis of the 9 alternatives is presented in later in this section.

Following is a discussion of the benefits of improved fish passage for the Green River basin historical anadromous fish runs. Previously, all tent fish passage alternatives have been reviewed by the FPTC for technical feasibility and probable survival of downstream migrants.

To place the Headwaters Green River basin in perspective, and the exceptional benefits that could result from fish passage to the basin, and thereby reconnecting the upper basin habitat to the lower basin habitat (Table 3), following are some hydrologic facts -- 1) the Headwaters Green River has 220 mi^2 or 45.5% of the 483 mi^2 for the entire basin; 2) there are over 23 miles of mainstem habitat and 27 tributaries (adding 83 accessible stream miles, 159 miles inaccessible) or 41.27% out of 643 lineal basin miles; 3) virtually the entire upper Green is unconstrained (by levees or dikes) while below RM 34, much if not most of the lower river is artificially constrained; 4) very few areas in the upper Green exceed 14° C, which is near the optimum range for growth of most life stages of salmon, whereas the lower Green/Duwamish has extensive areas that often exceed 18° C (beyond the preferred range of almost all life stages of Pacific salmon); 5) upper basin habitat is in generally good condition, with percent pools ranging from 28-73% and (in comparison with the lower Green) with abundant instream cover; 6) upper basin water quality is rated AA, or excellent, by the Washington Dept. of Ecology (DOE), whereas lower river areas are rated B, and may experience extended periods of poor water quality (low dissolved oxygen (DO), high salinity, algal blooms, organic and nutrient loading, etc.). The total watershed area of the Headwaters Green River is near equivalent to the Elwha River above of the two dams considered for removal.

TABLE 3. GENERAL WATERSHED FACTS FOR THE GREEN RIVER BASIN, KING COUNTY, WASHINGTON.

	Lower Green River	Upper Green River
Watershed Area	263 mi^2	220 mi^2
Accessible Stream Length	125 miles	106 miles
Native Anadromous Species	Coho, Chum, Chinook, Steelhead	Steelhead, Coho Chinook
Natural Production (Escapement)	11,800-15,800	9,900 (potential)

The Corps of Engineers, in conjunction with agency and tribal fish biologists, have estimated -- 1) the potential anadromous fish production potential for the upper watershed if the restoration goal is met through implementation of all components (fish passage, habitat restoration, flow augmentation); and 2) the adult escapement necessary to maintain this production (Table 4). These estimates are discussed in Section 2A. Through use of a deterministic fish passage model, which uses 7 parameters to estimate smolt to adult survival, the nine fish passage models were evaluated under incremental analysis. Alternative 4, the modular incline screen/fish lock, was selected as the incrementally justified alternative. Potential smolt and adult outputs from the Headwaters watershed are listed in Table 5, assuming full seeding of juvenile salmonids and the fish facility performs as expected. The adult run-size is within the range of historical estimates for steelhead and coho and is within the range of estimates for potential production from other researchers (Section 2A.).

TABLE 4. POTENTIAL PRODUCTION POTENTIAL OF SALMON AND STEELHEAD IN THE UPPER GREEN RIVER AND ESCAPEMENT GOAL NECESSARY TO SUSTAIN POPULATIONS.

	Smolts	Adult Escapement
Coho	161,000	6500
Steelhead	25,000	1350
Fall Chinook	890,000	2300

TABLE 5. POTENTIAL ESTIMATED PROJECT SURVIVAL AND SMOLT AND ADULT RUN-SIZE PRODUCTION WITH AND WITHOUT THE PREFERRED FISH PASSAGE FACILITY (ASSUMING FULL SEEDING OF THE UPPER WATERSHED).

	Project Survival		Smolt Number	
	Without Project	**With Project**	**Without Project**	**With Project**
Coho	**20.0%**	**87.5**	**32,000**	**141,000**
Steelhead	**8.7%**	**90.0**	**2500**	**225,000**
Chinook	**8.1%**	**60.0**	**72,000**	**535,000**

	Adult Run-size (pre-harvest)		
	Without Project	**With Project**	**Incremental Increase**
Coho	4710	20,750	16,040
Steelhead	210	3,090	2,880
Chinook	950	7,070	6,120
Total	5870	30,910	25,040

8D.2 HYDROLOGY AND FLOW AUGMENTATION

Hydrology and flow augmentation. Major components of this measure are a) low-flow augmentation; b) downstream temperature control and water quality improvements; and c) mimic natural hydrology;. This measure seeks to maintain existing hydrological features below HHD and will help restore instream habitat throughout the lower Green River, from RM 0.0 to 64.5.

Low-flow augmentation. Objective, to provide flows (below HHD) greater than minimum flows as provided in operating regimes such as Scenario No. 7 for improved water quality, quantity, temperature, dissolved oxygen, and additional habitat for anadromous and resident fish. Flow augmentation would be available under Phase II through storage of 9,600 ac-ft of water to augment the existing 25,400 ac-ft and 5,000 ac-ft of Section 1135 for a total volume of 40,000 ac-ft.

Since 1906, there has been a large decrease in late spring, summer, and early fall instream flows of the Green River from RM 61 to the Duwamish. These losses of flow were from -- 1) in 1906, the White River was diverted to the Puyallup River affecting flows downstream from RM 35; 2) in 1917, the Cedar River was diverted into Lake Washington affecting flows downstream from RM 11; at RM 61 3) from 1913 to 1948, 85 cfs was diverted by Tacoma; 4) from 1948 to present, 113 cfs (28 cfs above 1913-1948) has been diverted; and 5) and beginning in 2-5 years, an additional 100 cfs will diverted during the high flow season. Without current HHD conservation storage, it is estimated that in about 2 of every 10 years the river would de-water for at least one day (King County SWM unpublished data). In 1987, flows were so low that Washington Dept. of Fish and Wildlife (WDFW) and Muckleshoot Indian Tribe (MIT) personnel had to excavate a low flow channel to free chinook salmon trapped in downriver areas (H. Cocolli, pers. comm.).

The AWSP would provide increased instream flows from June through October and provide greater control over flow releases during April and May. Targets for instream flow release are considered to be major improvement for summer rearing salmon and steelhead and near or within the optimum spawning of chinook during the fall. With low flow augmentation, flows in the lower Green River downstream of RM 35 will be partially restored, flows from RM 35 to 61 will be restored and improved, and flows from RM 61 to 64 will be improved. To demonstrate benefits of greater water quantity for one lifestage of salmon -- rearing habitat will be restored and improved by increases in 1) pool depth; 2) wetted perimeter (important for fry); 3) the river edge will also be closer to riparian zone and resultant shade and LWD; 4) amelioration of water quality/temperature problems (see discussion below); 5) and increases in overall habitat area.

NOTE TO READERS: This discussion below was prepared prior to agreement that Section 1135 5,000 ac-ft would become a yearly storage in Phase I; the prior situation was the 5,000 ac ft would be stored yearly in Phase II. A generic measure of the additional flow available to augment baseflows over the maximum time necessary, from July 1 to October 31, is that the 14,600 ac-ft can provide an additional 65 cfs for 113 days or a 60% increase (to 175 cfs) over the existing instream flow requirement at Palmer, 110 cfs. Hydrologic modeling of the historic database (1964-1995) was conducted to determine reliability of Phase II refill for storing the existing flow volume, 25,400 ac-ft, flow augmentation storage, 14,600 ac-ft and meeting baseflow targets. Storage and maintenance of minimum baseflows from the flow augmentation water was met in 29 of 32 years or 91% of the time. The only years not meeting baseflow targets were 1987, 1989, and 1991. Flow augmentation for fall spawning salmon in these years was depleted in mid to late October.

Downstream temperature control and water quality improvement. Improve temperature (mimic inflow temperatures) and other water quality outputs (dissolved oxygen, nutrient dilution from nonpoint sources, algal growth, organics).

The selected fish passage alternative, near-surface MIS screen and fish lock, would incorporate downstream temperature control through flow releases at surface and lower reservoir depths. In the majority of years, releases from HHD would improve instream temperatures up to 6 miles downstream of the dam (discussed in Water Quality Appendix) meeting maximum target temperature criteria, 59°F, 70% of the time (which is more restrictive than existing water quality criteria, 60.8°F). The outflow temperature regime will follow a more natural progression, rising in the spring and summer and cooling in the fall. Degree days during the critical fall salmon spawning season will be improved over Baseline conditions.

In addition to direct temperature control below HHD, the extra water from flow augmentation should help reduce maximum instream temperatures, dilute nonpoint source pollution, and increase dissolved oxygen in the lower Green River. Maximum summer temperatures in nearshore areas can reach near lethal levels, 72-75°F, particularly during drought years. Increased flows during the summer can help alleviate these maximum temperatures by increasing water velocities, increasing water depth, and potentially by increasing the amount of intergravel flow and cool-water refugia. Maximum temperatures in the mainchannel exceed 70 F most years which can create a thermal barrier to the upstream migration of salmon. Freshets could be used to mix cool and warmwater areas and to encourage salmon to migrate upstream to cooler water areas. A freshet was used in September of 1992 for just such a reason.

In the Duwamish River, the additional flow releases will also increase the amount of available freshwater estuary habitat, possibly by over 1/3 the existing available freshwater habitat. Because of low flows in August and September of 1994, the salt wedge (upper extent of saltwater intrusion into the Duwamish) intruded further into the Duwamish River (river km 19) than ever before recorded.

Mimic natural hydrology. Provide flexibility in operations that allow emulation of the natural river flows, particularly 1) use of a maximum refill rate, and 2) maintenance of peak flows during the spring refill period. A maximum daily refill rate has been implemented under Baseline, not to exceed 400 cfs from April 15 to May 31, and was modeled for Phase I and Phase II, not to exceed 300 cfs April 15-31 and 200 cfs May 1-31. These refill rate maximums are during the peak of smolt outmigration through the reservoir and out of the lower watershed. Outmigration studies conducted at HHD in 1984, and 1991-1995, show that inflow, outflow, and refill rate all may have some influence on successful smolt outmigration. The higher the inflow into and higher the outflow is from HHD the greater the 1) return of adult coho salmon, 2) the number of salmon passing the dam, and 3) the faster smolts migrate through the reservoir. Higher flows during late April and in May will also improve several measures important for juvenile rearing and outmigration in the lower watershed -- 1) the amount of wetted side channel area, 2) duration of wetted side channel periods, 3) frequency of side-channel connection to the mainstem; and 4) survival of outmigrating juvenile salmon and steelhead.

To maintain and restore aquatic habitat during spring, periodic “flushing” flows or freshets will be used to mimic natural peaks in the spring. These freshets are necessary to decrease the travel-time of outmigrating smolts through HHD reservoir and for smolts transiting the lower river to the estuary and to maintain connections between floodplain and mainstem habitats. Phase I targets are for Auburn are: 1) normal years -- two 2500 cfs, 38 hour freshets, and 2) dry years -- two 1250 cfs, 38 hour freshets. Phase II targets are for: 1) normal years -- four 2500 cfs freshets, and 2) dry years -- four 1250 cfs freshets, with modeled average frequency for 32 years of 2.91/year.

8D.3 HABITAT RESTORATION PROJECTS

Habitat restoration for fish and wildlife. This management measure has two components, stream channel restoration (fish) and habitat manipulation (for fish and wildlife). Several components of stream channel restoration and habitat manipulation have been identified -- a) gravel nourishment of the Middle Green River (discussed in *Section 4, Gravel Nourishment in the Middle Green River*); b) Upper Green River side-channel restoration; c) Headwaters Green River channel restoration; and d) large woody debris management. Following is a description of the projects and some context for the projects, either in describing current conditions or potential ecological benefits.

Habitat Restoration Measure 1. Gravel Bar Nourishment of the Middle Green River. The objective of this restoration measure is to halt the downstream migration of bed armoring by maintaining the supply of gravel sized material delivered to RM 40.2 during annual high flows, and to replenish gravels suitable for salmonid spawning which may have been lost as a result of armoring between RM 46 and 40.2. To accomplish this 3900 yd^3 of gravel-sized material will be placed annually in the Flaming Geyser Reach, RM 40.2-46.

The disruption of sediment transport from the Headwaters watershed due to the interception of almost all course sediment (including gravel) by the original construction of HHD may be causing fundamental changes in the mainstem channel and associated habitats of the Upper to Lower Green River. Two concerns are 1) the elimination of spawning gravels downstream of HHD; and 2) "perching" or disconnection of off-channel habitat from the mainstem as the channel bed as downcutting occurs and the bed is armored. Existing flood control operations at HHD are generally effective and have therefore disconnected the mainstem channel from its floodplain. Similarly, changes in flow regimes have reduced the channel-forming effects of high flows, and largely curtailed side-channel formation and maintenance of existing side-channel/mainstem connections. Storage of sediment behind HHD, and the reduction in channel forming flows appear to be causing a zone of streambed armoring (loss of spawning gravels, downcutting of main-channel and side-channel disconnection) to be advancing downstream at a rate of 700-900 ft per year. This advancement of the "hungry river" represents an annual potential loss of mainstem habitat quantity of 160,000 ft^2 (800 ft x 200 ft width, Flaming Geyser) or habitat quality of 48,000 ft^2 (assume 30% of quantity is available and used by salmonids).

Gravel nourishment could be used to replenish areas presently deficient of salmon and steelhead spawning-sized sediments and slow or stop the downstream extent of streambed armoring. Slowing or stopping the downstream extension of streambed armoring was evaluated as part of the AWSP since the effects of springtime water storage on fish in the lower river are influenced by ongoing stream processes. Reductions in flow resulting from implementation of the AWSP between February 15 and May 31 will not increase the rate of gravel movement through the Green River; however, gravel nourishment provides an opportunity to restore natural stream processes. The results of a preliminary analysis of sediment transport indicate that up to 11,700 cubic yards (yd^3) of gravel could be placed annually below HHD to benefit the sediment transport regime of the Green River. However, because of uncertainty over the actual amount required and potential impacts to flood protection, annual placement of 3,900 yd^3 was selected. This amount equals average annual maintenance of 400,000 ft^2 of useable spawning habitat (year 25 of the 50 year project). Even with this maintenance amount, an additional 800,000 ft^2 of spawning habitat could be lost if the actual annual sediment transport amount is 11,700 yd^3.

To execute the selected project, additional evaluation of sediment transport is recommended. Two alternatives are suggested --1) during PED phase (1998-2000), detailed sediment transport modeling of the Flaming Geyser segment could be conducted to better quantify amounts, rate of redistribution, and specific placement location; and 2) at any time, experimentally place and monitor the minimum (selected amount) pre-HHD contribution of 3900 yd^3 in the Flaming Geyser reach. For either alternative, annual placement could be reduced or halted if monitoring identified problems. The selected project description is listed below.

<u>**Project Package Name:**</u> **Mainstem Green River Gravel Bar Nourishment**
<u>**Activity Name:**</u> **Middle Green River Gravel Bar Nourishment**
<u>Project Number:</u> LMS-01, LMS-02, LMS-03, LMS-04 (location shown in Figure 4.5 of the DFR/EIS)

<u>Current Conditions:</u> The Green River downstream of Howard Hanson Dam, RM 64.5, appears to be deficient in gravel sized. Sedimentation studies of the reservoir (Corps) and analysis by King County Surface Water Management suggest that materials of this size are trapped behind the dam because of the reduction in peak flows. The river reaches below the Green River Gorge, RM 40-46 or Flaming Geyser Reach, were identified as already being deficient with lower reaches (below RM 40) presumed to become deficient in the future. The decrease in sediment transport and peak flows below the dam has resulted in downcutting of the riverbed and isolation of off-channel areas at a rate of 700-900 lineal ft per year. Total quantity of mainstem habitat degradation equals approximately 140,000-180,000 ft^2 per year (200 ft cross-section at Flaming Geyser vs. 700-900 ft length). There is also 282,000 ft^2 of wetted side channel habitat from RM 34-46 that will become dewatered under Phase II of the AWSP for which gravel nourishment could provide additional relief.

<u>Proposed Project:</u> This project would provide 3900 yd^3 of screened, gravel-sized material to the Middle Green River just below the Green River Gorge beginning near RM 45-46. The gravel would maintain an increment of existing spawning habitat in the Middle Green River and can compensate for AWSP dewatering of existing (282,000 ft^2) and proposed improved side channel habitat (LVF-04, and LVF-06 and numerous Green/Duwamish Basin Restoration Projects). Because of the reduction in peak flows (with decreased sediment transport ability), gravel nourishment in the Flaming Geyser area is limited and will not equal the annual transport rate for the river (estimated range 3,900-11,700 cu yd^3/year, Section 4D). The replacement value for this project is approximately 50% of the median estimated loss of sediment. A second potential nourishment area was identified below the Tacoma Diversion Dam (MS-05, 06, and 07, described in Appendix) but was not selected. Gravel source would come from a nearby commercial gravel pit 2-3 miles from 2 of the 4 alternative sites. Gravel to be placed just within the active channel, to be moved by high flows. Access to river at the uppermost placement sites may come from

extension a 1500 ft extension of Washington State Dept. of Parks access road on north bank or from the eastern end of the Flaming Geyser State Park access road. Monitoring is discussed in Section 4.

Habitat Restoration Measure 2. Upper Green River Side-Channel Restoration. The objective of this measure is to restore a portion of the 7.7 miles of anadromous fish stream habitat lost from construction of the original dam and inundation of streams by the existing pool: Habitat Measure 3 (discussed below) also addresses this original dam impact. The total area affected was approximately 56 acres of instream habitat. In addition to the habitat loss from the dam upstream to pool elevation 1141 ft, there was a large left-bank side-channel, RM 59.4 to 58.8, impacted during re-alignment of the railroad grade during dam construction. This side-channel, and the accompanying side-channel on the right bank, represent the largest floodplain area between end the Middle Green, RM 46, to HHD at RM 64.5. The lower 1,000 ft of channel of a left bank, major mainstem side-channel was filled, channelized, and disconnected by Corps during construction of Howard Hanson Dam and re-alignment of the BNR railroad in 1960 and 1961. Average channel width in 1940 had been 75-125 ft, in 1995 width is estimated at 10-15 ft. The original culvert or bridge was replaced with a 48 in culvert. During construction in 1960-61, when the channel was filled and temporarily cut-off from the Green River, over 1,000 adult salmon were trapped in the channel (L. Signani, Army Corps of Engineers, personal communication 1995).

This restoration measure would restore river routing through one relic natural side-channels, RM 58-59, that was isolated or cut-off by the relocation of the railroad grade during original dam. This habitat restoration would provide adult salmon and steelhead spawning habitat, and juvenile habitat for salmon and steelhead reared near the side-channel and for outmigrating salmon and steelhead using the new Howard Hanson fish passage facility.

Project Package Name:	**Upper Green River Side Channel Restoration**
Activity Name:	**Signani Side-Channel Reconnection and Restoration**
Project Number:	VF-04 ()

Current Condition: The lower 1,000 ft of channel of a left bank, major mainstem side-channel was filled, channelized, and disconnected by Corps during construction of Howard Hanson Dam and re-alignment of the BNR railroad in 1960 and 1961. Average channel width in 1940 had been 75-125 ft, in 1995 width is estimated at 10-15 ft. The original culvert or bridge was replaced with a 48 in culvert. During construction in 1960-61, when the channel was filled and temporarily cut-off from the Green River, over 1,000 adult salmon were trapped in the channel (L. Signani, Army Corps of Engineers, personal communication 1995).

Project Description: Restore up to 3.4 acres of side-channel habitat to quality fish habitat which was lost due to isolation from the river, channelization, and filling by the

Corps during realignment of BNR Railroad during construction of HHD. This would be accomplished in the slough channel through 1) excavation of fill material; 2) replacement of a 48" culvert with one or two 16' culverts; 3) addition of LWD (large organic debris) and excavation in the floodplain to restore habitat complexity; and 4) diversion of 35 cfs flow from the Green River to provide additional water for the entire channel length.

All work will be performed within the historic Green River floodplain. Tacoma Headworks road will be breached at two points to provide flow diversion at the upstream end (2-4 ft culvert, none existing) and replacement of an existing 4 ft culvert with either one or two 16 ft culverts. Flow diversion to the upstream end will require starting 600-1,000 ft upstream of the breach near RM 59.6. The diversion pipe will probably have to follow pipeline 1 or pipeline 5 to protect against flood damage. The outlet channel may require re-alignment and may extend further downstream than the current channel.

Context and Expected Ecological Benefits: This project would add to the quantity and quality of fish habitat in the upper Middle Green River, for 1) adult coho and steelhead, and 2) juvenile spring and fall chinook, steelhead and coho. This is the only available off-channel spawning and rearing habitat of any significance for 25 miles in the middle Green, from RM. 45 to RM. 70. This may be a unique habitat type to the entire Green, a groundwater-fed slough. To ensure restoration of the historical anadromous fish stocks in the upper Green River, the combined Signani (VF-04) and Brunner (VF-03, Mitigation) Side-channels may be critical for providing off-channel habitat for juvenile and smoltified salmon and steelhead that are successfully passed through the Howard Hanson Dam project. Without this restored and maintained downstream habitat, the increased production from the upper Green River stocks could be minimized, or these restored stocks could impact the production of lower river stocks through competition for already limited habitat.

Habitat Restoration Measure 3. Headwaters Green River Channel Restoration.
The objective of this measure is restore a portion of stream habitat function and value lost by inundation of stream and riparian areas with construction of the dam and raising of the existing pool. This includes two zones of channel restoration - 1) Upper Green River and North Fork Green channel restoration (1177-1240 ft elevation); and 2) HHD tributary stream habitat restoration (from 1177 to 1240 ft elevation). Improvement and restoration of the mainstem Green River and up to 15 tributary streams will include several treatments -- 1) removal of migration barriers to juvenile and adult fish; 2) addition of structural elements (large woody debris (LWD) or boulders) to increase pool depth, sediment routing, and instream cover; 3) restoration or creation of off-channel habitat in large tributaries (side channels or meanders); and 4) protection and expansion of riparian zone buffer strips.

Project Package Name: **Howard Hanson Reservoir Inundation Zone**
Activity Name: **Mainstem and North Fork Channel Restoration (1080-1141 ft elevation).**
Project Number: MS-01, TR-02 (location shown in Figure 4.6 of the DFR/EIS)

Project Location: RM. 65-70, Upper Green River from winter low pool (elev. 1080 ft) to additional pool elevation (1141 ft), North Fork Green from winter low pool (elev. 1080 ft) to additional pool elevation (1141 ft)

Project Description: Partial restoration of up to 20,000 lineal ft of mainstem river habitat, and up to 6,000 ft of large tributary habitat (North Fork) which was lost by original clearing and inundation of the Green and North Fork (1080 to 1141 ft elevation). Over 2.5 miles of in-river habitat was permanently lost by dam construction and continual inundation by winter pool (1015-1070 ft elevation). Partial restoration would be accomplished by 1) placement of large structural elements to contain the braided channel and 2) addition of LWD (anchored to the structures or embedded into the riverbank) to create limited cover for fish.

Project Package Name: **Howard Hanson Dam Restoration Zone (1177-1240)**
Activity Name: **Headwaters, North Fork, and Tributary Restoration**
Project Number: MS-03, TR-06, TR-07 (location shown in Figure 4.6 of the DFR/EIS)

MS-03 Headwaters Mainstem Green River Habitat Restoration from RM 69-72 (elevation 1177-1240 ft)

Project Location: Mainstem and valley floor of Green River from upper edge of the Phase II Additional Storage pool, 1177 ft to elevation 1240 ft.

Project Description: Restore and improve 8,000 lineal ft of mainstem and valley floor habitat of the Green River in areas adjacent to the raised pool 1177 ft and up to elevation 1240 ft. Restoration and improvement of channel habitat will include several treatments including -- 1) addition of structural elements (LWD or boulders) to increase pool depth, sediment routing, and instream cover, bank stability and channel confinement; and 2) restoration or creation of off-channel habitat (side channels or meanders); 3) protection and expansion of riparian zone buffer strips.

TR-06 North Fork Green River Large Tributary Habitat Restoration from Elevation 1177 ft to 1240 ft

Project Location: Main channel and valley floor of North Fork Green River from upper edge of the Phase II Additional Storage pool, elevation 1177 ft to elevation 1240 ft.

Project Description: Restore and improve 4,000 lineal feet of main channel and valley floor habitat of North Fork Green in areas adjacent to the raised pool 1177 ft and up to elevation 1240 ft. Restoration and improvement of channel habitat will include several treatments including -- 1) addition of structural elements (LWD or boulders) to increase pool depth, sediment routing, and instream cover, bank stability and channel confinement; and 2) restoration or creation of off-channel habitat (side channels or meanders); 3) protection and expansion of riparian zone buffer strips.

TR-07 Large and Small Tributary Habitat Restoration from Elevation 1177 ft to 1240 ft

Project Location: Main channel and valley floor of Charley, Gale, McDonald, Cottonwood, Piling, and 3 unnamed tributaries from upper edge of the Phase II Additional Storage pool, elevation 1177 ft to elevation 1240 ft.

Project Description: Restore and improve 10,00 lineal ft of channel habitat in small and large tributary areas adjacent to the raised pool (1177 ft) and up to elevation 1240 ft. Restoration and improvement of channel habitat will include several treatments including - -- 1) addition of structural elements (LWD or boulders) to increase pool depth, sediment routing, and instream cover, bank stability and channel confinement; and 2) protection and expansion of riparian zone buffer strips.

Context and Expected Ecological Benefits: Upper Green River and North Fork Green channel restoration (1177-1240 ft elevation). Restoration and improvement of mainstem and valley floor fish and wildlife habitat in the mainstem Green river and the North Fork Green in areas adjacent and nearby the additional conservation pool, 1177 to 1240 ft. elevation. This project was originally slated to only go from 1177 to 1206 ft elevation. However, field surveys and review of aerial photos showed there was not enough restoration opportunity in the flood control zone (1117-1206) to restore lost habitat associated with the original pool inundation.

The addition of structural elements would occur concurrently with restoration or creation of off-channel habitat. The number of pieces of LWD/1,000 lineal ft of stream varies from 1.2 to 47 in these large tributaries (in the proposed inundation zone). The mainstem Green and Charley Creek have the lowest numbers, 1.2 and 8.6, respectively. Much of the LWD that was historically present in the Green River basin has been removed and there is a very small source of future recruitment remaining. Addition of LWD to one or more of these large tributaries could result in increased smolt production and potentially increased spawning habitat for adult steelhead or salmon. The greatest benefits for smolt production would result from restoration or creation of off-channel habitat in the mainstem Green or North Fork (description discussed under separate project). The confluence of these two tributaries, now inundated by the reservoir, once had an extensive off-channel habitat area. Now, there is only about 5% of the total stream habitat for each tributary that is in off-channel areas. This type of habitat is very productive for coho and chinook juveniles. Wunderlich and Toal (1992) found the highest density of juvenile chinook (in the inundation zone) in a side-channel of the North Fork. The authors also pointed out that high densities of juvenile coho were found in backwater areas next to rootwads.

Habitat Restoration Measure 4. Large woody debris management. Set aside and utilize debris collected during HHD operations for fish and wildlife habitat restoration projects throughout the basin. This operation measure was begun under the existing operations and maintenance program for the dam. The AWSP will continue this practice. For example, in 1996, the Corps set-aside over 60 pieces of 1-3 ft diameter, 20 ft or longer, pieces of large woody debris for use in a habitat improvement project below the dam. The practice will involve having HHD project staff work with Environmental Resources Section staff to select specific habitat logs. These logs will then be set-aside by HHD staff in debris clearing areas for eventual pick-up and transport by Corps, resource agency or non-profit groups for use in habitat restoration. Selected logs must be picked and moved by the end of September each year or they could become a flood hazard, collecting on the trashracks of the intake tower. As there is a finite number of quality logs available in one year and that the need for these logs are increasing as more groups begin restoration efforts, priority of use will be set by the Seattle District.

One selected use under Adaptive Management would include truck and haul of large oody debris to river areas below the Tacoma Diversion. Large wood would be transported by log or dump truck from the collection area to the Palmer river reach and deposited into the active channel. High flow events would transport and collect wood in areas downstream of the release site from Palmer to the Green River Gorge.

MS-09 Truck and Haul of Large Woody Debris

Project Location: The debris collection area will be within the new Phase I inundation pool and will be considered part of the normal operations of the project. The truck will use existing roads to haul the wood below the Tacoma Diversion Dam. Ideally, two to three river access points would be used to distribute the wood to more than one location. However, due to the advanced state of the Feasibility Study and short time available for real estate, we will only use one river access site for real estate estimation: additional release sites may be investigated in PED phase. The river access point will be the same used for the Signani Slough restoration project, VF-04, at RM 59.6 on the left bank.

Project Description. Operations collects large woody debris every year out of Howard Hanson Reservoir. This debris is collected and stored by the end of August at the upper end of the reservoir and is normally burned or selected pieces (large conifers) are used by agencies for fish habitat projects throughout western Washington. Under the AWS project we would take a portion of this collected wood by log-truck or dump truck, haul it to a river access point below the Tacoma Diversion Dam and place it within the active channel of the Green River. At this time, we will be using a generic volume of wood: 100-150 pieces, minimum size 1 ft x 20 ft, to maximum size of 4 ft x 40 ft or an average size of 2.5-3 ft diameter, 30 ft length with rootwad attached. The actual volume of wood collected varies tremendously year to year dependent on high flows from the previous winter(s). The wood would be loaded by equipment normally used by operations to collect the debris (rental track-hoe). The self-loading log and/or dump truck would be rented on a seasonal basis, September, and used for as long as it takes to haul the collected wood: at this time assume approximately 5 days. Once at the river access point, either use the self-loading feature of the truck(s) or rent a track-hoe to unload the wood into the active channel.

Context and Ecological Significance. Large woody debris provides a number of functions in freshwater ecosystems, including sediment and nutrient retention, salmonid habitat enhancement, and stable colonization sites for incipient floodplain vegetation. Howard Hanson Reservoir sits at the confluence of the three largest tributaries in Headwaters Green River sub-basin. Prior to creation of the reservoir, these tributaries carried a large volume of woody debris that was transported downstream. Since creation and operation of the dam and reservoir, this normal river transport of wood has been disrupted as all pieces of wood are either collected by Operations staff or is stranded at higher elevations following a flood pool raise. This project would re-introduce movement of a portion of the historical large wood transport. Release of this wood in the Palmer reach would be below both dams and would be in a stretch of the Green River that is severely lacking in many of the functions a normal river loaded with large wood could perform. This release of large wood should interact with the restoration of the Signani side-channel, improved instream flows and lower-ambient water temperature to improve the quality of instream habitat from the Diversion Dam downstream into areas of the Green River Gorge.

SECTION 8E INCREMENTAL ANALYSIS OF RESTORATION AND MITIGATION PROJECTS

8E.1 MITIGATION PROJECTS

8E.1.1 Reservoir Survival

There is no incremental analysis provided for mitigation under reservoir survival. Mitigation projects are discussed in Section 8B above. Additional habitat improvements related to tributary inundation with unaccounted for compensation for reservoir survival are discussed below.

8E.1.2 Riparian and Tributary Inundation

Purpose and Scope. The primary objective of this mitigation measure is no net loss of riparian and tributary habitat functional value resulting from inundation of riparian and tributary areas from the AWSP pool raise. A secondary objective of this mitigation measure is to provide for protection of instream and reservoir habitat required as cover for juvenile salmon and steelhead migrating through the reservoir. Mitigation is required for the loss of 17.4 acres of stream habitat and 120.3 acres of riparian habitat. Requirements by AWSP Phase are 1) Phase I -- 78.2 acres of riparian and 11.5 acres of stream habitat; Phase II -- 42.1 acres of riparian and 5.9 acres of stream habitat. There are two tasks for mitigation from the above recommendations: 1) maintenance of existing habitat within the new inundation zone; and 2) replacement of lost habitat in areas above the new inundation zone.

<u>Assumptions and Parameters for Analysis:</u>

- The first choice for mitigation options are for in-kind and in-place to maintain existing habitat value in the reservoir. However, the very nature of the pool raise is that much of the stream and riparian habitat is covered for several months of the year. Second, USFWS surveys show degradation will eventually eliminate all native riparian species and instream habitat will degrade to only a fraction of its previous functional value. Thus, much of the mitigation must be in areas above the inundation zone.
- <u>Riparian Habitat.</u> There are 4 means available for maintaining and replacing riparian habitat: 1) retain standing timber in AWSP inundation zone; 2) plant species (non-native, in some cases) able to withstand inundation along selected stream corridors; 3) hold major riparian areas in reserve in the upper watershed; and 4) manage riparian reserve areas for late-successional forest characteristics by thinning and planting of successional trees.

- Stream Habitat. There are 5 means available for maintaining and replacing stream habitat, some of which overlap with riparian habitat, rather than clearing all flooded areas: 1) retain standing timber in the AWSP inundation zone; 2) place structural elements along the bank and within the channel for bank stability and cover in the AWSP inundation zone; 3) improve or create new habitat types at the uppermost edge of the inundation zone, side-channels and ponds, and floating debris in the reservoir pool by rearing fish; 4) add structure and create new habitat (ponds) in major streams above the AWSP; and 5) above the AWSP, replace impassable culverts on selected small to larger streams to open new rearing and spawning habitat.
- Riparian and stream habitat mitigation is not dependent on another measure. It would be dependent on the fish passage facility if we used an output that measured increase in adult fish returns.
- There are other benefits unaccounted for (under restoration of existing inundation areas) but available if existing mitigation is not considered adequate. Restoration projects include stream habitat improvements from the edge of the AWSP pool, 1177 ft, to the 1240 ft elevation will be improved and limited improvements will occur in the existing pool, 1080-1141 ft elevation.
- Selected measures must equal the habitat area required for mitigation: 17.4 acres of instream habitat and 120.3 acres of riparian habitat. Requirements by AWSP Phase are 1) Phase I -- 78.2 acres of riparian and 11.5 of stream habitat; Phase II 42.1 acres of riparian and 5.9 acres of stream habitat. For riparian habitat there are two sub-measures: reservoir inundation zone riparian area maintenance objective, 13.8 acres (assuming 15,000 lineal ft, one-half of entire inundation length, 40 ft riparian width for a minimum riparian zone), and above reservoir area objective, 106.5 acres.
- Outputs are in habitat units, area and quality. AWSP riparian habitat unit loss is 120.3 acres assumes total loss of quantity and quality from pool inundation. AWSP stream habitat unit loss is reflected in the 17.4 acres, this loss incorporates degradation and duration of inundation.
- Project names and project identification numbers for considered riparian and stream habitat projects are listed in Table 6.

TABLE 6. SUMMARY TABLE OF AQUATIC MITIGATION MEASURES FOR THE RIPARIAN AND TRIBUTARY INUNDATION, PROJECT NAME AND PROJECT IDENTIFICATION.

Riparian and Tributary Mitigation Projects	Project ID[1]
Page Mill Pond and Page Creek Maintenance	VF-05
Side-channel Enhancement, Mainstem and Smay Creek	VF-06
Mainstem and North Fork Channel Maintenance	MS-02, TR-04
Tributary Stream Channel Maintenance	TR-05
Mainstem and Sunday Creek Habitat Enhancement	MS-04,TR-08
Tacoma Wildlands Set-asides in Conservation and Natural Forest Zones	MS-08, TR-09
Lower Bear Creek Stream Restoration	TR-01
Headwaters Culvert Replacement	TR-10

1. Project Identification: VF=valley floor projects; MS=mainstem Green River projects; TR=tributary projects.

Analysis and Selection. Riparian, wetland, and stream habitat project construction costs, project life, and replacement rate are presented in Table 7: wetland planting mitigation is in project VF-05. Additional wetland mitigation outside of riparian area is discussed in the Wildlife Appendix, Appendix F, Part Two. Cost-engineering provided total costs for combined riparian and stream habitat projects, Table 7 lists costs by separate aspects, riparian or stream habitat. For example, VF-05 total project cost is $208,000, Table 7 lists riparian cost $64,000 and stream habitat cost of $144,000 or total of $208,000. Phase I and Phase II costs for final selected projects are listed in Tables 11 and 12. Project life is 50 years, some projects are replaced once in 50 years others are replace up to 2.5 times. Project scope for riparian and stream habitat projects, with some comment on HSI or HU (habitat unit), assumptions are listed in Table 8.

TABLE 7. LIST OF RIPARIAN, WETLAND, AND STREAM HABITAT CONSTRUCTION COST AND REPLACEMENT PERIOD. THE ONLY LISTED WETLAND MITIGATION IS VF-05. CONSTRUCTION COST INCLUDE CONTINGENCY BUT NOT EDS&A COST.

RIPARIAN AND WETLAND MITIGATION PROJECTS

Project ID	Construction Cost (1996)	Replacement Period	Percent of Project Maintained
VF-05	64,000	5	10%
MS-02 TR-04	93,000	5	10%
TR-05	36000	5	10%
MS-08	114,000	5	10%
TR-09	13,700	5	10%
MS-04 TR-08	11,500	5	10%

1. Replace 10% every 5 years for total replacement in 50 years.

TABLE 7 CONTINUED.

STREAM HABITAT MITIGATION PROJECTS

Project ID	Construction Cost (1996)	Replacement Period	Percent of Project Maintained[1]
VF-05	144,000	10	20%
TR-10	216,000	15	30%
TR-01	64,000	10	40%
MS-02	402,000	5	20%
TR-04			
TR-05	122,000	5	20%
VF-06	294,000	10	20%
MS-08	65,800	10	40%
TR-09	14,400	10	40%
MS-04	82,100	5	25%
TR-08	293,000	5	20%

1. Replace 20-40% of the project every 5-15 years: loss of woody debris, ponds need re-excavation, culverts need replacement.

TABLE 8. PROJECT SCOPE FOR RIPARIAN AND STREAM HABITAT PROJECTS, WITH SOME COMMENT ON HSI OR HU (HABITAT UNIT), AND ASSUMPTIONS.

RIPARIAN AND WETLAND HABITAT MITIGATION PROJECTS

Project ID	Scope, HSI or HU assumptions
	In-reservoir riparian maintenance projects.
VF-05	Wetland Planting, 5 acres, 1.0 HSI/acre, areas within and above 5 ft max. inundation
MS-02	Planting, 10 acres, 0.375 HSI/acre, 3.75 HU, HSI from HHD Section 1135 PMR
TR-04	Planting, 15 acres, 0.3 HSI/acre, 4.5 HU, HSI from HHD Section 1135 PMR
TR-05	Planting, 5 acres, 0.375 HSI/acre, 1.9 HU, HSI from HHD Section 1135 PMR
	Above-reservoir riparian improvement projects.
MS-08	Set-aside 210 acres at 5 acres reserved per 1 acre affected. 42 HU, 0.2 HSI/acre
	Thinning, 90 acres, equivalent of 27 HU, 0.3 HSI/acre, 50% greater than HSI for reserve
	Planting, 100 acres, equivalent to 30 HU, 0.3 HSI/acre, 50% greater than HSI for reserve
TR-09	Thinning, 5 acres, equivalent to 1.5 HU, 0.3 HSI/acre, 50% greater than HSI for reserve
	Planting, 26 acres, equivalent to 2.6 HU, 0.3 HSI/acre, 50% greater than HSI for reserve
MS-4/TR-8	Planting, 8 acres, equivalent to 2 HU, 0.4 HSI/acre, unvegetated areas

STREAM HABITAT MITIGATION PROJECTS

Project ID	Scope, HSI or HU assumptions
VF-05	Create 2 ponds, HU 1 acre, reconnect 1/2 acre pond, add 150 logs, 0.75 HU.
VF-06	Restore relic side-channel, 2 ponds, 75 logs, connect to existing side-channel
	Improve 2,000 ft long side-channel, 150 logs
TR-10	Replace 2 small culverts and reconnect up to 4,000 linear ft
	Replace 1 large culvert, large tributary reconn. of up to 3,000 linear ft.
TR-01	Improve 1.4 acres, 60 boulders, 150 logs, HSI of 0.45/acre
MS-02	10 Floating Debris Islands, 1.0 HU, 10 islands already planned for Section 1135
TR-04	Place 5 culverts in railroad grade, decreasing stranding, 0.05 HSI/HU
	Place 300 boulders, 260 logs, instream and in ponds, 2.4 HU
	Reconnect relic side-channels, reshape areas in ponds, divert Elder Crk for water source.
TR-05	Place 5 culverts in railroad grade, decreasing stranding, 0.05 HSI/HU
	Replace 1 large trib culvert, 2500 x 20 ft, 1.2 HU
	Add 130 LOD, 165 boulders, 2500 ft, 0.8 HU
MS-08	Place 18 2-3 keystone log clusters, create 6,000 ft2 pool by year 5, 2.35 HU
	Cover-Backwater HSI is 0.3, dropping 270 logs from thinning, increases HSi to 0.32
TR-09	Place 2 2-3 keystone log, creating 4,000 ft2 pool by year 5, 0.2 HU
MS-04	Place mainstem back into 4,000 ft historic channel, excavate and divert, HSI increase from 0.5 to 0.8
TR-08	Create 3 ponds, 1 HU, add 275 logs, 1.6 HU

Riparian Habitat Mitigation. Eight riparian and wetland projects were used for the incremental analysis. These projects are found from 1147-1185 ft, within and just above the AWSP inundation zone, and 1240-1320 ft on the North Fork, from 1240-1280 ft on Gale Creek, and RM 71.3 to 80.1 on the mainstem Green. All projects are located on City of Tacoma Forest Lands. Total outputs from all riparian management measures exceeds required mitigation by about 5.2 acres, 120.3 required and 125.5 produced by the projects (Table 9). Phase I requirements are for 78.2 acres of riparian habitat or 65% of the total riparian mitigation requirement. Phase II requirements are for 42.1 acres of riparian habitat or 35% of the total riparian mitigation requirement.

In-reservoir areas had an additional objective to provide for a minimum length and width of riparian zone and wetland area replacement, 13.8 acres. Phase I in-reservoir projects requires 9 acres, and Phase II requires 4.8 acres. The total outputs from four projects was 15.2 acres. The output represents 5 acres of wetland plantings around Page Mill Pond (VF-05), almost 5.9 acres of combined bald-cypress and Oregon ash (MS-02, TR-04, TR-05), and 4.5 acres of combined Pacific willow and Oregon ash plantings (MS-02, TR-04). Actual acres planted for the cypress, ash, and willow was about 2.5 times greater than the estimated output (HSI OF 0.375). The HHD Section 1135 PMR presents a discussion of these non-native plants and their suitability for use in artificial habitats, seasonal inundation within reservoirs.

The objective for riparian habitat compensation for areas above the AWSP reservoir inundation zone is 106.5 acres. Phase I above-reservoir projects require 69.2 acres, and Phase II requires 37.3 acres. Total replacement output for all considered management measures is 110.3 acres, or 3.8 acres over the total mitigation requirement (Table 9).

Replacement value for these inundated acres comes from riparian forest reserve acreage and management of riparian reserve forests on Tacoma Forest lands adjoining the mainstem Green River, RM 71.3-80.1, North Fork Green, elevation 1240-1320 ft, and Gale Creek, 1240-1280 ft. These riparian reserve and managed mitigation lands begin at the upper extent of the Howard Hanson Reservoir Zone Habitat Restoration Area, 1240 ft elevation. These riparian lands will abut the restoration areas and (in combination with the restoration areas) will provide a continuous zone of reserved and managed lands from the AWSP pool, 1177 ft elevation, to the upper extent of City of Tacoma owned riparian forestland on the Mainstem Green, North Fork, and Gale Creek. Compensation value for these riparian reserve and managed land is based on a ratio of impacted area to reserve land and impacted area to managed land. Riparian reserve lands were given an HSI value of 0.2/acre, or 5 acres of reserve is equivalent to 1 inundated acre. Managed riparian lands, thinning and planting, were given an HSI value of 0.3/acre. This equates to 210 acres of riparian reserve=42 replacement acres, 95 thinned acres=28.5 replacement acres, and 126 planted acres=37.8 replacement acres.

TABLE 9. INCREMENTAL OUTPUTS FOR RIPARIAN HABITAT MITIGATION PROJECTS: 13.8 ACRES IN-RESERVOIR, 106.5 ACRES ABOVE-RESERVOIR ARE OBJECTIVES TO MEET THE TOTAL COMPENSATION REQUIREMENT OF 120.3 ACRES; HABITAT UNITS=ACRES, HU.

Project ID	Mitigation Measure	With-Project/ With Mitigation HU
In-Reservoir		
VF-05	Wetland Planting	5
MS-02	Riparian Planting	3.8
TR-04	Riparian Planting	4.5
TR-05	Riparian Planting	1.9
IN-RESERVOIR SUBTOTAL		**15.2**
Above-Reservoir		
MS-08	Riparian Reserve	42
	Thinning	27
	Planting	30
TR-09	Thinning	1.5
	Planting	7.8
MS-04	Planting	2
TR-08		
ABOVE-RESERVOIR SUBTOTAL		**110.3**
TOTAL ACREAGE		**125.5**

Stream Habitat Mitigation. Twelve stream habitat mitigation projects were used for the incremental analysis. These projects are found from 1147-1185 ft, within and just above the AWSP inundation zone, and 1240-1320 ft on the North Fork, from 1240-1280 ft on Gale Creek, and RM 71.3 to 80.1 on the mainstem Green. All projects are located on City of Tacoma Forest Lands. Total outputs from these projects exceeds required mitigation by about 3.1 acres, 17.4 required and 20.5 produced by the projects (Table 10). Phase I requires 11.5 acres (66% of total requirement) and Phase II requires 5.9 acres (34% of total requirement) of stream habitat mitigation. In-reservoir projects will receive a greater weight in selection of the final mitigation project package. In-place mitigation is especially important in this area for juvenile rearing habitat both summer and overwintering. A significant number of juvenile fish rear in the existing reservoir and even greater numbers are expected with the increased pool size. As the pool is drawn down, many of the juveniles will seek quality rearing areas upstream (in the exposed inundation zone) that would not be available without the proposed mitigation projects.

TABLE 10. INCREMENTAL OUTPUTS FOR STREAM HABITAT MITIGATION PROJECTS: 17.4 ACRES ARE NECESSARY FOR COMPENSATION; HABITAT UNITS=ACRES, HU.

Project Name	Project ID	With Project Without Mitigation HU	With Project With Mitigation HU	HU Increase
In-Reservoir Projects				
Page Mill Pond	VF-05	0.4	2.3	2.0
Bear Creek	TR-01	1.4	2.0	0.6
Mainstem and North Fk	MS-02	1.0	2.0	1.0
Channel Maintenance	TR-04	0.0	0.3	0.3
		5.5	6.3	0.8
		0.0	1.1	1.1
Tributary Stream	TR-05	0.0	0.3	0.3
Channel Maintenance		0.0	1.2	1.2
		3.0	3.8	0.8
Above-Reservoir Projects				
Headwaters Culvert	TR-10	0.0	1.2	1.2
Replacement		0.0	1.7	1.7
Relic Side-channel &	VF-06	0.3	1.5	1.3
Side Channel Enhan.		0.7	1.5	0.8
Tacoma Wildlands	MS-08	36.0	38.4	2.4
Mainstem Set-asides		24.0	25.6	1.6
Tacoma Wildlands	TR-09	1.0	1.2	0.2
Tributary Set-aside				
Mainstem and	MS-04	2.8	4.4	1.7
Sunday Creek	TR-08	5.1	6.7	1.6
TOTALS BY CATEGORY		**81.0**	**102.0**	**20.5**

Incremental Cost Benefit Analysis. Incremental cost and output runs were completed for in-reservoir riparian mitigation measures, above-reservoir riparian measures, in-reservoir stream mitigation measures, and above-reservoir stream mitigation measures.

Riparian Habitat Measures. In-reservoir riparian measures selected were VF-05, MS-02, and TR-04, these measures produced 13.3 acres of habitat. Above-reservoir measures selected were MS-08 and TR-09, these measured produced 108.3 acres. Combining in-reservoir and above-reservoir measures exceeds the mitigation requirement of 120.3 by 1.3 acres for a total of 121.6 acres. Measures dropped were TR-05 (1.9 acres) and MS-04/TR-08 (2.0 acres), total of 3.9 acres. These projects were more costly than the incrementally selected alternatives and were beyond the mitigation requirement. Phase I will require that 65% of the selected projects be implemented or 79.2 acres (78.2 acre mitigation requirement) of the total 121.6 acres. Phase II will require 35% of the selected projects be implemented or 42.4 acres (42.1 acre mitigation requirement) of the total 121.6 acres (Table 11).

TABLE 11. SELECTED RIPARIAN HABITAT MITIGATION PROJECT COST AND HABITAT UNIT OUTPUTS PER PHASES OF THE AWSP: PHASE I 65% AND PHASE II 35% OF TOTAL ACREAGE REQUIREMENT.

Project Cost (1996$)[1]

Project ID	Measure	Phase I Cost	Phase II Cost	Total Cost
In-Reservoir				
VF-05	Wetland Pl.	41600	22,400	64,000
MS-02/TR-04	Riparian Pl.	60500	32,500	93,000
Above-Reservoir				
MS-08	Thin/Plant	74100	39,900	114,000
TR-09	Thin/Plant	8900	4,800	13,700
TOTAL COST		**185,100**	**99,600**	**284,700**

1. Includes contingency but not EDS&A cost.

HABITAT UNIT OUTPUTS

Project ID	Measure	Phase I HU	Phase II HU	Total HU
In-Reservoir				
VF-05	Wetland Pl.	3.3	1.7	5
MS-02	Riparian Pl.	2.5	1.3	3.8
TR-04	Riparian Pl.	2.9	1.6	4.5
IN-RESERVOIR SUBTOTAL		**8.7**	**4.6**	**13.3**
Above-Reservoir				
MS-08	Riparian Res.	27.3	14.7	42
	Thinning	17.6	9.4	27
	Planting	19.5	10.5	30
TR-09	Thinning	1.0	0.5	1.5
	Planting	5.1	2.7	7.8
ABOVE SUBTOTAL		**70.5**	**37.8**	**108.3**
TOTAL ACREAGE		**79.2**	**42.4**	**121.6**

Stream Habitat Measures. In-reservoir stream habitat measures incrementally selected were VF-05, TR-01, and TR-05, these measures produced 4.9 acres of habitat. Combined in-reservoir measure MS-02/TR-04 had the highest annualized cost of all stream measures, for both above and within the reservoir. Above-reservoir stream measures incrementally selected were TR-10, VF-06, MS-08, TR-09, MS-04, and TR-08, these measures produced 12.5 acres of habitat. Using incremental analysis along, combined above and in-reservoir measures gives a total of 17.4 acres of habitat, meeting the required mitigation acreage.

However, the selected mitigation measures will not rely on incremental outputs alone, location of projects is a second consideration. MS-02/TR-04 is the costliest annualized output, almost 50% greater than the next nearest project. It is however one of the most critical for location, representing the mainstem and North Fork within the new inundation zone. The mainstem is the migration corridor for 80% of all juveniles migrating out of the Headwaters watershed. In-place mitigation is called for to maintain the instream habitat within this migration corridor. To meet the mitigation requirement, MS-02/TR-04 will be included (1.3 acres) but the next costliest projects, TR-08 (1.6 acres) and VF-06 (2.1 acres) will be dropped: another alternative could include modifying MS-02/TR-04 to minimize costs. The new output from the selected measures is 16.9 acres. Phase I will require that approximately 66% of the selected projects be implemented or 11.2 acres, Phase II will require 34% of the selected projects be implemented or 5.7 acres of the total 16.9 acres (Table 12).

The additional 0.5 acres required to meet the 17.4 acres of stream habitat mitigation can be compensated through the leave of trees around the reservoir and/or restoration projects below and above the dam: 1) 3.2 acres of side-channel habitat below HHD; or 2) stream habitat improvements above HHD, 8,000 lineal ft of mainstem and 4,000 lineal ft of the North Fork Green. The leave of inundated trees around the reservoir will provide some cover for stream and reservoir perimeter areas at higher pool elevations, 1147-77 ft. The trees will eventually rot and will break at the stem or rootball but broken stems will provide longer lasting habitat for this upper 30 ft of pool elevation. This type of project, tree leave in reservoir areas, has been shown to provide excellent habitat for fish in other impoundments throughout the U.S., including the Pacific Northwest (Laufle and Cassidy 1988).

TABLE 12. SELECTED STREAM HABITAT MITIGATION PROJECTS AND HABITAT UNIT OUTPUTS PER PHASES OF THE AWSP: PHASE I 66% AND PHASE II 34% OF TOTAL ACREAGE REQUIREMENT.

Project Costs(1996$)[1]

Project ID	Phase I Cost	Phase II Cost	Total Cost
In-Reservoir Projects			
VF-05	95000	49,000	144,000
TR-01	42200	21,800	64,000
MS-02/TR-04	265300	136,700	402,000
TR-05	80500	41,500	122,000
Above-Reservoir Projects			
TR-10	142600	73,400	216,000
MS-08	42900	22,100	65,000
TR-09	9500	4,900	14,400
MS-04	54200	27,900	82,100
TOTALS	**732200**	**377300**	**1,109,500**

1. Includes contingency but not EDS&A cost.

HABITAT UNIT OUTPUTS

Project ID	Phase I HU	Phase II HU	Total HU
In-Reservoir Projects			
VF-05	1.3	0.7	2
TR-01	0.4	0.2	0.6
MS-02	0.7	0.3	1
TR-04	0.2	0.1	0.3
	0.5	0.3	0.8
	0.7	0.4	1.1
TR-05	0.2	0.1	0.3
	0.8	0.4	1.2
	0.5	0.3	0.8
SUBTOTAL	**5.3**	**2.8**	**8.1**
Above-Reservoir Projects			
TR-10	0.8	0.4	1.2
	1.1	0.6	1.7
MS-08	1.6	0.8	2.4
	1.1	0.5	1.6
TR-09	0.1	0.1	0.2
MS-04	1.1	0.6	1.7
SUBTOTAL	**5.8**	**3.0**	**8.8**
TOTALS	**11.2**	**5.7**	**16.9**

The total cost for all selected riparian and stream habitat mitigation is $1,394,000. Riparian and stream habitat mitigation construction costs were also broken into Phase I and Phase II costs. Most projects can be broken into components such that a portion can be completed in Phase I and the remainder in Phase II. Project MS-04 is the one exception that cannot be broken into components: requiring a series of channel deflectors and channel excavation to replace the historic mainstem channel. Costs for this project are in Phase I. Phase I and Phase II costs are listed below.

Riparian and Wetland Project Cost (1996$)

Project ID	Phase I Cost	Phase II Cost	Total Cost
In-Reservoir			
VF-05	41600	22,400	64,000
MS-02/TR-04	60500	32,500	93,000
Above-Reservoir			
MS-08	74100	39,900	114,000
TR-09	8900	4,800	13,700
RIPARIAN HABITAT TOTAL COST	185000	99,600	284,700
Stream Habitat Project Cost (1996$)			
Project Costs(1996$)1			
Project ID	Phase I Cost	Phase II Cost	Total Cost
In-Reservoir Projects			
VF-05	95000	49,000	144,000
TR-01	42200	21,800	64,000
MS-02/TR-04	265300	136,700	402,000
TR-05	80500	41,500	122,000
Above-Reservoir Projects			
TR-10	142600	73,400	216,000
MS-08	42900	22,100	65,000
TR-09	9500	4,900	14,400
MS-04	82000		82,000
STREAM HABITAT TOTAL COST	760000	349,400	1,109,400
TOTAL RIPARIAN/STREAM HABITAT COST	945000	449,000	1,394,000

8E.1.3 Side-Channel Connection and Downstream Outmigrant Survival

Selected Measures. Four side-channel projects were selected to meet the mitigation requirements of 280,000 ft^2 (6.4 acres) wetted side-channel area in the Middle Green and 85,000 ft^2 (2 acres) in the Upper Green. Two other side-channel projects were considered but were rejected for: 1) not addressing mitigation requirements; and 2) being too costly. Three of the four projects are in the Middle Green, at RM 38 to RM 45 and the fourth is at RM 58 in the Upper Green. The Middle Green River projects are at: 1) Loans Levee/Burns Creek; 2) Metzler-O'grady Park; and 3) Flaming Geyser State Park. Loans Levee is a levee removal and set-back reconnecting a 2500 ft relic side-channel to the river. Metzler-O'grady is an improvement of 7 acres of large side-channels. Flaming Geyser is an improvement of one large, long (over 4,000 ft) side-channel. In addition, 0.9 acres of gravel nourishment is considered as compensation to complete the 6.4 acre impact requirement for the Middle Green River. The Upper Green has a single project, Brunner Side-Channel Reconnection, that fully compensates for the near 2 acres of impacted side-channel habitat.

Purpose and Scope. There are three elements of Middle Green River, RM 34.9 to 45.6, and Upper Green River, RM 57.0-60.3, side-channel habitat quantity and quality discussed in *Section 7, Green River Side Channel Inventory* -- magnitude of wetted side channel area, duration of continuously wetted side channel area, and frequency of connection to the mainstem, that the AWSP may adversely affect. Two of these three areas are negatively impacted by the AWSP with Magnitude or total wetted area most severely impacted. Magnitude. Under Phase II, average daily wetted side channel area decreases by 367,000 ft^2 for the spring refill period: 282,000 ft^2 in the Middle Green and 85,000 ft^2 in the Upper Green. Under Phase II, both natural freshets and baseflows may be substantially reduced during early spring. Duration. Under Phase II, the average amount of continuously wetted side-channel habitat decreases slightly (<800 ft^2), but interannual variation decreases more, 96,000 to 337,000 ft^2. Although there appears to be no discernible impact, although there is a degree of uncertainty associated with these estimates. Frequency. Periodic freshets are recommended to temporarily reconnect side-channels to maintain juvenile salmon and steelhead survival.

The objective of AWSP mitigation is to have no net loss of Middle and Upper Green River habitat and maintain downstream outmigrant smolt survival. Therefore, in the Middle Green River, replacement of 280,000 ft^2 of wetted side-channel area is required and in the Upper Green River 85,000 ft^2 of wetted side-channel area is required with additional habitat quality improvements required for maintenance of chum smolt survival.

Assumptions and Parameters for Analysis:

- There are 2 basin locations available for wetted side-channel area mitigation: a) Middle Green River from RM 34.0-46.0; b) and Upper Green River from RM 57.0 to 60.3, Headworks to Palmer.

- There are three means available for replacing lost side-channel area: a) creation of new side-channel habitat (reconnection of relict side-channels to mainstem); b) maintenance of existing side-channel connections (lower inlet of side-channels or increase mainstem water surface elevation); and c) improve existing side-channel habitat quality (addition of gravel, cover (large wood), riparian plantings, extend existing channel length).
- Side-channel mitigation is not dependent on another management measure. However, additional benefits can accrue from gravel nourishment, a restoration measure. For this analysis, assume an estimated area of side-channel mitigation from gravel nourishment is 10% of the annual average value of mainstem spawning habitat quality, 400,000 ft^2, or 40,000 ft^2=0.92 acres, of new back-bar channel habitat.
- Total Middle Green River habitat to be mitigated for is 280,000 ft^2 or 6.4 acres. Upper Green River habitat to be mitigated for is 85,000 ft^2 or 2.0 acres. Total area is 367,000 ft^2 or 8.4 acres.
- Outputs of side-channel projects are a combination of area (ft^2) and quality. One mitigation project is reconnection of relic side channels, these have no existing areal or quality value so existing score is 0.0. Lengths and widths of side-channels are computed from 1 of 3 sources; 1) AWSP side-channel inventory; 2) measured off aerial photographs; or 3) estimated by AWSP or Green Duwamish GI study. Habitat quantity is in acres. Quality is a measure of 4 quality components -- 1) connectivity, 0-0.5 value; 2) gravel coverage, 0-1.0 of total area; 3) pieces of wood/mile vs. ideal 400/mile, 0-1 value; and 4) potential species use and life stages, score 0-1. The new habitat score is an average and additive incorporating the increase in total area (new channel, reconnection), and improvement in 4 quality components.
- Selected measures must have 1) the greatest increase of improved habitat score over existing score; and 2) total selected project area must equal or exceed the mitigation value of 6.4 acres for the Middle Green River, and 2.0 acres for the Upper Green River. Total selected project area will include 0.92 acres from gravel nourishment. Total habitat quality incorporates additional benefit to mitigate for chum smolt losses. Impacts are to several dozen side-channels in the Middle Green, spread out over 12 miles, selected side-channels are distributed over 9 miles covering most of the impacted area.
- Costs for side-channel projects are totaled by construction cost (1996 value), and for replacement rate (how often the entire project must be replaced). Replacement rate is primarily a function of the life of large woody debris and maintenance of side-channel inlet elevation. Reconnection of relic side-channels are assumed to have lower replacement rate as much of their value comes from reopening the floodplain to re-working from the main-channel (Table 13). Project LVF-04 has the highest replacement rate as it is in a high energy section of the river: the project area has the greatest density of salmon and steelhead in the basin.

TABLE 13. SUMMARY COST TABLE OF SIDE-CHANNEL MITIGATION PROJECTS WITH CONSTRUCTION COST (1996 DOLLARS), REPLACEMENT PERIOD (HOW OFTEN MAINTENANCE OCCURS), AND PERCENT OF PROJECT MAINTAINED. PROJECT LIFE IS 50 YEARS.

Project ID	Side-Channel ID	Construction Cost (1996$)	Replacement Period (years)	Percent of Project Maintained
LVF-06	R 45.10	359,000	6	20
LVF-07	R 44.4	26,000	5	25
LVF-04	L 40.63			
	R 40.21			
	R 40.01			
	L 39.45			
LVF-04	SUBTOTAL	167,000	3	20
LVF-03	R 38.1	732,000	6	20
LVF-01	L 33.8	904,000	6	20
VF-03	R 58.7	208,000	6	20

Analysis and Selection. Existing habitat conditions (with project, without mitigation) for side-channel projects are presented in Table 14. New side-channel habit conditions (with project, with mitigation) are presented in Table 15. Six side-channel projects were used for the incremental analysis. Inlets for these projects are found in the Middle Green River between RM 45.1 and RM 33.8, Flaming Geyser State Park to Auburn Narrows State Park, in the Upper Green River at RM 58.7. With the exception of LVF-03 and VF-03, all projects are located within existing parks, county or state, and are presumed to be non-standard estates, requiring no acquisition. Area is increased for all projects based on reconnection of relic or disconnected areas or creation of new channel. Connectivity values are equalized under new habitat conditions as all inlets for selected projects are presumed to be open to flows of approximately 1000 cfs or less: the lower end of LVF-03 is assumed to be permanently wetted with reconnection of Burns Creek. Area of gravel has increased for several projects as new gravel is added or excavation will turn and clean existing gravel. Large woody debris pieces per side-channel segment are greatly increased over baseline conditions with between 25 to 100 pieces/1,000 ft. Except for a limited number of key-stone log debris jams in the mainstem, the great majority of wood is added to side-channels or in flood-plain areas. Pieces will be incorporated into larger jams or anchored in some manner.

Species and lifestage use is improved for most projects as reconnection provides new opportunities. LVF-03 has a score greater than 1, 1.5, this project presumes use by up to 3 species and 3 life-stages. LVF-03 is a reconnection of the mainstem to a relic side-channel and re-alignment of Burns Creek to flow into this relic side-channel. Historically, Burns Creek had all species of salmon and steelhead, coho, chum, chinook and steelhead. LVF-07 has the lowest score, 0.25, presuming that only coho spawners or juveniles will use this channel.

For the three selected projects for the Middle Green River, LVF-03, LVF-04, LVF-06 the increased habitat score over existing scores range from 0.65 to 0.99, representing an increase of 5.43 acres. The Middle Green River selected projects are spaced between Neely Bridge and the upper end of the Middle Green Reach, Flaming Geyser. Two of these projects LVF-04, Metzler and O-Grady Parks, and LVF-06, Flaming Geyser North, incorporate 3 of the 6 largest side-channels found in the Middle Green River. LVF-03, Loans Levee Removal, would re-create a relic side-channel that would be equivalent to the 7th largest side-channel in the Middle Green. For new side-channel area alone, these three projects do not equal the habitat area necessary for Middle Green River side-channel mitigation, 6.4 acres. However, this measure does not incorporate improvements in quality, the three highest total habitat scores were selected for the mitigation measures, as such, additional value is unaccounted for. Quality improvements include addition of cover to all side-channel areas (debris), addition or re-working of gravel (up to 6,000 yd^3), and planting of riparian vegetation. To equal the total side-channel area required for mitigation, gravel nourishment is assumed to annually contribute 0.92 acres of side-channel habitat (back-bar) and is added to the area of the 3 side-channel projects, 5.43 acres (Table 16).

Chum salmon smolt losses are considered compensated for by quantity and quality improvements for Middle Green River side-channel mitigation and from the increment of gravel nourishment.

The Upper Green River site, VF-03, creates 2.4 additional acres and provides a variety of quality improvements including reconnection of a tributary to the side-channel, addition of logs for cover, creation of small pond habitat, and reworking of embedded gravels. Site VF-03 fully mitigates for the 2.0 acres (85,000 ft^2) of Upper Green River wetted side-channel area lost in Phase II. This rightbank side-channel mitigation site is complemented by a leftbank side-channel restoration site, VF-04, which re-connects another relic side-channel and creates an additional 3.2 acres of habitat. The leftbank site is restoration of a side-channel disconnected by construction of HHD, discussed under Habitat Restoration projects.

TABLE 14. INCREASE IN NEW HABITAT AREA FROM FOUR SELECTED SIDE-CHANNEL MITIGATION PROJECTS AND FROM GRAVEL NOURISHMENT: INCREASE IN TOTAL ACREAGE MUST EQUAL 8.4 ACRES -- 6.4 ACRES MIDDLE GREEN, 2.0 ACRES UPPER GREEN.

	With Project/Without Mitigation Habitat (acres)	With Project/With Mitigation Habitat (acres)	Additional Area (acres)
Middle Green			
LVF-03	0	2.01	2.01
LVF-04	4.81	6.92	2.11
LVF-06	2.44	3.75	1.31
LMS-01 to 04	0	0.92	0.92
	Middle Green River Subtotal		6.35
Upper Green			
VF-03	0.55	2.96	2.40
	Upper Green River Subtotal		2.40
	Total Habitat Increase		8.75

Incremental Selection of Mitigation Measures. LVF-03, 04, 06 and 07 were incrementally selected based on cost and output. LVF-01 was dropped from consideration as it was the most expensive project for annualized cost and incremental output, being 2 times more costly than the next nearest neighbor. LVF-07 was incrementally selected but is not included in the final selection of mitigation measures. This measure primarily provides rearing habitat for juvenile coho and does not address mitigation needs for chum salmon. Measure VF-03 was not included in the analysis as it is dependent, required for mitigation of Upper Green River side-channel area losses.

TABLE 15. HABITAT CONDITIONS (WITH PROJECT, WITHOUT MITIGATION) FOR SIDE-CHANNEL AREAS IN THE MIDDLE AND UPPER GREEN RIVER.

Project ID	Side-Channel ID	Type	Side-Channel Bankfull area (acres)	Connectivity Value (0-0.5)	Area of Gravel (0-1)	Pieces of LWD (No/mile vs. 400/mile)	Species Use + Lifestage(0-1.5)	Without Mitigation Total Score
LVF-06	R 45.10	Abandoned	2.44	0.40	0.1	0.008	0.75	0.77
LVF-07	R 44.4	Wall-based	0.00	0.15	0.1	0	0.25	0.10
LVF-04	L 40.63	Backbar	2.68	0.15	0.6	0.05	0.5	0.80
	R 40.21	Abandoned	2.13	0.50	0.2	0.06	1	0.78
	R 40.01	Abandoned	0.24[2]	0.00	0.2	0	1	0.29
	L 39.45	Backbar	1.21[2]	0.00	0.6	0.05	0.5	0.35
LVF-04	SUBTOTAL		4.81	0.16	0.4	0.04	0.75	1.23
LVF-03	R 38.2	Relic/Aban.	0.00	0.00	0.1	0	1	0.00
LVF-01	L 33.8	Relic/Aban.	0.00	0.00	0.1	0	0.5	0.00
VF-03	R58.7	Relic/Aban.	0.55	0.15	0.10	0.00	0.25	0.21

1. Species Use: Index score of expected species and life-stage use: a score of 0.25=1 species and 1 life stage; a score of 1 = 2 species and 2 life stages).
2. Not included in LVF-04 subtotal. No value was available for 40.01, and inlet connection for 39.45 was estimated at 4900 cfs.
3. The total score combines area with the four habitat quality indicators: connection, gravel area, large wood, species use.

TABLE 16. NEW HABITAT CONDITIONS (WITH PROJECT, WITH MITIGATION) FOR SIDE-CHANNEL MITIGATION PROJECTS IN THE MIDDLE AND UPPER GREEN RIVER. SELECTED PROJECTS ARE IN BOLD.

Project ID	Side-Channel ID	Type	New Side-Channel Bankfull area (acres)	Connectivity Value (0-0.5)	Area of Gravel (0-1)	Pieces of LWD (No/mile vs. 400/mile)	Species Use + Lifestage(0-1.5)	With Mitigation New Total Score	Increase in Total Habitat Over Without Mitigation
LVF-06	R 45.10	Abandoned	3.75	0.50	0.8	1.03	1	1.42	**0.65**
LVF-07	R 44.4	Wall-based	0.09	0.50	0.3	0.75	0.25	0.38	**0.28**
LVF-04	L 40.63	Backbar	2.68	0.50	0.6	0.5	0.5	0.96	
	R 40.21	Abandoned	2.13	0.50	0.2	0.5	1	0.87	
	R 40.01	Abandoned	0.39	0.50	0.2	0.83	1	0.58	
	L 39.45	Backbar	1.21	0.50	0.6	1.38	0.5	0.84	
	Tributary		0.52	0.50	0.3	1.29	1	0.72	
LVF-04	SUBTOTAL		6.92	0.50	0.38	1.25	1	2.01	**0.78**
LVF-03	R 38.2	Relic/Aban.	2.01	0.50	0.6	0.35	1.5	0.99	**0.99**
LVF-01	L 33.8	Relic/Aban.	1.15	0.50	0.1	0	0.5	0.45	**0.45**
VF-03	R58.7	Relic/Aban	2.96	0.50	0.40	0.80	0.75	1.08	**0.87**

1. Species Use: Index score of expected species and life-stage use: a score of 0.25=1 species and 1 life stage; a score of 1 = 2 species and 2 life stages; a score of 1.5 = 3 species and 3 lifestages.

8E.2 RESTORATION PROJECTS

NOTE TO REVIEWERS: This section is in revision and will not be consistent with the Plan Formulation Appendix and the Economic Appendix. The approach will be the same the revisions will change the outputs and discussion.

8E.2.1 Fish Passage Facility Evaluation

Selected Fish Passage Measure. The selected alternative, fish passage Alternative 4, consists of a new intake tower with a single modular incline screen (MIS) (400-1250 cfs outflow volume, still meets all screen criteria) and single fish lock. A live box would capture fish within the lock when the lock is being evacuated. Outflow routed into existing flood control tunnel. Considered equivalent to Alternative 7. This facility is the culmination of 4 years of technical design and review by the FPTC and is considered "state of the art", combining separate passage features in a unique, one-of-a-kind facility. If feasible, the expected survival is 95% or greater

Fish Passage Model. We developed a deterministic fish passage survival model for three Green River stocks, coho salmon, winter steelhead, and fall chinook salmon. This model was a multiplicative model (each parameter is multiplied against the previous parameter) made up of 7 parameters affecting total adult run size and adult escapement. The parameters were:

- Baseline and ten fish passage alternatives (FP 1-9) (including an "Old" no. 4 and "New" no. 4, see below). Description of the nine passage alternatives is listed in Table 17.
- Species: coho, steelhead and fall chinook salmon: spring chinook were modeled but not included in final analysis (Green River stock is extirpated).
- Juvenile life-stage: coho, yearling; steelhead yearling or two-year old, fall chinook were proportioned, 90% subyearling and 10% yearling (Dilley and Wunderlich 1992, 1993).
- Juvenile mortality through the reservoir, entitled "% delay", fish delayed beyond the "biological window" are considered moralities (baseline survival). Three estimates of reservoir mortality were applied to provide a sensitivity analysis, these 3 mortality estimates varied as did ocean survival (Appx. A).
- Increase in reservoir mortality with the larger AWSP pool, entitled "with increase", this was additive to % delay to create "reservoir mortality."
- Juvenile mortality through 9 dam bypass alternatives, entitled "dam mortality". Up to 10 parameters used to estimate bypass survival from trash rack entrance to flume exit. Baseline survival estimated at 46% for juvenile fall chinook.

- Project passage survival is the product of reservoir mortality * dam mortality -1, entitled "survival."
- Headwaters watershed smolt production under Baseline conditions is the input (see Section 2A).
- Project passage survival multiplied by the smolt production results in the "output" or smolt outmigrant numbers under Baseline or each alternative.
- The increase in smolt outmigrant numbers with each fish passage alternative improvement (over Baseline) is entitled "smolt incremental increase."
- Ocean survival of each stock is adult return rate from Western Washington tagged fish returns or literature references. Two to three levels of survival were applied, natural production rate and hatchery production rate.
- The incremental increase in adult run size is the product of the smolt incremental increase x the ocean survival.
- Originally, two types of harvest rates were applied, a literature reference of "optimum" harvest rates, and later, a maximum harvest rate that the highest producing alternative could support and still meet estimated escapement goals. The final harvest rate used for the incremental evaluation presented in the Economics Appendix was an "approximate" long-term average from the late 1970's to the mid-1990s'.
- Adult escapement was used as the final check, if an alternative did not meet escapement within a certain range of harvest rates it was not considered.
- Costs for each fish passage alternative are listed in the economics appendix.

TABLE 17. DOWNSTREAM FISH PASSAGE MANAGEMENT MEASURES USED TO INCREMENTAL ANALYSIS AND SELECTION OF THE PREFERRED FISH PASSAGE FACILITY.

Alternative AI This alternative consists of only a modification of the existing bypass outlet to provide for more fish friendly outlet conditions through addition of a 4 ft diameter pinch valve.

Alternative A2 This alternative consists of a combination of Alt. 1 (above) in addition to smoothing the three downstream bends in the existing 4 ft bypass.

Alternative A3 This alternative consists of a combination of Alt. 1 and 2 (above) in addition to excavation of a wet well chamber within the existing intake tower. This would consist of an extension of the existing bypass intake port from elevation 1068 to elevation 1140 providing near surface collection: with a sliding trash rack and panels in the gate guide slots.

OLD Alternative A4 This alternative consists of a combination of Alt. 1 and 2 above in addition to an upstream 'gulper' collector similar to that used at Green Peter Dam on the Santiam River in Oregon. It would be mounted on the existing intake tower and gate lift hoist structure.

NEW

Alternative A5 This alternative consists of a new intake tower with a single MIS screen (maximum 560 cfs outflow volume) and single fish lock. A live box would capture fish within the lock when the lock is being evacuated. Outflow routed into existing flood control tunnel.

Alternative A6 This alternative consists of a new intake tower as for Alt. 5 above with a single MIS screen and fish lock, except that outflow conduits will be routed through a new tunnel about 2000 ft long to a portal area downstream of the existing spillway discharge point.

Alternative A7 This alternative consists of a new intake tower as for Alt. 6 above, except that two intake horns, two MIS screens, and two fish locks will be used. As for Alt. 6 above, the outflow will be routed through a new tunnel to the downstream portal and stilling basin.

Alternative A8 This alternative consists of a new intake tower with a single MIS screen (400-1250 cfs outflow volume still meeting all screen criteria) and single fish lock. A live box would capture fish within the lock when the lock is being evacuated. Outflow routed into existing flood control tunnel. Considered equivalent to Alternative 7.

Alternative B1 This alternative consists of an upstream collector on the mainstem Green at elevation 1181 ft. The collector consists of a bank of 4 MIS, a permanent spillway, a seasonal rubber dam (March 15-September 30), and open channel around the reservoir using the railroad grade (approx. 5.5 miles) to Bear Creek. MIS meet all screen criteria.

Alternative B2 This alternative consists of an upstream collector on the mainstem Green at elevation 1181 ft. The collector consists of a bank of 4 MIS, a permanent spillway, a seasonal rubber dam (March 15-September 30). Transport would be by truck around the project. A holding facility would be at the collector and release would be at the Palmer Rearing Ponds. MIS meet all criteria.

NOTE: For purposes of fair comparison, Fall Chinook Smolts are assessed with Qout = 400 cfs, Pool Elevation (PE) = 1177 ft for all alternatives here.
The existing bypass assumes 54% mortality for Qout = 400 cfs, PE = 1140.

Dam Bypass Survival. An example of the original worksheet used to assess dam bypass mortality and survival for the 10 fish passage alternatives is shown in Table 18. The mortality rates for various aspects of Baseline and the 9 passage alternatives were calculated based on hydraulic equations or past studies of mortality for other juvenile bypass projects: Baseline dam passage survival was calculated using similar methods with an overall survival rate of 46% (mortality is 1-survival=54%). Fall chinook salmon smolts were selected as the indicator of mortality for all stocks as they are considered the smallest smolt likely to use the fish passage. This survival rate assumes operation of the 48" bypass throughout the outmigration period, which has occurred in 3 of the past 5 years. Observed direct mortality rates for the bypass have been shown to exceed 30% with no estimate of latent mortality (Section 2D). This table has since been revised and new outputs are shown in the total project survival Tables 21 to 23 at the end of this section.

Under the fish passage model preferred alternative, FP 4, dam mortality rates were the same for each species (using chinook as smallest smolt) - 5.7% for coho, steelhead, and fall chinook.

Reservoir Delay. The second aspect of project survival used in the incremental analysis, reservoir delay otherwise known as reservoir mortality, was broken out by species as recommended by the FPTC: an earlier analysis had used mean delay (all stocks) to assess impacts of the reservoir. The percent delay, column 2, is from the percentage of fish delayed beyond their "biological window" in the 1991/1992 outmigration study at HHD (Dilley and Wunderlich 1992 and 1993). Information on reservoir delay was available for coho, subyearling chinook, and steelhead smolts: spring chinook were interpolated from fall chinook and coho rates. Development of reservoir delay, and ultimately reservoir mortality, are also discussed under Appendix B Table 1, 2 and 3.

These reservoir survival estimates were initially based on the highest delay of outmigrating smolts from the 1991/1992 outmigration study. For coho, the worst year was 1992 where 41.6% of all smolts outmigrated after their "biological window" (1991=zero delayed). Steelhead had a very poor capture record so only 1991 had an estimate, where 61% of all smolts migrated after their biological window. Chinook had a high of 62% delay in 1991. These numbers were then adjusted to get a range of values for reservoir survival. Reservoir mortality was broken out by species as recommended by the FPTC. We used three different reservoir survival estimates with our beginning baseline survival for a sensitivity analysis of total adult returns and adult escapement.

To incorporate the AWSP pool raise into project survival we applied an additive factor to reservoir mortality. The reservoir length increases from 4.3 miles at low pool to 5.7 miles under AWSP Phase II a 33% increase. The pool depth increases from 71-106 ft depth under baseline to 107-142, again about a 33% increase in depth. We applied this proportional factor, an additive 33% increase in reservoir mortality to create total reservoir mortality under the AWSP. The impact of the AWSP is represented by column

3, "with increase", the assumed increase in mortality with the additional pool from the AWSP.

The baseline and AWSP reservoir mortality estimates were used as a starting point. These reservoir mortality values were constant for alternatives 1 and 2 as these bypass alternatives did nothing to improve surface attraction. When a surface exit was provided, beginning with alternative A3, reservoir mortality was (see discussion below). The baseline steelhead survival is lower than coho and chinook because of greater uncertainty in their migration through the reservoir. Only 259 and 27 steelhead were estimated to exit through the dam in 1991 and 1992. Tom Cropp (WDFW) also felt steelhead had the greatest uncertainty in traversing the reservoir.

We used the highest reservoir mortality rate (reservoir mortality = 1-survival) for baseline in the fish passage model final incremental analysis outputs -- 42% for coho, 61% for steelhead, and 62% for fall chinook.

TABLE 18. HOWARD HANSON DAM BYPASS SURVIVAL WORKSHEET. THIS WORKSHEET ATTEMPTS TO DEVELOP CUMULATIVE DAM SMOLT MORTALITY ESTIMATES FOR THE HHD FISH BYPASS ALTERNATIVES CURRENTLY UNDER CONSIDERATION. BYPASS MORTALITY FROM THE TRASHRACK INTAKE TO THE BYPASS OUTFALL. RESERVOIR MORTALITY AND DELAY ARE INCLUDED IN THE TOTAL PROJECT SURVIVAL WORKSHEETS BY SPECIES (THAT FOLLOW).

Alternative A1	Losses thru Trashrack	Bypass pipe at port entrance loss	Bypass pipe bend losses	Outlet loss - pressure release	Outlet loss - striking against valve	**Total cumulative loss (%)**
Mortality Est.(%)	2.5	1	6.4	2.5	12	**24.4**

Alternative A2	Losses thru Trashrack	Bypass pipe at port entrance loss	Bypass pipe bend losses	Outlet loss - pressure release	Outlet loss - striking against valve	**Total cumulative loss (%)**
Mortality Est.(%)	2.5	1	2.4	2.5	12	**20.4**

Alternative A3	Losses thru Trashrack	Bypass pipe at port entrance loss	Bypass pipe bend losses	Outlet loss - pressure release	Outlet loss - striking against valve	**Total cumulative loss (%)**
Mortality Est.(%)	2.5	0.2	2.4	2.5	12	**19.6**

Alternative A4	Entrance to gulper mouth	Gulper bend induced losses	Screen losses*	Bypass entrance losses	Flexible & Fixed bypass pipe bend losses**	**(see * & ** below)**
Mortality Est.(%)	0.02	0.3	19	0	5	**8.32**

Alternative A5 This Alternative has not been analyzed here.

Alternative A6	Trashrack losses entrance to tower	Intake horn losses	Screen losses	Bypass entrance losses	Bypass pipe bend losses	Losses within fish lock***	Live box losses	Lock exit losses	Flume losses	Flume exit losses	**Total cumulative loss (%)**
Mortality Est.(%)	0	0	0.25	0.13	0.01	2	3.1	3.5	0	0	**8.99**

Alternative A7 **Alternative A8 4**	Trashrack losses entrance to tower	Intake horn losses	Screen losses	Bypass entrance losses	Bypass pipe bend losses	Losses within fish lock***	Live box losses	Lock exit losses	Flume losses	Flume exit losses	**Total cumulative loss (%)**
Mortality Est.(%)	0	0	0.25	0.13	0.01	2	3.1	3.5	0	0	**8.99**

Alternative B1	Trashrack losses entrance to tower	Intake horn losses	Screen losses	Bypass entrance losses	Bypass pipe bend losses	Losses within fish lock***	Lock exit losses	Flume losses	Flume exit losses	**Total cumulative loss (%)**
Mortality Est.(%)	0	0	0.25	0.13	0.01	2	3.5	0	0	**5.89**

NOTES: *The Green Peter-style screen is undersized and does not meet our current criteria. This loss could be reduced to as low as 2% by enlarging screen.

**Losses through the Green Peter bypass may have been largely due to roughness within this pipe. If the pipe were of very smooth material, losses could be reduced to as low as perhaps 1%.

*** Predation losses are really only rough estimates. I assumed that only a few predator smolts (steelhead and/or yearling chinook) would inhabit the lock during the peak outmigration of fry and subyearlings of either species (March thru June).

Attraction with Increased Facility Outflow and Decreased Reservoir Mortality. With surface attraction provided from Alternative FP3 to FP7, reservoir mortality was assumed to decrease with increasing flow for steelhead and coho. Studies on the Elwha, at Wynoochee, and Howard Hanson have demonstrated that steelhead and coho reservoir migration and passage through the dam is related to flow. Chinook have been shown to have a lower response to flow than either coho and steelhead: Revised assumptions include an increase in attraction for fall chinook with increased flow from surface collection, I used 1/4-1/3 the increased assumed for coho and steelhead. As such, coho and steelhead reservoir mortality was decreased at a greater rate than chinook for the fish passage with surface attraction and increased flow (FP4, FP5 and FP7). Therefore, as an example, <u>medium</u> reservoir survival increases from 44.1% for coho under baseline to 94.7% under the double lock (FP7). Steelhead increases from 18.9% to 92.4% and fall chinook from 17.5% to 64.5%.

Under the final incremental analysis, the fish passage model preferred alternative, FP 4, reservoir mortality is -- 5.2% for coho, 7.6% for steelhead, and 36.5% for fall chinook. We used the lowest reservoir mortality rate (reservoir mortality = 1-survival) for baseline in the fish passage model final incremental analysis outputs -- 42% for coho, 61% for steelhead, and 62% for fall chinook.

Project Survival. Project survival represents the product 1 - dam mortality * reservoir mortality. A variety of baseline project survival rates were used, sensitivity analysis, and are presented in tables in Appendix A (bottom of each table).

Under the final incremental analysis, the baseline project survival rate was 20.3% for coho, 8.7% for steelhead, and 8.1% for fall chinook. The highest reservoir survival rate (lowest mortality rate) was used to calculate the baseline. The only "yardstick" we can measure these baseline project survival estimates against is the preliminary CWT returns for coho salmon. Compared with the adult return rates for the first two years of adult coho CWT returns, the 20% baseline survival is fairly close, but slightly below the "test" project survival estimate of 33% (Section 2E)

Under the final incremental analysis, the fish passage preferred alternative, FP 4, project survival rates were 89% for coho, 87% for steelhead, and 60% for fall chinook. These project survival rates appear to be reasonable for estimates of survival through the preferred fish passage facility, about 94% for all stocks, and survival through the reservoir, 94% coho, 93% steelhead, and 65% for fall chinook: given what we can predict about smolt passage through the new pool and out the new facility.

Smolt Production and Adult Escapement Estimates. *Section 2A.* presents the full methodology and outputs used to estimated smolt production and adult escapement for the Headwaters Green River watershed. A variety of habitat based production models were used to estimate the smolt production potential and adult escapement requirements for the Headwaters. The smolt production and adult escapement estimates used as input to the fish passage evaluation model are listed below. Distinct smolt production estimates were required for the upstream collectors, Alternatives 8 and 9. As the collector occurred upstream of the reservoir, estimates of smolt production above and below the collector were required. The production estimates for alternatives 8 and 9 used the same total smolt production number but required breaking the estimate into components for habitat area and smolts produced above and below the collector. Spring chinook were used in the model but were not included in the final accounting of total run size and adult escapement for selection of the preferred alternative.

Selected AWSP Smolt Production and Adult Escapement Estimates

	Smolts	**Adult Escapement**
Coho	161,705	6468
Steelhead	25,257	1339
Fall Chinook	890,000	2277
Spring Chinook	279,971	1342

NOTE: The adult escapements used were rounded to the nearest hundred for use in the incremental evaluation presented in the Economics Appendix: for example, coho was changed from 6468 to 6500.

The smolt incremental increase is the amount of smolt production from the AWSP over the Baseline condition (that is the pool raise to 1177 with improvement in passage).

Ocean Survival and Harvest. Two to three (coho) estimates of ocean survival were used, natural produced stocks and hatchery produced stocks. The two estimates were used as part of a sensitivity analysis in combination with 3 variants of baseline project survival. Natural production ocean survival was considered the desired condition while hatchery production ocean survival was used to give the full range of conditions. Natural production ocean survival comes form coded-wire tag (CWT) data, coho is average from three Puget Sound streams (Big Beef Creek, South Fork Skykomish, and Deschutes River, from D. Seiler, unpublished data), steelhead is from Johnson and Cooper (1994), fall chinook is from Green River hatchery data and estimated natural production, and spring chinook from the Elwha reported in Warren (1994 (used in model but not reported here).

For the fish passage model two estimates of natural production ocean survival for coho were used 15% (75% of CWT average of 3 Puget Sound streams, or near-equivalent of potential natural production rate of HHD CWT return fish, Section 2E) and 20% (actual CWT average of 3 streams). The hatchery or low estimate for coho (8.8%) is from Green River hatchery (J. Parkhurst, WDFW, unpublished data). Steelhead low estimate (10%) is from Johnson and Cooper (1994) and the high steelhead (15%) is from Cedarholm (1983). Fall chinook hatchery production estimate (1.0%) is from the Green River hatchery (J.

Parkhurst), the high fall chinook estimate or natural production estimate (1.5%) is equivalent to increasing the Green River estimate by 50% (typical natural/wild stock survival is 50-100% greater than hatchery).

Under the final incremental analysis, the fish passage model preferred alternative, FP 4, ocean survival under natural production was -- 15% for coho, 15% for steelhead, and 1.5% for fall chinook.

We applied a variety of harvest rates to each species adult run size to assess potential maximum harvest rates under different parameters of baseline survival and ocean survival. The range of harvest rates (maximum) are reported in Appendix A, Cost-Benefit Tables 1-8. A second, earlier application of harvest rates was used from Lucchetti and White (1995) and were assumed to be "optimum rates" and are not presented here.

Under the final incremental analysis, the fish passage model preferred alternative, FP 4, harvest rates were - 70% for coho, 50% for steelhead, 55% for fall chinook.

No escapement goals have been established for the Upper Green so the final harvest rates were from the "approximate" long-term average harvest rates from Lower Watershed salmon and steelhead from the late 1970's to the 1990's. Harvest rates for salmon populations in the Green/Duwamish River peaked in the 1980's: chinook salmon harvest for all Puget Sound ranged from 69-83% (NMFS press release February 27, 1998); coho salmon harvest in the Green River was assumed to average 90% from 1986-1991 (WDFW draft Wild Salmonid Policy, 1995). In the 1990's with five years of El Nino ocean conditions (1992-1995, 1997) harvest years have been drastically reduced with total closures in selected years. Over the long-term, harvest rates are lower than the peak 1980 years, but higher than the 1990's: coho salmon is less than 70%; chinook salmon is less than 60%; and winter steelhead the average is approximately 35% (1977-1992).

These harvest rates provide one more mortality factor influencing the number of adults returning to spawn that are required to maintain existing runs or that could be necessary for recovery and restoration of natural runs above the Upper river man-made barriers (Tacoma Diversion and HHD). Recent harvests (1992-1996) have been greatly reduced from the long-term average; most biologists believe that reduced ocean survival resulting from climatic changes (El Niño) is the main cause for the reduced fish numbers. These reduced numbers of returning adults have resulted in the closure of commercial salmon harvesting in most of the saltwater along the entire west coast over the last 3-4 years. The harvest rates for wild salmon and steelhead may remain reduced in the future, the Washington Department of Fish and Wildlife is considering a wild salmonid policy that could increase the escapement of natural spawners with a potential reduction in future harvests.

In-river survival. This represents adult mortality in the Green River from entry to migration upstream and from Trap and Haul/fallback problems (Hosey and Associates 1988).

Incremental Assessment of Total Project Survival through 10 Fish Passage Alternatives. The Corps developed nine Fish Passage Alternatives to conduct the required incremental analysis. The alternatives were previously described in Table 17. These nine alternatives ranged from a simple improvement to the existing bypass outlet pipe, Alternative A1, to construction of a second dam, Alternative B1 and B2, to capture fish before they enter the reservoir.

Initially, dam survival estimates for 8 alternatives were reviewed by the HHD Fish Passage Technical Committee in 1995 (FPTC). Fish Passage (FP) Alternative no. B1, upstream collector with truck and haul was reviewed later: two truck and haul mortality rates were applied, from a low of 2% to high of 10% for coho/steelhead, and 10 to 15% for fall and spring chinook. This mortality rate is the normal rate assumed for barging on the Columbia River. For the upstream collectors, alternatives B1 and B2, there are two rows, survival and smolt production from areas below and above the upstream collector.

Since review of the 9 alternatives (10% design) by the FPTC, the first selected alternative, "Old" FP Alt no. 4, has gone through substantial revision. "Old" FP Alt. no. 4, has been revised to the point where it is considered equivalent to FP Alt. no. 7: survival rates for no. 7 were applied FP Alt no. 4 for the final incremental analysis. In the total project passage survival tables that follow, Old. no. 4 and New no. 4 are both included.

Total smolt incremental increase and total adult run size used in the incremental analysis is presented in Tables 19 and 20. Fish Passage Alternative A8, combined MIS/Fish Lock was the selected alternative. An example of the fish passage model output used for Tables 19 and 20 is presented in Tables 21. Further discussion of each parameter is provided below.

TABLE 19. FISH PASSAGE ALTERNATIVES 1-9, INCREMENTAL INCREASE IN SMOLT NUMBER OVER BASELINE BY SPECIES. FPA8 IS THE SELECTED FISH PASSAGE ALTERNATIVE. THIS TABLE IS REVISED WHERE ALTERNATIVE FPA8 OUTPUT IS EQUAL TO FPA7 TO REFLECT THE IMPROVEMENTS IN FACILITY DESIGN THAT MAKE FPA8 NEAR-EQUIVALENT TO FPA7 IN TOTAL DISCHARGE CAPACITY (DISCUSSED BELOW).

Alternative	Coho Increm. Smolt Increase	Steelhead Incremental Smolt Increase	Fall Chinook Incremental Smolt Increase	Spring Chinook Incremental Smolt Increase	Total Incremental Smolt Increase	Fall Chinook, Coho, Steelhead *Primary Restoration Stocks*
FpA1	11657	778	25588	11057	49080	38023
FPA2	13168	879	28905	12490	55442	42952
FPA3	43376	7624	136352	82501	269853	187352
FPA4						
FPA5	103039	17907	426581	194210	741737	547527
FPA6	103039	17907	426581	194210	741737	547527
FPA7	111716	19821	463237	214107	808881	594774
FPA8	**111716**	**19820**	**463248**	153575	748359	**594784**
FPB1	95164	17531	676178	174575	963448	788873
FPB2	96358	17721	753233	185334	1052646	867312

Baseline	32833	2192	72071	31142	138238	107096

TABLE 20. FISH PASSAGE ALTERNATIVES 1-9, INCREMENTAL INCREASE IN TOTAL RUN SIZE OVER BASELINE BY SPECIES. ASSUMPTIONS: PASSAGE MODEL USED HAD LOW SMOLT BASELINE SURVIVAL, ADULT SURVIVAL IS NATURAL PRODUCTION RATES.

Alternative	**Coho** *Adult*	**Steelhead** *Adult*	**Fall Chinook** *Adult*	**Spring Chinook** *Adult*	**Total Incremental** *All species Run size*	**Fall Chinook, Coho, Steelhead** *Primary Restoration Stocks*
FpA1	1673	109	338	50	2170	2120
FPA2	1890	123	382	56	2451	2395
FPA3	6227	1069	1800	371	9467	9096
FPA4	**16037**	**2780**	**6115**	**963**	25895	**24931**
FPA5	14791	2512	5631	874	23808	22934
FPA6	14791	2512	5631	874	23808	22934
FPA7	**16037**	**2780**	**6115**	**963**	25895	**24931**
FPA8						
FPB18	13661	2459	8926	786	25831	25045
FPB29	13832	2485	9469	834	26621	25787
Baseline	**4713**	**307**	**951**	**140**	**6112**	5972
Escapement Estimate	**6478**	**1339**	**2287**	**1342**	**11446**	**10104**
Ocean Survival	***15.0%***	***15.0%***	***1.5%***	***0.6%***		

Selected Fish Passage Measure. The selected alternative, fish passage Alternative A8, consists of a new intake tower with a single modular incline screen (MIS) (400-1250 cfs which still meets all screen criteria) and single fish lock. A live box would capture fish within the lock when the lock is being evacuated. Outflow routed into existing flood control tunnel. Considered equivalent to Alternative A7. This facility is the culmination of 4 years of technical design and review by the FPTC and is considered "state of the art", combining separate passage features in a unique, one-of-a-kind facility. If feasible, the expected dam passage survival is 95% or greater.

TABLE 21. FISH PASSAGE MODEL WITH COHO SMOLT SURVIVAL THROUGH HOWARD HANSON DAM AND RESERVOIR, POTENTIAL SMOLT PRODUCTION, AND INCREMENTAL INCREASE WITH 9 FISH PASSAGE ALTERNATIVES. TOTAL ESCAPE

Passage Alternative	Coho % Delay	With Increase	Reservoir Mortality	Dam Mortality	Project Survival	Input	Output	Smolt Incremental Increase	Ocean Survival	In-river Survival	Adult Run Size Increment	Harvest Rate	Escapement Incremental Increase	BASELINE + INCREMENT
Pristine	0	0	0.00%	0.00%	1	194314	194314		15.00%		29147	70.00%	8744	
Baseline	42.00%	13.86%	55.86%	54.00%	20.30%	161705	32833		15.00%	95.70%	4713	70.00%	1414	
FPA1	42.00%	13.86%	55.86%	37.67%	27.51%	161705	44490	11657	15.00%	95.70%	1673	70.00%	502	1916
FPA2	42.00%	13.86%	55.86%	35.55%	28.45%	161705	46001	13168	15.00%	95.70%	1890	70.00%	567	1981
FPA3	21.00%	6.93%	27.93%	34.61%	47.13%	161705	76210	43376	15.00%	95.70%	6227	70.00%	1868	3282
FPA8	**3.94%**	**1.30%**	**5.24%**	**5.67%**	**89.39%**	**161705**	**144543**	111716	**15.00%**	**95.70%**	16037	**70.00%**	4811	6225
FPA5	7.88%	2.60%	10.48%	6.14%	84.02%	161705	135872	103039	15.00%	95.70%	14791	70.00%	4437	5851
FPA6	7.88%	2.60%	10.48%	6.14%	84.02%	161705	135872	103039	15.00%	95.70%	14791	70.00%	4437	5851
FPA7	3.94%	1.30%	5.24%	5.67%	89.39%	161705	144549	111716	15.00%	95.70%	16037	70.00%	4811	6225
FPB1	2.00%	0.00%	2.00%	3.95%	94.13%	124310	117012							
Baseline Below B1	29.40%	9.70%	39.10%	54.00%	28.01%	39217	10986							
							127998	95164	15.00%	95.70%	13661	70.00%	4098	5512
FPB2	1.00%	0.00%	1.00%	3.95%	95.09%	124310	118206							
Baseline Below B2	29.40%	9.70%	39.10%	54.00%	28.01%	39217	10986							
							129192	96358	15.00%	95.70%	13832	70.00%	4150	5564

8E.2.2 Habitat Restoration Measure 1. Gravel Bar Nourishment of the Middle Green River

Selected Measure. The least-cost gravel nourishment alternative was selected, 3900 yd^3 of gravel placed in the Flaming Geyser reach from RM 40.2-46. Two additional measures were considered, 7800 and 11,700 yd^3. These quantities were rejected as too expensive and with to many uncertainties regarding impacts to downstream flood protection. This measure will require either monitoring or a sediment transport modeling to refine gravel nourishment amounts and/or placement locations.

Purpose and Scope. Storage of sediment behind HHD, and the reduction in channel forming flows appear to be causing a zone of streambed armoring (loss of spawning gravels, downcutting of main-channel and side-channel disconnection) to be advancing downstream at a rate of 700-900 ft/year. This advancement of the "hungry river" represents an annual potential loss of mainstem habitat quantity of 160,000 ft^2 (800 ft x 200 ft width, Flaming Geyser) or habitat quality of 48,000 ft^2 (assuming 30% of quantity is used by salmonids). The goal of this restoration measure is to halt the downstream migration of bed armoring by maintaining the supply of gravel sized material delivered to RM 40.2 during annual high flows, and to replenish gravels suitable for salmonid spawning which may have been lost as a result of armoring between RM 46 and 40.2. This analysis considers the acceptable level of gravel nourishment for the Flaming Geyser reach. The Palmer Reach, RM 57.0-60.3, was not considered in this analysis as there is uncertainty in ability to hold sediments in this high energy reach *(Section 4D, Gravel Nourishment in the Middle and Upper Green River).*

Assumptions and Parameters for Analysis:

- There are 2 basin locations available for gravel nourishment: a) Middle Green River from RM 40.2-46.0, Flaming Geyser; b) and Upper Green River from RM 57.0 to 60.3, Headworks to Palmer. The Upper Green River is not considered.
- There are 3 levels of annual nourishment at the Flaming Geyser reach, 3900, 7800, and 11,700 cu yd. These levels are based on the annual minimum, median, and maximum sediment transport rates estimated for the Middle Green River. Table 22 shows preferred size range for screened gravel used in gravel enhancement projects.
- Gravel Nourishment is not dependent on another management measure.
- Output is replacement rate of annual lost mainstem spawning habitat (ft^2). Unquantified is the additional value to side-channel connection as the raised bed should provide additional connection to existing and future "perched" side-channel habitat.
- Areal coverage or quantity. The Middle Green River is estimated to annually lose 700-900 lineal ft per year of unarmored mainstem spawning habitat. Cross-section at Flaming Geyser is approximately 200 ft. The areal loss of mainstem habitat is equivalent to 140,00 to 180,000 ft^2 per year. The median value, 160,000 ft^2 per year, was selected for this analysis.

- Quality loss. Habitat quality is assumed to be a percentage of mainstem habitat quantity loss. For this analysis we assume a 30% loss in spawning quality for the median annual loss of quantity, 160,000 ft^2, or 48,000 ft^2.
- Replacement value of gravel for loss of mainstem habitat quality: 1) the maximum nourishment rate, 11,700 cu yd., is equivalent to maintaining the annual estimated loss of habitat quality, 48,000 ft^2; 2) the median nourishment rate, 7800 cu yd., is equivalent to maintaining 32,000 ft^2, or 67% of the annual estimated loss; and 3) the minimum nourishment rate, 3900 cu yd., is equivalent to maintaining 16,000 ft^2, or 33% of the annual estimated loss.
- Costs for gravel excavation, transportation, and placement were estimated by Cost-Engineering for screened river rock at commercial gravel pit (CADMAN Sand and Gravel) within 5 miles of four alternate gravel placement sites (LMS-01 to 04). First year costs for road construction for a 1500 ft road for river access on the north side are $78,800 (originally included under side-channel mitigation for North Flaming Geyser Side-Channel). Annual operation and maintenance costs are excavation, transportation, and placement (includes backhoe for placement). Overall, annual operation and maintenance cost per cu yd in 1996 dollars is $24.00 (this includes 20% profit and 20% contingency). Sediment transport modeling or annual monitoring costs are not included in the cost estimate.

TABLE 22. RECOMMENDED SPAWNING-GRAVEL SIZE DISTRIBUTION (ALLEN AND MEEKIN 1973).

Sieve Size (mm)	Percent passing by weight
101.6	100
63.5	80-90
50.8	70-85
38.1	55-70
25.4	25-50
19	0-20
12.7	0

Analysis and Selection. The annual alternate levels of nourishment, cost, and mainstem habitat quality replacement value are presented in Table 23. Outputs for year 1, 25, and 50 are presented in Table 24. The output in year 25 is equivalent to the average annual output for this management measure. The three levels of input, cost, and output are simple measures of minimum, median, and maximum levels of assumed sediment transport reduction from HHD. Costs for any alternative could be reduced if angular pit-run rock (vs. screened) is used or if the rock is simply dumped at the site (without placement by backhoe). Angular pit-run rock is expected to become rounded by abrasion within 3 km (1.9 miles) of any placement site. Annual cost without backhoe and using pit-run rock (estimate $12.00/cu yd) for 3900 yd^3 would be $67,400 or $17.25 per cu yd. This represents a 27% reduction in annual costs.

To allay concerns that gravel nourishment could reduce flood protection of down-river areas, the area of placement is restricted to the uppermost reaches of the Middle Green River -- Flaming Geyser Reach, RM 40-46, and the selected level of nourishment is the minimum level of sediment transport reduction, 3900 cu yd. per year. This level of nourishment is estimated to be one-third the level of assumed maximum average annual pre-HHD bedload of 19,700 tons per year (assuming 0.6 cu yd./ton or 11,700 cu yd.). This level of nourishment should annually maintain approximately 400,000 ft^2 (year 25 of the 50 year project) of useable spawning habitat in the Flaming Geyser Reach. Even with this maintenance amount, an additional 800,000 ft^2 of spawning habitat could be lost if the actual annual sediment transport amount is 11,700 yd^3 (Table 24).

In addition, to execute the selected project, evaluation of sediment transport is recommended. Two alternatives are suggested --1) during PED phase (1998-2000), detailed sediment transport modeling of the Flaming Geyser segment could be conducted to better quantify amounts, rate of redistribution, and specific placement location; and 2) at any time, PED or at inception of AWSP, experimentally place and monitor the minimum (selected amount) pre-HHD contribution of 3900 cu yd. in the Flaming Geyser reach. For either alternative, annual placement could be reduced or halted if monitoring identified problems.

TABLE 23. ALTERNATIVE LEVELS OF MIDDLE GREEN RIVER ANNUAL GRAVEL NOURISHMENT, ANNUAL COST, AND EQUIVALENT MAINSTEM SPAWNING HABITAT QUALITY REPLACEMENT VALUE (SQUARE FEET).

Alternatives	Location	Annual Amount (yd^3)	Annual Screened Cost (1996$)[1]	Annual Pit-run Cost (1996$)[1]	Area of Coverage (ft^2)
GN1	Middle Green	3900	$94,000	$67,300	16000
GN2	Middle Green	7800	$188,000	$134,600	32000
GN3	Middle Green	11700	$282,000	$201,900	48000

1. Two alternative costs are available: 1) screened gravel with backhoe placement, $24.00/cu yd; and 2) pit-run gravel without backhoe, $17.25/cu yd. First year cost of 1500 ft access road on north side of Flaming Geyser, $78,700, are not included here.

TABLE 24. GRAVEL NOURISHMENT ANNUAL MAINSTEM HABITAT QUALITY OUTPUTS WITH AND WITHOUT PROJECT FOR -- YEAR 1, YEAR 25 (AVERAGE ANNUAL OUTPUT FOR 50 YEAR PROJECT), AND YEAR 50.

WITH PROJECT
REPLACEMENT VALUE OF MAINSTEM HABITAT (FT^2)

Measure	Year 1	Year 25	Year 50
GN1	16,000	400,000	800,000
GN2	32,000	800,000	1,600,000
GN3	48,000	1,200,000	2,400,000

WITHOUT PROJECT
LOSS OF MAINSTEM HABITAT (FT^2)

Sediment Transport Rate	Year 1	Year 25	Year 50
7,800 yd^3/year	32,000	800,000	1,600,000
11,900 yd^3/year	48,000	1,200,000	2,400,000

8E.2.3 Habitat Restoration Measure 2 and 3. Upper Green River Side-Channel Restoration and Headwaters Green River Channel Restoration.

Selected Measures. Management measure E-1, Signani Side-channel reconnection, and G-1, Headwater Channel Restoration, were selected as the habitat restoration projects. A third project was considered, F-1, channel restoration in the existing inundation zone, but provided too little benefit for the estimated cost and outputs. Measure E-1 will restore portions of a large, relic side-channel between RM 58-59 in the Upper Green River. Measure F-1 will improve habitat in the mainstem river and large tributaries from the edge of the AWSP, 1177 ft, to an elevation of 1240 ft.

Purpose and Scope. Three projects were considered under the habitat restoration incremental analysis (Table 25). The objective for these projects is to restore a portion of the instream habitat lost or impacted by original dam construction and by inundation by the existing full pool. Existing storage and dam construction have covered permanently or seasonally 7.7 miles and 58.9 acres of stream habitat. In addition, up to 10 acres of Upper Green River side-channel habitat was filled-in and isolated by an impassable culvert during re-alignment of the railroad grade. Project VF-04, Signani Side-Channel, is a restoration design for the filled/isolated side-channel. Projects MS-01 to TR-07 are designed to restore a portion of the 7.7 miles with in-reservoir and above reservoir stream habitat improvements.

TABLE 25. HABITAT RESTORATION MEASURES, PROJECT ID, NAME, AND ESTIMATED COST.

Project ID	Project Package Name	Activity Name	Estimated Cost
VF-04	Upper Green River Side-Channel	Signani Side-channel	$ 947,000
MS-01 TR-01-3	Howard Hanson Dam Inundation Zone	Mainstem, North Fork Channel, and Tribs.	$ 769,000
MS-03 TR-06-7	Howard Hanson Dam Restoration Zone	Mainstem, North Fork Channel, and Tribs.	$ 341,000

Location and Scope. Three distinct project types are considered under this analysis: 1) reconnection of a major side-channel, left bank RM 58-59, impacted during re-alignment of the railroad under dam construction, 1959-1962; 2) improvement of instream habitat in the mainstem and major tributaries within the existing reservoir inundation zone, elevation 1080-1141 ft; and 3) improvements of the mainstem and major tributaries above the AWSP inundation zone, 1177 to 1240 ft elevation. The side-channel is below HHD, the two mainstem and tributary habitat improvements are above HHD.

Assumptions and Parameters. Two inputs were used to assess outputs for the three projects: 1) total habitat area, low flow and winter; and 2) smolt production from the habitat areas. Estimated smolt production was then put into a simplified life-cycle model to estimate total adult returns (output) for coho salmon, winter steelhead, and fall chinook salmon. Parameters affecting total adult returns were:

- For the two projects above the dam, smolt production was reduced by mortality through the reservoir and dam, applying mortality estimates from the selected fish passage facility (FP 4).
- Ocean survival rates were applied against all three projects (discussed under Fish Passage Incremental Analysis Evaluation, above).
- In-river survival rates were applied after ocean survival (see Fish Passage Analysis).
- These factors, fish passage survival, ocean survival, and in-river survival, were applied to smolt production to estimate total adult returns (pre-harvest). Pre-harvest adult returns were used in the incremental analysis.
- Harvest rates within the range of maximum harvest rates used in the fish passage survival model were also applied to estimate escapement. These numbers are available, but were not applied in the incremental analysis.
- It was assumed no existing production is available in the side-channel (it is isolated, impassable culvert and sections are dry).
- Smolt production for F-1, streams in the existing reservoir pool, was discounted by 75% for the percent of time the pool is inundated during the AWSP.

Habitat Area Estimates. Instream habitat area was estimated for each project by habitat unit type. Project E-1 had five distinct habitat areas -- regular stream channels, spawning channel, beaded ponds, dendrites (backwater "fingers"), and a slough-area (larger ponded channel). Project F-1 had the simplest habitat types, existing mainstem river, and mainchannel tributaries. Project G-1 had existing mainstem and tributary mainchannel habitat, and new habitat -- ponds, side-channels, and dendrites. Habitat area for E-1, F-1 and G-1 was from measured widths of existing channel (Corps measurement or USFWS) and estimated length and width for new habitat types.

Smolt Density Estimates. Coho smolt density estimates were from Beechie et al. (1994) for the side-channel reconnection and were used for winter rearing estimates. Distinct estimates were applied to the slough, pond, and channel areas. Estimates for projects above Howard Hanson Dam (F-1, G-1) used density estimates from Baranski (1989), the same values used in the Headwaters watershed production estimates for coho smolts.

Steelhead smolt density estimates were from Gibbons et al. (1985). Estimates for the habitat restoration projects are the same values used in the Headwaters watershed production potential estimates for steelhead smolts. I did not apply density estimates to many areas of the side-channel, I assumed these were not acceptable habitat types for steelhead, more likely used by coho.

Fall chinook smolt density estimate was the mean **from Northwest Resource Associates (1991) and were the same estimates used in the Headwaters watershed estimate of smolt production. Density estimates were not applied to many areas of the side-channel, it was assumed these were not acceptable habitat types for chinook, more likely used by coho.**

Smolt Production. For F-1 and G-1, density for existing habitat areas was estimated first, then multiplied by 2 (a standard multiplier for habitat improvement projects, White and Lucchetti 1995) to account for increased habitat complexity from addition of instream structure. New habitat area was multiplied by the appropriate density estimate and then added to the estimate from existing habitat. Appendix Table C-5 shows an example of the production model for the three projects, using habitat area and coho smolt density estimates. Project F-1 habitat areas are inundated for up to 6 months requiring a discounting of production potential (75% discount, same percentage used in the Headwaters watershed smolt production estimates, Section 2A).

Life-Cycle Model. Smolt production estimates were then applied against 1) smolt mortality estimates for F-1, G-1, as these smolts migrate through the reservoir and dam; 2) ocean survival rates; 3) and in-river survival. Appendix Tables C-1 to C-4 provide incremental increase in smolts and adults for each of the three projects. The total adult returns were then used in the incremental analysis (Table 26).

TABLE 26. HABITAT RESTORATION MEASURES WITH INCREMENTAL INCREASE IN ADULT RUN SIZE (PRE-HARVEST) OVER BASELINE. THIS ASSUMES SMOLT SURVIVAL THROUGH THE PROJECT FOR MS-01, MS-03, TR-1,2,3 AND 6/7, WITH FISH PASSAGE ALTERNATIVE FP 4 WITH REVISED SURVIVAL ESTIMATES (EQUAL TO FP 7).

Management Measure	Coho Run Size	Steelhead Run Size	Fall Chinook Run Size	Incremental Increase Over Baseline
E-1	1598	68	52	1,718
F-1	449	26	205	680
G-1	2536	603	438	3,577

Incremental Cost-Benefit Analysis and Management Measure Selection. Annualized cost of the three measures per returning adult ranged from $17 for G-1, to $83 for G-1, and $150 for F-1. There appears to be no clear break in the incremental output/cost between the measures. The authority and direction for selection of management measures includes 1) use of the incrementally justified measures; and 2) best professional judgment. Measure G-1 is certainly justified based on incremental analysis. The cost of the Fish Passage facility is approximately $42.00 per adult, as such G-1 and F-1 are 2 to 3.5 times more expensive per fish than the facility.

All three measures represent critical habitat areas for the impoverished Green River anadromous fish stocks. The methods used to estimate each of the restoration measures has drawbacks. Using smolt density is a typical method of estimating outputs for instream habitat improvements in the Pacific Northwest. These density estimates cannot account for additional benefits that could accrue to selected measures based on watershed location.

The side-channel habitat of E-1 is one of only two significant floodplain habitat areas available for improvement between HHD and the Middle Green River, RM 45. The other area (project VF-03) is being used as mitigation for Upper Green River side-channel wetted area impacts, and provides 0.4 acres beyond the identified impact (2 acres). These two side-channels could be critical in providing additional rearing habitat for juveniles that pass through HHD and rear in lower river areas. The same argument could be made for the F-1, mainstem and large tributary habitat exposed when the pool is drawdown in the fall, and G-1, instream habitat just upstream of the reservoir. F-1 however, is unavailable as habitat for up to 6 months and is made up of only one habitat type, mainstem or tributary mainchannel.

Even with the additional annualized cost of E-1 above the Fish Passage Facility, **G-1 with E-1 are selected as the two habitat restoration measures.** F-1 could certainly provide important instream habitat during fall and winter but E-1 and G-1 provide year-round habitat for both spawning and rearing for most of the Green River stocks.

The two selected projects will restore up to: 1) 3.2 acres of off-channel habitat in the Upper Green; and 2) improve 3.5 miles of river and stream habitat improvement in tributaries above the AWSP inundation pool (from 1177 to 1240 ft elevation). These habitat restoration projects connected to the mitigated habitat areas within the AWSP inundation zone create a near-continuous band of habitat from just above the reservoir to the critical floodplain rearing areas below the dam. Under existing conditions (well below full-seeding), 30,000 coho juveniles and over 100,00 chinook juveniles are found in the reservoir during fall drawdown. It is presumed many if not most of these juveniles do not survive from poor passage and lack of sufficient instream habitat. Even more juveniles will be seeking rearing habitat if the restoration goal of self-sustaining runs is realized. If the Corps, Tacoma and resource agencies hope to meet the restoration goal of establishing and maintaining self-sustaining runs of salmon and steelhead in the Headwaters, habitat areas such as these the two selected measures could be critical to achievement of the goal.

8.5 LITERATURE CITED

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Baranski, C. 1989. Coho smolt production in ten Puget Sound streams. Technical Report Number 99. Washington Department of Fisheries, Olympia.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Fuerstenberg, R.R., K. Nelson, and R. Blomquist. 1996, Ecological conditions and limitations to salmonid diversity in the Green River, Washington, U.S.A: Structure, function, and process in river ecology. King County Surface Water Management.

Hickman, T. and R. Raleigh. 1982. Habitat suitability index models: cutthroat trout. . U.S. Fish and Wildlife Service FWS/OBS-82/10.5.

Hosey and Associates. 1988. Elwha Project, FERC No. 2683, Glines Project, FERC No. 588, Appendix 6: Fish production potential. Draft response to request for additional information of May 28, 1987.

Laufle, J.C. and R.A. Cassidy. 1988. Retention of standing timber for fish and wildlife habitat in reservoirs. Lake and Reservoir Management 4(2):271-279.

McMahon, T. 1983. Habitat suitability index models: coho salmon. . U.S. Fish and Wildlife Service FWS/OBS/82/10.49.

Natural Resource Consultants. 1991. Review of the draft environmental impact statement, Glines Canyon, (FERC No. 588) and Elwha (FERC No. 2683) Hydroelectric Projects, Washington. *In:* Comments on FERC's DEIS of February, 1991, Elwha Project and Glines Canyon Project, prepared by Harza Northwest, Inc.

Raleigh, R.F., T. Hickman, R. Solomon, and P. Nelson. 1984. Habitat suitability information: rainbow trout. . U.S. Fish and Wildlife Service FWS/OBS-82/10.60.

Raleigh, R.F. W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish and Wildlife Service Biological Report 82 (10.122).

Seiler, D., and S. Neuhauser. 1985. Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Progress Report No. 235, Washington Department of Fisheries, Olympia.

Warren, B. 1994. Estimated escapement goal for White River spring chinook. Puyallup Indian Tribe Technical Report.

Wunderlich, R.C. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. Western Washington Fishery Resource Office, Olympia, Washington.

NOTE TO REVIEWERS: These tables (Appx. A) are from earlier Cost-Benefit runs and are inconsistent with the Economics and Plan Formulation Appendix.

Appendix A. Adult outputs (escapement with maximum harvest) from incremental runs of 9 fish passage alternatives with various parameter changes: baseline survival (affected by changes in reservoir survival), ocean survival, and harvest rates. Total run size was used for actual selection of the fish passage alternative, harvest and escapement are presented here for further information.

Cost Benefit Run 1, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	*Coho*	*Steelhead*	*Fall Chinook*	*Spring Chinook*	*Total Escapement*
Maximum Harvest Rate	*50%*	*35%*	*65%*	*0%*	
A1(FP1)	1874	181	295	49	2398
A2(FP2)	1937	187	305	51	2479
A3(FP3)	3209	597	629	128	4563
A4(FP4)	**6087**	**1338**	**1616**	**275**	**9316**
A5(FP5)	5722	1221	1505	253	8701
A6(FP6)	5722	1221	1505	253	8701
A7(FP7)	6087	1338	1616	275	9316
B1(FP8)	5390	1199	2259	231	9078
B2(FP9)	5440	1210	2383	243	9276
B1C3	**5810**	**1286**	**2260**	**247**	**9604**
B1C4	**6242**	**1372**	**2288**	**263**	**10165**
					0
Escapement Estimate	6478	1339	2287	1342	11446
Ocean Survival	8.8%	10.0%	1.0%	0.2%	
Baseline Survival	20.3%	8.7%	8.7%	11.1%	

Cost Benefit Run 2, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	*Coho*	*Steelhead*	*Fall Chinook*	*Spring Chinook*	*Total Escapement*
Maximum Harvest Rate	*55%*	*45%*	*70%*	*0%*	
A1(FP1)	2245	315	482	49	3091
A2(FP2)	2322	325	499	51	3197
A3(FP3)	3182	268	727	128	4305
A4(FP4)	**5558**	**1155**	**1539**	**275**	**8527**
A5(FP5)	5308	1080	1460	253	8101
A6(FP6)	5308	1080	1460	253	8101
A7(FP7)	5558	1155	1539	275	8527
B1(FP8)	4921	1032	1941	231	8125
B2(FP9)	4966	1042	2047	243	8299
B1C3	**5692**	**1221**	**2112**	**247**	**9272**
B1C4	**6084**	**1294**	**2135**	**263**	**9776**
					0
Escapement Estimate	6478	1339	2287	1342	11446
Ocean Survival	8.8%	10.0%	1.0%	0.2%	
Baseline Survival	27.3%	17.9%	15.4%	18.3%	

Run3escape

Cost Benefit Run 3, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	*Coho*	*Steelhead*	*Fall Chinook*	*Spring Chinook*	*Total Escapement*
Maximum Harvest Rate	*70%*	*60%*	*75%*	*0%*	
A1(FP1)	1916	166	322	190	2594
A2(FP2)	1981	172	333	196	2682
A3(FP3)	3282	550	688	511	5031
A4(FP4)	**6225**	**1235**	**1767**	**1103**	**10330**
A5(FP5)	5852	1128	1646	1014	9639
A6(FP6)	5852	1128	1646	1014	9639
A7(FP7)	6225	1235	1767	1103	10330
B1(FP8)	5512	1106	2469	926	10014
B2(FP9)	5564	1117	2605	974	10259
B1C3	**5942**	**1187**	**2471**	**1167**	**10767**
B1C4	**6384**	**1266**	**2501**	**1183**	**11334**
					0
Escapement Estimate	6478	1339	2287	1342	11446
Ocean Survival	15.0%	15.0%	1.5%	0.6%	
Baseline Survival	20.3%	8.7%	8.1%	11.1%	

Run4escap

Cost Benefit Run 4, Maximum Harvest to Still Meet Escapement Under Any Alternative

Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.

Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	***Coho***	***Steelhead***	***Fall Chinook***	***Spring Chinook***	***Total Escapement***
Maximum Harvest Rate	*70%*	*60%*	*75%*	*0%*	
A1(FP1)	2551	343	616	313	3823
A2(FP2)	2638	355	637	324	3953
A3(FP3)	3615	643	928	576	5762
A4(FP4)	**6315**	**1260**	**1963**	**1121**	**10659**
A5(FP5)	6031	1178	1863	1049	10120
A6(FP6)	6031	1178	1863	1049	10120
A7(FP7)	6315	1260	1963	1121	10659
B1(FP8)	5592	1126	2476	939	10132
B2(FP9)	5643	1137	2611	987	10378
B1C3	**5985**	**1204**	**2495**	**1002**	**10686**
B1C4	**6431**	**1284**	**2525**	**1067**	**11307**
					0
Escapement Estimate	6478	1339	2287	1342	11446
Ocean Survival	15.0%	15.0%	1.5%	0.6%	
Baseline Survival	27.3%	17.9%	15.4%	18.3%	

Cost Benefit Run 5, Maximum Harvest to Still Meet Escapement Under Any Alternative

Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.

Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	***Coho***	***Steelhead***	***Fall Chinook***	***Total Escapement***
Maximum Harvest Rate	*45%*	*35%*	*60%*	
A1(FP1)	257	8	134	400
A2(FP2)	266	9	139	414
A3(FP3)	2584	506	553	3643
A4(FP4)	**6440**	**1314**	**1711**	**9465**
A5(FP5)	5785	1173	1570	8529
A6(FP6)	5785	1173	1570	8529
A7(FP7)	6440	1314	1711	9465
B1(FP8)	5129	1070	2435	8633
B2(FP9)	5627	1174	2719	9520
B1C3	**5699**	**1179**	**2465**	**9343**
B1C4	**6156**	**1263**	**2496**	**9915**
Escapement Estimate	6478	1339	2287	10104
Ocean Survival	8.8%	10.0%	1.0%	
Baseline Survival	2.5%	0.4%	3.2%	

Cost Benefit Run 6, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	*Coho*	*Steelhead*	*Fall Chinook*	*Total Escapement*
Maximum Harvest Rate	*65%*	*55%*	*75%*	
A1(FP1)	239	9	129	376
A2(FP2)	288	9	133	430
A3(FP3)	2802	526	530	3858
A4(FP4)	**6985**	**1364**	**1637**	**9986**
A5(FP5)	6274	1218	1503	8995
A6(FP6)	6274	1218	1503	8995
A7(FP7)	6985	1364	1637	9986
B1(FP8)	5487	1091	2319	8897
B2(FP9)	6027	1199	2591	9817
B1C3	**6106**	**1205**	**2348**	**9659**
B1C4	**6601**	**1292**	**2378**	**10270**
Escapement Estimate	6478	1339	2287	10104
Ocean Survival	15.0%	15.0%	1.5%	
Baseline Survival	2.5%	0.4%	3.2%	

Cost Benefit Run 7, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis..

Restoration Alternative	*Coho*	*Steelhead*	*Fall Chinook*	*Total Escapement*
Maximum Harvest Rate	*50%*	*40%*	*65%*	
A1(FP1)	1874	167	295	2335
A2(FP2)	1937	172	305	2414
A3(FP3)	3209	551	629	4389
A4(FP4)	**6087**	**1235**	**1616**	**8938**
A5(FP5)	5722	1127	1505	8354
A6(FP6)	5722	1127	1505	8354
A7(FP7)	6087	1235	1616	8938
B1(FP8)	5390	1106	2259	8754
B2(FP9)	5440	1117	2383	8940
B1C3	**5796**	**1189**	**2260**	**9244**
B1C4	**6227**	**1268**	**2288**	**9782**
Escapement Estimate	6478	1339	2287	10104
Ocean Survival	8.8%	10.0%	1.0%	
Baseline Survival	20.3%	8.7%	8.1%	

Cost Benefit Run 8, Maximum Harvest to Still Meet Escapement Under Any Alternative
Gray-shaded areas meet escapement goal with assumption that escapement met if within 10% of the goal.
Bold Alternatives are within the Federal Interest for Cost/Benefit Analysis.

Restoration Alternative	***Coho***	***Steelhead***	***Fall Chinook***	***Total Escapement***
Maximum Harvest Rate	*50%*	*35%*	*65%*	
A1(FP1)	1874	181	295	2349
A2(FP2)	1937	187	305	2428
A3(FP3)	3209	597	629	4435
A4(FP4)	**6087**	**1338**	**1616**	**9041**
A5(FP5)	5722	1221	1505	8448
A6(FP6)	5722	1221	1505	8448
A7(FP7)	6087	1338	1616	9041
B1(FP8)	5390	1199	2259	8847
B2(FP9)	5440	1210	2383	9033
B1C3	**5810**	**1286**	**2260**	**9357**
B1C4	**6242**	**1372**	**2288**	**9902**
				0
Escapement Estimate	6478	1339	2287	10104
Ocean Survival	8.8%	10.0%	1.0%	
Baseline Survival	20.3%	8.7%	8.7%	

Appendix B. Baseline reservoir migration delay, otherwise considered as reservoir mortality.

Table 1. First scenario using smolt outmigration numbers by generalized smolt "biological window" to determine reservoir migration delay (numbers from Dilley and Wunderlich 1992 and 1993). Any smolts outmigrating within their biological window were considered "survivors." Smolts outmigrating after their biological window were considered delayed beyond the biological window and counted as "mortalities." Biological windows were 1) coho February to June 30, 2) steelhead February to June 15, and 3) chinook May 15 to August 31. . Numbers of chinook before May 15 were not counted as these were considered non smolt-ready fish that would likely not contribute to adult returns. These biological windows were developed in 1995 and are not completely consistent with periodicity charts and incremental analysis developed and used in Section 2 and Section 6.

Outmigration Number by Time Period	1991	Percent	1992	Percent	Percent Used for Delay
Coho			0		
Feb-19 to Jun-30	5904	100.0%	4380	58.4%	
Jul-1 to Nov 30	0	0.0%	3116	41.6%	42.0%
	5904		7496		
Steelhead					
Feb-19 to Jun-15	102	39.4%	27	100.0%	
Jun-16 to Jun-30	157	60.6%	0	0	61.0%
	259				
Chinook					
May-15 to Aug-31	7386	38.5%	82728	61.4%	
Sept-1-Nov-30	11781	61.5%	52085	38.6%	62.0%
	19167		134813		

Appendix C. Habitat Restoration Project Outputs. Tables C-1 to C-5.

Appendix C-1. Habitat restoration projects and potential coho smolt production and incremental smolt and adult increase for individual projects.

Smolt Production

Management Measure Number	Pre-Project Density Estimate	Post Project Production Factor	Revised Production	Smolt Incremental Increase	Fish Passage Smolt Survival	Incremental Increase in Smolt No
E1	0	0	10650	10650	100.0%	10650
F1	3350	2	6700	3350	89.4%	2995
G1	15621	2	34529	18908	89.4%	16904

Adult Production

Management Measure Number	Incremental Increase in Smolt No	% Ocean Survival	Incremental Increase in Run Size	% Harvest	In-River Survival	Incremental Increase in Escapement
E1	10650	15.00%	1598	60.00%	100%	639
F1	2995	15.00%	449	60.00%	96%	172
G1	16904	15.00%	2536	60.00%	96%	971

Appendix C-2. Habitat restoration projects and potential steelhead smolt production and incremental smolt and adult production for individual projects.

Smolt Production

Management Measure Number	Pre-Project Density Estimate	Post Project Production Factor	Revised Production	Incremental Increase	Smolt Survival	Incremental Increase in Smolt No
E1	0	0	454	454	100.0%	454
F1	200	2	400	200	87.2%	174
G1	4608	2	9216	4608	87.2%	4018

Adult Production

Management Measure Number	Incremental Increase in Smolt No	% Ocean Survival	Incremental Increase in Run Size	% Harvest	In-River Survival	Incremental Increase in Escapement
E1	454	15.00%	68	50.00%	100%	34
F1	174	15.00%	26	50.00%	94%	12
G1	4018	15.00%	603	50.00%	94%	282

Appendix C-3. Habitat restoration projects and potential fall chinook smolt production and incremental smolt and adult increase for individual projects.

Smolt Production

Management Measure Number	Pre-Project Density Estimate	Post Project Production Factor	Revised Production	Incremental Increase	Smolt Survival	Incremental Increase in Smolt No
E1	0	0	1816	3497	100.0%	3497
F1	22760	2	45520	22760	60.0%	13656
G1	48642	2	97284	48642	60.0%	29185

Adult Production

Management Measure Number	Incremental Increase in Smolt No	% Ocean Survival	Incremental Increase in Run Size	% Harvest	In-River Survival	Incremental Increase in Escapement
E1	3497	1.5%	52	60%	100%	13
F1	13656	1.5%	205	60%	88%	43
G1	29185	1.5%	438	60%	88%	92

Appendix C-4. Habitat restoration projects and potential spring chinook smolt production and incremental smolt and adult increase for individual projects. Note: spring chinook presented but outputs not counted in incremental analysis.

Smolt Production

Management Measure Number	Pre-Project Density Estimate	Post Project Production Factor	Revised Production	Incremental Increase	Smolt Survival	Incremental Increase in Smolt No
E1	0	1.5	7061	7061	100.0%	7061
F1	5602	2	11204	5602	87.6%	4907
G1	32363	2	68164	35801	87.6%	31362

Adult Production

Management Measure Number	Incremental Increase in Smolt No	% Ocean Survival	Incremental Run Size Over Baseline	% Harvest	In-River Survival	Incremental Increase in Escapement
E1	7061	0.60%	42	0.00%	100.00%	42
F1	4907	0.60%	29	0.00%	75.00%	22
G1	31362	0.60%	188	0.00%	75.00%	141

Appendix C-5. Habitat restoration projects with habitat area and potential coho smolt production for individual projects.

Management Measure No.	Project Name	Habitat Type	Low Flow Width (ft)	Segment Length (accessible in ft)	Low Flow Area (ft2)	Low Flow Area (M2)	Gradient	Density Estimate	Smolt Production
E1	Signani Side-Channel	Outlet Channel	18.8	400	7520	699	0	0.54	377
		Spawning Channel	18.8	700	13160	1223	0	0.54	660
		Main Channel	18.8	1500	28200	2620	0	0.54	1415
		Dendrites	10	50	500	46	0	0.78	36
		Beaded Ponds	56.3	600	33780	3138	0	1.16	3650
		Small Channel	7.5	900	6750	627	0	0.54	339
		Upper Channel	18.8	1200	22560	2096	0.01	0.54	1132
		Ponded Upper Channel	56.3	500	28150	2615	0	1.16	3041
					140620	13064			10650
F1	Green River	Mainstem	85	8,000	680000	63172	0.01	0.18	11371
	North Fork Green	Mainstem	30	4,000	120000	11148	0.02	0.23	2564
	Tributaries	Main Channel	16.5	10,000	165000	15329	.02-.04	0.11	1686
									15621
G1	Green River/North Fork	Side Channel	15	1,500	22500	2090	0	0.32	667
		Ponds	40	1,500	60000	5574	0	0.38	2090
		Dendrites	20	1,000	20000	1858	0	0.32	593
									3350

Appendix Table D-1. Summary Table of All Aquatic Restoration and Mitigation Management Measures for the Howard Hanson Dam Additional Water Storage Project Feasibility Study

Project Package Name	Activity Name	Project Number	Mitigation/ Restoration	Location
Howard Hanson Dam Fish Passage	Dam Fish Passage Alternative 4	FP-04	M/R	Howard Hanson Dam, Right Bank, Intake Tower, 1070-1177 ft Elevation
Headwaters Green River Habitat Mitigation	Mainstem and Sunday Creek Habitat Restoration	VF-06, MS-04, TR-08	M	Headwaters Floodplain, RM 77-84, Sunday Creek Floodplain, RM 1.2
Headwaters Green River Habitat Mitigation	Tacoma Wildlands Set-asides in Conservation and Natural Forest Zones	MS-08, TR-09	M	Headwaters Floodplain, RM 71.3-80.1, Gale Creek 1240-1280 ft el., N. Fork 1240-1320 ft el.
Headwaters Green River Habitat Mitigation	Headwaters Culvert Replacement	TR-10	M	Three tributaries in Headwaters Watershed, two small tribs and one large tributary
Howard Hanson Reservoir Mitigation Zone	Mainstem and North Fork Channel Maintenance	MS-02, TR-04	M	Headwaters and North Fork in New Inundation, 1146-1177 ft Elevation
Howard Hanson Reservoir Mitigation Zone	Tributary Stream Channel Maintenance	TR-05	M	Tributaries to Reservoir in New Inundation, 1146-1177 ft Elevation
Page Mill Pond Mitigation	Page Mill Pond and Page Creek Maintenance	VF-05	M	North Fork Green Floodplain, Left Bank, 1147-1185 ft Elevation
Bear Creek Channel Improvement	Lower Bear Creek Stream Improvement	TR-01	M	Upper Green River, Left Bank, RM 63
Middle Green River Side Channel Mitigation	Mueller Side Channel Improvement	LVF-01	M	Middle Green River Floodplain, Left Bank, RM 33.4
Middle Green River Side Channel Mitigation	Loans Levee Removal and Bums Creek Reconnection	LVF-03	M	Middle Green River Floodplain, Right Bank, RM 37.9-38.1
Middle Green River Side Channel Mitigation	Metzler and O-grady Connector Side Channel Improvement	LVF-04	M	Middle Green River Floodplain, Left and Right, RM 39-40.2
Middle Green River Side Channel Mitigation	Flaming Geyser North: Cutoff Channel Reconnection	LVF-06	M	Middle Green River Floodplain, Right Bank, RM 44.3
Middle Green River Side Channel Mitigation	Flaming Geyser South: Wetland/Oxbow Reconnection	LVF-07	M	Middle Green River Floodplain, Left Bank, RM 44.4

Project Package Name	Activity Name	Project Number	Mitigation/ Restoration	Location
Upper Green River Side Channel Mitigation	Brunner Side-Channel Restoration	VF-03	M	Upper Green River Floodplain, Right Bank, RM 58
Howard Hanson Reservoir Inundation Zone Restoration	Mainstem and North Fork Channel Restoration	MS-01, TR-02	R	Headwaters and North Fork in Reservoir, 1080-1141 ft Elevation
Howard Hanson Reservoir Inundation Zone Restoration	Tributary Stream Channel Restoration	TR-03	R	Tributaries to Reservoir, 1080-1141 ft Elevation
Howard Hanson Reservoir Restoration Zone	Mainstem, North Fork and Tributary Restoration	MS-03, TR-06, TR-07	R	Headwaters, North Fork, Reservoir Tributaries, 1177-1240 ft Elevation
Upper Green River Side Channel Restoration	Signani Side-channel Reconnection and Restoration	VF-04	R	Upper Green River Floodplain, Left Bank, RM 58.6-59.6.
Mainstem Green River Gravel Nourishment	Upper Green River Gravel Bar Nourishment	MS-05, MS-06, MS-07	R	Upper Green Mainstem, 3 Alternate Locations, RM 59-60.5
Mainstem Green River Gravel Nourishment	Middle Green River Gravel Bar Nourishment	LMS-01, LMS-02, LMS-03, LMS-04	R	Middle Green Mainstem, 4 Alternate Locations, RM 40-45

SECTION 9 MODELING PARAMETERS FOR BASELINE, PHASE I, AND PHASE II RESERVOIR OPERATIONS

NOTE TO READERS: *At the original writing of this Appendix F, Part 1, the discussion reflected the HHD AWS Project, and potential impacts, at mid-1997. During the fall of 1997, negotiations with resource agencies and tribal representatives resulted in a change in the project. The project now includes storage under Section 1135 of 5,000 ac-ft on a yearly basis beginning in Phase I of the project: previously, the 5,000 ac-ft was considered a 1-in-5 year event until initiation of Phase II when it would become yearly. Part F1 has been revised to reflect this change; however, there may be some omissions. These omissions, if any, will be corrected in the final edition.*

An exception to this is modeling. Modeling was conducted with Phase I only having drought year storage of the 5,000 ac-ft, and re-modeling will not be conducted for this change.

9.0 INTRODUCTION

The Howard Hanson Dam operation is being modeled to evaluate the effects of proposed flow conditions under Phase I and Phase II of the Additional Water Storage Project to Baseline conditions.

Baseline is defined as the operation of Howard Hanson Dam utilizing the existing 98 percent rule curve, operations similar to year 1996, and assuming the Pipeline 5 storage of the Second Supply Water Right (SSWR) is operational in accordance with, "*Agreement Between The Muckleshoot Indian Tribe and The City of Tacoma Regarding the Green/Duwamish River System, 1995*" (the Agreement). In addition, the 5,000 acre-feet of active storage from the Section 1135 project is assumed to be available for drought years.

Phase I of the Additional Water Storage Project adds to Baseline the fish passage facility at the dam, a larger volume of storage behind the dam in the spring to store water for augmenting fish flows at Auburn during spring refill, 20,000 acre-feet of additional active M&I water storage collected by storing Tacoma's SSWR, and yearly storage of the Section 1135 5,000 ac ft (per fall 1997 negotiations and agreement between the Corps, TPU, WDFW, USFWS, NMFS, and Muckleshoot Tribe). The storage of 20,000 ac ft of the SSWR in HHD reservoir is near equivalent of 100 days of 100 cfs diversion.

Phase II of the Additional Water Storage Project adds to Phase I the storage of an additional 9,600 acre-feet of water for fisheries use in the fall and an additional 22,400 ac-ft for M&I use (replacing the 20,000 ac-ft SSWR provided in Phase I): reservoir total M&I storage volume only increases 2,400 (from 20,000 ac ft to 22,400 ac ft)

9.1 BACKGROUND

The Green River Watershed was modeled from the USGS gage in Auburn upstream to the USGS gage at Palmer and finally upstream to the Howard Hanson Dam. The model runs on a daily time step and will provide information regarding reservoir volume and level, flow into and out from the dam, flow at Palmer, diversion to Tacoma's pipelines 1 and 5, and flow at Auburn. The model simulates the storage of water behind the dam in the winter for flood control, using 12,000 cfs as the control flow at the Auburn gage (including local inflow), any water stored behind the dam during flood control operations is released in a manner that does not exceed the 12,000 cfs Auburn target. In the summer, 24,200 acre-feet of active storage (there is 25,400 ac ft of total storage including 1,200 ac ft of dead storage from turbidity pool) is used for fisheries instream flow protection and 5,000 ac-ft for debris removal in the Baseline Condition. In Phase I and 2, the storage volume is increased to 44,200 and finally to 61,200 ac-ft for fisheries and water supply: per Fall 1997 negotiations, Phase I storage is now 49,200 ac ft every year with the inclusion of yearly storage of the 5,000 ac ft of Section 1135 water that had been drought year storage. Outflow from the dam is determined by the inflows to the dam, downstream instream flow requirements established at Palmer and Auburn USGS gages, water supply diversions and maximum levels and rates of change allowed behind the dam and in the lower river.

The storage behind Howard Hanson Dam is hypothetically split into a maximum of 3 modeled storage allocations, each with different rules for use. The first is called Fish Dam 1 and it is the existing storage which strictly follows the 98 percent rule curve and meets a 110 cfs base flow, at Palmer, all summer for instream flow protection. The second is called Fish Dam 2 and it represents the storage volume available to protect and improve instream flow conditions. The third is called the Diversion Dam and it is storage volume available to Tacoma for M&I water uses.

Water inflow records for the modeling simulation are comprised of three sets of data; flow into the reservoir behind the dam, flow into the river between the dam and the Palmer gage, and flow into the river between the Palmer and Auburn gages. The inflow records into the reservoir were computed by the Corps and the record extends from calendar year 1964 to 1995. The daily Corps data was used unaltered in this study. The flow between the dam and Palmer is calculated by multiplying the inflow to the reservoir by 0.03 (The Corps has found that the runoff observed in the reach between the outflow and the diversion intake averaged approximately 3 percent of the inflow to Howard Hanson Dam during the low-flow seasons such as during 1973 and 1987). The inflow between Palmer and Auburn is determined by subtracting the observed Palmer gage reading from the observed Auburn gage reading. This calculation produces occasional negative values, which are set to zero.

9.2 MODELING CHARACTERISTICS

Modeling rules were developed during a succession of meetings among a team of water managers, fish biologists, and other engineers-planners experienced with the regulated hydrologic cycle and biological resources of the Green River. The purpose of the meeting was to update the water resource development proposed as Scenario #7 into a more detailed simulation that matched biological need with increments of water storage as they became available in future phases in an adaptive management process.

Modeling computations were performed using an Excel spreadsheet in Windows 95 operating environment. Operating rules are input to the model as a series of macros that are methodically applied to the daily inflow data stream. Modeling characteristics that simulate the Green River/Howard Hanson Reservoir system are described below.

9.3 BASELINE

1. The start of refill of Howard Hanson Dam is 15 March;
2. The refill rates for Fish Dam 2 are:
   * From 15 March to 15 April: 200 cfs or 400 acre-feet/day (rounded to nearest 100)
   * From 15 April to 31 May: 400 cfs or 800 acre-feet/day.

   Fish Dam 1 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above.
3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:
   1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows
   2) 110 cfs base flow at Palmer
   3) Fish Dam 1 storage following the 98 percent rule curve
   4) Palmer and Auburn instream flows as approved in the Agreement
   5) SSWR/Pipeline 5 water right of 65 mgd (100 cfs)
   6) Fish Dam 2 instream flow requirement of 900 cfs from 15 March to 1 May, and 900 cfs to 400 cfs ramp from 1 May to 1 July
   7) Fish Dam 2 storage requirements following refill level and rate limitations; and
   8) Instream release
4. The refill targets for active storage, as shown in Figures 1 and 2, are:

TABLE 1

Date	Fish Dam 1 Average (Acre-Feet)	Fish Dam 2 Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
15 March	0	0	0	0
1 April	0	5,100	8,100	0
15 April	0	5,100	20,300	0
1 May	8,100	5,910	23,800	0
15 May	20,300	5,910	26,700	2,500
1 June	23,800	5,400	26,700	2,500
15 June	29,200	0	26,700	2,500(1)
30 June	24,200	0	26,700	0

(1) 2,500 acre-feet are in Fish Dam 2 for use in fisheries protection.

5. The maximum volume of water stored in Fish Dam 2 (Fish Dam 2 being the facility that stores water to augment flows at Auburn when the natural inflows drop below the

instream flow levels) is equal to the difference between the refill rates shown above and the existing 98 percent Corps refill rule curve as shown in Table 1 under Fish Dam 1. All water stored in Fish Dam 2 is outside the storage required to meet the flood responsibilities of the dam. In addition, the water stored in Fish Dam 2 is limited to 5,100 acre-feet or elevation 1100 feet until April 15 to allow downstream migrating fish to pass the dam. Until Phase I is complete, there is no fish passage facility at the dam and fish must dive down in the reservoir to pass through the existing valves.

6. The instream flow level for refill of Fish Dam 2 is 900 cfs from 15 March to 1 May. Water will be stored in the dam when flow exceeds 900 cfs at Auburn; up to a maximum equal to the storage levels and fill rates discussed in 2, 3, and 4 above. Water will be released from storage in Fish Dam 2 when flows begin to dip below 900 cfs at Auburn; up to the volume stored in Fish Dam 2. The instream flow levels linearly decrease from 900 cfs on 1 May to 400 cfs on 1 July.

7. There are no induced freshets or shaving of peaks.

8. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

9. All water diverted for SSWR/Pipeline 5 is in accordance with the instantaneous rate and volume restrictions of the state water right and the Agreement.

10. From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the Agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*"

9.4 PHASE I

1. The start of refill is 15 February. Prior to 1 March, a maximum of 3000 acre-feet is stored in the Diversion Dam for water supply diversion within the SSWR/Pipeline 5 water right.

2. The maximum refill rates for the Diversion Dam and Fish Dam 2 are:

   * From 15 February to 28 February: 100 cfs or 200 acre-feet/day (SSWR/Pipeline 5 water only)

   * From 1 March to 30 March: 400 cfs or 800 acre-feet/day

   * From 1 April to 30 April: 300 cfs or 600 acre-feet/day

* From 1 May to 30 June: 200 cfs or 400 acre-feet/day.

Fish Dam 2 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above. For any day or group of days where the reservoir fill targets are not met, the reservoir is allowed to make up any shortfall in one day if water is available.

To provide protection for the fish passing through the reservoir, the refill rates between 15 April and 30 June limit the refill to the point that no additional water is available for storage above the needs of Fish Dam 1. To allow for storage of the SSWR/Pipeline 5 water, 200 acre-feet of water per day is moved from Fish Dam 2 to the Diversion Dam during this period. Without this reallocation of previously stored water, the water from the SSWR/Pipeline 5 water right could not be stored in many years from 15 April to 30 June, decreasing the normal storage volume by approximately 42 percent.

3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:

    1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows

    2) 110 cfs base flow at Palmer

    3) Fish Dam 1 storage following the 98 percent rule curve

    4) Palmer and Auburn instream flows as approved in the Agreement

    5) SSWR/Pipeline 5 water right of 65 mgd (100 cfs); this water is stored behind the dam from 15 February to 30 June

    6) Fish Dam 2 instream flow requirement of 900 cfs from 15 February to 28 February, and from 1 March to 1 May flows of 900 cfs, 750 cfs, and 575 cfs for a wet, average, and dry spring, respectively, and 900 cfs to 400 cfs ramp from 1 May to 1 July

    7) Fish Dam 2 storage requirements following refill level and rate limitations

    8) Instream release

4. The refill targets for active storage, as shown in Figures 3 and 4, are:

TABLE 2

Date	Fish Dam 1 Wet & Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Diversion Dam Wet, Average, & Dry (Acre-Feet)	Fish Dam 2 Wet & Average (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
February 15	0	0	0	0	0
March 1	0	0	3,000	0	0
March 15	0	0	6,000	9,000	9,000
April 1	0	0	9,000	18,800	18,800
April 15	0	8,100	12,000	24,800	16,700
May 1	8,100	20,300	15,000	21,100	13,700
May 15	20,300	23,800	18,000	5,900	7,400
June 1	23,800	26,700	20,000	400	2,500
June 15	24,200	26,700(1)	20,000	0	2,500(1)
June 30	24,200	26,700	20,000	0	0

(1) 2,500 acre-feet are in Fish Dam 2 for use in fisheries protection.

5. The maximum volume of water stored in Fish Dam 2 is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1. All water stored in Fish Dam 2 is outside the storage required to meet the flood responsibilities of the dam.

6. The conditions in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March and if it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. In addition, the snow water equivalent is measured again on 1 May. If it exceeds 12 inches, the summer is average or better and if it is 12 inches or less, then drought conditions are implemented in accordance with the Agreement.

7. The instream flow levels for refill of Fish Dam 2 are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

8. Freshets, at a duration of 38 hours and a level of 2,500 cfs, as measured at the Auburn gage, are delivered on 1 May and 15 May under wet and average conditions, and at a level of 1,250 cfs on only one day, 1 May, under dry conditions.

9. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in

accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

10. All water diverted for SSWR/Pipeline 5 is in accordance with the state water right and the Agreement. All water stored for diversion in the Diversion Dam is deducted from the Pipeline 5 water right and is within the instantaneous rate and volume restrictions of that right.

11. From July 1 through the end of reservoir operation (generally December 8), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*"

9.5 Phase II

1. The start of refill is 15 February. Between 15 February and 1 March, a maximum of 5,000 acre-feet is stored in Fish Dam 2 for use by the Corps for fisheries protection.
2. The maximum refill rates for the Diversion Dam and Fish Dam 2 are:
   * From 15 February to 15 April: 750 cfs or 1,500 acre-feet/day
   * From 16 April to 30 April: 300 cfs or 600 acre-feet/day
   * From 1 May to 31 May: 200 cfs or 400 acre-feet/day.

   Fish Dam 1 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above. For any day or group of days where the reservoir fill targets are not met, the reservoir is allowed to make up any shortfall in one day, if water is available.

   To provide protection for the fish passing through the reservoir, the refill rates between 15 April and 31 May limit the refill to the point that no additional water is available for storage above the needs of Fish Dam 1.
3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:
   1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows
   2) 110 cfs base flow at Palmer
   3) Fish Dam 1 storage following the 98 percent rule curve
   4) Palmer and Auburn instream flows as approved in the Agreement

5) SSWR/Pipeline 5 water right of 65 mgd (100 cfs)

6) Fish Dam 2 and Diversion Dam instream flow requirement of 900 cfs from 15 February to 28 February, and from 1 March to 1 May flows of 900 cfs, 750 cfs, and 575 cfs for a wet, average, and dry spring, respectively, and 900 cfs of 750 cfs to 400 cfs ramp from 1 May to 1 July for a wet and average spring and 575 cfs to 250 cfs for a dry spring

7) Fish Dam 2 and Diversion Dam storage requirements following refill level and rate limitations, with the water allocated to Fish Dam 2 and Diversion Dam equal to the percentage of required storage; approximately 60 percent to Diversion Dam and 40 percent to Fish Dam 2. This allocation will provide the opportunity for both Fish Dam 2 and Diversion Dam to fill to the same percentage of full in any given year.

8) Spill.

4. The refill targets for active storage, as shown in Figures 5 and 6, are:

TABLE 3

Date	Fish Dam 1 Wet & Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Diversion Dam Wet & Average (Acre-Feet)	Diversion Dam Dry (Acre-Feet)	Fish Dam 2 Wet & Average (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
Feb 15	0	0	0	0	0	0
March 1	0	0	0	0	5,000	5,000
March 15	0	0	13,500	13,500	14,000	14,000
April 1	0	0	22,400	22,400	29,100	29,100
April 15	0	8,100	22,400	22,400	38,800	30,700
May 1	8,100	20,300	22,400	22,400	30,700	18,500
May 15	20,300	23,800	22,400	22,400	18,500	15,000
June 1	23,800	24,200	22,400	22,400	15,000	14,600[1]
June 15	24,200	24,200	22,400	22,400	14,600	14,600
June 30	24,200	24,200	22,400	22,400	14,600	14,600
July 1	24,200	26,700	22,400	21,150	14,600	13,350

1. Fish Dam 2 includes the yearly storage of Section 1135 water: this yearly storage will begin in Phase I per negotiations in Fall 1997 but for this modeling exercise, yearly storage begins in Phase II.

5. The maximum volume of water stored in Fish Dam 2 is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1.

6. In Phase II, the level of snow in the watershed and the level of water stored in the Fish Dams are evaluated four times between March and September (four decision points) to set the condition for that particular season, for example, wet, average, or dry, in accordance with the following criteria:

   * The snow water equivalent levels in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March. If it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. The conditions are reevaluated on 1 July, 15 September, and 30 September.

   * If the total storage in Fish Dam 1 and 2 exceeds <u>37,000</u> acre-feet, then the summer is considered average; less than <u>37,000</u> acre-feet and it is considered dry: per Fall 1997 negotiations, Phase II storage volume is now <u>32,000</u> ac ft reflecting the reduction of 5,000 ac ft of Section 1135 storage that begins in Phase I . This requirement designates a condition which sets the requirements for Fish Dam 2 but it also is proposed to be used instead of 1 May to set the summertime condition under the Agreement.

   * The conditions are examined again on 15 September and if Fish Dam 1 is in Zone 1, storage exceeding 15,740 acre-feet, and the summer condition was average, then the condition is reset to wet for the fall. If Fish Dam 1 is outside Zone 1 or the summer condition was dry, then no change to the condition is made on 15 September and the summer condition remains in effect until 30 September.

   * The amount of water in storage on 30 September in Fish Dam 1 sets the fall condition. If Fish Dam 1 is in Zone 1, then the condition is set as wet, if it is in Zone 2 or 3 then it is average, if it is in Zone 4 , below 8,261 acre-feet, then it is set as a dry fall.

7. The instream flow levels are set in accordance with the conditions set on the four decision points. The various flow levels are:

   * For refill of Fish Dam 2 and Diversion Dam, the instream flow requirements are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

   * For the summer, Fish Dam 1 supports 350, 300, 250, and 225 cfs in an average summer and 250 and 225 cfs for a dry summer. Fish Dam 2 supports 300 cfs in an average summer and 250 cfs in a dry summer. In Phase II, no condition anticipates having the flow at Auburn drop below 250 cfs.

   * A wet condition set on 15 September increases the flow provided by Fish Dam 2 to 400 cfs for the period 16 September to 30 September.

* On 30 September, the flow in the river at Auburn is supported by Fish Dam 2 at a level of 450 cfs for the month of October in a wet condition, 400 cfs in an average condition, and 350 cfs in a dry condition. The levels set in September are supported by the water stored in Fish Dam 2 through the remainder of the year, until Fish Dam 2 is empty or until the rains return and the water is spilled to provide the needed flood control storage.

8. Freshets, at a duration of 38 hours and a level of 2,500 cfs as measured at the Auburn gage, are delivered on April 1, April 15, May 1, and May 15 under wet and average conditions, and at a level of 1,250 cfs on the same four days under dry conditions. Whenever Fish Dam 2 is below 65 percent of full on any of the four days where freshets are to be sent, then the freshet for that day is skipped. On September 1 in all years, a summertime freshet 700 cfs, as measured at Auburn, is delivered.

9. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

10. All water diverted for SSWR/Pipeline 5 is in accordance with the instantaneous rate and volume restrictions of the state water right and the Agreement. All water stored for diversion is done so through the rights held by the Corps of Engineers for this project.

11. From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*" In addition, Fish Dam 2 in Phase II has the ability to increase flows during the summer and fall.

9.6 MODEL RESULTS - YEARS 1964 TO 1995

Results are used in impact analyses (or are described) of the AWS Project and are found in various sections of the Appendix F, Parts 1 and 2 the Fish and Wildlife Appendices, respectively. In particular, results were used or described in subsection 2B-5, Sections 3-8 of the Fish Appendix. Otherwise, the original model outputs in the form of figures and tables was printed in a limited number of binders for use in the impact analysis. These binders have not been distributed for public review but selected sections can be copied and provided upon request. The sections of the binder are listed below.

The results of the model runs are summarized in a series of tables in the binder. These results are summarized by section and are:

Section 1: These tables and figures for 1990, 1992, and 1994 show the reservoir levels, diversions to Pipelines 1 and 5, flow at Palmer, and flow at Auburn.

Section 2: These tables, for Baseline, Phase I, and Phase II, show the number of freshets, if fish flows are met, and the condition set, (either wet, average, or dry) on 1 May for Baseline, 1 March and 1 May for Phase I, and 1 March, 1 July, 15 September, and 30 September for Phase II. In addition, the volume of water in storage in Fish Dam 1, Fish Dam 2, and Diversion Dam for 30 June-1 July for Baseline and Phase I, and 30 June-1 July for Fish Dam 2 and Diversion Dam, and 15 September and 30 September for Fish Dam 2 in Phase II.

Section 3: These tables, for natural inflow, Baseline, Phase I, and Phase II, list the number of days that the average daily flow exceeds 1,800, 2,000, and 2,500 cfs at Howard Hanson Reservoir, Palmer, and Auburn, by month for each year. In addition, the number of non-contiguous flow events that exceed 1,800, 2,000, and 2,500 cfs are included.

Section 4: For Baseline, Phase I, and Phase II, the tables show the 2-day low flow (2-day low flow defined as the lowest 2-day high flow for 2 consecutive daily flows) at Auburn for each month.

Section 5: For natural inflow, Baseline, Phase I, and Phase II, the tables show half-monthly average flows at Palmer and Auburn.

Section 6: For natural inflow to Howard Hanson Dam, the tables show average half-monthly flows.

Section 7: For natural inflow, Baseline, Phase I, and Phase II, the tables show average half-monthly Howard Hanson Dam storage levels, volumes, and outflow.

Section 8: For natural inflow, Baseline, Phase I, and Phase II, the tables show 10, 20, 25, 50, 75, 80, and 90 percent, half-monthly exceedance flows at Auburn and Palmer.

Section 9: For Baseline, Phase I, and Phase II, the tables show, for the period 15 February to 31 October, the number of days by month, that river flows at Palmer and Auburn fall below regulatory minimum flow levels, MIT/TPU target levels, and AWSP target levels.

Section 10: For Baseline, Phase I, and Phase II, the tables show the 7-day low flow (average of a running 7-day period), for each month at Auburn, Palmer, inflow to HH Reservoir, and HH outflow.

Section 11: For Baseline, Phase I, and Phase II, the tables show the amount of protected and unprotected river width potentially used by steelhead spawning assuming a 50-day incubation period and maximum allowable flow drops of 1.0 feet and 0.5 feet as alternatives. The spawning period used is from 1 March to 10 June.

Section 12: For Baseline, Phase I, and Phase II, the tables show the amount of protected and unprotected river width potentially used by salmon spawning, assuming a 75-day incubation period and maximum allowable flow drops of 1.0 feet and 0.5 feet as alternatives. The spawning period used is from 15 September to 31 January.

Section 13: For Phase II, the tables show the volume of water stored for fisheries use in Fish Dam 2 on 1 March, 1 July, 1 September, and 1 October.

Section 14: For Baseline, Phase I, and Phase II, the tables show, for the period 15 February to 31 October, the date that each pool elevation (1,141 feet, 1,147 feet, 1,150 feet, 1,160 feet, 1,167 feet, and 1,177 feet) is initially reached, total number of days pool elevations are exceeded, the last date a pool elevation is exceeded, and the periods when pool elevations are exceeded.

Section 15: For Baseline, Phase I, and Phase II, the tables show the half-monthly average and maximum daily fill rates for Howard Hanson Dam.

Figure 1
Baseline - Wet & Average Year
(AF x 1000)

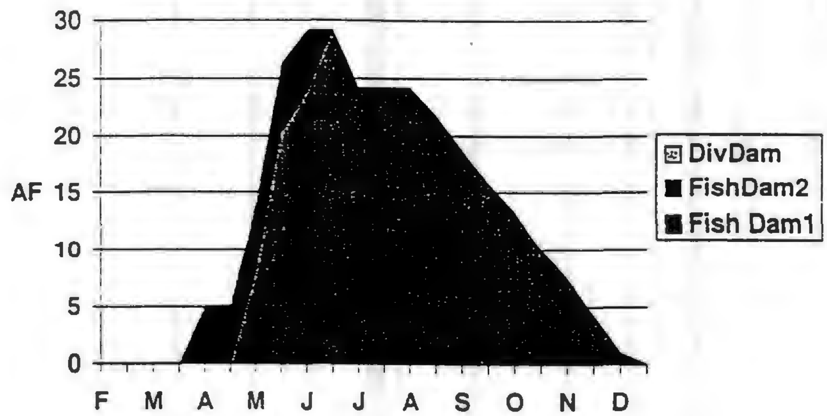


Figure 2
Baseline - Drought Year
(AF x 1000)

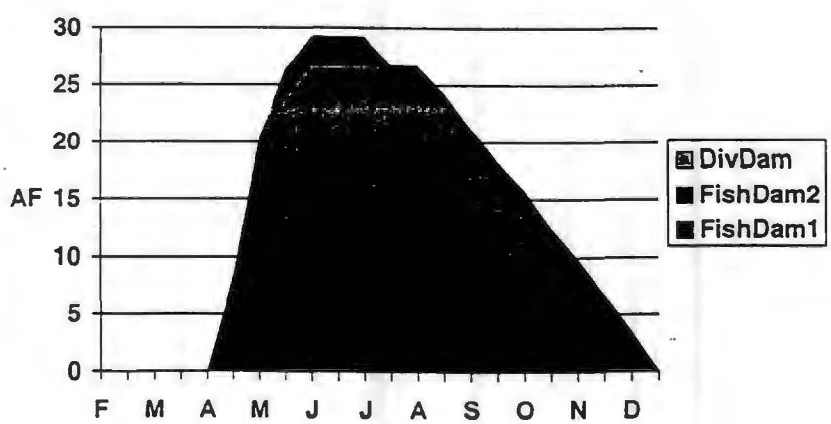


Figure 3
Phase I - Wet & Average Year
(AF X 1000)

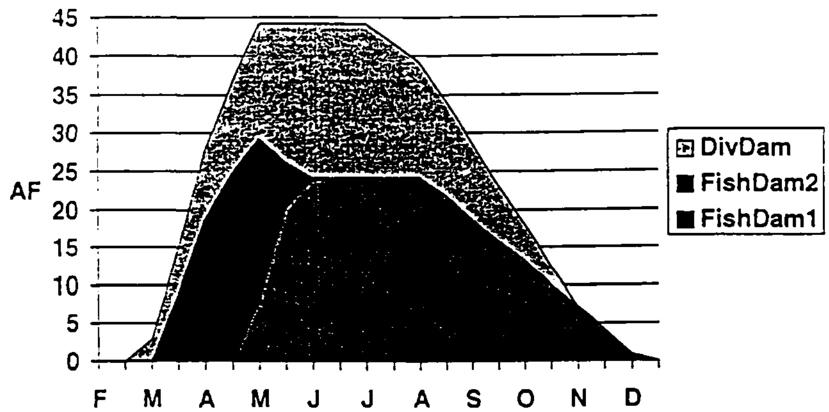


Figure 4
Phase I - Drought Year
(AF X 1000)

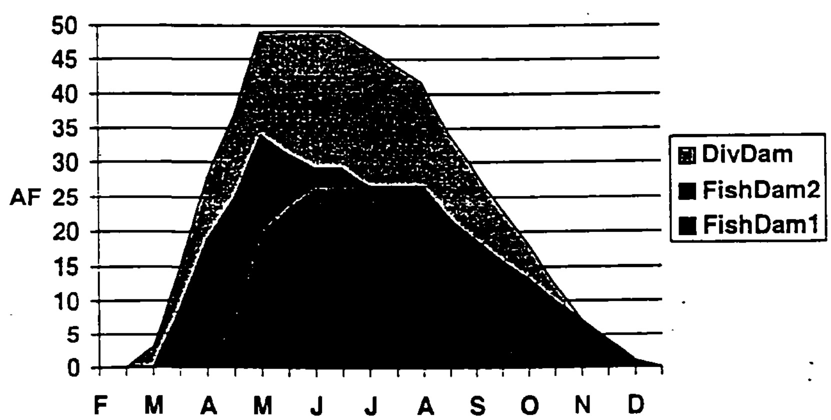


Figure 5
Phase II - Normal Year
(AF X 1000)

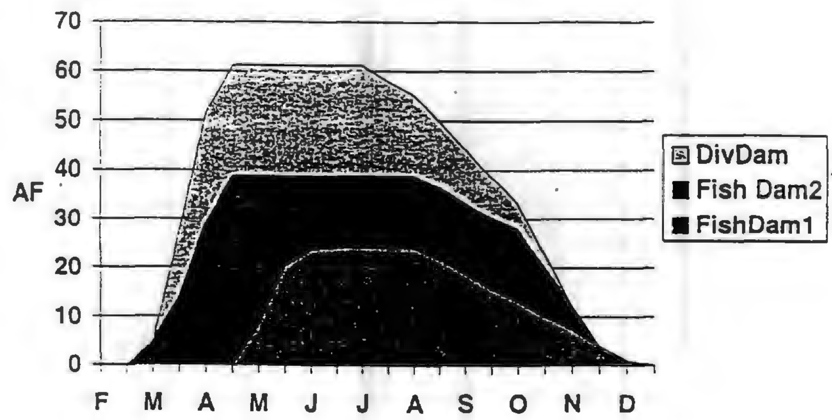
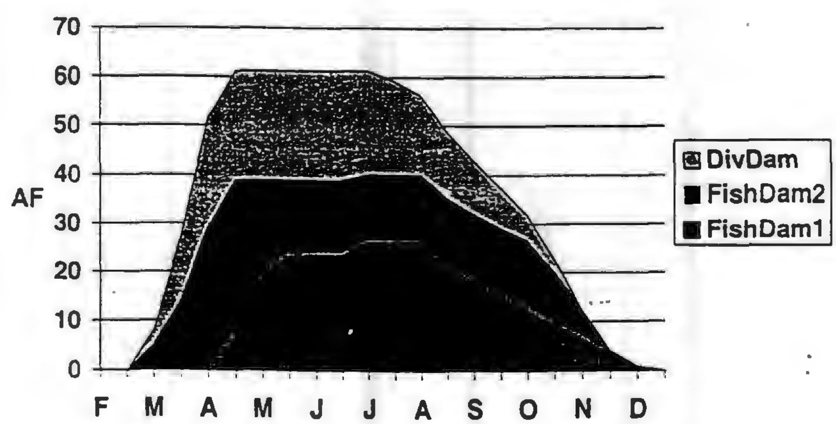


Figure 6
Phase II - Drought Year
(AF X 1000)



SECTION 10 PROPOSED ADAPTIVE MANAGEMENT MONITORING AND EVALUATION PROGRAM

10.1 INTRODUCTION

This section describes the framework of an Adaptive Management Monitoring and Evaluation Program. There are six Issue Areas for Monitoring and Evaluation, these six Issues are:

1. Downstream Fish Passage through Howard Hanson Reservoir and Dam (*10.A Project Fish Passage*);
2. Impacts to Downstream Habitat and Aquatic Resources (*10.B Downstream Impacts*)
3. Adult Fish Returns to the Upper Green River (*10.C System-wide Analysis*)
4. Restoration of Middle, Upper, and Headwaters Green River Stream Habitat (*10.D Fish Habitat Restoration Projects*)
5. Mitigation for Tributary and Riparian Habitat Inundated by the Phase I Pool (*10.E Fish Habitat Mitigation Projects*); and
6. Mitigation for Wildlife and Forest/Sedge Habitat Inundated by the Phase I Pool (*10.F Wildlife Habitat Mitigation*).

Monitoring and Evaluation plans for Issue Areas 1 through 6 are discussed in order in the following separate sub-sections 10.A-10.F, Wildlife Mitigation is discussed in more detail in *Section V, Operation and Maintenance and Monitoring Plan, Appendix F, Part-Two.* The post-construction monitoring and evaluation of downstream fish passage through the project is the most developed part of the plan (Section 10.A), for the other monitoring items simple summaries of plan concept, methods and costs are provided. A pre- and post-construction monitoring plan will be developed for all items during the first and second years of the plans and specifications phase in 1999 and 2000.

10.1 COST ALLOCATION AND SCHEDULE

EC-1105-2-100, paragraph 21.b.(3) identifies the federal sponsor's responsibility for long-term monitoring. As part of the HHD Additional Water Storage Project Monitoring and Evaluation Program, we have proposed an allocation of costs for monitoring and evaluating fish and wildlife mitigation (Phase I) and restoration projects. A listing of Issue Areas, Monitoring Items, and Cost-Allocation, and an overall length of monitoring (project years) are provided in Table 1. Under each Issue Area is a listing of Monitoring Items. These Items are specific elements of the project that require monitoring, analysis and evaluation to provide feedback to refine adaptive management of project operations. Costs for each Monitoring Item is based on one of three allocations: 1) 85% Federal and 15% Sponsor (85:15) ; 2) 65% Federal and 35% Sponsor (65:35); and 3) 0% Federal and

100% Sponsor. Allocation of costs by Monitoring Item is discussed in the *Economics Appendix.*

Monitoring costs are considered to be part of project construction costs. Depending on actual impacts, monitoring may extend beyond the specified time frames below. Although these costs are not included in the total costs, at this time we have assumed the sponsor would be responsible for any additional costs. The plan focuses on impacts/needs associated with phase I. At this time any necessary monitoring associated with phase II, beyond what is stated above, cannot be determined. Additional monitoring, if necessary, would depend on results of monitoring phase I impacts and would likely be targeted to assessing two areas: 1) survival of juvenile fish migrating through the larger reservoir; and 2) evaluation of the effects of additional storage on downstream resources. Therefore the assumption for overall project costs is that the above plan is adequate for both phase I and II. If additional monitoring for phase II is required, the proposed cost allocation would be based on the increase in reservoir elevation; 80% for low flow augmentation, 20% for water supply. Eighty percent of any monitoring costs project would be cost shared 65% federal and 35% non-federal. The remaining 20% would be 100% the non-federal sponsors responsibility. The costs reflect primarily labor costs and minor equipment such as tagging. The costs shown in the referenced tables do not include contingency. Total monitoring costs reflected in the official project cost estimate and the cost allocation include a 20% contingency amount. Capitol costs, specifically for monitoring equipment for the fish passage facility is included in the general project costs and has been allocated according to the general cost-allocation methodology.

A distinction is made between scientific evaluation and operation and maintenance (O&M) under Corps Ecosystem Restoration monitoring: the purpose of evaluation is to assure that fish passage and habitat improvement projects part of the restoration program are actually functioning for the intended purpose. This is usually accomplished through scientific study over selected time periods or at selected intervals. The primary purpose of O&M, on the other hand, is to maintain plants, structures and other elements so that they continue to perform their intended functions; O&M will then provide the funding for replacing plants, fish habitat structures, etc. However, routine O&M inspections can also disclose the need for maintenance of certain measures, such as woody debris structures damaged or dislocated by high flow events.

A proposed schedule of monitoring elements for evaluation is provided in Table 2. The table lists Monitoring Items, Monitoring Type or Technology, and what years the monitoring and evaluation will occur: years are listed as calendar and project years: the proposed monitoring and evaluation plan includes monitoring of all restoration projects and monitoring of Phase I mitigation projects, if Phase I is successful and we move to Phase II additional monitoring of Phase II mitigation projects would be necessary. Table 3 lists costs by Monitoring Type by project year and Table 4 summarizes annual costs by Monitoring Item using October 1997 values.

TABLE 10-1. PROPOSED ALLOCATION OF COSTS FOR MONITORING OF FISH AND WILDLIFE RESTORATION AND PHASE I MITIGATION PROJECTS.

Issue	Monitoring Item	Cost-Allocation % Fed:%Spon.[1]	Project Years
Project Fish Passage	Reservoir Passage of Juvenile Fish	85:15[2]	1-15
	Fish Collection Efficiency	85:15	1-15
		0:100	16-50, as necessary
	Fish Collector Passage	85:15	1-15
		0:100	16-50, as necessary
	Water Quality Monitoring	85:15	Equipment
		0:100	1-50
Downstream Impacts	Side-channel Connectivity	85:15[3]	1-5
		0:100	6-15 by sponsor, as necessary
	Juvenile Instream Migration/Habitat Use	85:15	1-5
		0:100	6-15 by sponsor, as necessary
	Adult Spawning and Egg Incubation	85:15	1-5
		0:100	6-15 by sponsor, as necessary
Adult Fish Returns	System-wide Analysis	Cooperatively Funded[4]	1-10
		0:100	11-15
Fish Habitat Restoration	M. Green Gravel Nourishment	65:35	1,2,5, 10, 15 5 yr. increment after 15 by sponsor
	U. Green Side Channel Improvement	65:35	1,2,5, 10, 15 5 yr. increment after 15 by sponsor
	Headwaters Stream Improvement	65:35	1,2,5, 10, 15 5 yr. increment after 15 by sponsor
Fish Habitat Mitigation	Instream Habitat Projects	0:100	1,2,5, 10 5 yr. increment after 10
	Riparian Habitat Projects	0:100	1,2,5, 10 5 yr. increment after 10
Wildlife Mitigation	Elk Habitat Use	0:100	1,2,5, 10
	Forest Habitat Use	0:100	1,2,5, 10

1. Capitol costs are included for the Project Fish Passage monitoring and labor costs are to be developed.
2. Cost-allocation of 85% federal for restoration and 15% water supply/sponsor is based on the height of the Fish Passage Facility.
3. Cost-allocation used for the fish passage facility is also a correlated measure to storage volume; refill of the reservoir is the primary impact to downstream habitat so the same cost-allocation was applied to downstream monitoring.
4. Cooperative funding is encouraged under Ecosystem Restoration. In this situation, the Corps would fund 1/3 of a larger basin-wide analysis of adult salmon and steelhead returns in relation to overall system impacts.

TABLE 10-2. PROPOSED SCHEDULE OF COST-SHARED MONITORING ELEMENTS FOR FISH AND WILDLIFE MITIGATION AND RESTORATION PROJECTS BY PROJECT YEAR.

	Monitoring Type/Technology	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Post-Construction**
Monitoring Item	**Project Year**	**0[a]**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total Yrs**
Reservoir Passage/Habitat Use[c]	Fyke Nets at Head of Reservoir		X	X	X	X	X			X	X			X	X		X	10
	Mobile Hydroacoustic Survey and Gill Netting			X	X					X					X			4
	Paired PIT Tag Release/Detection[b]		X	X	X	X	X			X	X			X	X			9
	Predator Monitoring/Manipulation				X		X					X					X	4
	Zooplankton/neuston				X					X					X			3
Fish Collection Efficiency	Paired PIT Tag Release/Detection[b]		X	X	X	X	X			X	X			X	X			9
	Hydroacoustic Monitoring of Forebay and Horn		X	X	X	X	X			X	X			X	X			9
Fish Collector Passage	Paired PIT Tag Release/Detection[b]		X	X	X	X	X			X	X			X	X			9
	Marked Fry		X	X	X													3
	Sampling Station Evaluation		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15
	Hydroacoustic Monitoring of Wetwell		X	X	X	X	X			X	X			X	X			9
Water Quality Monitoring	Thermistor or other Water Quality	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15
Side-channel Connectivity	Habitat Survey of Inlets/Outlets		X			X												2
	Habitat Use Survey – CPUE/Fyke			X		X												3
Instream Migration/Habitat Use	Migration – Screw-trap at RM 35		X	X	X	X	X											6
Spawning and Egg Incubation	Monitor Redd Dewatering/Emergence		X	X	X													3
System-wide Analysis[c]	Coded-wire Tagging of smolts		X	X	X	X	X											5
	Spawner Surveys		X	X	X	X	X											5
M. Green Gravel Nourishment	Gravel Distribution; Quality; Cross-sections	X	X	X			X					X					X	6
U. Green Side Channel Improvement	Project Inspection/Functioning		X	X			X					X					X	5
Headwaters Stream Improvement	Project Inspection/Functioning			X			X					X					X	4
	Stream Habitat Survey – Control/Treatment	X			X	X												3
	Habitat Use Survey – Abundance	X			X	X												3

Instream Habitat Projects	Project Inspection/Functioning			X			X	X	X	4
	River/Stream Habitat Survey	X			X	X				3
	Habitat Use Survey -- CPUE/Abundance	X			X	X				3
Riparian Habitat Projects	Riparian Habitat Project Inspection		X	X			X	X	X	5
Wildlife Monitoring	Pellet counts; Amphibian, bird, & mammal survey		X	X			X	X		4
Vegetation Monitoring	Sedge cover; canopy cover; forb cover & wetlands		X	X			X	X		4

a. Project Year 0 indicates monitoring of sites/conditions during construction phase (any year between 2001-03 when conditions permit) for immediate pre-project conditions.

b. Paired PIT-tag releases and detections overlap in monitoring of three different fish passage issues -- 1) reservoir passage/survival; 2) fish collection efficiency; and 3) fish collector passage - costs are only listed for fish collection efficiency but monitoring will cover all three issues.

c. This study monitoring item would be initiated only if a problem is identified in other annual monitoring and is not included in sub-totals: 1) radio tracking of juvenile salmon in the reservoir would occur if paired PIT tag releases shows smolt survival in the reservoir is lower than expected ($120,000 yr. 4 or 5); 2) radio tracking of adults would occur only if a problem is identified
by observation of adults -- such as adults milling below Diversion Dam fish ladder; adults monitored by hydroacoustics near HHD, etc. ($75,000).

TABLE 10-3. PROPOSED COSTS (IN THOUSANDS OF DOLLARS, OCTOBER 1997 COST) OF COST-SHARED MONITORING ELEMENTS FROM FISH AND WILDLIFE MITIGATION AND RESTORATION PROJECTS BY PROJECT YEAR.

		Annual Cost (in thousands of dollars)															
Monitoring Item	Monitoring Type/	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Project Years	0[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Reservoir	Fyke Nets		15	15	15	15	15			15	15			15	15		15
	Mobile Hydroacoustics			50	50					50					50		
	Paired PIT Tag[b]		Below[c]	Below[c]	Below[c]	Below[c]	Below[c]			Below[c]	Below[c]			Below[c]	Below[c]		
	Predator Manipulation				45		45					45					45
	Zooplankton/neuston				30					30					30		
Collection	Paired PIT Tag[b]		120[c]	120[c]	120[c]	120[c]	120[c]			120[c]	120[c]			120[c]	120[c]		
	Hydroacoustic Forebay and Horn[b]		40	40	40	40	40			40	40			40	40		
Collector Passage	Paired PIT Tags[b]		Above[c]	Above[c]	Above[c]	Above[c]	Above[c]			Above[c]	Above[c]			Above[c]	Above[c]		
	Marked Fry		20	20	20												
	Sampling Station[b]		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Hydroacoustic in Wetwell[b]		30	30	30	30	30			30	30			30	30		
Water Quality	Thermistor	60	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M	O&M
	SUBTOTAL	60	245	295	370	225	270	20	20	305	225	65	20	225	305	20	80
Side-channel	Inlets/Outlets		35			35											
	Habitat Use			50		50											
Instream Migration	Screw-trap		90	90	90	90	90										
Spawning /Incubation	Redds/Emergence		30	30	30												
	SUBTOTAL	0	155	170	120	175	90	0	0	0	0	0	0	0	0	0	0
System-wide Analysis	CWT smolts		50	50	50	50	50										
	Spawner Surveys		15	15	15	15	15										
	SUBTOTAL	0	195[d]	195[d]	195[d]	195[d]	195[d]	0	0	0	0	0	0	0	0	0	0
M. Green Gravel	Distribution; Quality	10	25	25			25					25					25
U. Green Side	Inspection		7.5	7			7.5					7.5					7.5

Channel Headwaters Stream	Inspection			7.5			7.5					7.5					7.5
	Habitat Survey	15			25	25											
	Habitat Use	5			10	10											
	SUBTOTAL	30	32.5	39.5	35	35	40	0	0	0	0	40	0	0	0	0	40
Instream Habitat	Inspection			7.5			7.5					7.5					7.5
	Habitat Survey	15			25	25											
	Habitat Use	5			10	10											
Riparian Habitat	Inspection		7.5	7.5			7.5					7.5					7.5
	SUBTOTAL	15	7.5	15	35	35	15	0	0	0	0	15	0	0	0	0	15
Wildlife	Animal Surveys		45.34	45.34			45.34					45.34					
Vegetation	Vegetation Surveys		23	23			23					23					
	SUBTOTAL		68.34	68.34			68.34					68.34					

a. Project Year 0 indicates monitoring of sites/conditions during construction phase (any year between 2001-03 when conditions permit) for immediate pre-project conditions.

b. Assumes hardware costs are already incorporated in the FPF construction cost: 1) $200,000 for PIT tag detector/monitor in juvenile bypass system; 2) $225,000 for Hydroacoustic transducers, rotators, cables, for the forebay/horn/trashrack/wetwell; and 3) $200,000 for Sampling station; total cost of $625,000 (D. Chow pers comm. said $750,000 set-aside for hardware).

c. Paired PIT-tag releases and detections overlap in monitoring of three different fish passage issues -- 1) reservoir passage/survival; 2) fish collection efficiency; and 3) fish collector passage - costs are only listed for fish collection efficiency but monitoring will cover all three issues.

d. The Adult Return/System-wide Analysis cost is for items the Corps would fund as part of analyzing adult returns to the Upper Green River Basin. Additional monitoring of adult returns would also be conducted and funded as part of state, tribal and City of Tacoma activities. We are assuming such a basin wide program would nominally cost $195,000 and the cost the Corps is funding reflects approximately 1/3 ($65,000) of that total cost and participating agencies and the sponsor would cover 2/3 of the cost ($130,000).

TABLE 10-4. SUMMARY TABLE OF YEARLY COSTS BY MONITORING ISSUE FOR THE HOWARD HANSON DAM ADDITIONAL WATER STORAGE PROJECT.

	Annual Cost (in thousands of dollars)															
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Issue	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Reservoir Passage/Habitat Use	0	15	65	140	15	60	0	0	95	15	45	0	15	95	0	60
Fish Collection Efficiency	0	40	40	40	40	40	0	0	40	40	0	0	40	40	0	0
Fish Collector Passage	0	70	70	70	50	50	20	20	50	50	20	20	50	50	20	20
SUBTOTAL FOR FISH PASSAGE	60	245	295	370	225	270	20	20	305	225	65	20	225	305	20	80
Side-channel Connectivity	0	35	50	0	85	0	0	0	0	0	0	0	0	0	0	0
Instream Migration/Habitat Use	0	90	90	90	90	90	0	0	0	0	0	0	0	0	0	0
Spawning and Egg Incubation		30	30	30	0		0	0	0	0	0	0	0	0	0	0
SUBTOTAL FOR DOWNSTREAM	0	155	170	120	175	90	0	0	0	0	0	0	0	0	0	0
System-wide Analysis	0	195[a]	195[a]	195[a]	195[a]	195[a]	0	0	0	0	0	0	0	0	0	0
SUBTOTAL FOR ADULT RETURNS	0	195[a]	195[a]	195[a]	195[a]	195[a]	0	0	0	0	0	0	0	0	0	0
M. Green Gravel Nourishment	10	25	25	0	0	25	0	0	0	0	25	0	0	0	0	25
U. Green Side Channel Improvement	0	8	7	0	0	8	0	0	0	0	8	0	0	0	0	8
Headwaters Stream Improvement	20	0	8	35	35	8	0	0	0	0	8	0	0	0	0	8
SUBTOTAL FOR FISH RESTORATION	30	33	40	35	35	40	0	0	0	0	40	0	0	0	0	40
Instream Habitat Projects	15	0	8	35	35	8	0	0	0	0	8	0	0	0	0	8
Riparian Habitat Projects		8	8	0	0	8	0	0	0	0	8	0	0	0	0	8
SUBTOTAL FOR FISH MITIGATION	15	8	15	35	35	15	0	0	0	0	15	0	0	0	0	15
Wildlife Monitoring	0	45	45	0	0	45	0	0	0	0	45	0	0	0	0	0
SUBTOTAL FOR WILDLIFE MITIGATION	0	45	45	0	0	45	0	0	0	0	45	0	0	0	0	0
YEARLY TOTAL FOR RESTORATION	90	628	700	720	630	595	20	20	305	225	105	20	225	305	20	120
YEARLY TOTAL FOR MITIGATION	15	53	60	35	35	60	0	0	0	0	60	0	0	0	0	15
COMBINED YEARLY TOTAL[b]	105	681	760	755	665	655	20	20	305	225	165	20	225	305	20	135

a. We are assuming this is a basin wide program that would nominally cost $195,000 and the cost the Corps is funding reflects approximately 1/3 ($65,000) of that total cost -- participating agencies and the sponsor would cover 2/3 of the cost ($130,000).

b. Numbers presented do not include a 20% contingency: contingency has been added in the project cost estimate, see Economics Appendix.

10.2 RESTATEMENT OF ADAPTIVE MANAGEMENT PRINCIPLES

Adaptive management is a form of natural resource management that states explicitly that uncertainty is inherent in all decisions related to management of natural systems. It is a management form that uses scientific information to develop management strategies in order to learn from programs or projects so that subsequent improvements can be made in creating both successful policy and managed programs and projects (Lee and Lawrence 1986). As such, adaptive management is managing by experimentation where "experimentation is not just a study," but is a major process of organizational change. Fluharty and Lee (1988) describe four essential elements to implement adaptive management:

1. The possibility of failure must be acknowledged and included in policy decisions.
2. Front end costs for planning, experimental design, and baseline measurement of natural systems must be incurred, and a long-term commitment to continue is necessary.
3. Interventions must be large, but should not be applied universally.
4. Information must be collected, analyzed, and reflected in program and project redesign, over time periods greater than the terms of policy or program managers.

Under the Agency Resolution Process, the Corps and Tacoma agreed to an adaptive management plan for the AWSP. The key elements of the Plan include experimentation, monitoring and analysis, and synthesis of results, followed by adaptive management practices responsive to the scientific results of those efforts. The AWSP Adaptive Management Plan involves: 1) phased implementation, so changes in the ecosystem can be studied with long-term monitoring; 2) incorporation of potential changes in project design and management/operation as we learn from phased implementation studies and monitoring; 3) implement changes in program structure if monitoring results and outcomes justify changes; and 4) ongoing coordination with agencies and the MIT throughout the project to ensure that good science is incorporated into management strategies and decision making.

The following sections describe the concepts and methods for the monitoring and evaluation of the six issue areas listed in Paragraph 10.1. A more complete pre- and post-construction monitoring and evaluation plan will be developed during the next phase of the AWS Project design process, Plans and Specifications (PED), in 1999.

10.A PROJECT FISH PASSAGE: DOWNSTREAM PASSAGE THROUGH HOWARD HANSON DAM AND RESERVOIR

Monitoring and evaluation will assess how well fish move through the larger reservoir, the efficiency of juvenile collection, survivability/passage through the fish collector and passage structure, water quality/limnology and fish use of the larger reservoir. The proposed period is for 15 years, corresponding to 3-4 life cycles of fish. This longer monitoring period is also required to learn the optimal facility and reservoir operation depending on variability in water years. Because new fish passage technology is being utilized, extensive monitoring is necessary to learn how best to operate the project. Fish passage is primarily associated with restoration of functions impacted by original project construction. Costs have been allocated based on the height of the fish passage facility attributable to restoration and to water supply: 85% of the costs are allocated to restoration, and 15% to water supply. Eighty-five percent of these monitoring costs will be cost shared, 65% federal and 35% non-federal. The 15% of the total is attributable to water supply and the non-federal sponsor will be responsible for 100% of these costs. A pre- and post-construction monitoring plan will be developed for all items during the first and second years of the plans and specifications phase in 1999 and 2000.

10.A.1 INTRODUCTION

From 1991-1995, the U.S. Fish and Wildlife Service (USFWS) performed a series of studies to evaluate the downstream fish passage facilities incorporated into Howard Hanson Dam (Dilley and Wunderlich 1992, 1993; Dilley 1994; and Aitkin et al. 1996): results are discussed in previous parts of Section 2 of this Appendix. In addition to the USFWS studies, in 1984, Washington Department of Fish and Wildlife (WDFW) conducted pre-feasibility project smolt trapping to monitor of smolt outmigration through the existing radial gate outlet. The results from these studies were incorporated into the design process and information used by the HHD Fish Passage Technical Committee in designing modifications to the HHD outlet facilities (Modular Incline Screen, MIS, fish bypass, and fish lock) and spring refill rule curve change. Without the results from this Baseline monitoring program, accurate requirements for project modifications to the dam fish passage facilities and refill period would not be available today.

As project proponent of the AWSP, the Corps, in conjunction with all participating resource agencies, is responsible for developing a monitoring plan to evaluate the project's new fish passage facilities and various refill and release strategies for reservoir operations. The Ecosystem Restoration Authority has no pre-determined length for post-project monitoring and evaluation. In addition to the restoration monitoring authority, no restriction is outlined for monitoring associated with mitigation requirements. The Corps is proposing a 15 year monitoring and evaluation plan under to evaluate the effectiveness of the modified MIS, juvenile fish bypass system, fish lock, and spring refill rule curve modification. This plan parallels and incorporates many of the elements used during the 1991-1995 USFWS studies which should provide better comparisons for pre and post project survival estimates. Objectives of this downstream fish passage monitoring and evaluation plan include: 1) estimating the reservoir survival rate of outmigrating smolts; 2) estimating the attraction rate of the modified intake and MIS, with and without changes in outflow (freshets); 3) testing the screen efficiency of the MIS and fish bypass and lock system; and 4) estimating the total project survival of downstream migrants passing through the reservoir and dam.

10.A.2 PROPOSED MONITORING AND EVALUATION METHODS

Study methods for downstream fish passage include four monitoring and evaluation types: 1) passive integrated transponder (PIT) tagging and release of coho, chinook, and steelhead smolts for estimating reservoir survival and fish passage facility attraction; 2) fin clip or freeze brand mark and release of coho or chinook fry to test efficiency of the MIS Screen and fish bypass; 3) hydroacoustic monitoring of the reservoir and fish passage facility and radial gates; and 4) weekly evaluation of species composition, growth characteristics, and injury rates (if necessary) in a sampling station. The first monitoring type will include 9 years of study, the second type will include two years, the third type 9 years and 15 years for the fourth type. Assumes hardware costs are already incorporated in the FPF construction cost: 1) $200,000 for PIT tag detector/monitor in juvenile bypass system; 2) $225,000 for Hydroacoustic transducers, rotators, cables, for the forebay/horn/trashrack/wetwell; and 3) $200,000 for Sampling station; total hardware cost of $625,000 (D. Chow pers. comm., set-aside $750,000 which includes 20% contingency). Most monitoring work items will be contracted either to the resource agencies or to one or more private consulting firms.

Estimation of Reservoir Survival, Attraction Rate of Fish Passage Facility, and Total Project Survival Using PIT-tags. To estimate reservoir survival, fish passage facility attraction rate, and total project survival, the Corps is proposing that 5,000 coho, chinook and steelhead smolts will be tagged, released and monitored during 9 of the first 15 years of project operation: 15,000 PIT tags/year or 135,000 total tagged fish. Final numbers of marked fish will be determined through agency coordination and discussion with a biostatistician. Tagged fish would be supplied either from the MIT Fish Restoration Facility from the upper Green River cohort reared for outplanting above the dam, WDFW or MIT smolt rearing facilities at Palmer or Auburn, and/or naturally reared juveniles could be trapped. Two or more release locations would occur upstream of the fish bypass facility and will include releases at 1) the forebay, and 2) 0 to 0.5 miles upstream of the reservoir at various pool levels. Release groups will include simultaneous (at both release locations), systematic releases of 500-1,000 fish/species and will be spread out over a 3-4 week period. Release times would bracket the peak outmigration period for steelhead (April 24 - May 7), coho (May 1-15), and chinook (May 15-June 15).

Paired PIT-tag releases and detections overlap in monitoring of three different fish passage issues -- 1) reservoir passage/survival; 2) fish collection efficiency; and 3) fish collector passage - costs are only listed for fish collection efficiency but monitoring will cover all three issues.

PIT tags can be used for large scale marking (1000s) of fry to smolt-sized fish (55-65 mm and larger) to assess reservoir survival and overall fish passage efficiency of the fish collection facility (during refill and high pool)(Prentice et al. 1990; Peterson et al. 1994). PIT tags provide an individual tag number of each marked fish, and when passed through a fish monitor (sensor), provide an immediate return on arrival time of that marked fish at the fish passage facility. PIT tags can be used to activate fish separation facilities so marked fish could be automatically diverted to a sampling station. PIT tags can also be used alone or in combination with coded-wire tags during outplants of fry in the upper watershed so fry to smolt survival could be assessed and used for evaluation of overall success of the restoration project (Peterson et al. 1994; Newman 1995; Achord et al. 1996).

Tagged fish would be monitored by a 2 or 3 coil system (24 in, 134.2 KHz tunnel monitor with estimated 90-95% detection probability, Biomark Inc.) downstream of the screen near the bypass outfall. A similar, more elaborate system is used at the Cowlitz Falls fish bypass monitoring system. Detection efficiency of the coil system can be calculated using marked objects ("fish sticks," for example). Reservoir survival can be generally estimated by subtracting the detection rate of above reservoir releases from forebay releases. The forebay release groups can be used to calculate attraction rate of the fish passage facility.

The proposed PIT tag monitoring system would include:

- One portable PIT tagging station for tagging fry/smolts in the hatchery or field: electronic balance, digitizer, tag detector, automatic tag injector, multi-port controller, laptop or other portable computer.
- Two or three PIT tag extended range fish monitors: fish monitor is able to detect pit tags in a 2 ft diameter flume and at velocities up to 30 fps (current technology suggest velocities of 5 fps or less are required, new technology may overcome this limitation). One monitor located at the beginning of the juvenile bypass system and the second near the bypass outfall.
- Separation system for PIT-tagged fish near outfall of the bypass: once a fish monitor detects a PIT-tag, a controller activates a trigger mechanism that opens a slide gate to separate the tagged fish from the juvenile bypass flume and into a secondary flume to holding tanks in a sampling station (described below). Components should include an adjustable slide gate and double-read firmware. National Marine Fisheries Service has done a prototype and should have specifications.
- PIT-tags: five years of monitoring for initial requirements for reservoir and project survival (Phase I of AWSP), four years of monitoring for evaluation of restoration and mitigation during project years 8,9 and 12, 13, total of 9 years. Tag requirements of 5000 tags/species/year for the first 5 years (15,000/year for 5 years for 3 species) and an equal number per year for an addition four years. Total tags of 135,000. Estimated cost for three 24" PIT-tag monitors, communication system installation, and diverter gates is $200,000 and is considered part of the fish passage facility construction cost. Annual tag costs at $2.25/tag wholesale price is $34,000/year in 1996 dollars. We are estimating an annual monitoring and evaluation cost (tags, tagging, sampling, and reporting) of $120,000.

Efficiency of the MIS Screen and Fish Bypass Facility. The MIS screen is still considered experimental technology and although laboratory tests have shown juvenile survival rates exceeding 95%, a controlled test of the screen is necessary (Smith 1993; Taft et al. 1993;

Winchell et al. 1993). A series of coho, chinook salmon or steelhead fry releases will occur during normal juvenile outmigration period to test the efficiency of the MIS screen and fish bypass facility: releases would number 6000 marked fry/year for 12,000 total marked fish over two years. Final numbers of marked fish will be determined through agency coordination and discussion with a biostatistician. Assumed marking methods include cold branding or fin clips. Marked fish would be supplied by the MIT Fish Restoration Facility from the upper Green River coho broodstock (or other stock) collected for outplanting above the dam. Three planned test group release locations would include plants: 1) above the fish passage facility either above the trashrack or at the entrance to the facility; 2) below the MIS screen in the bypass flume; and 3) at or below the wetwell exit. Test group 1 would be used to evaluate screen efficiency; test group 2 would be used to evaluate the bypass system; test group 3 would be used to evaluate the wetwell exit and bypass flume. Test groups of 500 coho, chinook salmon or steelhead fry per release location will occur weekly for 4 weeks. Release times would begin in mid-April through mid-May.

Test group 1 could be introduced directly above the trashrack or passage facility inlet by boat. Test group 2 would require introduction to the bypass system through a portal. A portal would have to be added to the design of the facility. Test group 3 would be introduced directly into the lock chamber. Recovery of marked fish would occur downstream at the sampling station near the bypass outfall (described below). A shunt gate would divert fish into a small sampling station with Wolf Trap collection system approximately 100 ft upstream of the bypass outfall. The recaptured fish would be assessed for screen efficiency and potential injury rate. Injuries would be rated following National Marine Fisheries Service protocol.

Sampling Station at Outfall of Fish Passage Facility. A sampling station to assess condition (injury, mortality, length/weight, smoltification, and stress) of test and natural outmigrants after passage through the collection facility. The sampling station could be used for assessment of marked (fin-clipped and PIT-tagged) and unmarked outmigrants. Marked juveniles and smolts would be analyzed in conjunction with travel time, reservoir survival and fish passage efficiency monitoring. Unmarked smolts could be analyzed in conjunction with hydroacoustic monitoring to develop species percent composition of estimated outmigrant numbers. Components of a sampling station include:

- A separation system: for marked fish -- PIT-tag monitor, adjustable slide gate, double read firmware; for unmarked fish, just use the adjustable slide gate.
- Building and components: located next to the bypass outfall, vehicle access, electrical/mechanical, flume from juvenile bypass, water supply separate from diverted bypass flume or a recirculating water supply, secondary flume to return sampled smolts to the river, holding tanks or troughs for diverted fish. Estimated construction cost for the building including 2 slide gates, dewatering section from main flume (30 cfs) to secondary flume (1 cfs), one sample tank, one holding tank and electronic fish counters (Smith Root) is $200,000 which is included in the construction cost of the fish passage facility.

- During the first 15 years of project operation, a weekly evaluation (2-3 hours/day, every other day -- 3 days per week) of species composition, growth characteristics, and injury rates (if necessary) would occur. This cost is estimated at $20,000 per year and is cost-shared with the project sponsor. After year 15, this sampling would continue as a project operation and maintenance cost and would be fully funded by the project sponsor. In addition to the planned weekly evaluations, fish will be evaluated using the sampling station in conjunction with other study components such as PIT-tag release and recapture, assessment of the MIS/Fish Passage Facility efficiency, hydroacoustic monitoring of the forebay and wetwell.

Forebay Scanning of the Dam. Hydroacoustic monitoring can be used to continuously map the number and location of outmigrant juveniles and larger resident salmonids in the forebay above the fish passage facility and at the entrance to the facility (the horn). Fish densities and fish trajectories (direction fish are moving) can be quickly mapped over relatively large areas using a combination of target tracking and stepped-scanning hydroacoustic techniques. A split-beam transducer on a dual-axis rotator can continuously sample the forebay area and near the facility horn for outmigrants and larger fish (potential predators). This could prove to be a very important tool in assessing the utility of flow ramp-ups (freshets) and ramp-downs in attracting and collecting juveniles into the fish passage facility.

A scanning system for tracking fish in the forebay will require a hydroacoustic system with one or two 6x10 degree elliptical split-beam transducers with rotators. The transducers and rotators could be mounted on the trashrack and would require power and data transmission cable connected to a PC. We are estimating operation costs of $40,000 per year for project years 1-5, 8-9, and 12-13: estimated cost for equipment and mounting (hardware) is included in the construction cost of the Fish Passage Facility and are included in hydroacoustic monitoring of fish passage facility, below. If forebay scanning in conjunction with freshets (flow ramp-up) proves effective, this could become an annual O&M item to improve smolt survival through the project.

Hydroacoustic Monitoring to Provide Estimated Outmigration Numbers and Fish Behavior in Fish Lock. The objective of this monitoring component is to provide detailed evaluation of juvenile fish passage into/in the fish lock and evaluate potential passage at high flows through the radial gates. Hydroacoustic monitoring and evaluation for outmigrant juvenile anadromous salmonids and larger salmonids (trout) would occur at various locations around the facility including: behind the trashrack for entrainment estimates to the collector and radial gates; wetwell exit; and lock chamber. This system can be linked to an automatic lock control system (discussed below). This intensive evaluation is in addition to the standard daily monitoring of the wetwell that is necessary for operating the fish passage facility.

In 1991 and 1992, the USFWS conducted baseline project hydroacoustic monitoring (single beam) of smolt outmigration through the existing bypass and radial gate outlets (Dilley and Wunderlich 1992, 1993). Hydroacoustic monitoring was used in conjunction with scoop trapping below the outlet to determine the daily passage rates of coho and chinook salmon juveniles and smolts through the dam. This type of monitoring can provide important data to supplement the PIT-tag, screen efficiency tests, and sampling station assessments. This type of monitoring has provided estimates of the behavior and total number of fish passing through each potential dam outlet.

The proposed hydroacoustic monitoring system required to monitor three locations (behind the trashrack for entrainment estimates into the fish passage facility and radial gates, wetwell exit; and within the lock chamber) would require: 1) two 6x10 degree split-beam transducers mounted at the bottom and in the mid-water column behind the trashrack; 2) a single 6 degree conical transducer with rotator to sample the wetwell exit; 3) two 6x10 degree transducers to sample the lock chamber; and 4) two spare transducers and cable as back-ups. Estimated cost of the system to purchase the system is $225,000 for hydroacoustic transducers, rotators, cables, for the forebay/horn/trashrack/wetwell. Annual cost for this study component to intensively monitor and evaluate passage through the fish passage facility is $30,000 (daily monitoring of hydroacoustics in the wetwell is an assumed annual operation cost and is not included in this study component), which would be cost-shared and occur in project years 1-5, 8-9, 12-13. These costs were separated from the forebay scanning above with total hydroacoustic costs of $70,000 per year ($40,000 forebay + $30,000 wet-well). These costs presume that hydroacoustic equipment daily monitoring of the After project year 15, wet-well monitoring would continue as an operation and maintenance item fully funded by the project sponsor.

Automatic Lock Control System/Hydroacoustic Monitoring. Hydroacoustic monitoring in the lock chamber can be linked to an automatic lock control system to vary the cycle time of the lock based on the number of smolts in the chamber. The facility as now planned would have an automatic control that regularly cycles lockages at pre-programmed times. The linked control to the hydroacoustics would be more biologically based, giving actual estimates of fish density in the lock chamber required before locking fish through. Estimated cost to install and program the automatic linked lock-control system is $100,000-150,000. Hydroacoustic monitoring is described above.

Observation of the MIS. There is concern that at certain flow rates the normal and sweeping velocities over the bypass screen may exceed the swimming ability of juvenile outmigrants. The screen surface should be periodically monitored at various flow rates/velocities to assess impingement of smolts against the screen. The bypass and screen are currently proposed to have viewing portals so an observer can look directly at the screen: portals are used to monitor smolts at the Puntledge Fish Passage Facility on Vancouver Island. Monitoring of the screen will occur on a regular basis to assess impingement and potential build-up of debris or damage to the screen. Annual cost of this is an O&M item.

An additional option of remotely monitoring the screen could include video. This would require infrared lighting (which may be necessary for direct viewing too) and high-speed video equipment. Infrared lighting is invisible to smolts and should not alter their behavior. Either direct or video monitoring of the screen can be used to assess smolt behavior, determine species composition, note impingement on the screen, and debris accumulation. A rough estimate of cost for a video monitoring system including lighting, camera, monitor, and digital compression software for fish/recognition/compression of data files would be $30,000. This item has not been included as a project cost.

Fyke Netting at the North Fork and Mainstem Reservoir Confluence. The objective of the monitoring component is to characterize immigration of juvenile salmonids into the reservoir from winter through early summer. During the first 15 years of project operation, a weekly evaluation (2-3 days/week) of immigration timing of juvenile fish entering the reservoir will be performed included metrics on species composition, growth characteristics, and stomach contents (if necessary) would occur. The monitoring would be performed in project years 1-5, 8-9, and 12-13 at an annual cost of $15,000 and is cost-shared with the project sponsor. After year 15, this sampling would continue as a project operation and maintenance cost and would be fully funded by the project sponsor. In addition to the planned weekly evaluations, sampled fish can be marked (PIT-tags, fin-clips or other) and re-evaluated using the sampling station in conjunction with other study components such as PIT-tag release and recapture, assessment of the MIS/Fish Passage Facility efficiency, hydroacoustic monitoring of the forebay and wetwell.

Mobile Hydroacoustic Surveys of the Reservoir. The objective of this monitoring component is to characterize the diel and seasonal horizontal and vertical distribution of juvenile and adult anadromous and resident salmonids in the reservoir (paralleling work done by USFWS in 1993 (Dilley 1994)). This information would be used to evaluate total project survival of juvenile emigrants and necessary actions such as periodicity of predator build-up at tributary confluence (selective removal), and build-up of juvenile outmigrants above the passage facility (need for increase in outflow). In addition to distribution data, post-construction surveys would include collection of morphometric (growth) and limited stomach content analysis. Periodic mobile hydroacoustic surveys would either be contracted with resource agencies or private consulting firms and would require a complete hydroacoustic system that should include: 1) a stable boat of minimum 20-ft length; the boat must have a covered area to protect the electronic equipment; 2) a hydroacoustic system (PC, echosounder, chart recorder, oscilloscope, mobile transducer boat mount, or towed fin attached to the boat) with paired surface and down-looking conical split beam transducers. Variable mesh gill nets would be set at selected points throughout the reservoir to verify species composition of hydroacoustic surveys and to provide fish for morphometric and stomach content analysis. Surveys are planned to primarily occur with years of zooplankton/neuston surveys in the reservoir. Surveys are planned for project years 2, 3, 8 and 13 at an annual cost $50,000.

zooplankton/Neuston Sampling in the Reservoir. The objective of this monitoring component is to characterize the reservoir foodwebs, zooplankton and neuston, and to evaluate changes in the foodweb as the reservoir environment changes through time. To complement reservoir surveys for information on juvenile rearing, sampling for composition of invertebrate community including distribution and densities would be conducted in 5-year increments. The reservoir will be undergoing dynamic changes during the initial years of the pool raise with continuing long-term changes as the system attempts to reach equilibrium. These changes will include a large influx of nutrients from inundating surrounding vegetation, run-off from short-term landsliding, increase in heat budget and development of a more dramatic thermocline, and lastly, the re-introduction of salmon carcasses and increased juvenile rearing densities. These changes can result in dramatic changes to the reservoir food web upon which salmonids are dependent.

In selected years, on a seasonal basis, surveys would be performed to collect invertebrate data in the upper and lower sections of the reservoir and would be analyzed in conjunction with stomach contents collected during sampling for juvenile salmonids (described under mobile surveys). More intensive surveys (semi-monthly) could be conducted during the main outmigration/spring refill season. Invertebrate surveys of the reservoir are planned for project years 3, 8 and 13 with estimated annual cost of $30,000. Water quality monitoring would be conducted in conjunction to invertebrate and salmonid surveys in the reservoir and is described in the first sentence of the paragraph below.

Predator Monitoring – Pre- and Post-Construction. The objective of this monitoring component is document Baseline (pre-construction) of trout distribution and abundance and to monitor and evaluate the changes in trout populations and consumption rates under restoration of salmon runs with the AWS Project (post-construction). Beginning in 1999, before project construction, two years of monitoring of resident trout and/or avian predator abundance in the reservoir will be conducted. This is a preventative measure to insure successful outmigration of chinook juveniles (the smallest migratory fish). Members of an interagency team of biologists were concerned about the possible increase in predation that may occur at migratory transition points such as the confluence of the tributaries with the reservoir and at the fish passage facility. Monitoring of predators would continue in Phase I and II and would be evaluated in relation to the larger juvenile outmigration study using PIT-tags, hydroacoustics and other sampling methods. If there is an increase in overall predator abundance in response to juvenile migratory presence, a selective predator removal program could be initiated. If this tool proves effective, this could become an O&M item to improve smolt survival through the project. Such a program would be developed by the appropriate state, federal or tribal fish and wildlife managers and would require coordination with the City of Tacoma. The pre- and post-construction predator-monitoring plan will be developed during 1999. Surveys are planned during pre-construction for 1999 and 2000 and post-construction in years 3, 5, 10 and 15 at an estimated annual cost of $45,000.

Water Quality Monitoring. The Corps Water Management Section currently conducts semi-monthly water quality surveys of the existing pool, measuring temperature, dissolved oxygen, and conductivity at a depth throughout the reservoir -- these surveys would be continued post-construction. In addition to these boat surveys, three permanent water quality stations would be added in order to continuously monitor temperature, dissolved oxygen, and conductivity in the lower reservoir and at the dam outfall. These stations are primarily for monitoring temperature stratification of the reservoir and will be used to assess changes in flow releases in order to meet outflow temperature requirements (see discussion in the Hydraulics and Hydrology Appendix). The purchase cost of the three water quality stations is $60,000 and will be cost-shared with the sponsor, the additional cost of maintaining will be covered by the Corps (M. Valentine, pers. comm.).

10.A.3 SUMMARY OF THE PROJECT FISH PASSAGE MONITORING AND EVALUATION PLAN

A pre- and post-construction monitoring plan will be developed for all items during the first and second years of the plans and specifications phase in 1999 and 2000. The proposed monitoring plan for the AWSP fish passage facility and reservoir operations is made up of 11 components:

- A nine-year monitoring and evaluation program using PIT-tags. Marked fish can be used to answer objectives of determining 1) reservoir survival; 2) estimating attraction rate; and 3) estimating total project survival. This monitoring is conducted annually for the first 5 years of project operation and then in two 2-year follow-ups in project years 8,9 and 12, 13.
- A two-year test of using marked salmon fry to assess the efficiency (injury and mortality) of the MIS, fish bypass, and fish lock.
- A sampling station at the bypass outfall will be used weekly to evaluate condition of marked and unmarked fish. The station is tied to the PIT-tag program, the marked fry test, and overall monitoring of outmigrant health.
- Intensive hydroacoustic evaluation of unmarked fish will occur for nine years. PIT-tagged fish are important tools to measure various aspects of project performance however the vast number of outmigrants will eventually be unmarked (naturally reared). Hydroacoustic monitoring is the one tool available to instantly/constantly monitor the number of outmigrants moving through the fish passage facility and radial gates and provides critical information for daily operation of the passage facility and reservoir fill: outside this more intensive evaluation, daily monitoring of the lock will occur as a normal O&M item.
- The forebay scanning will be conducted for nine years and maybe a long-term option to assess build-up of smolts above the facility, with the potential necessity to ramp-up outflow (release freshets). If it proves effective, this could be become an O&M item to improve smolt survival through the project.
- Observation of the MIS screen is an annual O&M item and will be conducted on a regular basis.
- Fyke netting of juvenile fish immigrating into the reservoir will occur for nine years.
- Mobile hydroacoustic surveys and gill netting will assess juvenile habitat use and rearing in the reservoir.
- Zooplankton/Neuston surveys will be conducted in conjunction with the reservoir surveys of fish use.

- Predator monitoring will occur pre- and post-construction to assess whether additional mitigation (removal of predators) is necessary to maximize to smolt survival through the project. If it proves effective, this could become an O&M item to improve smolt survival through the project.
- Water quality monitoring will continue pre- and post-construction.

10.B DOWNSTREAM IMPACTS: IMPACTS TO DOWNSTREAM HABITAT AND AQUATIC RESOURCES

The purpose of this element is to assess the impacts/needs of Lower Watershed anadromous fish during spring re-fill. The expected time frame is 5 years. The results will improve our evaluation of effects of existing storage and potential impacts from the AWS Project and help assess the design and efficacy of tools (baseflows, refill rates, freshets etc.) designed to minimize existing effects and future impacts of additional water storage. The focus will be on side-channel connectivity, juvenile instream migration and adult use of habitat. Although the re-fill under the proposed project is primarily associated with water supply, monitoring under this element provides valuable information on impacts (and opportunities for adaptive management) associated with the existing project. The same allocation as described above is proposed for this element.

Side Channel Monitoring Pre- and Post-Construction. The objective of this component is to monitor Middle Green River side channel habitat under 1) Baseline (existing or pre-construction) side-channel habitat quantity and quality and rearing and movement of juvenile salmonids and AWS Project (post-construction) habitat and juvenile salmonid habitat use and 2) use this information to develop an adaptive storage and release program that minimizes impacts to side channel habitat and habitat use.

Beginning in 1998, the Corps and Tacoma are cost-sharing a three year pre-construction monitoring study of side-channel habitat quantity and quality and juvenile salmonid use of these habitats in the Middle Green River (and selected areas of the Upper Green). Year one, 1998, will include 1) semi-monthly surveys (electrofishing catch-per-unit effort; snorkeling) of juvenile salmonid habitat use during spring refill (late Feb-June) of side channel and mainstem margin habitat under day and night conditions and 2) response of juvenile salmonids to natural freshets and one artificial freshet (CPUE and fyke net of one side-channel) as part of 1998 refill. Year two will continue semi-monthly habitat use surveys and will include habitat quantity and quality surveys of most side channels in the Upper and Middle Green River.

In 1996, the Corps and Tacoma conducted a fall habitat survey of all side channels from the Tacoma Diversion Dam to RM 35. This survey provided an initial estimate of habitat quantity at low flow and following limited flooding of off-channel habitats in fall, this may not have been reflective of habitat quantity under spring refill following winter flooding of the majority of these off-channel areas. Work in Year two will replicate the fall 1996 study by inventory of side-channel habitat area in spring and will build on this with more intensive surveys of microhabitat features in selected side channels. In addition, stomach content analysis and benthic sampling (performed by U.S. Geological Survey) for invertebrate community composition and density will be performed. Year three, 2000, will include a third year of juvenile salmonid habitat use sampling. Pre-construction monitoring costs by year are -- year one cost $65,000, year two $80,000, and year three, $45,000.

Post-construction sampling of habitat quantity will be conducted in project years 1 and 4 and sampling of habitat use will be conducted in years 2 and 5. Post-construction study will replicate pre-construction sampling for habitat use and habitat quantity: estimated annual survey costs are $35,000 for habitat quantity and $50,000 for habitat use.

Instream Migration Pre- and Post-Construction. The objective of the monitoring component is to minimize the impact of AWS Project storage and release on the survival of emigrating (natural-reared and hatchery) juvenile salmon and steelhead.

The analysis of AWS Project effects on salmonid emigration through the Lower Watershed includes several untested assumptions – including whether artificial freshets are an appropriate mitigation tool. In order to minimize the risk of unforeseen project impacts, monitoring of juvenile salmonid instream migration through the lower river will be conducted pre- and post construction. This before and after AWS project monitoring will provide important feedback through an adaptive management process so storage and release regimes can be adjusted in response to observed results.

Beginning in 1999, the Corps and Tacoma are cost-sharing a two-year pre-construction monitoring study of the instream migration of juvenile salmonids in the Lower Watershed. The objective of this study is to document existing characteristics of juvenile instream migration – season and diel timing, response to environmental changes (flow, turbidity, day length, temperature), by species and life-stage – and observed responses during HHD refill and release. This Baseline monitoring will be evaluated and used to refine an adaptive refill and release schedule for the planned AWS Project. A floating trap (screw-trap) will be the primary method of sampling migrating fish. This trap will be located near RM 34 and will be operated from February through June. Sampling will be 5 days per week from dawn until dusk with one 24-hour sample period per week (randomly selected). Monitoring within each year will be adjusted to the planned refill strategy including study of natural and planned freshet releases.

After project construction, five years of instream monitoring will be conducted utilizing the screw-trap purchased during Baseline monitoring. Post-construction monitoring will be tied to the specific adaptive management objective of minimizing impacts of spring refill on juvenile outmigration (survival). To accomplish this, post-construction monitoring will continue to document instream migration characteristics, including potential changes to migration timing and species response if Lower Watershed fish management practices are changed in response to ESA listings and as Upper Watershed fish begin increasing in number. In addition, post-construction monitoring will refine the understanding of the migratory fish response to flow changes. The new Fish Passage Facility at HHD provides us the ability to sample fish migrating from the Upper Watershed. Fish sampled at the bypass outfall (RM 64.5) could be marked and recaptured at the Middle Green River trap (RM 35) providing a measure of instream survival of these marked fish. Alternatively, or in addition to marking at the FPF, a second screw-trap could be operated at some intermediate river location to provide shorter reach measurements: a second screw-trap is not included in the budget for the monitoring component.

Pre-construction monitoring and evaluation will occur in 1999 and 2000 at an annual cost of $103,000: year one cost includes purchase of one screw trap at $37,000. Post-construction monitoring will occur for project years 1 through 5 at an estimated annual cost of $90,000 using the screw-trap purchased during PED phase.

Spawning and Egg Incubation. The objective of this monitoring component is to avoid dewatering salmon redds and incubating eggs during late winter and early spring refill. Salmon redd surveys would be conducted during the fall and winter to identify off-channel and mainstem margin habitats that could be affected by earlier refill in late winter during Phase I. Redds would be monitored to incubation during refill. Water surface elevations necessary to maintain continuously wetted substrates will be assessed and used to refine baseflow targets used during refill. Post-construction monitoring and evaluation will occur in project years 1-3 at an estimated annual cost of $30,000.

10.C SYSTEM-WIDE ANALYSIS: ADULT FISH RETURNS TO THE UPPER GREEN RIVER

Monitoring of the number of returning adults and spawning in the Upper Watershed is a critical system-wide need. Although juvenile emigrant survive through the project will be monitored through item one (see Section 10.A), how well returning adults utilize the Upper Watershed and system wide impacts and variables related to overall adult returns will be assessed through this element. The proposed time frame is 5 years. Because the Corps and Tacoma as well as resource agencies will use this information, a cooperative cost sharing agreement is proposed. Additional monitoring of adult returns could also be conducted and funded as part of state, tribal and City of Tacoma activities. Assuming such a basin wide program would cost $195,000 and the cost the Corps is funding reflects approximately 1/3 ($65,000) of that total cost, participating agencies and the sponsor would cover 2/3 of the cost ($130,000). Under this agreement the Corps could fund 33 1/3% of the total 5-year cost, and the resource agencies in combination with the non-federal sponsor could fund 67%. (33 1/3% each). The mechanism to gain agency participation is unknown at this time, but would be pursued during Plans and Specifications state (PED – 1999-2000).

Coded-wire Tagging. Under the basin-wide analysis, five years of coded-wire-tagging (CWT) of up to 500,000 chinook salmon fry reared in the Fish Restoration Facility and planted in the Upper Watershed will be covered under the restoration monitoring program. Evaluation of the adult returns of the CWT juveniles and tagging of other species would be considered the responsibility of the WDFW and/or the Muckleshoot Indian Tribe: state policy and legislation directs that all future hatchery releases include CWT of planted fish. The CWT of chinook salmon fry parallels adult return studies conducted by the USFWS and Muckleshoot Tribe during the feasibility study. Longer term monitoring of this element, at least up to 10 years, may be desirable, however, no costs have been identified beyond the five-year period, and at this time, the Corps does not expect to participate beyond the 5-year period. Annual costs for tag purchase and tagging of fish are expected to average $50,000 and do not include evaluation and reporting of adult returns.

Upper Watershed Spawner Surveys. In addition to CWT of chinook fry, 5 years of spawner surveys in selected areas of the Upper Watershed and/or below the Tacoma Diversion Dam would be funded under this monitoring item. Currently, the WDFW and Muckleshoot Tribe have conducted limited spawner surveys in the Upper Watershed for steelhead and in 1997, conducted their first intensive salmon spawner surveys below the Tacoma Diversion Dam. Under this monitoring item, either Corps and Tacoma personnel will conduct additional steelhead and salmon spawner surveys (beyond current surveys) in selected areas of the Upper Watershed or will fund WDFW and/or Muckleshoot biologists to conduct these surveys. Annual funding for this item is $15,000 for 5 years.

10.D FISH HABITAT RESTORATION PROJECTS: RESTORATION OF MIDDLE, UPPER, AND HEADWATERS GREEN RIVER HABITAT

This element is for monitoring the side-channel, gravel nourishment and instream restoration projects. Monitoring would take place at years 1, 2, 5 and 10. The proposed cost share is 65% federal, 35% non-federal; like typical restoration projects pursued under the G.I. authority. Pre-project monitoring will include survey of the project areas to determine scope and design layout including cross-sections of channel areas and topographic mapping of excavated areas.

Middle Green River Gravel Nourishment. Pre and post-project monitoring will include monitoring of the distribution and quality of gravels in the Middle Green River. Pre-construction surveys will include evaluation of aerial photographs and river cross-sections at points upstream and downstream of the proposed nourishment area. Post-construction will include re-survey of cross-sections and aerials and evaluation of water surface elevations in downstream flood protection areas. Cost-shared surveys would occur project years 1, 2, 5, 10, and 15; after year 15 costs become a fully funded O&M requirement.

Upper Green River Side Channel Improvement and Headwaters Channel Improvement. Surveys of habitat quality and habitat use will occur pre- and post-construction. Standard stream survey techniques will be used. Surveys will occur prior to construction and in project years 3 and 4; post-construction survey is estimated to cost $35,000 per year. In addition to the evaluation of the use of the habitat restoration projects, periodic intensive inspections of how well the projects are functioning (example: is large wood still in place or washed out) will occur in years 1, 2, 5, 10 and 15 at an estimated annual cost of $7500. Annual spot inspections of structures will occur as an O&M item.

10.E FISH HABITAT MITIGATION PROJECTS: MITIGATION FOR TRIBUTARY AND RIPARIAN HABITAT INUNDATED BY THE PHASE I POOL

This element is for impacts associated with the larger reservoir for water supply, and since it is a mitigation element, the non-federal sponsor would be expected to pay 100%.

Instream Habitat Projects. Surveys of habitat quality and habitat use will occur pre- and post-construction. Standard stream survey techniques will be used. Surveys will occur prior to construction and in project years 3 and 4; post-construction survey is estimated to cost $35,000 per year. In addition to the evaluation of the use of the habitat mitigation projects, periodic intensive inspections of how well the projects are functioning (example: is large wood still in place or washed out) will occur in years 2, 5, 10 and 15 at an estimated cost of $7500. Annual spot inspections of structures will occur as an O&M item.

Riparian Habitat Projects. Periodic inspections of how well the reservoir and above-reservoir riparian plantings and thinning projects are functioning will occur in years 1,2, 5, 10 and 15 at an estimated cost of $7500.

10.F WILDLIFE HABITAT MITIGATION: MITIGATION FOR WILDLIFE AND FOREST/SEDGE HABITAT INUNDATED BY THE PHASE I POOL

This element is also mitigation for the increased pool, and the sponsor would be expected to pay 100% of the costs. Monitoring would also take place during project years 1, 2, 5, and 10.

A detailed discussion of wildlife mitigation monitoring is found in *Section V, OPERATION AND MAINTENANCE AND MONITORING PLAN, Appendix F2, Wildlife*. To summarize that discussion, we expect to monitor wildlife use of the sites, and plant survival, in years 2, 5, and 10 following planting of vegetation. Per EC 1105-2-100, paragraph 21.b (3), the primary goal is to assess whether elk use of pastures is sufficient to justify continuing O&M of the pasture(s), or perhaps that different management could lead to greater use of pastures. The goal of monitoring the sedge meadows and wetlands is to assure maximum survival of plants. If it is found that some areas will not support plants, those areas will be avoided, and other areas, where plants are found to be robust, will be planted with replacement plants. These monitoring efforts would require studies of plant growth, density, and nutritional content; and of actual elk usage of the sites (a resumption of the elk exclusion cage study, Section VI of Appendix F2 would be conducted), and of elk pellet composition. In addition, nest boxes and wetlands would be monitored for actual wildlife usage during years 2, 5, and 10. It is anticipated that the local sponsor would pay 100% of these wildlife monitoring costs, and that the costs would be funded through the O&M account.

10.G LITERATURE CITED

Achord, S., G.M. Matthews, O.W. Johnson, D.M. Marsh. 1996. Use of passive integrated transponder (PIT) tags to monitor migration timing of Snake River chinook salmon smolts. North American Journal of Fisheries Management 16:302-313.

Aitkin, J.K, C.K. Cook-Tabor, and R.C. Wunderlich. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S. and R. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Dam and Reservoir, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Dilley, S.J. 1994. Horizontal and vertical distribution of juvenile salmonids in Howard Hanson Reservoir. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Newman, K. 1995. Survival information provided by combined PIT-CWT tagging. Bonneville Power Administration Division of Fish and Wildlife Report, Proj. No. 91-051 Contract DE-AI179-87BP35885.

Peterson, E.F. Prentice, and T.P. Quinn. 1994. Comparison of sequential coded wire and passive integrated transponder tags for assessing overwinter growth and survival of coho salmon. North American Journal of Fisheries Management 14:870-873.

Prentice, E.F., T.A. Flagg, C.S. McCutcheon, and D.F. Brastow. 1990. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Smith, H.A. 1993. Development of a fish passage solution at the Puntledge Hydro intake facility. Pages 197-204 in K. Bates, editor. Fish Passage Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.

Taft, E.P., S.V. Amaral, F.C. Winchell, C.W. Sullivan. 1993. Biological evaluation of a new modular fish diversion screen. Pages 177-188 in K. Bates, editor. Fish Passage

Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.

Winchell, F., N. Taft, and T. Cook. 1993. EPRI's evaluation of the Elwha Dam Eicher Screen and subsequent design changes and hydraulic tests. Pages 189-196 in K. Bates, editor. Fish Passage Policy and Technology: Proceedings of a Symposium. Bioengineering Section, American Fisheries Society, Portland, Oregon.