Mainstem Passage Strategies In the Columbia River System: Transportation, Spill, and Flow Augmentation

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January 31, 2002

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LIST OF ABBREVIATIONS

BO	Biological Opinion
BON	Bonneville Dam
BPA	Bonneville Power Administration
CBFWA	Columbia Basin Fish and Wildlife Authority
COE	Army Corps of Engineers
COLTEMP	COE temperature model
CRiSP	Columbia River Smolt Passage Model
CWT	Coded wire tag
D	Differential Delayed Effects associated with transporting smolts
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
F	Fahrenheit
FA	Flow Augmentation
FCRPS	Federal Columbia River Power System
FGE	Fish Guidance Efficiency
FPC	Fish Passage Center
GBT	Gas Bubble Trauma
HEC-2	Hydraulic Model
IH	Ice Harbor Dam
ISG	Independent Science Group
JD	John Day Dam
kcfs	Kilo-cubic feet per second
LGO	Little Goose Dam
LGR	Lower Granite Dam
LMO	Lower Monumental Dam
Maf	Million acre feet
MCN	McNary Dam
NMFS	National Marine Fisheries Service
NPPC	Northwest Power Planning Council
PATH	Plan for Analyzing and Testing Hypotheses
PIT tag	Passive Integrated Transponder Tag
PRD	Priest Rapids Dam
RIS	Rock Island Dam
RRH	Rocky Reach Dam
SAR	Smolt-to-Adult Return Rate (%)
SIMPAS	NMFS Simulated Passage Model
SOR	System Operation Review
TDA	The Dalles Dam
TDG	Total Dissolved Gas
TIR	Transport Inriver Ratio
Vc	Inriver Migrant Survival
WAN	Wanapum Dam
WE	Wells Dam

EXECUTIVE SUMMARY

The National Marine Fisheries Service 2000 Biological Opinion (BO) for the Federal Columbia River Power System (FCRPS) prescribes guidelines for smolt transportation, spill and flow augmentation to improve survival of salmonid stocks listed under the ESA (Appendix A). With respect to these strategies the NPPC is concerned about the following issues:

1. What does the scientific literature inform us regarding the benefits, shortcomings, or risks associated with each passage strategy, and as compared to other passage options?
2. Which aspects of the scientific information are in dispute?
3. What are the critical uncertainties attending each strategy?
4. What is being, or could be done to reduce uncertainty and disputes?

In terms of scope, the NPPC seeks information for both ESA-listed and unlisted salmonid populations across a range of water years. The Council seeks clear, concise and succinct treatment of these issues. Our approach is to review key research and analyses that have appeared in the literature, then distill out the key findings and synthesize the results. The focus is on evaluations conducted under contemporary river operations, which were initiated in the early 1990s and formalized as guidelines in the 1995 and 2000 Federal Columbia River Power System Biological Opinions. Additionally, we identify key uncertainties and gaps in the information base, and identify research that is in place or planned to fill those gaps.

Smolt Transportation

Using general, annual indices of performance, both NMFS and CBFWA analyses showed that the majority of the time, fish transported from Lower Granite and Little Goose dams produced TIRs higher than or equal to corresponding inriver control groups. Bouwes et al. (2001) concluded modest transportation benefits were evident for hatchery chinook, and slight to negligible benefits for wild fish. Sandford and Smith (in press) state that, “once a juvenile fish is entrained in a bypass system at a “collector dam”, transporting the fish maximizes the probability of its eventual return as an adult.” Based on assessments by those two investigations, it appears that there is a survival advantage associated with transporting Snake River hatchery spring/summer chinook and steelhead, particularly from the upper two dams, Lower Granite and Little Goose dams. However, the rationale for transporting smolts from Lower Monumental and McNary dams is less clear. The benefits of transporting Snake River hatchery fish from those dams are equivocal.

In some years, small sample sizes have resulted in poor or undefined precision for key estimates. This can limit the ability to make statistically defensible conclusions. Authors examining recent estimates do not confidently state that transported fish survive at significantly higher rates than inriver counterparts. Neither Sandford and Smith (in press), nor Bouwes et al. (2001) explicitly tested key hypotheses such as; $D > V_c$, or $TIR > 1.0$. Presumably future analyses by these two research groups will do so. In recent times the resurgence in adult returns offers improved precision and opportunities for meaningful statistical tests

Whether or not wild fish respond favorably to transportation is difficult to ascertain at this juncture. Even though the limited numbers` of evaluations indicate higher return rates for transported smolts, the estimates are based on such small sample sizes that the precision for wild fish is particularly poor. Thus, reliance on the point estimate as a representative value is questionable.

Survival from smolt to returning adult (SAR) for hatchery and wild spring summer chinook has increased substantially since 1993, and has been increasing steadily from 1997-1999, reaching SAR levels in 1999 that approach and in some cases exceed the 2% minimum recovery threshold for wild stocks as identified in PATH (Figures 1.5 and 1.6). This suggests that neither transport nor inriver migration conditions may be a bottleneck to recovery, when marine-based survival is at some adequate level.

No mass transportation study has been conducted that targets Snake River fall chinook. Such evaluations are warranted, and planned for initiation in 2002

There is evidence to suggest that homing fidelity may be impaired for some species of transported fish, including fall chinook, sockeye, and steelhead. Studies that target spring/summer chinook and steelhead require emphasis. Straying may in part contribute to delayed effects associated with transporting smolts. It may be advantageous to ascertain the extent of straying associated with transport of all species to address certain ESA concerns. Excessive straying may result in increased hatchery fish intermingling among wild adults on the spawning grounds. This may not be desirable. Ongoing telemetry/PIT tag-based studies of adult passage should offer additional insight on this matter.

Delayed differential effects relative to inriver migrants are consistently evident for transported fish. However, by-and-large adult return rates to Lower Granite Dam exceed those of inriver migrants designated as controls. In such cases, there would still be a survival advantage to transport Snake River fish from Lower Granite and likely Little Goose dams.

Spill

Apart from the Snake River stocks, which can largely be transported, the majority of smolts emanating from the rest of the basin continue to migrate in-river to below Bonneville Dam. Optimizing smolt survival during downstream migration has been a longstanding goal of fisheries managers.

We focus on contemporary passage survival estimates and estimation techniques (balloon-, radio-, and PIT-tag methods) developed during the 1990's that continue to be applied this decade.

The collective information indicates that spillways appear to be the safest passage routes available at dams, even more benign than many smolt bypass systems, particularly those involving the screening of turbine intakes. The magnitude of smolt survival through spillways varies across dams and species. This is particularly evident when total effects are reflected in the

empirically obtained estimates. This suggests that species- and dam-specific estimates should be updated for each dam and applied in any future passage modeling analyses.
Spillway flow deflectors (gas abatement devices) appear to increase smolt mortality relative to a standard spillbay, by 1-3 percentage points. Even so, survival will typically still exceed the turbine route at most dams. The potential for increased smolt losses at the concrete needs to be balanced against gains associated with gas abatement. It is not clear that passage models currently provide an accurate assessment of this tradeoff.

Studies assessing the direct and total effects associated with spillway passage indicate that survival is related to discharge at some sites, with mortality increasing at excessive discharge volumes. The difference in survival across discharges can range from negligible to nearly 7 percentage points, depending on the dam and species.

In passage modeling analyses, values for model parameters should be periodically updated for each dam and species. The set of empirical estimates that characterize smolt passage survival through spillways, as well as spill efficiency, are being continually expanded. However, that collective information is not being systematically compiled and synthesized on a regular basis for the hydrosystem at large. Notable exceptions include papers by Muir et al. (2001a), Ploskey et al. (2001) and Anglea et al. (2001) for selected sites.

Passage modeling may afford the only practical means to evaluate the relative benefits of various spill scenarios, at the level of the overall smolt population. The other approach requires obtaining reliable empirical survival estimates linked specifically to spill conditions. This requires a well-designed experimental protocol that will likely be very difficult to implement in this complex system of competing uses

The NMFS Total Dissolved Gas standard of a maximum 120% saturation in the tailrace of Columbia River dams is generally achievable by following the dam-specific gas caps identified in the Biological Opinion, and implementing the spill program currently in place in the Mid-Columbia. The exception occurs in higher flow years when spill volumes cannot be effectively controlled due to flows exceeding the hydraulic capacities at the various dams. The standard appears satisfactory for protecting salmonid species within the hydro-system, but it exceeds water quality guidelines established by the Environmental Protection Agency.

The full biological impacts of a spill program have not been evaluated in their entirety. Smolt survival receives emphasis. Model analyses try to predict changes in smolt survival to below Bonneville Dam. Quantitative system analyses have not formally addressed the potential for impacts on adult mortality. Empirical evaluations conducted in situ, have limitations as well. For example those recently conducted by Zabel et al. (in press) and FPC (2001) observed changes over small segments (projects), thus cumulative effects through the system are not evident. Furthermore, results from empirical evaluations are equivocal, because spill effects have not been clearly isolated from other factors.

The effects of spill operations and levels on adult passage behavior as linked to long-term survival are not well understood. Some of the recent adult passage research suggests that higher spill volumes may exacerbate migration delay and fallback. But, convincing quantitative relationships have not been developed. Adult passage studies are continuing and may provide insight on these matters.

Flow Augmentation

Flow augmentation (FA) is the intentional release of water from storage reservoirs for the purpose of increasing flows to enhance migratory conditions for juvenile and adult life stages of salmonids in the Snake and Columbia rivers. Flow augmentation provided to the upper Columbia River (downstream from Chief Joseph Dam) comes from large storage reservoirs such as Grand Coulee Dam and a complex of storage reservoirs that drain into it from Canada and Montana. In the Snake River flow augmentation is provided from Dworshak Dam and through the Hells Canyon Complex in Idaho (Figure 3.1). The foundation for prescribing such actions is based on two premises:

1. Increased water velocity → increases migration speed of smolts → increases survival.
2. Lowering water temperature (summer) → improves migratory and rearing conditions for both juvenile and adult salmonids → results in improved survival.

Information obtained or reported since the early 1990's is the focus of this report, but a brief historical backdrop is provided where needed. Both river operations and the mark-recapture tools and associated analytical procedures have changed markedly from previous decades. Thus, the contemporary information is most applicable today.

Flow effects on smolt migration speed: For most spring-migrating species the evidence indicates that increased flow (water velocity) contributes to swifter migration speed. Information regarding fall chinook is equivocal.

- River discharge appears to be the most influential variable affecting migration speed of steelhead and sockeye salmon in the Snake and mid-Columbia rivers.
- Two factors, flow and the degree of smolt physiological development, explain the observed variation in the migration rate of yearling chinook salmon (except in the mid-Columbia where only smolt development has been identified as a predictor variable).
- At least four variables have been implicated as influencing the migration speed of sub-yearling (fall or summer/fall) chinook; flow, water temperature, turbidity and fish size. However, strong correlations among these predictor variables confound the ability to identify causative agents.

Flow effects on smolt survival: PIT tag based smolt survival estimates acquired since 1993 provide the most relevant data set for characterizing smolt survival dynamics through the impounded mainstem Snake and Columbia rivers.

- Based on recent PIT tagged based estimates there is little evidence supporting a flow survival relationship across the water years experienced from 1993-2000, for yearling chinook or steelhead.
- However, in 2001 under the extreme low flow conditions, steelhead survival decreased dramatically to about 63% per project (typically it is near 90%). Slow migration speed

and rapidly increasing water temperatures are implicated as causative factors affecting residualization and mortality.

- A complex of factors is implicated as influencing Snake River fall chinook survival including, flow, water temperature and turbidity. These environmental variables are strongly correlated during the summer migration, confounding the ability to identify the most influential one. Knowing if water velocity or temperature is the most influential could be important when the decision is to use Dworshak or Hell's Canyon for flow augmentation, since the temperature of those water sources differs greatly.

The premise for reducing summer water temperature, particularly in the Snake River, to improve rearing and migratory conditions for juvenile fall chinook and adult salmonids appears sound.

- The literature indicates that maintaining river temperatures at or below 20°C is advantageous to both life stages of fall chinook, and adult steelhead, all of which are in the river in August and early September.

However, it is not clear that releasing cool water from Dworshak effectively alters the thermal structure of most of the Lower Snake River. The major effect is localized at two upper reservoirs (LGR, LGO) according to results reported by Bennett et al. (1997).

- When cool water enters the reservoirs it sinks to the bottom. This can provide cool refugia in deeper waters, but not uniform cooling of reservoirs.
- The greatest change in temperature attributable to FA releases from Dworshak are evident at LGR, where water temperatures under FA are predicted to be as much as 4-8 °F below base conditions at certain times. At Ice Harbor the difference is on the order of 1-2 °F.

Flow Augmentation Evaluations are generally lacking. Only a handful of studies have attempted to:

- Quantify the volume and shape of water provided specifically as FA.
- Translate that incremental increase in flows to changes in water velocity and temperature.
- Predict the change in smolt travel time and survival attributable to those increases
- Identify whether populations of interest (e.g. ESA stocks) have encountered FA events.

The last such evaluation treated information through the 1995 water year, and only for the Snake River. Given the community's sensitivity to this controversial management action, a holistic comprehensive updated evaluation seems prudent, and long overdue. The scope of future evaluations need to more fully address the balance of benefits and risks between anadromous and resident fish resources.

INTRODUCTION

This issue paper was prepared at the request of the Northwest Power Planning Council (NPPC). It is meant to assist their understanding the state of the scientific information pertaining to three smolt passage strategies employed in the mainstem Columbia River System. Those strategies of particular interest to the NPPC include the use of transportation, spill, and flow augmentation as means to improve smolt survival. We have organized this paper to treat each strategy separately.

The National Marine Fisheries Service 2000 Biological Opinion (BO) for the Federal Columbia River Power System (FCRPS) prescribes guidelines for using each of these strategies (Appendix A). With respect to these strategies the NPPC wants the following issues addressed:

1. What does the scientific literature inform us regarding the benefits, shortcomings, or risks associated with each passage strategy, and as compared to other passage options?
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1.0 TRANSPORTATION

Three dams in the lower Snake River, Lower Granite (LGR), Little Goose (LGO), and Lower Monumental (LMO), and McNary (MCN) on the Columbia River are equipped with screened bypass systems that permit the interception, collection and transport of migrating smolts (Figure 1.1).

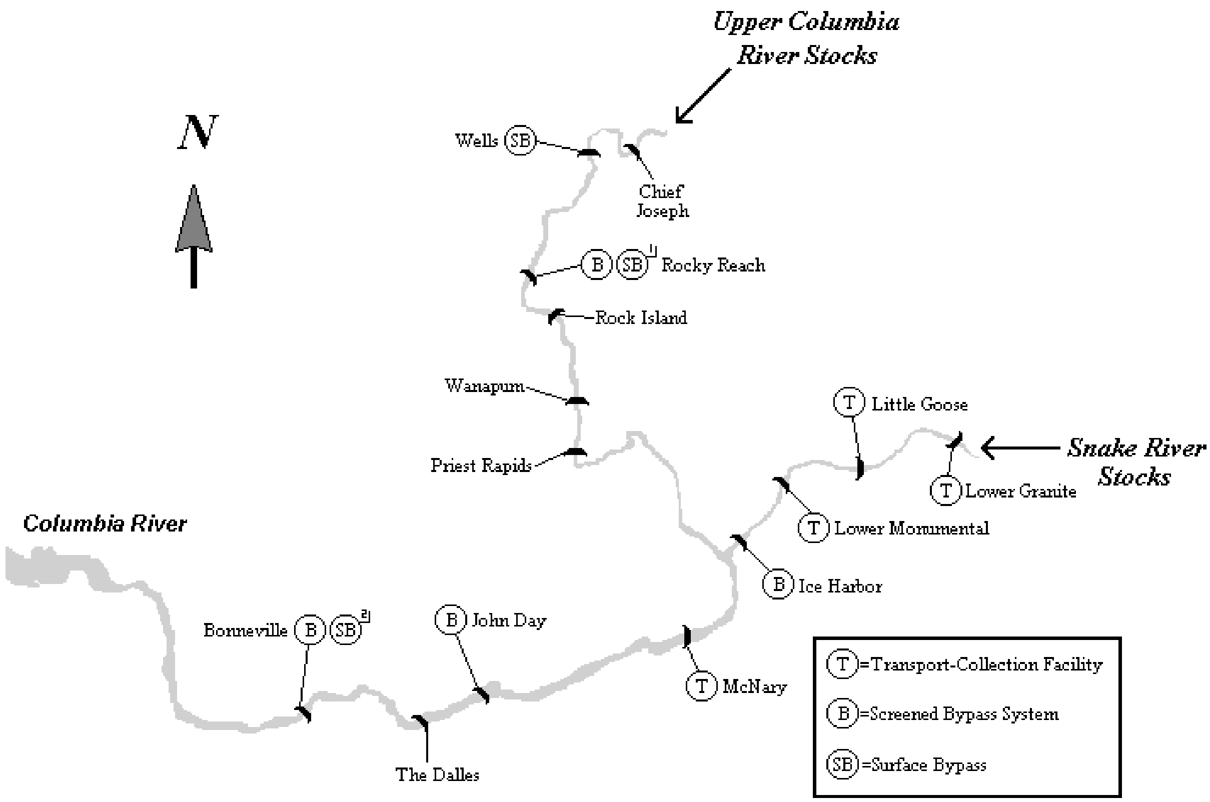

Figure 1.1—Location of collection-transport facilities (T), screened-bypass systems (B), and surface flow bypass systems (SB) on the Columbia and Snake rivers. Transport-collection facilities can be operated in bypass mode. Transport facilities can also be operated in a bypass mode. Surface bypass systems are to be installed at Rocky Reach[1] and Bonneville[2] dams in 2002 and functional in 2003.

These dams have facilities for holding, and loading large numbers of smolts (up to several hundred thousand per day) onto barges or trucks. Transported smolts are then taken to release sites downstream from Bonneville Dam (BON), where they are liberated. Barging is the preferred conveyance, and is typically employed. Trucks are rarely used, typically only when fish numbers are so few that barging becomes impractical. By virtue of the location of these facilities Snake River salmonid stocks are the principal populations subject to transport. Upper Columbia River stocks encounter only one collector dam, McNary Dam, which under current management operations, de-emphasizes transport in favor of spill as a passage option. Specifics regarding operations and time frames for transport, spill and flow management can be viewed in the Annual Fish Passage Plan compiled by the COE, and in the 2000 NMFS BO (NMFS 2000a, see excerpts Appendix A in this report). Most transport evaluations that involve survival estimation have focused on Snake River stocks, since transport targets them.

Even before all the dams were completed on the lower Snake River, the collection and transportation of smolts was being considered as a passage strategy to maximize smolt survival. Studies were first initiated in the late 1960s and were staged at Ice Harbor, Little Goose and Lower Granite dams as they were constructed (Park 1993). With the development of screened diversion systems that diverted smolts from turbines, a dilemma arose regarding their fate. Should they be collected and transported around all dams to below Bonneville Dam, or should they be bypassed and returned to the tailrace to continue migration downstream? The primary goal of transportation research was to assess whether the collection and transport of smolts from Snake River dams yielded higher survival to returning adult than permitting smolts to migrate inriver.

After three decades of transportation evaluations, disputes regarding the efficacy of transportation persisted among fisheries managers. The proponents of transportation argued that in the majority of years the survival through to returning adults was higher for transported smolts than for fish migrating inriver. The critics of transportation argued that the estimates were not robust and may be biased, and that the absolute survival rates were far too low to consider transport an appropriate passage strategy. That dispute continued in the 1990s, when armed with a new tool (PIT tag), a new era of evaluation emerged. That new era is the focus of this paper.

The transportation debate has focused on Snake River populations, because they encounter a series of collector dams that can accommodate transportation. Nevertheless, a limited number of studies have been conducted at McNary Dam in the 1980s (Park 1993), and at Priest Rapids Dam from 1984-1988 using sockeye salmon (Chapman et al. 1997).

In the 2000 BO, NMFS provided estimates of the percentage of the Snake River populations that were transported during the years 1994-1999 (Table 1.1). The estimates are for the population-at-large, a mixture of hatchery and wild fish. Assuming that fish guidance efficiency (FGE) is relatively stable among years, fluctuations in annual percentages are attributable to variation in spill provided annually at the collector dams. High spill levels shunt more fish away from the powerhouse, where the screened collection/bypass system is situated. Averaged over six years, 72-77% of the Snake River spring/summer chinook salmon and steelhead in the Snake River were collected and transported to below Bonneville Dam (Table 1.1). Over a 5-year period, approximately 48% of the juvenile fall chinook salmon were collected and transported to below Bonneville Dam.

Table 1.1—Proportion of juvenile Snake River spring/summer and fall chinook salmon and steelhead outmigrants collected from LGR, LGO, and LMO transported below BON during the period 1994-1999 (Data from 2000 NMFS BO).

	Proportion ESU Transported		
	Chinook Salmon		
Year	**Spring/Summer**	**Fall Chinook**	**Steelhead**
1994	89.2	---	89.0
1995	64.0	59.6	71.4
1996	70.9	42.4	74.8
1997	65.5	26.5	78.5
1998	72.0	48.1	75.0
1999	72.2	61.8	73.1
5-Year Average	---	**47.7**	---
6-Year Average	**72.3**	---	**77.0**

1.1 Survival Evaluation

The most direct means to determine if transporting smolts improves survival over inriver migration is to compare the survival rates of fish subjected to each passage option. NMFS has been conducting such evaluations since the 1970s. Reviews of historical estimates are provided in the NMFS White Paper that treats smolt transportation (NMFS 2000b). Herein, we do not revisit the dated historical evaluations, but concentrate on investigations and analyses conducted during the most recent decade. These evaluations are most instructive because they reflect smolt exposure to contemporary operating conditions, and include upgraded state-of the-art collection facilities, and the use of PIT tags to provide survival estimates.

Over the last decade the PIT tag has emerged as the preferred marking tool for use in transportation evaluations. Juveniles are implanted with the tag, which they retain through adulthood. In the Snake and Columbia rivers, Lower Granite Dam is currently the only site where returning adult salmonids can be interrogated for the presence of PIT tags, and as such is the only terminal sampling facility. The development of the contemporary PIT tag detection and diversion systems have enabled new and improved analytical capabilities.

Prior to 1993, inriver reference (control) groups did not reflect the actual known fate of marked control groups that were released to continue their migration inriver. The contemporary PIT system changed that and produced more complete capture history information for downstream migrants. As a consequence, a variety of reference (control) groups can be constructed from the population of inriver migrants. This capability rectifies a long-standing concern that controls designated in previous evaluations were not entirely satisfactory, in that their actual capture history subsequent to leaving Lower Granite tailrace was unknown (Mundy et al. 1994, Ward et al. 1997). A chief concern was that some unknown fraction of the freeze-branded fish released to the river was subsequently transported at downstream sites.

In recent years, two research groups have been estimating smolt-to-adult return rates (SARs) and conducting smolt transportation evaluations. Investigators with NMFS (Harmon et al. 2000; Marsh et al. 1997, 2000; NMFS 2000b; Sandford and Smith in press), and investigators affiliated with the Columbia Basin Fish and Wildlife Authority (CBFWA) have conducted the majority of this research (Bouwes et al. 2001). Collectively, these investigations represent the best current evaluation of actual contemporary mass transport operations, since the experimental fish are commingled with the general population in production barges, in accordance with normally scheduled operations. Furthermore, the transport period for experimental groups spans the natural migration period when the bulk of downstream migrants are transported.

It is commonly held that implementing the river operations (spill, flow augmentation, etc.) specified in the BO, in conjunction with the predatory fish removal program, should substantially improve smolt survival through the impounded mainstem river. This in turn ensures that inriver migrants used in contemporary transport studies represent the best inriver survival that can be realized. Thus, a representative control (reference) group can be used for comparison with transported fish. There was concern in the previous era that this was not always the case (Mundy et al. 1994, Ward et al. 1997). Below we define four central estimates that emerge in most transport evaluations.

Smolt-to-Adult Return Rates (SAR)--In transportation studies, the foundation estimate is the smolt-to-adult return rate (expressed as a %). Its calculation requires counting or estimating the number of smolts comprising an experimental group of interest at a specific reference location. Today these fish are typically PIT tagged. The next step is to count or estimate the number of adults returning to an established sampling or reference location, from that same group. For any experimental group (e.g. transported or migrating inriver) the SAR is calculated as the proportion (%) of the number of smolts to the number that return as adults for any tagged group:

SAR = (number of returning adults)/ (number of smolts)

Transport to Inriver Ratio, (TIR)--For transport evaluations, SARs for a group transported as smolts are compared to a reference, or control group that migrated inriver downstream through the hydrosystem. The comparison is usually expressed as a ratio that is referred to by various synonymous terms including, transport/control ratio (T/C), transport benefit ratio (TBR), or transport to inriver ratio (TIR, or T/I). The magnitude of TIR is an index of the effectiveness of transporting fish as follows:

- **TIR > 1.0**-- Indicates that transported fish survive to returning adult at rates exceeding inriver controls.
- **TIR < 1.0**--Indicates that inriver fish survive to returning adult at higher rates than those transported.

For any experimental group (e.g., transported at LGR, or all transported fish) the TIR is calculated as the ratio of SAR of transported smolts to the SAR of the control group:

TIR = (SAR of transported fish)/ (SAR of inriver migrants)

Inriver Migrant Survival, (Vc)--Vc is defined as the estimated survival rate of smolts migrating inriver from point of release of controls to just downstream of Bonneville Dam. The magnitude for Vc has been estimated by using either passage models (e.g., SIMPAS), or extrapolating empirical reach-specific survival estimates.

Delayed Differential Effects, (D)--The parameter referred to as "D" represents the delayed differential effects associated with transporting smolts. It surfaced as part of the salmon modeling efforts conducted during the Plan for Analyzing and Testing Hypotheses (PATH). It is a means to express and quantify any delayed effects (usually presumed to be mortality) that accompany transported smolts relative to counterparts migrating inriver. The magnitude of D provides information that can be considered when selecting between transport or inriver migration as the preferred management strategy, but it is most useful for application in lifecycle model analyses.

- **D >1.0**--No differential delayed effects are indicated for transported fish, the survival to returning adult for transported fish exceeds that of inriver migrants.
- **1.0> D >Vc**--Delayed effects relative to inriver migrants are indicated and attributable to transport, but the survival of transported fish (through return as adults) still exceeds that of inriver migrants.
- **D < Vc**--Delayed effects associated with transport are severe and inriver migrants survive at overall higher rates than transported fish.

D can be calculated using empirical TIR estimates and independent estimates of smolt survival inriver (Vc), as described by Peters et al. (1999):

$$\boldsymbol{D = (TIR)\ (Vc)}$$

1.2 Recent Estimates

Typically, NMFS has estimated SARs for two different classes of tagged fish; those intercepted and tagged at dams, and those that were tagged prior to migration. The standard NMFS experimental protocol involved intercepting and PIT tagging smolts guided into the bypass system at Lower Granite Dam. One experimental group is then transported via barge from that site, while a corresponding reference group is released into the tailrace to migrate downstream. This process is repeated throughout the smolt migration period. At subsequent collector/transport dams some fraction of the reference group is removed and transported. PIT detectors document these removals. Some fraction of the tagged inriver reference group continues the migration downstream past Bonneville Dam. During their journey, fish can pass through turbines, spillways, sluiceways, screened bypass systems, or be diverted back to the river from collection systems at collector dams. These fish are the basis for designating various reference (control) groups of interest.

NMFS has also estimated SARs using fish tagged and released upstream from Lower Granite Dam (Sandford and Smith in press). Those authors recently updated and compiled SAR lgr-lgr (smolts at Lower Granite and adults back to Lower Granite Dam) estimates for the years 1993 through 1997 (the last year for which they had complete adult return data) for both fish tagged upstream from and at Lower Granite Dam. These estimates are considered the most reliable and should supersede any previously published estimates for those years (Gene Matthews, personal communication). SARs were estimated for several groupings of transported and inriver fish, as were ratios of the SARs (i.e. TIR, although the authors do not use the term). In this report we present their estimates for the group of fish transported from Lower Granite and Little Goose dams combined, because those dams extract the vast majority of the smolts for transport. Control fish presented herein as designated by Sandford and Smith (in press) are those that were never detected at any collector dam (including McNary Dam) below the site of release. The undetected control groups have gained favor as the most representative of the general untagged population of smolts (Sandford and Smith in press, Bouwes et al. 2001). They reported estimates for both the composite hatchery and wild populations.

Sandford and Smith (in press) reported transport control ratios, but did not refer to them specifically as such. In conversations, the authors noted that their paper did not mean to, nor did it, constitute a comprehensive transport analysis, but such an effort is forthcoming. This may explain why no statistical comparisons or hypotheses have been formally treated as yet. Herein we refer to their calculated ratios as TIRs, because they are equivalent.

The CBFWA investigators (Bouwes et al. 2001) relied solely on fish tagged upstream from Lower Granite Dam for their analyses. In fact, since 1997 they have intentionally PIT tagged and released several hundred thousand spring and summer chinook at hatcheries upstream from Lower Granite Dam in an attempt to ensure ample sample sizes. Under this protocol the history of fish tagged at each hatchery is tracked as they migrate seaward. Their transport and inriver fates are documented as they move downstream through the complex of PIT detectors. Bouwes et al. (2001) also tracked the passage history for wild spring and summer chinook tagged upstream from Lower Granite Dam. They produced SAR estimates for the different passage fates, which were used to calculate TIR. We focus on the group they documented as transported from Lower Granite Dam, and their designated undetected controls. These estimates are most similar to those reported in Sandford and Smith (in press) and provide a common currency for making comparisons between the studies. For the same reason we present their SAR lgr-lgr estimates, but not their SAR bon-lgr estimates.

Table 1.2—Percent smolt-to-adult returns (SAR) for transported (TR) and inriver (IR) migrant wild and hatchery chinook salmon and steelhead smolts PIT tagged and released at or upstream from Lower Granite Dam (LGR) and detected at LGR as adult (from Sandford and Smith, In press). Non-detected PIT tagged inriver fish are those smolts that were not detected at any collection facility downstream from LGR. We apply the term TIR to the ratios reported by the authors. Confidence intervals (95% CI) are for TIR estimates. Numbers of returning adults (n) for SAR estimates are in parenthesis.

	Chinook							**Steelhead**						
Migration	**SAR (%)**					**95 %CI**		**SAR (%)**					**95% CI**	
Year	**TR**	**(n)**	**IR**	**(n)**	**TIR**	**Lower**	**Upper**	**TR**	**(n)**	**IR**	**(n)**	**TIR**	**Lower**	**Upper**
							Wild							
1993	0.10	(3)	0.00	(0)	NA	NA	NA	0.18	(2)	0.00	(0)	NA	NA	NA
1994	0.68	(13)	0.26	(6)	**2.58**	1.38	7.18	1.09	(9)	1.05	(6)	**1.04**	0.39	4.19
1995	0.37	(9)	0.47	(9)	**0.79**	0.44	1.50	0.00	(0)	0.00	(0)	NA	NA	NA
1995*	0.38	(100)	0.22	(34)	**1.72**	1.05	2.85	-		-		-	-	-
1996	0.48	(2)	0.20	(4)	**2.43**	0.00	13.91	1.23	(2)	0.35	(2)	3.51	0.00	Inf
1996*	0.11	(9)	0.08	(3)	**1.42**	0.47	5.56	-		-		-	-	-
1997	1.61	(4)	1.63	(14)	**0.98**	0.15	2.50	0.98	(3)	0.43	(2)	2.27	0.00	Inf
							Hatchery							
1993	0.07	(4)	0.06	(2)	1.08	0.42	Inf	0.11	(3)	0.35	(2)	0.30	0.04	Inf
1994	0.09	(3)	0.09	(7)	**1.00**	0.31	2.54	0.54	(22)	0.10	(7)	**5.40**	3.26	12.12
1995	0.77	(26)	0.45	(27)	**1.73**	1.14	2.85	0.75	(22)	0.90	(11)	**0.83**	0.48	1.76
1995*	0.53	(466)	0.38	(178)	**1.40**	1.17	1.68	-		-		-	-	-
1996	0.22	(6)	0.17	(29)	**1.28**	0.73	1.91	0.38	(7)	0.36	(14)	**1.05**	0.55	1.88
1996*	0.13	(47)	0.12	(21)	**1.07**	0.68	1.77	-		-		-	-	-
1997	0.88	(232)	0.67	(162)	**1.32**	1.17	1.51	0.51	(10)	0.17	(7)	**2.98**	0.88	7.53

* Released at LGR. There were no "Non-detected" fish. Therefore, fish "Bypassed Once" were used as the divisor in the ratio.

1.2.1 Transport Inriver Ratio (TIR)

Sandford and Smith (in press) reported annual estimates of TIR and associated SARs for both hatchery and wild chinook for the years 1993-1999. Several of the TIR estimates were based on such low numbers of returning adults that 95% confidence intervals could not be reliably estimated with ranges from (0 to infinity) in some cases (Table 1.2). We considered only those

TIR estimates that had bounded confidence limits (not extending to either 0 or infinity) as being useful indices of performance, and use those to construct graphs herein. Bouwes et al. (2001) also calculated TIRs for chinook tagged above Lower Granite Dam, but over the years 1997-1999 (the authors note only partial returns for 1999). The calculations based on fish transported from Lower Granite Dam (T_{lgr}) and controls never detected inriver (C_o) generally comport with those presented by Sandford and Smith (In press).

Chinook Salmon--For hatchery fish tagged upstream from Lower Granite Dam and subsequently transported from Lower Granite and Little Goose dams, all four useable annual estimates were equal to or greater than 1.0 (Sandford and Smith, in press). As noted above, a TIR>1 indicates that transported fish survive at rates exceeding inriver controls. For wild chinook, two estimates were greater than 1.0, and two were less than 1.0 (Table 1.2, Figure 1.2). In general the 95% CI are broader for the wild fish due to smaller sample sizes. For wild and hatchery chinook smolts intercepted and tagged at Lower Granite Dam in 1994 and 1996, all four TIR estimates were greater than or equal to 1.0 (Table 1.2, Figure 1.2). In these cases too, wild fish had the largest confidence intervals (CI).

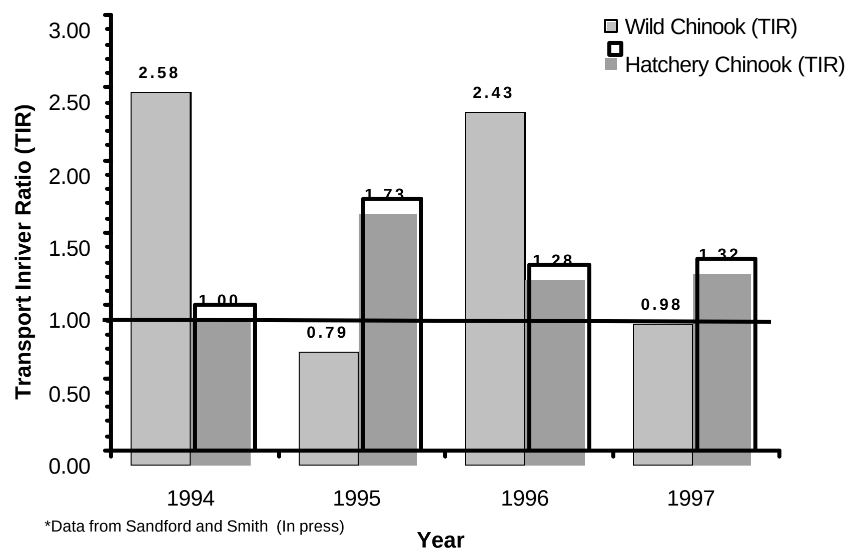

Figure 1.2—Transport inriver ratio (TIR) for hatchery and wild chinook salmon smolts PIT tagged and released at or above Lower Granite Dam. Only TIR estimates with bounded confidence intervals are plotted.

In Bouwes et al. (2001), TIRs for all three years of hatchery fish transported from Lower Granite Dam exceeded 1.0, as did the TIR estimates for fish transported from all dams (T_o) (Table 1.3, Figure 1.3). They did not report CI or measures of precision for these TIR estimates. However, the adult returns, and associated SARs (Table 1.3), are considerably higher than those witnessed from 1993-1996 (Table 1.2). This suggests precision should be improved over CI estimates reported by Sandford and Smith (in press). The findings of the two studies are consistent. In every year that has been studied, hatchery chinook salmon transported from Lower Granite and Little Goose dams have yielded annual TIR estimates greater than or equal to1.0, indicating a survival advantage to transporting them from those sites.

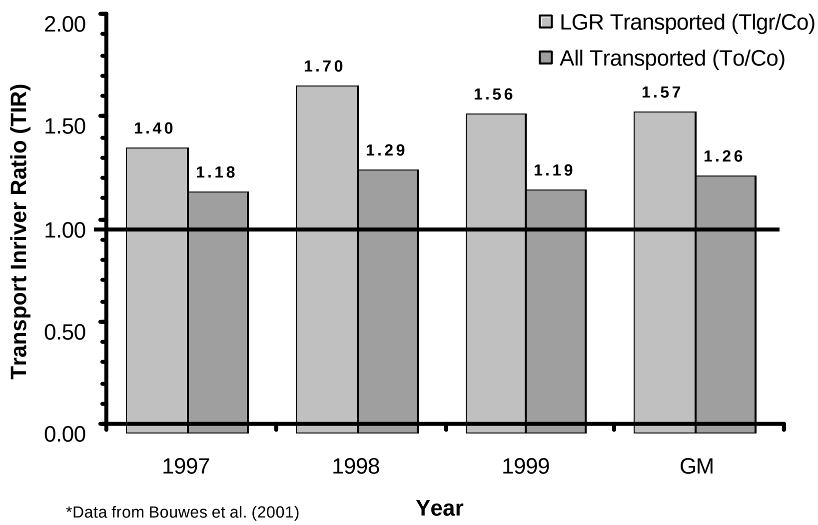

Figure 1.3—Transport inriver ratios (TIR's) for chinook smolts transported from Lower Granite Dam (Tlgr/Co) and chinook transported at all projects upon first detection (To/Co). The geometric mean (GM) for the three years is indicated.

Table 1.3—Smolt-to-adult returns (SAR) (LGR-LGR) estimates for PIT tagged hatchery and wild spring/summer chinook salmon transported and in-river migrants from the Snake River (from Bouwes et. al 2001). Hatchery fish were PIT tagged and released at spring/summer fish hatcheries upstream from Lower Granite Dam (LGR). The full complement of adult returns has not been realized for the 1999 SAR estimates. T_{lgr} =smolts transported at LGR, T_o=smolts transported from all Snake River dams upon first detection, C_o=smolts never detected, C_1=smolts detected at one or more dams. Numbers of returning adults (n) for SAR estimates are in parenthesis.

Migration	SAR								TIR	
Year	T_{lgr}	(n)	T_o	(n)	C_o	(n)	C_1	(n)	T_{lgr}/C_o	T_o/C_o
					Hatchery					
1997	0.85	(205)	0.77	(211)	0.60	(171)	0.51	(225)	1.40	1.18
1998	1.47	(697)	1.21	(757)	1.07	(263)	0.54	(341)	1.70	1.29
1999	2.37	(575)	1.76	(973)	1.40	(495)	1.17	(740)	1.56	1.19
1997-1999 (Geometric Mean)	**1.27**		**1.05**		**0.60**		**0.80**		**1.57**	**1.26**
					Wild					
1994	-		0.49	(11)	0.15	(6)	-		-	-
1995	-		0.30	(8)	0.35	(10)	-		-	-
1996	-		0.40	(2)	0.27	(6)	-		-	-
1997	-		1.71	(4)	1.76	(16)	-		-	-
1998	-		1.12	(15)	1.29	(42)	-		-	-
1999	-		1.88	(39)	1.93	(78)	-		-	-
1994-1999 (Geometric Mean)	-		**0.77**		**0.63**		-		-	-
1995-1999 (Geometric Mean)	-		**0.85**		**0.84**		-		-	-

Steelhead--For steelhead tagged above Lower Granite Dam and transported from Lower Granite and Little Goose dams, 3 of 4 annual TIR estimates for hatchery fish were greater than 1.0 (Figure 1.4, Table 1.2). Only one of the wild steelhead estimates had definable confidence intervals, and that estimate was near 1.0. Sound inferences are not possible at this time using wild fish tagged upstream from Lower Granite Dam. Moreover, no steelhead smolts were intercepted and tagged at Snake River dams in 1993-1997. In general, the results across years are more variable and thus equivocal than is the case for chinook salmon. It is difficult to conclude that transport or inriver passage is generally more favorable for this species.

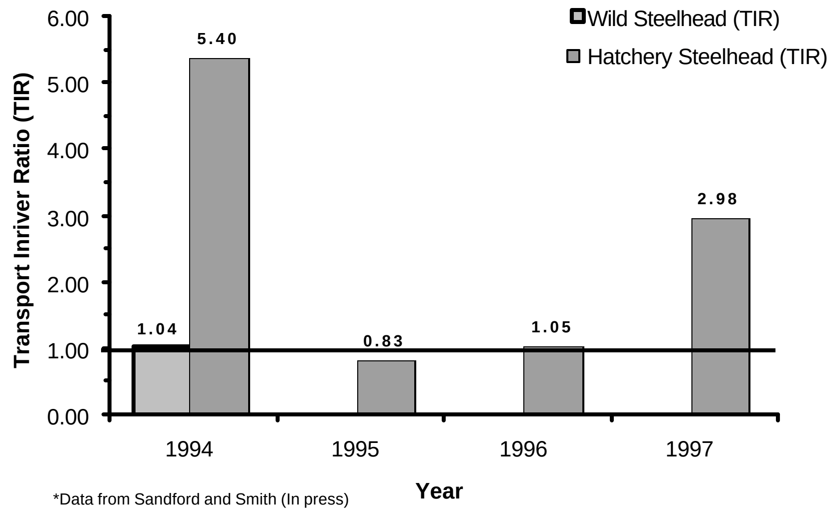

Figure 1.4—Transport inriver ratio (TIR) for hatchery and wild steelhead smolts PIT tagged and released at or above Lower Granite Dam.

Transport at LGR/LGO vs. LMO/MCN--The Bouwes et al. (2001) showed that Snake River chinook transported from Lower Monumental and McNary dams yield lower TIRs than fish transported from Lower Granite and Little Goose dams. To indicate this difference, we compared TIRs for fish transported from the upper two dams to fish collected and transported from all dams (Figure 1.3). Sandford and Smith (in press) also observed this pattern, where they compared transport control ratios for the combined smolts transported from Lower Granite and Little Goose dams to fish transported from all sites. Those authors concluded:

> "*…fish transported from Lower Granite or Little Goose dams and nondetected fish generally had higher SARs (sometimes significantly) than fish transported from Lower Monumental or McNary dams and bypassed.*"

Based on this assessment the survival advantage for transporting spring/summer chinook or steelhead from Lower Monumental Dam or McNary Dam is doubtful, or at best unclear.

Hatchery vs. Wild--Comparing TIR estimates for wild and hatchery fish revealed an inconsistent pattern. Only Sandford and Smith (in press) calculated transport to control ratios for both wild chinook salmon and steelhead. Across the years for which comparisons could be made (1994-1997), the TIR pattern for chinook salmon was evenly split. In two years (1994, 1996), wild fish exhibited higher TIRs, whereas in 1995 and 1996, hatchery chinook salmon TIR estimates were higher than wild fish (Figure 1.2). The pattern is inconclusive. It is not clear whether inriver migration or transport should be the preferred passage strategy for wild chinook salmon. In the single year when a valid steelhead comparison could be made, the TIR for wild steelhead (1.04) was far less than that for the hatchery fish (5.40) (Table 1.2, Figure 1.4). However, 95% CI were extremely broad compared to the annual estimates, diminishing the reliability of this comparison.

1.2.2 Smolt-to-Adult Return Rate (SAR)

The magnitude of the SAR estimates used to calculate the TIRs varied dramatically across years (Tables 1.2 and 1.3, Figures 1.5 and 1.6). Since 1993, SARs have increased an order of magnitude for chinook salmon. SARs for transported chinook salmon tagged upstream from Lower Granite Dam ranged from a low of 0.07% in 1993 (Table 1.2) to a high of 2.37% for the 1999 out-migration (Table 1.3). Furthermore, the 1999 estimate did not include a full complement of adult returns (Bouwes et al. 2001). The low SARs evident prior to 1997 are indicative of poor overall survival, as realized in very low numbers of returning adults. Small sample sizes result in broad and in some cases undefined (0 to infinity) confidence intervals associated with the TIRs prior to 1997 (Table 1.2). In general, poor precision limits the ability to conduct meaningful statistical tests or make strong inferences. Indeed neither group of investigators made statements regarding the statistical significance associated with their findings. Their interpretations and conclusions rely on patterns of point estimates (annual) as observed across a number of years.

However, the Columbia Basin is now realizing a dramatic increase in adult returns for all salmonid species. This is reflected in the dramatic increase in chinook SARs as estimated since 1997 (Table 1.3, Figure 1.5 and 1.6). If increased adult returns continue at these levels for a few more years, new opportunities for more statistically robust analyses may arise. Interestingly, some of the annual SAR estimates for transported fish from the 1997-1999 migration years are approaching 2%. This is the base threshold level that PATH identified as necessary to ensure a high probability of recovery for Snake River spring/summer chinook.

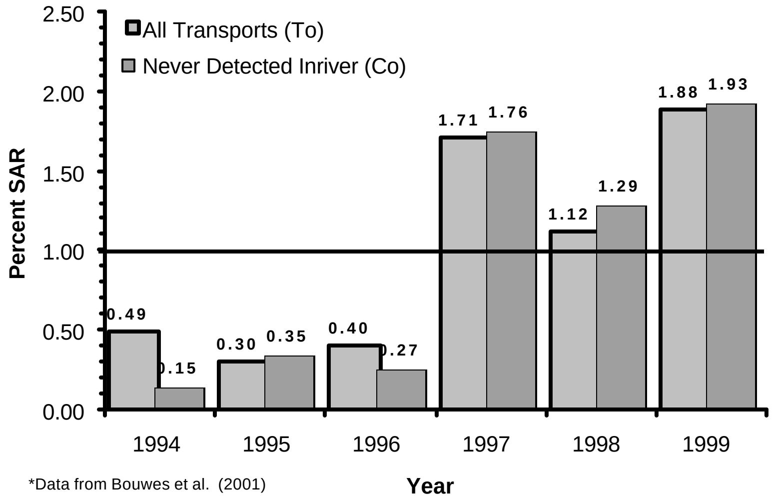

Figure 1.5—Comparison of wild chinook salmon SARs for transported and inriver controls before 1997 and after 1997.

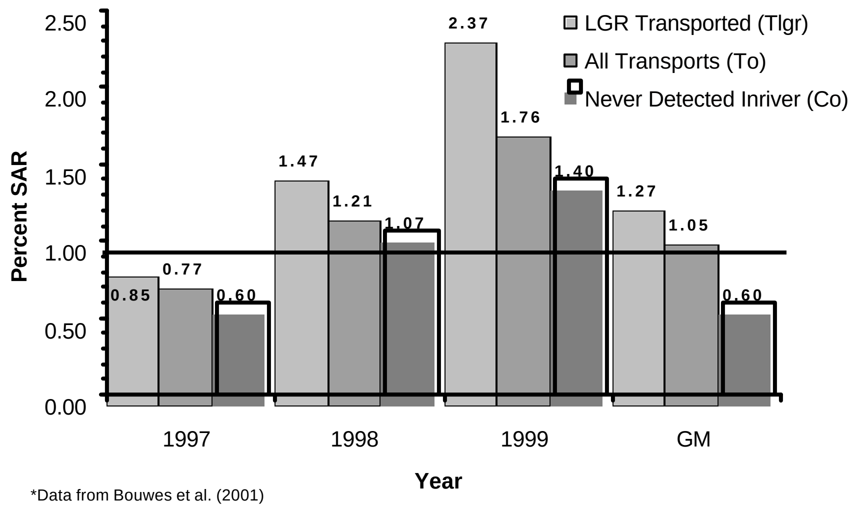

Figure 1.6—LGR-LGR SARs for different transport and inriver groups. Tlgr refers to the fish transported from LGR, To refers to smolts transported at all projects upon first detection, and Co refers to smolts that migrated inriver and were never detected upstream from McNary Dam (MCN). Geometric mean (GM) calculated for the three years.

Intra-annual changes in SAR--Some investigators have reported that SAR estimates for transported fish appear to increase over the smolt migration period. Using PIT tagged yearling chinook salmon released in 1995, Marsh et al. (2000) observed a seasonal trend in SARs, when they tracked the performance of replicate groups released throughout the spring migration season. Fish transported after the first week of May exhibited a 250% (hatchery) and 700% (wild) increase in SAR, compared to replicates released prior to that date. By comparison, control fish exhibited consistently low SARs that were of the same general magnitude as the early transport group. The precision of individual replicates is poorer than that previously noted for the annual estimates, so statistical significance could not be demonstrated. However, a similar seasonal increase in SARs for transported fish was observed in 1990 (Harmon et al. 1993). They reported that fish transported after mid-May produced SARs 400-600% higher than fish transported prior to that period. Marsh et al. (2000) suggest the pattern might be attributable to differential survival driven by estuarine/marine conditions that varied over the spring. During the spring there is a transition period by which marine processes shift influencing primary and secondary productivity. They reason that since transported fish make the journey to the estuary in about 3 days, while corresponding controls require 2-3 weeks, they may encounter different marine conditions. They imply that the early transported group got to the estuary too early, when conditions were not favorable to survival.

For chinook salmon, SARs for transport and control groups typically rise and fall in unison (Table 1.3, Figures 1.5 and 1.6). This suggests some factor(s) common to all passage groups influence absolute survival through to returning adult. This pattern seems less evident prior to 1997 when there were fewer returning adults (Table 1.2, Figure 1.2). Recent literature suggests climatological, marine-based processes are plausible mechanisms (Hare et al. 1999).

1.2.3 TIRs and Flow

Marsh et al. (2000) examined the relationship between transportation indices and river flow (kcfs) in 1995. The working hypothesis was that inriver survival should increase with flow, which in turn could depress the TIR estimate. Unexpectedly, they observed a significant positive correlation between the TIR estimates for replicate groups and flows ranging from 60 to about 120 kcfs. The authors theorized the counter-intuitive relationship had more to do with an increase in the survival of transported fish throughout the season as associated with timing of ocean entry. Whether or not the hypothetical, estuarine/marine mechanisms might be flow related has been an unresolved point of discussion. The inriver SARs showed no relationship to flow.

In 1998, NMFS investigators analyzed similar data but focused on inriver and transport SARs for individual replicates as the response variable (Marsh et al. 2001). They observed no relationship between control SAR and flow at Lower Granite Dam, ranging from 60 to 130 kcfs. They did observe a significant (P=0.02), but weak (R-squared = 0.09) positive relationship between transport SARs and flow at Bonneville Dam. We conclude that there is no evidence here of a meaningful relationship.

1.2.4 Differential Delayed Effects (D-Estimates)

Both NMFS (2000a) and Bouwes et al. (2001) have derived estimates of D from the recent PIT tag era datasets. The NMFS reported estimates in the BO that were calculated for wild chinook and steelhead stocks from the Snake River for the smolt years 1994-1997. Those authors note the estimates should be viewed with caution, since few adult returns were realized (Table 1.4), which translated to poor precision. They emphasize that much more data will be required before reliable D estimates can be derived. With those caveats, we are reluctant to infer much regarding insight associated with the reported estimates. The calculated geometric means for wild chinook ranged from 0.63 to 0.73, and 0.52 to 0.58 for wild steelhead for the years 1994-1997.

The range in reported geometric means is directly attributable to the manner in which Vc was estimated. NMFS used two different expansions of empirical reach-specific smolt survival estimates, one based on per project expansion and the other on a per kilometer expansion. This illustrates an important point in the interpretation and relevance of D estimates. Any given set of empirical SAR estimates or TIR estimates can generate different absolute D values, depending on how Vc is estimated. Given this sensitivity, reporting absolute D values alone (particularly when they are < 1.0) offers little insight. The key issue is whether D differs significantly from Vc. Its real value is as a performance measure relative to the inriver survival actually realized by smolts.

Table 1.4—D estimates for wild Snake River spring/summer chinook salmon and steelhead as reported in the 2000 BO by NMFS (2000a). SAR_T is the estimated SAR for transported fish. SAR_I is the estimated SAR for inriver (control) fish. Total adult returns are provided in parenthesis for all estimated SARs. Survival is the estimated survival from Lower Granite Dam to Bonneville Dam for inriver fish (per-project and per-kilometer extrapolation). D is estimated for each year (along with 95% confidence intervals), and geometric mean of the yearly D is provided. (1997 adult returns incomplete at time of calculation).

	Wild Chinook Salmon						Wild Steelhead					
Year	**SAR_T**	**SAR_I**	**Inriver-Survival (Vc)**	**D**	**95% CI**		**SAR_T**	**SAR_I**	**Inriver-Survival (Vc)**	**D**	**95% CI**	
						Per-project Extrapolation						
1994	0.52 (13)	0.25 (6)	0.335	0.85	0.01	1.69	1.29 (8)	1.16 (6)	0.416	0.51	-0.04	1.06
1995	0.30 (8)	0.33 (10)	0.557	0.55	0.03	1.06	0.40 (1)	0.00 (0)	0.583	NA		
1996	0.52 (2)	0.24 (5)	0.469	1.02	-0.69	2.72	0.59 (1)	0.58 (4)	0.531	0.54	-0.68	1.76
1997	2.46 (4)	2.05 (17)	0.474	0.61	-0.08	1.29	0.82 (3)	0.57 (3)	0.474	0.71	-0.45	1.87
Geometric Mean	1994-1997			**0.73**					94, 95, 97	**0.58**		
						Per-kilometer Extrapolation						
1994	0.52 (13)	0.25 (6)	0.260	0.66	0.01	1.31	1.29 (8)	1.16 (6)	0.336	0.41	-0.04	0.86
1995	0.30 (8)	0.33 (10)	0.501	0.49	0.02	0.96	0.40 (1)	0.00 (0)	0.528	NA		
1996	0.52 (2)	0.24 (5)	0.412	0.89	-0.60	2.39	0.59 (1)	0.58 (4)	0.476	0.49	-0.61	1.58
1997	2.46 (4)	2.05 (17)	0.417	0.54	-0.07	1.14	0.82 (3)	0.57 (3)	0.474	0.71	-0.45	1.87
Geometric Mean	1994-1997			**0.63**					94, 95, 97	**0.52**		

Bouwes et al. (2001) derived D estimates for the smolt years 1997-1999, recognizing that adults for the last year are still at large (Table 1.5). The D estimates reported by Bouwes et al. (2001) were produced somewhat differently than the NMFS estimates. They employed different SAR reference locations (BON-LGR), and included all fish transported from any collector dam for wild and hatchery fish. Then they produced another estimate for hatchery fish based on Lower Granite Dam transported fish only. Estimates of Vc were based on per kilometer expansions, similar to one of the NMFS protocols.

For wild chinook the geometric means were 0.568 and 0.511, for the years 1994-1999 and 1995-1999, respectively. Hatchery estimates based on To/Co and Tlgr/Co, were 0.62 and 0.77, respectively. Hatchery fish appear to respond more favorably to transport, but no statistical tests were performed.

Table 1.5—The ratios of SARs for different transport and in-river hatchery groups. T_{lgr} refers to the fish transported from LGR, T_o refers to smolts transported at all projects upon first detection (weighted by the proportion actually transported), C_o refers to smolts that migrated in-river and never detected above MCN dam. All SARs are the LGR-LGR SARs except for the D-value. The D-value is the ratio of the transport BON-LGR SAR to the control (in-river) BON-LGR SAR (from Bouwes et al. 2001).

	SAR		**D-Value**	
Year	**T_{lgr}/C_o**	**T_o/C_o**	**$D(T_{lgr})$**	**$D(T_o)$**
			Hatchery	
1997	1.401	1.183	0.532	0.450
1998	1.698	1.290	0.880	0.663
1999	1.558	1.190	1.024	0.775
1997-1999 Geometric Mean	1.5	1.262	**0.769**	**0.621**
			Wild	
1994	-	3.189	-	0.958
1995	-	0.867	-	0.403
1996	-	1.489	-	0.526
1997	-	0.975	-	0.480
1998	-	0.868	-	0.538
1999	-	0.974	-	0.637
1994-1999 Geometric mean	-	1.226	-	**0.568**
1995-1999 Geometric Mean	-	1.012	-	**0.511**

The difficulty in resolving differences between estimates reported by different research groups is that no single methodology is being used. D can be estimated by a number of similar methods that may yield different values. Furthermore, given the poor precision associated with D, the opportunity for sound statistically based inferences is absent. As a consequence, some may view D to be a confusing and rather abstract parameter that has little intuitive relevance. Furthermore, it appears that except for some modeling applications, D provides little more information to the fisheries manager than prevailing TIR estimates used to derive D. Obviously you can place no more statistical confidence in D estimates than the SAR and TIR estimates from which they are derived.

Collectively, the D estimates suggest that differential delayed effects are nearly always indicated for transported fish of either species, as indicated by the dominance of values < 1.0. However, that is not necessarily bad, if D > Vc. But given the poor precision attending estimates, this cannot be adequately tested.

The opportunity for deriving useful D estimates for Snake River fall chinook is even more questionable, because the foundation data are lacking. Basic inriver survival and SAR estimates for fall chinook smolts do not exist. Furthermore, no satisfactory fall chinook passage survival model has been developed to produce reliable alternative estimates of inriver survival (Vc). This means that useful estimates of D will likely not be available for this species in the foreseeable future. Nevertheless, it may be possible to obtain useful TIR estimates, if adequate numbers of juveniles can be PIT tagged.

1.2.5 Statistical Inferences

Some of the estimates reported herein have a weak statistical foundation. Rarely have the authors specified levels of statistical significance between or among estimates, or have formal hypothesis tests been explicitly conducted. Although, we expect NMFS will evaluate transportation in this manner, generally, investigators rely on interpreting patterns of annual estimates observed across years. Many of the annual SAR, TIR, and D estimates have such poor precision that their usefulness even as general indices may be questionable.

The only way to advance toward more quantitatively robust analyses is to increase the sample size of returning adults from experimental lots. This can be accomplished by increasing the numbers of juveniles PIT tagged. However, substantially increasing that effort by any substantial amount (2-10 fold) seems impractical. Alternatively, investigators can rely on the natural cycles, outside the hydrosystem, to improve survival during marine residence, and then take analytical advantage of the increase in adult returns. The latter appears more likely, and evidence for such is already apparent with the recent increases in adult abundance basin wide. The conventional position is that marine conditions have entered a phase conducive to fostering survival of northwest salmonid stocks (Hare et al. 1999).

1.2.6 Mechanisms Contributing to Delayed Differential Effects For Transport

Stress and Fish Condition--One mechanism potentially contributing to delayed transport effects could be stress incurred during the transportation process. Over the last two decades, researchers have investigated the potential for such effects (Matthews et al 1986, Maule et al. 1988). By-and-large those studies documented changes in certain physiological indices that were attributable to the collection and transport of smolts. The observed changes were typically of short durations, and depending on the index, levels returned to base conditions within 24-72 hours. For example, Maule et al. (1988) studied fall and spring chinook at McNary Dam. They used a variety of physiological measures (plasma cortisol and glucose, and white blood cell counts, as well as physical tests including, salt water challenge, secondary stress and swimming performance). They found that the most stressful event was loading fish into the barge. But fish started to recover during transport, and those in barges (16-h recovery), were more fully recovered than the shorter duration (3-h) truck transport.

Most investigations have used hatchery fish, and relevance to wild counterparts has regularly been questioned. However, Congleton et al. (2000) investigated transport effects on both wild and hatchery chinook and steelhead. For certain physiological indices, they observed differences between species and origin. They concluded that the collective results indicated chinook salmon were more stressed by barge transport than steelhead. They made no definitive conclusion as to whether overall wild and hatchery fish are differentially affected by barge transport, but note difference in many physiological indices. A key finding was that cortisol levels in chinook were positively and significantly correlated with the density of steelhead in the barge. They postulate that this may be a response to the aggressive behavior of steelhead. They go on to note that steelhead did not appear to be stressed by transportation. Importantly, they note that it is not known if the observed elevated stress indices are linked with reduced survival following liberation from barges.

Congleton et al. (2001) have addressed this last point by analyzing steelhead-loading densities, physiological indices of chinook and ensuing chinook SARs for fish transported from Lower Granite Dam in 1995, 1998 and 1999. Preliminary findings have not identified any obvious relationships between SARs estimates for wild or hatchery chinook and the density of steelhead in barges at the time of transport. They caution that any conclusion would be tentative, since the power of the test may have been insufficient to detect an effect, or an effect may not occur in all years.

Based on the collective information it is difficult to determine whether or not stress associated with the collection and transport of smolts contributes to delayed differential mortality. The thought has been if stress was an important factor, there may be some ways to minimize it and improve the long-term survival of transported fish.

Homing Fidelity-- SAR estimates for transported fish may reflect processes other than mortality. Impaired homing could be considered a delayed effect associated with transport, and may be reflected in D values as calculated by different groups. If adults en route to Lower Granite Dam that were transported as smolts stray at higher rates than inriver counterparts, then the SAR estimates for transported fish will be depressed, since they have no opportunity to be detected at Lower Granite Dam. Lower Granite Dam is currently the only fishway fitted with PIT tag detectors capable of interrogating returning adults. At this point we examine information that describes the potential for homing impairment as attributable to transportation.

There have been studies that indicate transport can impair homing. Bugert et al. 1997 conducted an investigation using coded wire tagged (CWT) fall chinook salmon (both sub-yearling and yearling aged) from Lyons Ferry Hatchery on the Snake River. The transport protocol for this study differed from that employed in general mass transportation operations, in that the transported fish were barged around only two dams, Lower Monumental and Ice Harbor, and were released in the Snake River rather than downstream from Bonneville Dam. Even with this short transport (<34h) and the constant replenishment of ambient water to provide homing cue, homing was affected. They found that transported fish strayed to freshwater areas outside the Snake River basin at a rate significantly higher than those released directly from the hatchery, at 5.9 and 0.3%, respectively.

Other investigators have also observed evidence of homing effects for transported sockeye salmon. Chapman et al. (1997) analyzed adult return data for sockeye salmon collected at Priest Rapids and Wanapum dams. In that study, one experimental group was released below Priest

Rapids Dam, whereas the transported group was released from the shoreline below Bonneville Dam. Those authors concluded that the truck transport impaired homing of adult sockeye between Bonneville and Priest Rapids Dam.

These studies suggest that a more systematic and comprehensive evaluation of homing as influenced by mass transportation of smolts is warranted, particularly as it is implemented in the Snake River. But as yet homing studies targeting the mass transport of Snake River populations have not received emphasis. Parties have recognized the need, but logistical and sampling constraints associated with a variety of marking tools have limited the opportunity.

A long-standing criticism of past transportation studies was that they failed to assess the potential effects on homing ability back to natal tributaries (Mundy et al. 1994). However, the recent Bouwes et al. (2001) experimental protocol could provide some insight on this issue, at least for stream-type hatchery chinook. The evaluation would require that the hatcheries above Lower Granite Dam interrogate returning fish for PIT tags to establish inter-hatchery stray rates. This information can be useful and may be available, but has not yet been analyzed. However, such estimates would still be limited, because they could not reflect straying that may occur prior to arrival at Lower Granite Dam.

Documenting straying rates en route to Lower Granite Dam would require the emplacement of adult PIT detectors at fishways at other dams on the river. Coverage would need to extend from Bonneville and include strategic sites throughout the mainstem river. Also, studies directed at wild stocks have been lacking, owing to sampling difficulties associated with detecting PIT tagged fish in streams. But a new detector plate suitable for deployment in streams may be available in the next few years and this could offer new sampling capabilities.

Just recently, an alternative approach has been developed that provides new capabilities including estimates of straying from Bonneville Dam upstream. Bjornn and Keefer (2001 abstract) reported preliminary results from research conducted in 2001. They intercepted spring migrating chinook and steelhead at Bonneville Dam and implanted radio tags into adults that had been PIT tagged as smolts. Therefore they could determine where the fish emanated (PIT information) and their migration fates as smolts, then as adults track their routes upstream with the radio tags. This is precisely the type of information that is required to assess the effects of transport on homing.

The data have not been completely analyzed as yet, but they made some preliminary observations thus far. They found that, in general, straying between the upper Columbia to the Snake (as far as LGR) was minimal. However, with respect to the effect of barging, they observed that transported steelhead had returned to Lower Granite Dam at rates lower than those that migrated inriver as smolts. The ultimate fate of the missing fish has not been indicated. However, the results are preliminary and they refrained from making firm conclusions until analyses are complete. Nevertheless, this observation does implicate homing impairment as a contributing mechanism to D. Further evaluations of this type will be most instructive.

The protocol of Bjornn and Keefer (2001) currently provides the best information for describing straying patterns and frequency between Bonneville Dam and the location where smolts were first PIT tagged. However, this protocol does not capture homing effects that may have been manifested prior to arrival at Bonneville Dam. Evaluation of homing effects that are expressed in that zone will no doubt prove to be much more challenging. We are not aware of any research that is being proposed to address that issue.

1.3 Summary

In some years, small sample sizes have resulted in poor or undefined precision for SAR, TIR and D estimates. This can limit the ability to make statistically defensible conclusions. Authors examining recent estimates do not confidently state that transported fish survive at significantly higher rates than inriver counterparts. Neither Sandford and Smith (in press), nor Bouwes et al. (2001) explicitly tested key hypotheses such as, D > Vc, TIR > 1.0. Presumably future analyses by these two research groups will do so. We say this because recent increases in observed SARs indicate that in the next few years, PIT tagged fish may be returning in numbers that sufficiently improve samples sizes, potentially resulting in improved precision and permitting stronger statistically supportable inferences. This increasing trend in adult returns has been apparent since the 1997 smolt migration year.

Using general, annual indices of performance, both NMFS and CBFWA analyses showed that the majority of the time, fish transported from Lower Granite and Little Goose dams produced TIRs higher than or equal to corresponding inriver control groups. Bouwes et al. (2001) concluded modest transportation benefits were evident for hatchery chinook, and slight to negligible benefits for wild fish. Sandford and Smith (in press) state that, "once a juvenile fish is entrained in a bypass system at a "collector dam", transporting the fish maximizes the probability of its eventual return as an adult." Based on assessments by those two investigations, it appears that there is a survival advantage associated with transporting Snake River hatchery spring/summer chinook and steelhead, particularly from the upper two dams, Lower Granite and Little Goose dams. However, the rationale for transporting smolts from Lower Monumental and McNary dams is less clear. The benefits of transporting Snake River hatchery fish from those dams are equivocal.

Whether or not wild fish respond favorably to transportation is difficult to ascertain at this juncture. Even though the limited numbers` of TIR estimates are generally >1.0, the estimates are based on so few adult returns that the precision for this class of fish is particularly poor (Table 1.2). Thus, reliance on the point estimate as a representative value is questionable in our opinion.

Survival from smolt to returning adult (SAR) for hatchery and wild spring summer chinook has increased substantially since 1993, and has been increasing steadily from 1997-1999, reaching SAR levels in 1999 that approach and in some cases exceed the 2% minimum recovery threshold for wild stocks as identified in PATH (Figures 1.5 and 1.6). This suggests that neither transport nor inriver migration conditions may be a bottleneck to recovery, when marine-based survival is at some adequate level.

No mass transportation study has been conducted that targets Snake River fall chinook. Such evaluations are warranted.

There is evidence to suggest that homing fidelity may be impaired for some species of transported fish, including fall chinook, sockeye, and steelhead. Studies that target spring/summer chinook and steelhead require emphasis. Straying may in apart contribute to D. It may be advantageous to ascertain the extent of straying associate with transport of all species to address certain ESA concerns. Excessive straying may result in increased hatchery fish intermingling among wild adults on the spawning grounds. This may not be desirable.

Delayed differential effects relative to inriver migrants are consistently evident for transported fish. However, the magnitude of the D regularly exceeds survival of the smolt stage through the hydrosystem (Vc), so the survival of transported fish (through return as adults) still exceeds that of inriver migrants. In such cases, there would still be a survival advantage to transport Snake River fish from Lower Granite and Little Goose dams.

1.4 Critical Uncertainties and Research Opportunities

Species Coverage-- Not all species have been adequately evaluated with respect to survival associated with transportation. By and large much of the useful data has been obtained using hatchery fish or run-of-river populations dominated by such. There is concern that wild stocks may react differently to transport. But it has been difficult to obtain robust SAR estimates for wild fish since their abundance has been low, and they need to be collected and tagged in their natal streams. The recent resurgence in returning adults should boost wild juvenile abundance, and provide new opportunity to increase the number of PIT tagged individuals for use in transport survival evaluations.

An evaluation of transporting Snake River fall chinook is warranted. NMFS with Army Corps of Engineers funding will conduct such an evaluation starting in 2002, using Lyons Ferry Hatchery stock.

MCN Evaluations--There have been no TIR studies conducted for stocks passing at McNary Dam since the 1980s. Evaluations under contemporary operating conditions using PIT tags are warranted. Such evaluations were planned by NMFS for 2001 but did not materialize. However, 2002 study designs are being formulated and the research is expected to go forward next year. These evaluations are critical in deciding the preferred management strategy for mid-Columbia stocks passing McNary Dam

Homing Fidelity--Quantifying the extent of straying attributable to smolt transportation may be useful in assessing hatchery stock introgression into wild spawning areas. Also, it may explain to what extent straying may be contributing to the composite delayed effects now reflected in the generic index, D. Analyses like those currently underway at the University of Idaho are most instructive and should continue. It is our understanding this line of research will continue. PIT and radio tag technologies offer improved capabilities to better document straying within the mainstem Columbia and Snake rivers. The emplacement of PIT tag detectors capable of interrogating adults at strategic dam sites in the Snake and Columbia rivers would provide new analytical capabilities.

Direct Mortality--Many may consider this a minor issue, but to date there are no reliable empirical estimates of the smolt mortality incurred from the time of collection through to release from either a barge or truck. The convention is to presume survival to be 98% (NMFS 2000a, 2000b). This value is based on general observations during barging. If the actual direct mortality is substantively higher than presumed, it may explain some of the effects currently packaged within the parameter D.

Statistically Defensible Inferences--Many of the SAR, TIR, and D estimates obtained early in the 1990s have such poor precision that there usefulness even as general indices are questionable. Only since the 1997-outmigration have adult returns increased to the degree that precision has greatly improved. It would be advisable to continue and expand transport evaluations, during this period when we are witnessing robust adult returns. This in turn should continue to realize increased sample sizes and improve precision of key estimates. It is our understanding that indeed transport studies will continue for spring chinook and steelhead, and be expanded to include Snake River fall chinook, as well as evaluations directed at upper Columbia River stocks transported from McNary Dam.

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2.0 SPILL

The 2000 Biological Opinion NMFS (2000a) specifies spill operations for the FCRPS during the smolt migration periods in the spring and summer (Appendix A). Apart from the Snake River stocks, which can largely be transported, the majority of smolts emanating from the rest of the basin continue to migrate in-river to below Bonneville Dam. Optimizing smolt survival during downstream migration has been a longstanding goal of fisheries managers. As early as the 1970's investigators identified a positive relationship between smolt survival and spill volumes discharged at Snake River dams (Sims and Ossiander 1981). Whitney et al. (1997) reviewed passage route survival studies that indicated smolt survival was generally higher through spillways than through turbines. Is the information acquired prior to the 1990's particularly relevant today? We suggest not. The spill operations in place today (as prescribed in the Mid-Columbia spill agreement and 2000 NMFS Biological Opinion), as well as the structural configurations of many spillways (e.g., flow deflector presence), differ substantially from those of the earlier era. Herein we focus on contemporary passage survival estimates and estimation techniques (balloon-, radio-, and PIT-tag methods) developed during the 1990's that continue to be applied this decade.

Recently, analyses conducted by Muir et al. (2001a) indicate that spillway survival of smolts exceeds that incurred through both turbines and collector/bypass systems at dams on the Snake River. For these reasons, routing smolts through spillways is generally considered to be the safest passage strategy at Columbia-Snake River dams. However, there are risks associated with spilling water for smolt passage. Two of the more prominent risks involve spill contributing to total dissolved gas super-saturation and also alteration of migratory behavior of adult salmon.

Total Dissolved Gas--Generally, total dissolved gas (TDG) increases with increased spill volumes. When TDG levels become excessive, it can create hazardous conditions for all life stages of salmonids, as well as other aquatic organisms. One means to control TDG is to impose caps on spillway discharge as prescribed in the NMFS Biological Opinion. Those caps can be effective until total river flow exceeds both powerhouse capacity and the dam-specific spill cap. One means to abate TDG concentrations is to minimize the depth to which water plunges into the stilling basin. To accomplish this, spillway flow deflectors have been designed and installed at a number of dams throughout the system. The flow deflectors are horizontal structures applied to the downstream face of each spillbay. These devices re-direct falling water horizontally, thus minimizing plunge depth and associated pressure that compresses gas in solution.

Adult Fallback--Large volumes of spill can delay adult migration by occluding or masking fishway entrances located in spillway tailraces (NMFS 2000b). Adult fallback can be exacerbated at some dams when spill occurs. Fallback is the process whereby adult salmonids pass upstream via the fishway, but fallback downstream through some portal (spillway, powerhouse or bypass system). Fallback can put adults at increased risk as associated with trauma, or migrational delay. Later in this report we describe a situation at Bonneville Dam that forms a sort of case study on this topic.

2.1 Spill-Related Smolt Survival

2.1.1 Smolt Survival Through Spillways

There are two types of survival estimates that can be used to characterize smolt survival through a spillway (or for that matter any dam passage route). One type reflects only direct effects, and the other is a broader measure that reflects both direct and indirect effects (total effects). The objectives for obtaining these types of spillway survival estimates are to:

- Identify the safest routes of passage at a dam.
- Determine the configuration of the spillway that maximizes survival (e.g. flow deflectors present/absent, or alternative design).
- Determine if the survival of spilled smolts is sensitive to spill discharge volumes or percent water spilled.

Mortality Associated with Direct Effects--The most fundamental level of smolt survival estimates are those that reflect only direct effects associated with passage through a route. At a spillway, that is from the time smolts enter the intake until they egress from the stilling basin. Mortality incurred during this phase is due to physical trauma experienced during spill passage.

The magnitude of direct mortality can be estimated for any passage route (spillway, turbine, or bypass).

Currently, the preferred method for estimating this type of survival involves a mark-recapture protocol using balloon tags (Normandeau et al. 1996a). Briefly, a group of smolts are fitted with a deflated tag, and individually injected into the entrance of the passage portal via a hose. Within a few minutes after arrival in the stilling basin, the tag inflates and buoys the smolt to the surface in the tailrace, where it is retrieved. Fish are netted from the tailrace from a vessel, and held for a 48-hour observation period. A corresponding control group is released in the tailrace close to the dam, and similarly recaptured and held for observation. The treatment and control groups are used to estimate survival through the spillway (Normandeau et al. 1996b). Since fish are removed from the tailrace within a brief period (minutes), the resultant spill survival estimates reflect only direct acute effects that are expressed in 48 hours.

Mortality Reflecting both Direct and Indirect Effects (Total Effects)--At some dams, and under some conditions, smolts passing through a spillway (or some other passage route) may be predisposed to encounter some additional hazard in the tailrace (e.g. a concentration of predatory fish staging downstream from the spillway tailrace). Survival estimates based on balloon tags will not reflect those additional indirect effects. A different experimental approach must be employed to reflect the total effects smolts incur when passing through a spillway. The typical procedure requires bracketing the zone of concern by releasing a tagged group at the spillway entrance (treatment), and another experimental group a few kilometers downstream (the control). PIT-tags have been used extensively in such studies (Muir et al. 2001a), particularly in the Snake River where an extensive complex of PIT detection systems are in place. However, in river reaches where PIT detection capabilities are limited, alternative procedures using radio tags have been developed (Skalski et al. 2001).

2.1.2 Estimating Survival of the Smolt Population as Related to Spill Conditions

Empirically Based Estimates--Neither of the types (direct and total effects) of empirically based survival estimates described thus far, in and of themselves, can be used to estimate the degree to which the population-at-large benefits from a spill program. To empirically establish this requires a different study design. One approach that has been used by fisheries agencies involves estimating the survival of the general population as it passes one or more projects (pool and dam) under different spill regimes (Zabel et al. in press). Such composite, project-wide, survival estimates reflect survival probabilities through the various routes and the percentage of the population using those routes. Obviously, the survival estimate through an entire project can reflect other processes in addition to spill effects. This can complicate isolating effects only attributable to the spill treatment, as we will observe later in recent case studies.

Model Analyses--An alternative approach for assessing the effects of a spill program on the smolt population is to conduct a computer-facilitated model analysis. This involves assembling an assortment of independent passage-related estimates and incorporating them into a smolt passage model such as SIMPAS or CRiSP. The model can then be configured to represent different river, dam, and spill conditions. The output from a smolt passage model would typically be the predicted overall smolt survival through the hydro-system under the different spill scenarios. The recent 2001 spill analysis conducted by NPPC staff is an example of such an application (NPPC 2001). Compiling the fish-related input for the model requires the acquisition of independent estimates of survival probabilities through each route at each dam, for each species, including indirect and reservoir effects. Also required are corresponding estimates of smolt passage proportions through the various routes, preferably across a range of operating conditions. Acquiring this set of data for each dam has proven to be difficult to accomplish. Typically, it has been necessary to adopt a consensus-selected set of site-specific values, or global default values that are applied in model analyses. The reader is referred to the NMFS FCRPS Biological Opinion and PATH analyses for a description of such components and values adopted in those forums.

2.1.3 Spillway Passage Efficiency

Spillway passage efficiency (SPE) is defined as the proportion of the smolt population passing a dam via the spillway (Anglea et al. 2001). This parameter in combination with the spillway survival probability, in large part, dictates the change in survival a smolt population experiences under different spill operations. Steig (1994) and Whitney et al. (1997) surveyed SPE estimates available at the time of their review. Investigators in PATH also recognized the importance of this parameter, and provided an initial review of SPE estimates available in 1996 for use in that modeling forum (Marmorek and Peters 1998). At that time, the estimates were incomplete and imprecise. As a consequence, PATH investigators concluded that a range of SPE values from 1.0 to 2.0 should be used in a sensitivity analysis to demonstrate the importance of this parameter. Subsequent to that survey, the regional effort to estimate SPE at dams throughout the hydro-system has expanded with the intention of improving the quality of estimates. NMFS (2000b) updated estimates reported up to that point. More recently, Anglea et al. (2001) and Ploskey et al. (2001) compiled and synthesized SPE data sets from two dams, John Day and The Dalles. The reader is referred to those documents for details regarding specific estimates.

There are two primary methods for estimating SPE, hydroacoustic monitoring and radio telemetry. Hydroacoustic monitoring involves the deployment of fixed beam transducers at passage routes, and monitoring targets passing through those beams. Alternatively, the passage routes can be fitted with telemetry equipment and the passage fate of radio-tagged smolts recorded. If sampling coverage is sufficient, estimates of SPE can be obtained. Spillway Passage Efficiency estimates based on Hydroacoustic sampling can be used to make inferences about the general mixed population of fish, whereas telemetry-based estimates are species-specific. The review and synthesis reports prepared by Anglea et al. (2001) and Ploskey et al. (2001) reveal several important considerations regarding SPE estimates. Spillway Passage Efficiency can:

- Vary by species.
- Display diel patterns at some dams.
- Vary depending on the tool employed.
- Vary with the percent of water discharged through the spillway.

These sources of variability make it very difficult to prescribe a single value that can be used to accurately represent SPE at a dam. It is likely the collective estimates available at a dam will need to be intensely inspected with the hope of identifying an algorithm suitable for predicting SPE.

2.2 Spillway Survival Estimates

Are Spillways The Safest Passage Routes?--To address this issue, we rely on survival estimates using PIT-tagged smolts where the control groups are released approximately 1-2 km downstream from a dam. This protocol captures both direct and indirect tailrace effects. In our opinion, these types of estimates are the most instructive in characterizing total effects associated with passage through a spillway, or other dam passage routes. This is critical to get a useful and representative comparison among routes. Estimates of this type have only been obtained at dams in the Snake and Lower Columbia rivers. Similar types of passage route- specific survival estimates have been obtained using radio tags, but typically controls have been released much closer to the dam (Lady et al. 2000; and Skalski et al. 2001), and thus may not fully capture the indirect effects incurred throughout the extended tailrace. We discuss those here, but do not emphasize them.

Muir et al. (2001b) compiled route-specific survival estimates for PIT-tagged steelhead and yearling chinook at Snake River dams (Appendix B). Across dams and species, the estimated relative survival was highest through spillbays (without flow deflectors), and ranged between 98.4-100%. The range of relative survival estimates through bypass systems and turbines was 95.3-99.4% and 86.5-93.4%, respectively.

The only other site where such PIT-tag investigations have been conducted is The Dalles Dam on the Lower-Columbia River. Ploskey et al. (2001) compiled route-specific survival estimates for that site, which were originally generated by NMFS investigators (Appendix B). The estimated relative survival of spring migrants (coho or yearling chinook) was 96%, 92%, and 81-86% for spillbays, sluiceways, and turbines, respectively (Ploskey et al. 2001). The authors further concluded that these estimates were all lower than estimates for other projects in the Columbia River Basin. For summer-migrating sub-yearling chinook, the respective relative survival estimates for spillbays, sluiceways, and turbines were 92%, 93%, and 84%.

There is additional supporting evidence in the Mid-Columbia River. Route-specific survival estimates obtained using radio tags at both Rock Island and Rocky Reach dams indicate that the highest relative survival is generally estimated for smolts passing through the spillway (Appendix B). This pattern was observed in four out of five assessments conducted in 1999-2000 (Lady et al. 2000; and Skalski et al. 2001). In the fifth assessment, yearling chinook at Rock Island dam survived at equivalent rates through the spillway and Powerhouse 2. In some cases, significant differences among passage route survival estimates could not be demonstrated due to the level of precision accompanying the point estimates. Nevertheless, precision always appeared reasonable. Furthermore, the ranking was consistent across dams and species with spillway survival being the highest of the passage routes. Based on these data, we conclude that spillways are the safest passage routes at dams where these types of evaluations have been conducted.

Do Flow Deflectors affect Smolt Survival?--We consider both PIT-tag and balloon tag estimates as being instructive for examining this issue. In general, the presence of spillbay flow deflectors decreases survival relative to the non-deflector condition. In the Snake and Lower Columbia rivers, PIT-tag based estimates comparing those conditions at Little Goose and Lower Monumental dams can be viewed in Figure 2.1. For those dams, Muir et al. (2001a) reported that the relative survival through spillways was highest with deflectors absent (98.4-100%) compared to deflectors present (92.7-100%). They also noted that although the point estimates were lower for the deflector present condition, statistically significant differences could not be demonstrated.

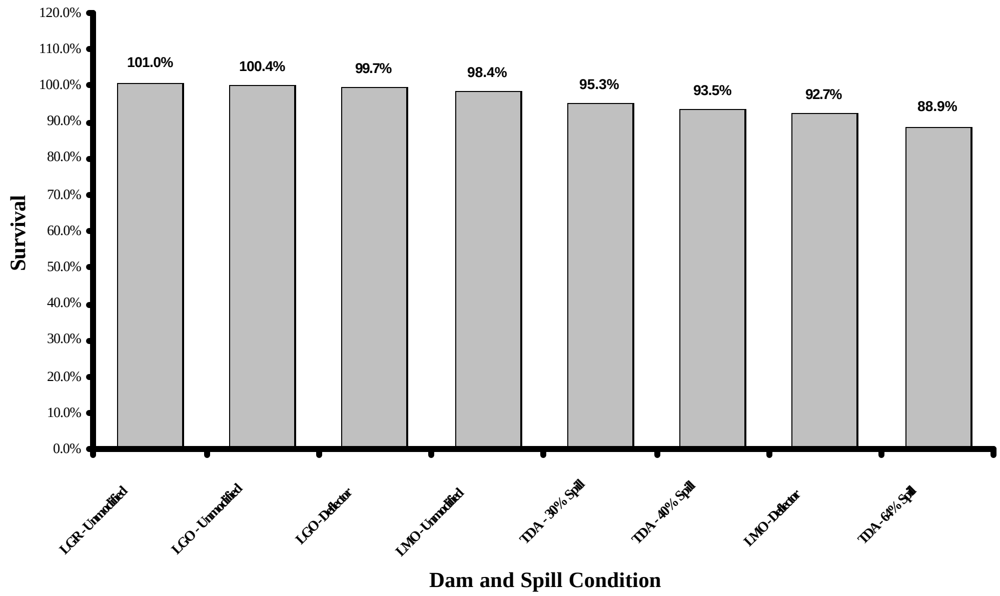

Figure 2.1—. Spill survival estimates reflecting total effects, using PIT tags in a paired-release design. Survival estimates represent the average across years and species for a given spill condition (i.e., deflector vs. unmodified spillbays and varying levels of spill). Averages were calculated using estimates reported in Muir et al. (2001a) and Ploskey et al. (2001).

A number of balloon tag studies have been conducted at Wanapum, Little Goose, and Bonneville dams, which are useful for comparing smolt survival through spillbays with and without flow deflectors. In those studies, 13 separate comparisons between spillbays with and without deflectors were made at varying spill levels. In 85% of the comparisons (11 of 13), survival of fish passing the project via a spillbay without a deflector was equal to or greater than spillbays with deflectors. Those data are summarized in Figure 2.2.

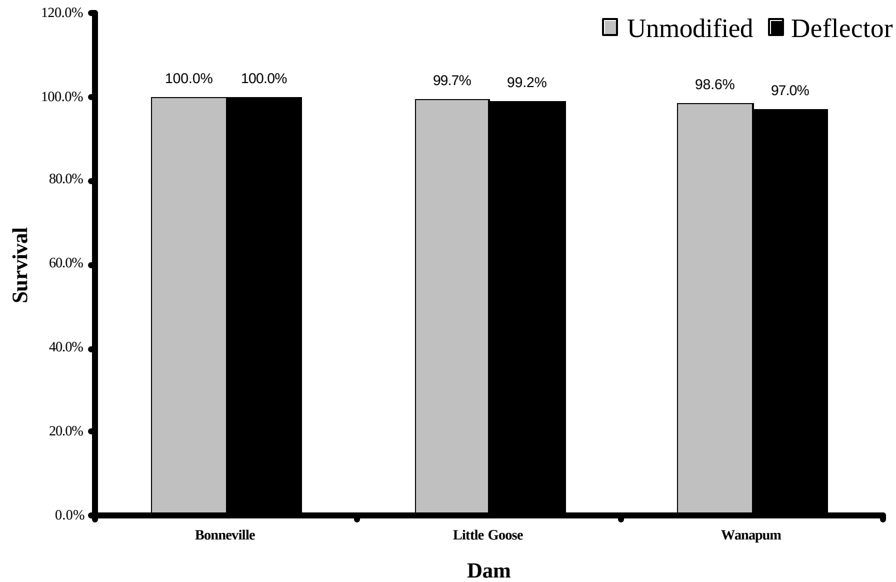

Figure 2.2— Mean survival (across years and species) that reflects only direct effects (balloon tag-based estimates) through spillbays with and without flow deflectors at Bonneville, Little Goose, and Wanapum dams.

Although differences in survival rates associated with the two spillway conditions have rarely been found to be significant, a consistent pattern is evident. Smolts passing spillways with flow deflectors consistently exhibit survival rates lower than spillways absent of deflectors. The reduction in survival equates to 1-3% depending on the dam and species, as well as the tool employed. It appears that flow deflectors depress survival, but survival still exceeds that evident in turbine passage (Muir et al. 2001a).

Whitney et al. (1997) reported that flow deflectors could reduce TDG by 10 to 20% at a particular spill discharge. This benefit must be weighed against the potential for increased smolt mortality that appears to be generally associated with the presence of flow deflectors. We have not encountered an analysis of this tradeoff in the general literature on this topic.

Is Smolt Survival Sensitive to the Volume of Water Spilled?--Survival estimates reflecting either direct or total effects can be instructive in addressing this issue. The effect of spill volume on smolt survival has been investigated at Wanapum, Rock Island, Little Goose, and The Dalles dams. Figure 2.3 and Table 2.1 summarize the results from those studies:

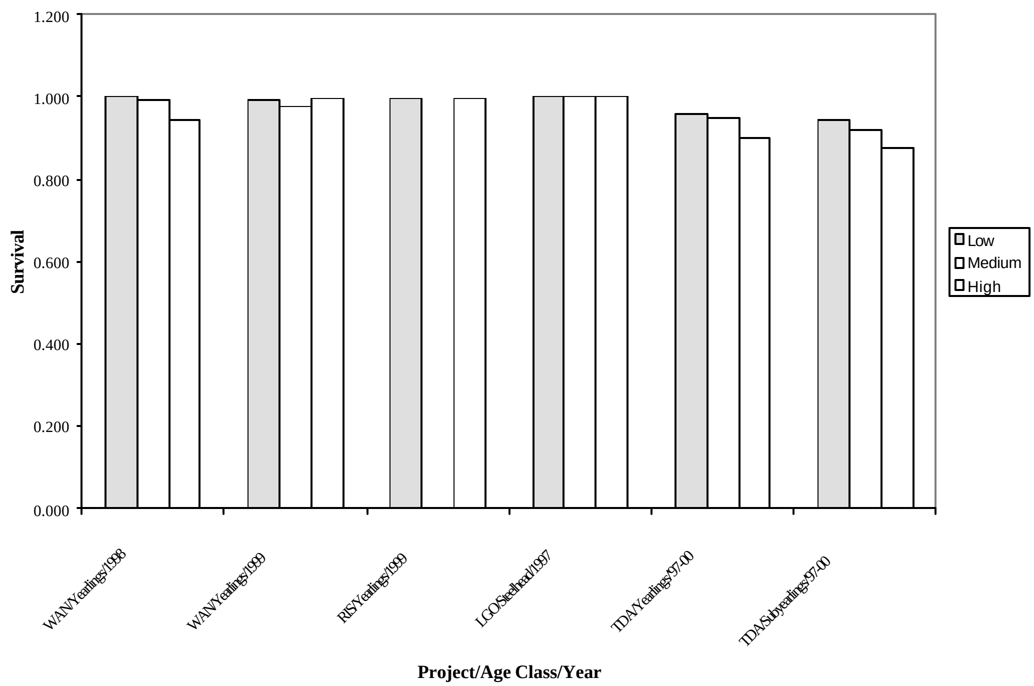

Figure 2.3— Survival rates of juvenile salmonids at low, medium, and high spill rates. Estimates of survival for Wanapum, Rock Island and Little Goose dams represent direct effects as estimated using balloon tags (Appendix B). Survival estimates at The Dalles Dam represent total effects obtained with PIT tags (from Ploskey et al. (2001); Appendix B).

Collectively, the survival estimates at varying spill levels indicate that some benefits may be associated with lower spill levels. However, the range in estimates spans from no effect to as much as nearly 7% difference in survival, depending on species. The most dramatic differences have been observed at the Dalles Dam, where spillway survival decreases steadily as spill fractions increase from 30% to 64% (Figure 2.3, Table 2.1). Clearly, there is a strong indication that spillway survival could be maximized by selecting the most benign level of spillway discharge at a specific site. Of course, these survival probabilities need to be balanced against spillway passage efficiency and other passage route usage, in order to determine the spill volume (or percent) that maximizes the survival of the smolt population passing the entire dam. That exercise involves a modeling analysis. We have not encountered any study that has systematically evaluated such across the various dams.

Table 2.1—Survival rates of juvenile salmonids at low, medium, and high spill rates. Estimates of survival for Wanapum, Rock Island and Little Goose dams represent direct effects. Survival estimates at The Dalles represent total effects.

Year	Project	Species	Survival	Condition
1998	WAN	Hatchery Yearling Chinook	1.000	2,000 cfs
			0.993	5,000 cfs
			0.945	10,000 cfs
1999	WAN	Hatchery Yearling Chinook	0.994	2,800 cfs
			0.976	6,000 cfs
			0.995	7,500 cfs
1999	RIS	Hatchery Yearling Chinook	0.995	2,500 cfs
			0.995	10,000 cfs
1997	LGO	Hatchery Steelhead	1.000	1,800 cfs
			1.000	5,600 cfs
			1.000	9,500 cfs
1997-2000	TDA	Coho and Chinook Yearlings	0.960	30% spill
			0.950	40% spill
			0.900	64% spill
1997-2000	TDA	Subyearling Chinook	0.945	30% spill
			0.920	40% spill
			0.877	64% spill

2.3 Population Level Responses to Spill Conditions

2.3.1 Empirical Based Observations

Muir et al. (2001a) estimated the survival of yearling chinook salmon and steelhead migrating through the Lower Snake and Columbia rivers for the years 1993-1998. They reported that the mean smolt survival per-project through the Snake River ranged from 86 to 94% for yearling chinook and 88 to 92% for steelhead. Although they did not conduct a formal spill analysis, they noted that survival was highest in years (1995-1998) when spill levels were highest and of longest duration (in terms of days provided). However, in four of those years total river discharge was high and may have been a contributing factor. Their observations are not definitive, but certainly suggest that spill was a likely agent contributing to the improved survival of smolts migrating in-river.

<u>2001 Analyses</u>--Recently, two different fisheries agencies (FPC and NMFS) have analyzed the effects of spill on smolt survival in 2001, one of the lowest water years on record. Both groups relied on project-specific (pool and dam combined) smolt survival estimates generated from PIT-tag data as the foundation for their analyses. Each, in their own manner, blocked the migration period into spill and non-spill periods, and then compared survival estimates during each treatment period. To our knowledge, these two analyses represent the only examples of empirically based spill evaluations of this sort.

<u>NMFS Analysis</u>-- In 2001, NMFS analyzed the effects of spill on survival of smolts passing several projects in the lower Columbia including McNary, John Day, and the reach encompassed by The Dalles and Bonneville dams (Zabel et al. in press). The response variable being smolt survival through one or more projects blocked by weekly release groups. Several stocks of PIT-tagged fish were monitored as they migrated downstream through the hydro-system, including: Snake River spring/summer chinook and steelhead, Upper Columbia spring chinook, Yakima spring chinook, and upper Columbia summer/fall chinook. During the 2001 smolt migration period, spill was limited to a single discrete temporal block extending from the latter part of May to the first part of June. Zabel et al. (in press) estimated survival during pre-spill, spill, and post-spill periods (treatment blocks). They tested whether survival was higher during the spill period.

As smolts migrated through the John Day project (McNary tailrace to John Day tailrace) Zabel et al. (in press) estimated the highest survival occurred during the spill period (Figure 2.4). This was the case for each of the five stocks they monitored, with only one (steelhead) failing to exhibit a significant difference in survival. Yet they did not conclude that the observed survival patterns were clearly attributable to the spill event. This is because they had additional information as a backdrop. That data indicated that survival of Snake River spring/summer chinook displayed a temporal trend of increasing survival during May, independent of spill conditions. The pattern was observed in 2001, as well as in three previous years (1998-2000) when spill occurred throughout the month of May (USACE 1998; 1999; 2000). They suggest that the spill event in 2001 appears to have occurred coincidentally with the period they historically observed peak survival. They suspect that a regular natural temporal rhythm of survival is occurring and confounds any *a posteriori* inferences regarding 2001 spill effects. Also, they noted that the pronounced decrease in survival during the post-spill period suggests other mechanisms affecting survival may be at play. Although Lower Columbia flows were relatively stable over the study period, water temperature increased from 9 to 18 degrees Centigrade over the study period. Temperature-mediated predator-related smolt mortality relationships are well accepted (Vigg and Burley 1991), and may explain the post-spill drop-off in survival. If, as Zabel et al. (in press) suggests, the inherent annual peak in survival coincided with the spill in 2001, then this may obfuscate the true extent of effects attributable to spill alone. For this reason NMFS felt the analysis was inconclusive.

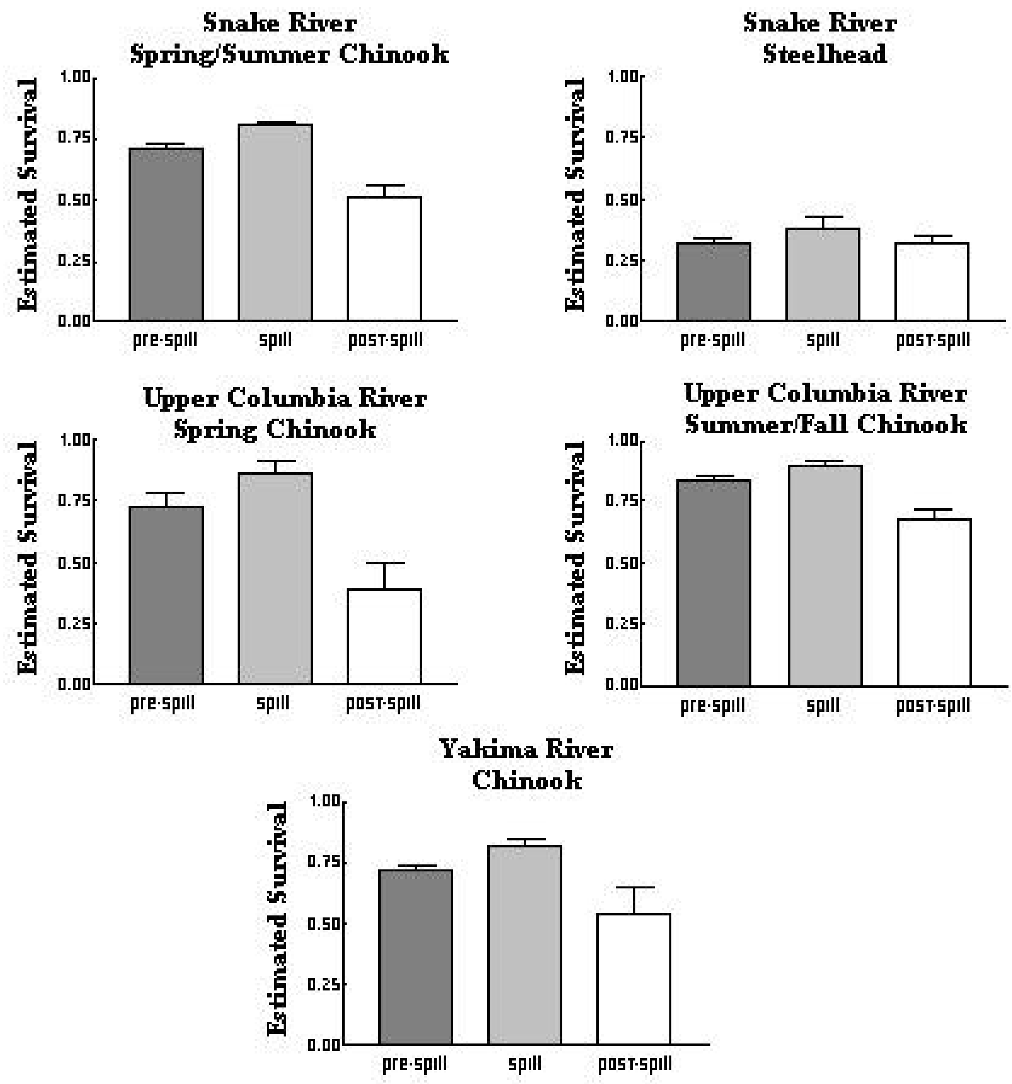

Figure 2.4—Estimated survival by stock for the pre-spill, spill and post-spill periods for fish migrating through McNary Dam and John Day reach. The line of above each bar represents one standard error (from Zabel et al. in press).

Zabel et al. (in press) observed that fish passing through other projects did not exhibit such consistent positive responses to the presence of spill, as was indicated at the John Day project. In assessing the effects of providing spill at McNary Dam, they observed that smolt survival was higher during the pre-spill period, for both stocks they analyzed (Table 2.2). There may be complicating factors here, in that the response variable in this case is survival from Lower Monumental tailrace through both the Ice Harbor and McNary projects. No spill occurred at Ice Harbor, and conditions encountered there may have influenced survival over this extended reach. Thus, we view this result with some caution.

Table 2.2— Spill analysis with associated survival estimates and standard errors (in parentheses) provided by spill blocks pre-spill, spill, and post-spill (from Zabel et al. in press).

		Survival Estimates (Standard Error)			P-values		
Stock	**Reach**	**Pre-Spill**	**Spill**	**Post-Spill**	**H1**	**H2**	**Conclusion**
Snake River Chinook	MCN-JDA	0.712 (0.018)	0.805 (0.018)	0.514 (0.045)	<0.001	0.001	All different
U. Columbia Spring Chinook	MCN-JDA	0.726 (0.064)	0.868 (0.048)	0.390 (0.107)	0.047	0.080	Spill different
U. Columbia Sum/Fall Chinook	MCN-JDA	0.845 (0.020)	0.904 (0.020)	0.680 (0.041)	0.004	0.001	All different
Yakima River Chinook	MCN-JDA	0.716 (0.025)	0.817 (0.037)	0.593 (0.110)	0.014	0.213	Spill different
Snake River Steelhead	MCN-JDA	0.312 (0.023)	0.371 (0.055)	0.130 (0.060)	0.253		No spill effect
Snake River Chinook	LMO-MCN	0.732 (0.004)	0.625 (0.007)	0.166 (0.023)	<0.001	<0.001	All different
Snake River Steelhead	LMO-MCN	0.311 (0.008)	0.218 (0.014)	NA	<0.001	<0.001	All different
U. Columbia Sum/Fall Chinook	JDA-BON	0.304 (0.152)	0.817 (0.095)	NA	0.017	NA	Spill different
Yakima River Chinook	JDA-BON	0.549 (0.272)	0.592 (0.088)	NA	0.310	NA	No spill effect

As smolts migrated from John Day tailrace to Bonneville tailrace, they passed two projects (The Dalles and Bonneville) where only a pre-spill and spill treatment period was encountered. Two stocks were analyzed. The survival of upper Columbia summer/fall chinook was dramatically and significantly higher during the spill period (0.817), compared to the pre-spill period (0.304). However, through the same reach over the same general timeframe, the survival of Yakima spring chinook was nearly the same during the pre-spill and spill period, at 0.549 and 0.592, respectively.

FPC Analysis--Analysts at the Fish Passage Center also conducted a preliminary analysis of spill effects on smolt survival at John Day Dam in 2001, and released the information in the form of a technical memorandum (FPC 2001). They too relied on project survival estimates derived from PIT tag data. In contrast to Zabel et al. (in press), they blocked the study into only two time periods, 1-21 May (no spill) and 22 May - 9 June (spill occurred at John Day). Additionally, the experimental population as designated was an admixture of PIT-tagged Upper Columbia and Snake River populations passing McNary Dam, not individual populations as treated by Zabel et al. (in press).

They observed that a significant increase in survival of both yearling chinook and steelhead occurred after 21 May (Table 2.3), coincident with spill. They also observed a decrease in collection efficiency between the two periods suggesting a pronounced shift of the smolt population toward and through the spillway, when spill was provided. The implication being that the pronounced increase in survival could be attributable to a substantial proportion of the smolt population using the spillway.

Table 2.3— Survival Estimates and collection efficiency estimates (parentheses) at the John Day project (FPC 2001).

Dates	Yearling Chinook	Steelhead
5/1-5/21	0.788 (0.369)	0.314 (0.400)
5/22-6/9	0.897 (0.204)	0.381 (0.096)

Based on their analyses, they advised that it would be prudent to provide spill even in low flow years like 2001.

The observed change in collection efficiency reflects both spillway usage and perhaps changes in fish guidance efficiency at screens in the powerhouse. Independent estimates of these parameters could be instructive when interpreting mechanisms that influence spillway passage and survival. In 2001, such estimates could be forthcoming from radio telemetry studies conducted by Counihan and Petersen (2001 abstract). But analysis of those data has not yet been completed.

Conclusions--For the spill assessment at John Day Dam, Zabel et al. (in press) make a compelling argument as to why the observed changes in survival may not actually reflect spill effects. We acknowledge the potential for confounding, associated with the observed temporal trend in smolt survival, is plausible and of concern. On the other hand, all five stocks they monitored exhibited the highest survival during the period spill was provided. Clearly, the experimental design will not permit resolution of this matter. These same concerns should apply in the FPC analyses as well. But they did not treat temporal trends to the extent that NMFS did. The apparent high passage rates of smolt through the spillway, as inferred from shifts in collection efficiency, certainly indicate a plausible mechanism that could magnify survival during the spill period.

The fact of the matter is, there is no clear hypothesis test that can be performed here. The analyses could not clearly isolate spill as a discrete treatment. Thus, it is not possible to estimate the change in survival attributable to spill alone. Nevertheless, the high spillway passage rates observed at John Day Dam, even under modest spill levels (FPC estimated near 13% of total discharge), suggest that providing spill contributed to the improved smolt survival. Perhaps pending radio telemetry estimates can provide more insight on this matter.

The FPC and NMFS analyses reinforce the consideration that it is very difficult in a system as complex as the FCRPS to isolate a single variable (in this case, spill) and its effect on survival. The 2001 conditions with spill off/on/off is probably the clearest delineation we have experienced over many years of survival studies, with respect to spill treatment. Since this fortuitous situation was not satisfactory for drawing sound conclusions, then only a more sophisticated and complex treatment design can resolve the matter. It is certainly possible to design such a treatment protocol. The difficulty will be implementing it in a normal, or above normal, water-year, when involuntary spill occurs naturally and unexpectedly. The lower water-years, or perhaps summer periods, offer the best opportunity to implement a more satisfactory planned experimental treatment schedule.

At projects other than John Day, results from Zabel et al. (in press) were even less clear. The McNary analysis involved a potentially complicating condition. The response variable was survival from the Lower Monumental tailrace through both the Ice Harbor and McNary projects. No spill occurred at Ice Harbor Dam, and conditions encountered there may have influenced survival over this extended reach. Thus, it is difficult to conclude anything related to McNary spill from that dataset.

At the lower Columbia dams (The Dalles and Bonneville), the two populations displayed dramatically different responses during the only two treatment periods available (pre-spill and spill) (Zabel et al. in press). Given this information, it is difficult to conclude that the pronounced increase in survival witnessed for the summer/fall chinook was strictly spill induced. The change in survival was so large (from 0.304 to 0.817) that it is difficult to postulate the spill-related mechanisms that would elicit a nearly three-fold increase in survival during the spill period.

2.3.2 Model Analyses

Computer-based smolt passage models (e.g., CRiSP or SIMPAS) can be employed to estimate the total mortality experienced by a smolt population encountering a particular spill scenario at either a single dam, or through a series of dams. A recent analysis by NPPC staff illustrates such an application (NPPC 2001). Within a passage model, the amount of water spilled can be prescribed at each dam, as can total river flow and temperature profiles. Using these environmental and operational conditions to characterize the system, the fate of smolts is traced through the hydro-system. The output of the models is smolt survival through some specified reach of river. Rules embedded in the model dictate what proportion of the smolt population passes through the different routes (spill, turbine and bypass), and what mortality rate is associated with each of those routes. Reservoir mortality can be reflected in different ways, depending on the construct of the model. Of course, the accuracy of the model-predicted smolt survival relies heavily on the quality of the estimates for route-specific survival, the fraction of the population using the route, reservoir mortality, and in this specific case - any indirect effects that are spill-related.

Our objective here is to highlight key issues pertaining to the application of passage models in spill analyses. We do not intend to contrast and compare various models and underlying assumptions. Several previous analytical forums have invested years and produced voluminous reports doing so (System Operation Review, and the Plan for Analyzing and Testing Hypotheses).

Passage models use various empirical estimates of smolt survival, passage route efficiencies, and behavioral characteristics as either input, or rules, to construct and drive the model. Where estimates are lacking or unsatisfactory, values are often assumed or generalized estimates applied. Considerable research has been directed at improving smolt passage-related estimates in recent years. Research on these topics has intensified under the auspices of the USACE Anadromous Fish Evaluation Program, particularly over the last three to five years. It stands to reason that the most useful model predictions are those based on the most current information. The information is becoming voluminous, thus compiling and selecting the most appropriate and representative sets of estimates can be a formidable task. Of particular concern are the criteria adopted for selecting the best estimate from a pool of competing candidate values or algorithms. In our opinion, it would be folly for one individual, or even a single fishery agency to establish the criteria and then select the "best" estimates. There will surely be factions that take exception to the resultant set of estimates. It seems more appropriate for diverse technical groups to develop and apply criteria for assembling the most representative set that could be adopted as a standard.

Most of the parameter values internal to SIMPAS were adopted from datasets assembled during PATH. Many of those values are due for updating. Therefore, analyses conducted with the model may not reflect the most current understanding of certain passage conditions. Furthermore, the SIMPAS model became available after PATH had terminated. As a consequence, it was not subjected to the model assessments, comparisons, and parameter sensitivity tests that prevailed during that forum. Since the SIMPAS model is becoming more commonly applied in regional assessments, it may be advisable that this model and the standard data sets used for input and calibration be reviewed and updated.

Recently, the NPPC staff used the SIMPAS model to evaluate relative changes in smolt survival under four spill scenarios (NPPC 2001). They found that the greatest change in survival across spill scenarios was evident for stocks emanating from the Lower Columbia River, followed by Mid-Columbia, then Snake River stocks. The difference among smolt sources was primarily attributable to their exposure to transportation. The analysis was sound, but did the tool they employ accurately represent spill-related survival, particularly under the extreme low flow conditions witnessed in 2001? Given our impression of the status of the model, that is not clear.

2.4 Incidental Effects of Spill

2.4.1 Total Dissolved Gas

The NMFS 2000 Biological Opinion specified that Total Dissolved Gas (TDG) levels were to be limited to 115 and 120 percent in the forebays and tailraces of hydroelectric facilities in the Federal Columbia River Power System (FCRPS), respectively. To ensure these constraints were implemented, the Biological Opinion specified that real time physical measurements of TDG were to be taken throughout the FCRSP.

According to an assessment in the recent Mainstem Provincial Review for the five years of physical monitoring, where spill volumes were dictated primarily by the BO regulated spill program, TDG levels have been successfully restricted to the desired levels. The biological monitoring program has demonstrated that compliance with the TDG limits outlined in the 1995 Biological Opinion typically results in less than 1% of the juvenile migrants sampled exhibiting signs of gas bubble trauma (GBT). In contrast, conditions producing involuntary spill (i.e., when river flow exceeds powerhouse capacity and spill caps) have resulted in TDG levels of 130 to 140 percent for a number of consecutive days, resulting in 3.2 to 3.3 percent of the migrants exhibiting signs of GBT. It should be noted however, that research correlating mortality associated with the exhibited level of GBT symptoms has not been conducted. Regardless, exhibited signs of GBT are low when TDG levels are managed as specified in the NMFS 2000 Biological Opinion.

Hydroelectric projects not part of the FCRPS, and therefore not regulated by the NMFS 2000 Biological Opinion, include Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells dams. Review of gas data in the Mid-Columbia reveals that the FERC projects are essentially operating within the NMFS Biological Opinion guidelines for TDG levels in the tailrace of the dams. That is, TDG levels for the most part do not exceed the 120 percent tailrace limit. To illustrate this, we present data from two recent years, 1999 and 2000 (Figures 2.5 and 2.6).

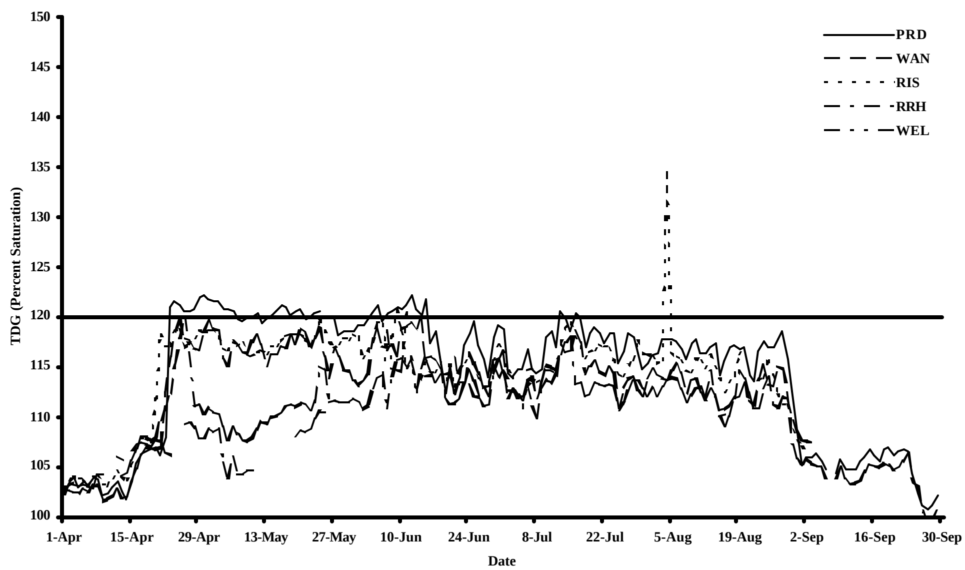

Figure 2.5— Total dissolved gas levels in the tailrace of Priest Rapids, Wanapum, Rock Island, Rocky Reach and Wells dams, April 1 – September 30, 1999. The solid horizontal line represents NMFS 2000 BO TDG tailrace standard.

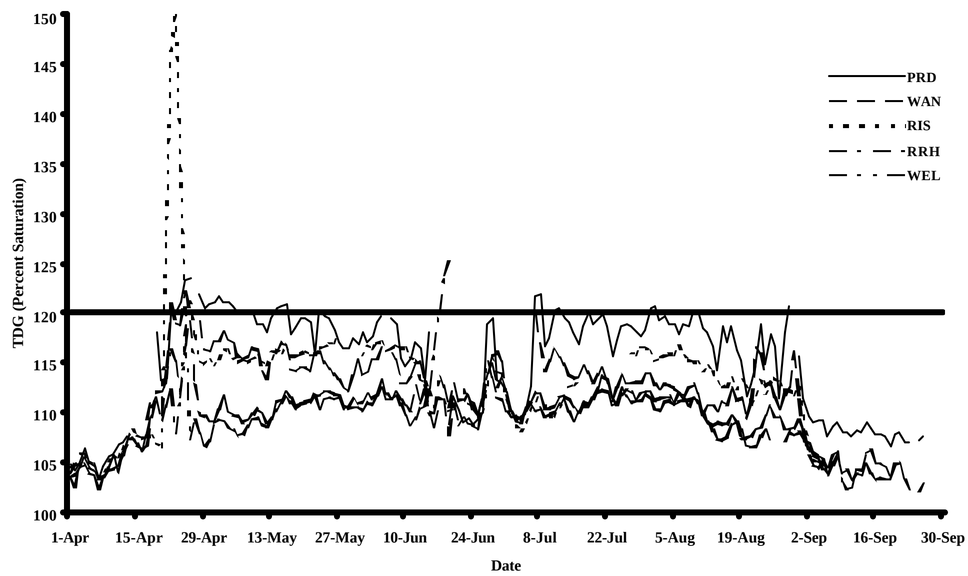

Figure 2.6— Total dissolved gas levels in the tailrace of Priest Rapids, Wanapum, Rock Island, Rocky Reach and Wells dams, April 1 – September 30, 2000. The solid horizontal line represents NMFS 2000 BO TDG tailrace standard.

In 1999, the total dissolved gas levels within the tailraces of most of the Mid-Columbia projects were well below the 120% NMFS standard. The exception was Priest Rapids Dam, where TDG levels in the tailrace exceeded 120% on 36 occasions between April 23 and June 15. However, TDG levels were seldom greater than 122%, and therefore, sustained TDG levels of this nature likely had minimal effects on salmonids. On August 4, TDG levels within the Rock Island tailrace reached 134.4%. However, this value appears suspect since gas levels at Rock Island prior to and after the event were low. Also, gas levels downstream of Rock Island did not exhibit similar trends on the same date.

Similar trends appear in the data from 2000 for the Mid-Columbia, where TDG levels were typically below the 120% tailrace threshold. Only TDG levels within the Priest Rapids tailrace approached or exceeded the 120 percent limit. However, the 120% threshold was exceeded infrequently, and at low levels. The 150.3% value for Rock Island on April 23 appears to be erroneous for the same reasons as explained above for the apparent outlier in 1999.

2.4.2 Adult Passage Impacts

Spilling water does not offer any direct benefit to migrating adults. However, there can be risks associated with spilling water. We previously discussed potential risks associated with total dissolved gas saturation, and concluded that the NMFS Biological Opinion spill program does not endanger salmonids. The spill discharge caps specified in the 2000 FCRPS Biological Opinion appear effective in this regard. This interpretation appears consistent with the characterization presented in NMFS assessment of adult passage with respect to the managed spill program (NMFS 2000b).

Apart from concerns regarding direct mortality, spilling water can also alter migratory patterns, and in some cases result in protracted migration of adults, particularly when flows and spill levels are high (NMFS 2000b). These river conditions can occlude fishway entrances and may increase fallback. Fallback is the behavior whereby adult fish move downstream past dams they have already ascended. It is disadvantageous because it can cause injury, mortality or migrational delay. Bjornn and Peery (1992) examined radio telemetry data for a relationship between fallback frequency and prevailing flow and spill levels at several Columbia River dams, and identified positive significant correlations at some of the dams. However, in 1996 Bjornn et al. (2000) examined the same type of data for chinook salmon. They reported that fallback appeared to increase with increasing spill and flow, but the correlations were very weak as evidenced by r-squared values that were all less than 0.17 at each of the 4 dams (Bonneville, The Dalles, John Day, and McNary) for both predictor variables. We would conclude that no meaningful relationship was demonstrated. These results contrast with their previous 1993 analysis. They also presented evidence indicating that increased fallback at dams may depress survival through to spawning. Approximately 71.4% of the chinook salmon that fell back at Bonneville Dam survived and were detected either entering major tributaries, or at least passing Priest Rapids Dam. In contrast, 77.7% of fish that did not fallback at Bonneville Dam survived to, and were detected at, those same locations. The implication is that fallback may induce trauma, or protract migration, which contributes to reduced survival.

English et al. (1998) compared migration rates and fallback rates for three species of salmon at Rocky Reach and Rock Island Dams. They observed increased travel times and fallback rates in 1997 compared to 1993. They noted that spill discharge was substantially higher in 1997, and implied that increased spill was a likely agent. However, they did not conduct a formal analysis of spill and other potential factors on fallback.

It is not clear if spilling water as prescribed in the NMFS Biological Opinion exacerbates fallback, and thus increases risk to adults. Results from the evaluations presented here are not consistent. The relationship between fallback and spill discharge appears to be dependent on the year and/or dams investigated. We have not encountered an analysis that specifically and explicitly evaluates the effects of existing spill programs on adult passage. In our view, this is a deficiency, and an analytical effort involving a meta-analysis of data across dams, years, and species may be warranted.

2.5 Summary

Spillways generally appear to be the safest passage routes available at a dam, even more benign than many smolt bypass systems, particularly those involving the screening of turbine intakes. The magnitude of smolt survival through spillways varies by dam and species. This is particularly evident when total effects are reflected in the empirically obtained estimates. A number of studies have indicated that survival is related to spillway discharge levels at some sites, with mortality increasing at excessive discharge volumes. The difference in survival across discharge levels can range from negligible to nearly 7 percentage points, depending on dam and species.

In passage modeling analyses, values for model parameters should be periodically updated for each dam and species. The set of empirical estimates that characterize smolt passage survival through spillways (and other routes) and spill efficiency are being continually expanded. However, that collective information is not typically being systematically compiled and synthesized on a regular basis. Notable exceptions include papers by Muir et al. (2001a), Ploskey et al. (2001) and Anglea et al. (2001) for selected site.

Passage modeling may afford the only practical means to evaluate the relative effectiveness of various spill scenarios. Obtaining reliable empirical survival estimates linked specifically to spill conditions will be extremely difficult.

Spillway flow deflectors appear to increase smolt mortality relative to a standard spillbay, by 1-3 percentage points. The potential for increased smolt losses at the concrete need to be balanced against gains associated with gas abatement. It is not clear that passage models currently provide an accurate assessment of this tradeoff. The Total Dissolved Gas standard of a maximum 120% saturation in the tailrace of Columbia River dams is generally achievable by following the dam-specific gas caps identified in the NMFS Biological Opinion and implementing the spill program currently in place in the Mid-Columbia. The exception occurs in higher flow years when spill volumes cannot be effectively controlled due to flows exceeding the hydraulic capacities at the various dams. During these periods, spill discharge naturally exceeds the caps prescribed in the Biological Opinion (Appendix A). The standard appears satisfactory for protecting salmonid species within the hydro-system.

The effects of spill operations and levels on adult passage behavior as linked to long-term survival are not well understood. Some of the research suggests that higher spill volumes may exacerbate migration delay and fallback. But convincing quantitative relationships have not been developed.

The full biological impacts of a spill program have not been evaluated in their entirety. Smolt survival receives emphasis. Model analyses try to predict changes in smolt survival to below Bonneville Dam. Empirical analyses such as those conducted by Zabel et al. (in press) and FPC (2001) observe changes over small segments (projects), thus cumulative effects through the system are not evident. Results from empirical evaluations are equivocal; spill effects are not clearly isolated from other factors. Quantitative system analyses have not formally included the potential for impacts on adult mortality.

2.6 Critical Uncertainties and Research Opportunities

<u>Evaluating Spill Effects at the Population Level</u>-- The only analysis that has attempted to assess the change in survival for the smolt population subjected to different spill scenarios is the 2001 model analysis conducted by NPPC staff. That analysis may not be entirely satisfactory because the SIMPAS model used in the analysis likely requires updating. An expanded and hopefully improved set of passage related estimates are available since it was constructed. We suggest this and other models be examined as candidates for similar applications. In our opinion passage models may offer the most tractable means to estimate the relative benefits associated with various spill strategies. We think it will be very difficult and likely impractical to conduct well-designed manipulative experiments that can isolate spill effects, in this complex, and often times uncontrollable, river system.

<u>Spill Effects on Adult Passage and Long-term Survival</u>-- The effects of spill levels on adult passage behavior and ultimately survival to spawning remain unclear. Some of the research suggests that higher spill volumes may exacerbate migration delay and fallback. But convincing quantitative relationships have not been developed. Telemetry-based passage monitoring is planned for 2002 in the FCRPS. We suggest that this be established as a long-term monitoring effort, with broad species coverage. The type of information being collected by University of Idaho investigators and the Mid-Columbia PUDs should provide a foundation for exploring these relationships.

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3.0 FLOW AUGMENTATION

Flow augmentation (FA) is the intentional release of water from storage reservoirs for the purpose of increasing flows to enhance migratory conditions for juvenile and adult life stages of salmonids in the Snake and Columbia rivers. Flow augmentation provided to the upper Columbia River (downstream from Chief Joseph Dam) comes from large storage reservoirs such as Grand Coulee Dam and a complex of storage reservoir that drain into it from Canada and Montana. In the Snake River flow augmentation is provided from Dworshak Dam and through the Hells Canyon Complex in Idaho (Figure 3.1). The foundation for prescribing such actions is based on two premises:

5. Increased water velocity → increases migration speed of smolts → increases survival.
6. Lowering water temperature (summer) → improves migratory and rearing conditions for both juvenile and adult salmonids → results in improved survival.

We focus on information obtained or reported since the early 1990's, but a brief historical backdrop is provided where needed. Our rationale for emphasizing contemporary conditions is consistent with what we expressed earlier. Both river operations and the mark-recapture tools and associated analytical procedures have changed markedly from previous decades. Thus, the contemporary information is most applicable today. In some cases we present a brief historical background. However, the historical material is more fully reviewed in the NMFS white paper regarding salmonid travel time and survival (NMFS 2000), in Giorgi (1993), and Cada et al. (1997).

3.1 Premise 1–Increasing water velocity in reservoirs increases smolt migration speed, which results in improved survival.

Reservoir Effects-- This premise has been examined and analyzed for over three decades since as early as the late 1970's (Raymond 1979, 1988; Sims and Ossiander 1981). According to the premise, as river discharge volumes increase (flow), the water velocity in the reservoirs increases. In response, the migration speed of salmonid smolts increases (or travel time decreases). The shorter smolt travel time, the shorter the exposure to predatory fish or birds, or seasonally increasing water temperature. All are potential agents causing smolt mortality in the reservoirs. Thus, it is reasoned that swifter migration should result in higher survival of smolts through the reservoirs.

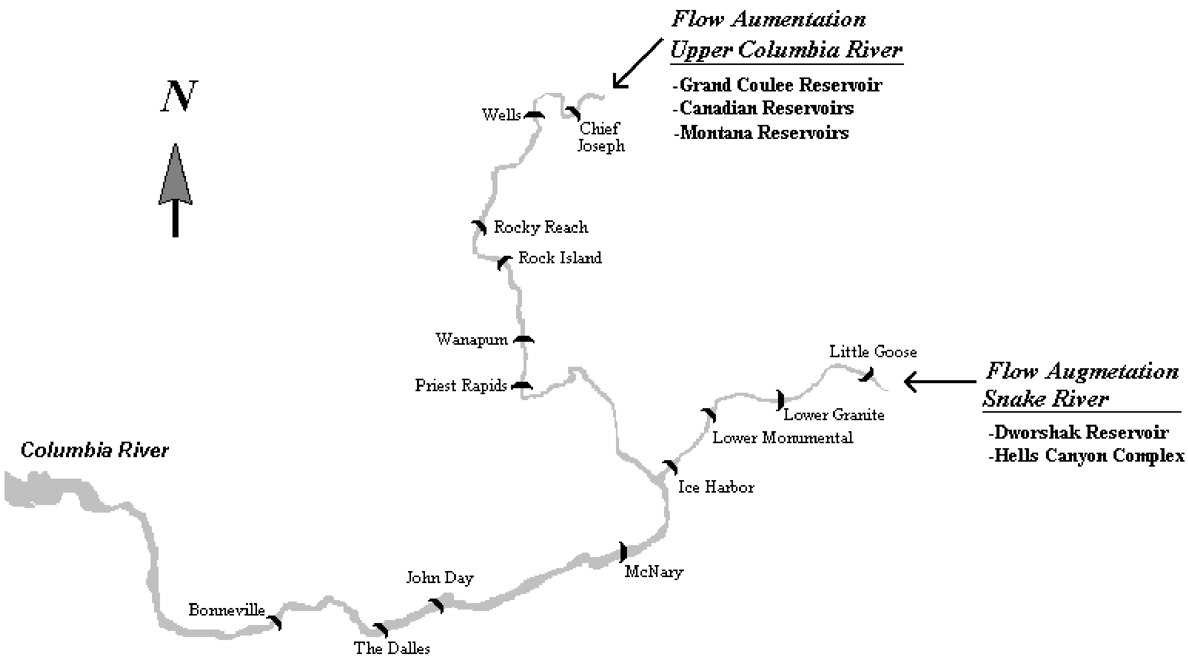

Figure 3.1—Flow augmentation provided to the Columbia Basin from the Upper Columbia and Snake River areas.

Biological Window--There is another aspect to the premise that has been argued as well. Apart from mortality incurred during passage through the hydrosystem, it has been suggested that migration delay may impair survival of smolts at seawater entry. The conceptual model holds that smolts are swept seaward by river currents, and historically the timing of seawater entry was dictated by the shape and intensity of the hydrograph, and this in turn was synchronized with a “biological window”. And thus, slower migration associated with impoundments has disrupted the natural timing of ocean-entry, potentially placing smolts at a disadvantage. This theoretical window has two aspects; the ecological/environmental condition of estuarine and marine waters, and the physiological preparedness for smolts to adapt to seawater. As yet there has been no definitive convincing research conducted on this topic. However, the community is now embarking on a new era of estuarine/marine research that may offer insight on these matters. In particular, research target processes influencing Extra Mortality as identified in PATH may be most instructive. That body of research is still being formulated as part of the Research Monitoring and Evaluation Plan, developed by the Action agencies, in response to the FCRPS BO.

3.1.1 Flow and Migration Speed

Early investigations described the migratory characteristics of spring/summer yearling chinook and steelhead through the Snake and Columbia rivers (Ebel and Raymond 1976, Bentley and Raymond 1976). Typically, travel time and/or survival estimates for the composite wild and hatchery populations were presented, often in the form regression analyses that included estimates from a number of years (Sims and Ossiander 1981).

Impoundment of the Snake and Columbia Rivers has decreased the migration speed of yearling chinook salmon and steelhead. Ebel and Raymond (1976) estimated that in 1973, yearling chinook salmon and steelhead took about 65 days to reach the Dalles Dam from trap sites on the Salmon River in Idaho. They suggested this was approximately twice the time required before dam construction. Bentley and Raymond (1976) also presented data that indicated migration of smolts was slower after impoundment. Following the construction of Lower Monumental and Little Goose dams on the Snake River, yearling chinook smolts took about twice as long to traverse the distance from release sites on the Salmon River to Ice Harbor Dam.

NMFS investigators first provided evidence that prevailing river discharge volumes influenced the rate of migration through certain segments of the Snake and Columbia rivers. Sims et al. (1978) observed that during the dramatically low flows in 1977, yearling chinook traversed the reach from those same Salmon River traps to the Dalles Dam in 57 days; whereas, in 1975 and 1976 Sims et al. (1976 and 1977) indexed travel time at 21 and 27 days, respectively, about half that observed in 1977 with the same numbers of dams in place. In 1976 and 1977, the flow index for the Snake River ranged from 110-140 kcfs, whereas in 1977 it was 40 kcfs as reported by Giorgi (1993). These data sets provided the first quantitative treatment of the relationship of flow on smolt migration speed through the hydroelectric system.

Sims and Ossiander (1981) expanded the data set and presented a synthesis of flow/travel time estimates for the yearling chinook and steelhead for the years 1973-1979. They correlated annual indices of travel time with the flow at Ice Harbor Dam during the migration peak. The correlation indicated that in years when flows were high, fish moved faster from the upper dam, either Little Goose of Lower Granite, to the Dalles Dam.

The Fish Passage Center has continued to add to this smolt travel time data set since 1984. In 1993, Berggren and Filardo (1993) synthesized information available through 1990, and analyzed smolt travel time as associated with a number of predictor variables including flow, water temperature, and release date (a surrogate for the level of smolt physiological development). They found that combinations of these variables provided the best explanation of the observed variability in smolt travel time. However, they reported that average river flow explained most of the variability observed in smolt travel time multiple-regression models for most stocks. They reported flow-travel time algorithms for Snake River yearling chinook and steelhead, and steelhead from the mid-Columbia, as well as sub-yearling chinook migrating through John Day Pool. No model could be developed that was satisfactory for explaining the observed travel time of yearling chinook in the mid-Columbia, from RIS to MCN Dam.
How much change in smolt travel time do these models predict per unit flow? To depict this we offer one example. Using the Berggren and Filardo (1993) bivariate flow-based model for Snake River yearling chinook, Giorgi (1993) predicted the change in travel time attributable to incremental increases in river discharge. He demonstrated that when base flows were low, the proportionate change in travel time was highest. For example, as Snake River flow increased from 40 to 50 kcfs, the average travel time per project decreased from 5.0 to 4.2 days, whereas when flows increased from 100 to 110 kcfs, travel time decreased by only 1/10 of a day, from 2.7 to 2.6. Clearly the most dramatic responses would be expected in low flow years.

Giorgi et al. (1994) examined a data set for freeze-branded sub-yearling chinook migrating through the John Day Pool. Using data from 1981-1983, they failed to find a consistent relationship between smolt travel time and any of the three-predictor variables (flow, water temperature or release date). They characterized the migratory patterns as a complicated mix of rearing and migratory behavior, often punctuated by extensive upstream excursions of several kilometers. They also noted that strong correlations among the predictor variables limited analytical opportunities for confidently identifying causative agents affecting travel time. Their findings differed from those of Berggren and Filardo (1993).

Recent Investigations--In the 1990's research focused on identifying a more complete suite of factors that influenced migration speed through the hydro-system. The collective research indicated that the species responded differently to various factors. Yearling chinook migration speed was linked to both flow (water velocity) and/or the level of smolt development (Beeman et al. 1991; Muir et al. 1994; Giorgi et al. 1997). Whereas, river discharge (flow) was the dominant factor that explained the majority of variability in steelhead migration speed (Giorgi et al. 1997; Buettner and Brimmer 2000), and sockeye salmon (Giorgi et al. 1997).

Fall chinook revealed a more complex situation. In the Snake River, flow, water temperature, and turbidity have been correlated with migration speed (Muir et al. 1999). Furthermore, the predictor variables were correlated among themselves. Over the course of the summer migration period, river discharge decreases, temperature increases, and turbidity decreases. In this situation, it is very difficult to analytically demonstrate effects attributable to a single predictor variable. In the mid-Columbia system Giorgi et al. (1997) found that the size of sub-yearling chinook was the best predictor of migration speed between Rock Island and McNary Dams. In their multiple regression analysis using four years (1992-1995) of PIT-tag data, no environmental variable was identified as being influential.

Evolution of Information--The Fish Passage Center (FPC) has been estimating the travel time of smolts for the impounded lower Snake and Columbia rivers since the 1980's. Over the last decade they have adopted the PIT-tag as the preferred tool for documenting migration. However, not since the work of Berggren and Filardo (1993) has there been a comprehensive multi-year analysis of factors affecting smolt travel time reported by the FPC.

Similarly, the NMFS has been calculating and reporting smolt travel time estimates on an annual basis since 1993. They, too, have not yet formally analyzed the data to assess the factors affecting smolt travel time. But it is our understanding such an analysis is underway. According to Smith et al. (2000), with regard to exploring relationships among smolt survival, smolt travel time, smolt quality, system operations, and environmental conditions, such analyses are forthcoming, "Such investigations are ongoing, and results will be published primarily in peer-reviewed scientific journals, as they become available."

Synthesis--Until NMFS and the FPC provide comprehensive analyses from 1993 through 2001, the community must rely on previous investigations to characterize smolt behavioral responses to water velocity. In summary;

- River discharge appears to be the most influential variable affecting migration speed of steelhead and sockeye salmon.
- Both flow and the level of smolt development explain variation in the migration rate of yearling chinook salmon (except in the mid-Columbia where only smolt development has been identified as a predictor variable).
- At least four variables have been implicated as influencing the migration speed of sub-yearling (fall or summer/fall) chinook; flow, water temperature, turbidity and fish size. Strong correlations among these predictor variables confound the ability to identify causative agents.

3.1.2 Flow and Smolt Survival

Translating river flow, or smolt migration rate, into smolt survival is the critical issue underpinning the rationale for providing flow augmentation. Its foundation extends back to the initial analyses of Sims and Ossiander (1981), who described a positive relationship between increased river discharge and the survival of smolts (yearling chinook and steelhead) migrating through the Snake River and portions of the Lower Columbia River. That relationship drove the adoption of the original "Water Budget" in the 1980s and ultimately flow augmentation, as we know it today. However, some investigators have identified limitations associated with those early estimates. According to Williams and Matthews (1995), the 1970s data (Figure 3.2) reflected conditions that no longer exist in the contemporary hydro-system. They suggest that the high smolt mortality witnessed in low flow years was in part associated with slow migration, but was exacerbated by sub-optimal turbine and powerhouse operations. Such operations are not in place today. For this reason they concluded that the Sims and Ossiander flow-survival relationship will probably not accurately predict the survival of yearling chinook under present hydrosystem conditions. They did not dispute the existence of a flow-survival relationship, just that the historical one had little application and new data were required. Their paper was a prelude to a new era of smolt survival analysis in the Columbia and Snake rivers. It set the stage for acquiring representative smolt survival estimates under contemporary conditions.

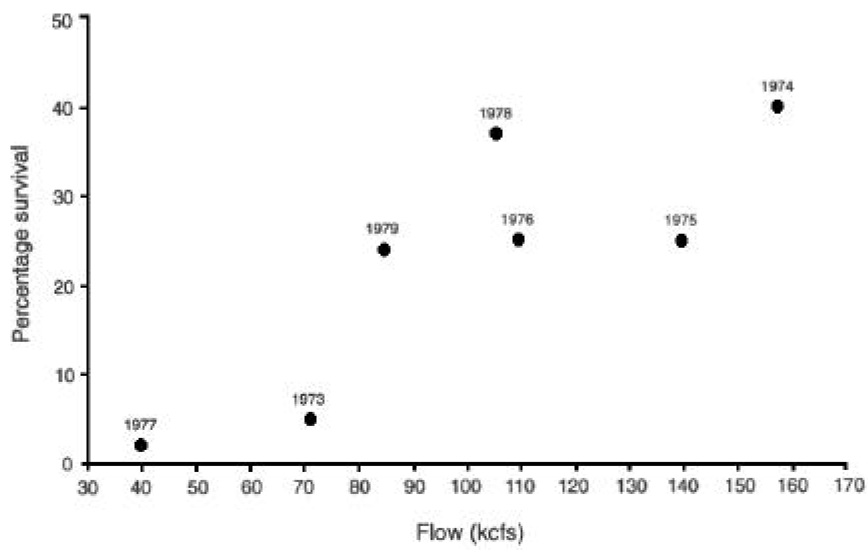

Figure 3.2— Survival estimates for juvenile spring and summer chinook salmon, *Oncorhynchus tshawytscha*, migration through the upper dam (Little Goose Dam, 1973-74; Lower Granite Dam, 1975-79) on the lower Snake River to either John Day Dam (1976-79) or The Dalles Dam (1973-75) compared with the average river flow at Ice Harbor Dam during the period (± 7 days) of peak migration for the years 1973 through 1979 (from Williams and Matthews 1995).

Cada et al. (1997), reviewed literature from within and outside of the Columbia River Basin relating to the influence of water velocity on the survival of juvenile salmon and steelhead. Most of the studies they reviewed identified a positive relationship between outmigration flows and survival, but they noted there was substantial uncertainty regarding many of the estimates. For example, early survival estimates made in the basin did not estimate variances or identify potential biases or errors. In many cases the relationships described did not investigate interactions with factors other than water velocity. Other influential factors that were examined in the review included predation, water quality, and physiological state of the smolts at the time of migration. Despite the limitation of existing data, Cada et al. (1997) felt the general relationship of increasing smolt survival with increasing flow in the Columbia River Basin still appeared to be reasonable.

3.1.3 Recent Estimates of Smolt Survival

Yearling Chinook Salmon and Steelhead--In the NMFS (2000) White Paper on smolt survival and flow, the authors summarized two decades of yearling chinook survival estimates and flow indices. Using annual survival and flow indices, they failed to identify a relationship between the two variables. Even more recently, Zabel et al. (in press) updated the multi-year flow-survival plot for yearling chinook salmon, including estimates from 2001-drought year (Figure 3.3). On an average per-project basis, 2001 inriver survival was certainly one of the lowest observed since 1993, but it was similar to estimates obtained in 1993 and 1984, and did not approach the depressed levels estimated in 1973 and 1977. Using their survival index as a performance measure, a pronounced flow effect is not readily apparent for yearling chinook. In contrast, on the same graph they depict data from the 1970's when a flow-survival relationship was evident.

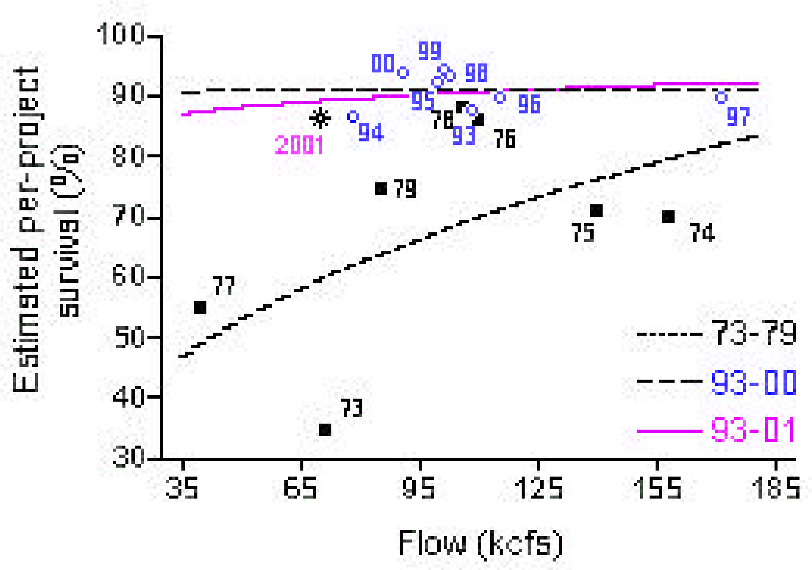

Figure 3.3—Per-project survival versus river flow for Snake River spring-summer chinook salmon (from Zabel et al. In press).

NMFS (2000b) also examined the PIT-tag data (1995-1998) in greater detail and plotted the survival of individual release groups against corresponding flow indices for both yearling chinook and steelhead (Figures 3.4 and 3.5). No relationship was apparent. They plotted the same survival estimates against the median travel time of each group and found no relationship with migration rate. They did, however, identify a strong consistent inverse relationship between travel time and flow for yearling chinook salmon. They suggest that in the absence of a flow or migration rate-survival relationship, some other benefits may be provided by the swifter migration as mediated by increased flow levels. They speculate that higher flows may improve estuary and Columbia River plume conditions and associated survival through those zones, but offered no empirical evidence for such. Interestingly, NMFS research efforts are now staged in an attempt to investigate such mechanisms in 2002 and beyond.

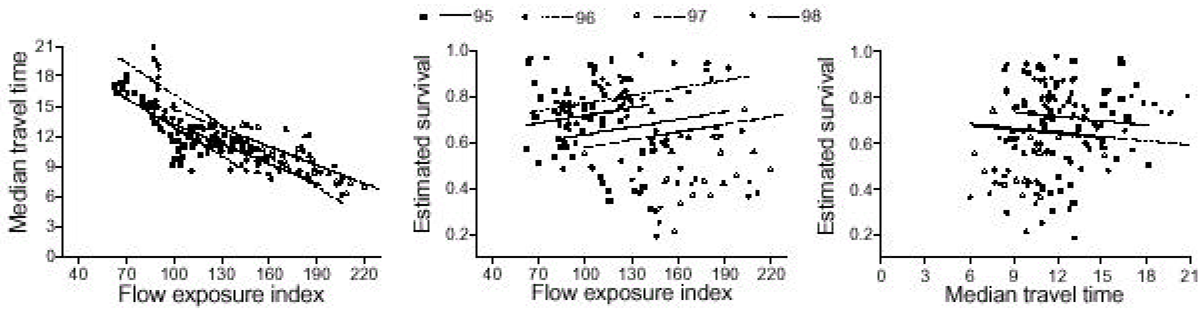

Figure 3.4 —Relationship among median travel time (days) and estimated survival from Lower Granite Dam to McNary Dam, and flow exposure index (kcfs measured at Lower Monumental Dam, yearling chinook salmon, 1995-1998 (from NMFS 2000b).

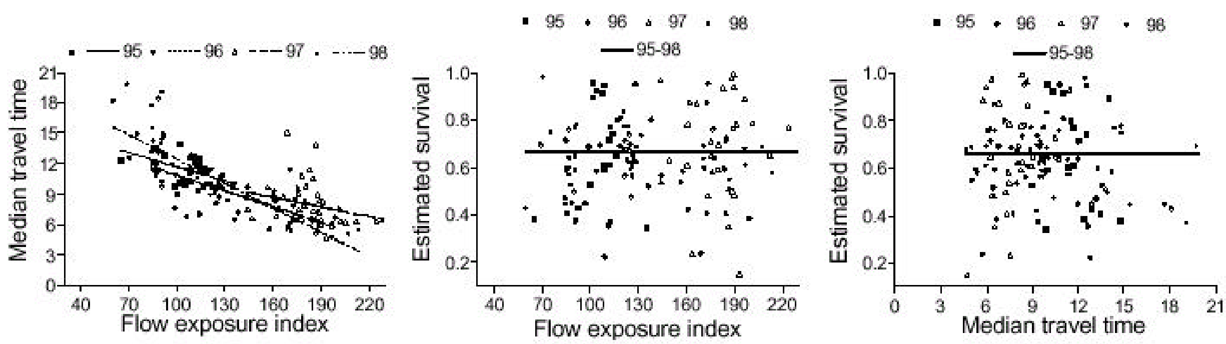

Figure 3.5—Relationship among median travel time (days) and estimated survival from Lower Granite Dam to McNary Dam, and flow exposure index (kcfs) measured at Lower Monumental Dam, steelhead, 1995-1998. (from NMFS 2000b).

In contrast to yearling chinook, estimates that Zabel et al. (in press) presented for steelhead indicate a dramatic decrease in survival during 2001 as compared to other years over the last decade (Figure 3.6). Two factors are implicated as causing this dramatic increase in inriver mortality of Snake River steelhead. First, of all the salmon species, steelhead migration speed appears to be the most sensitive to flow and associated water velocity. This position is based on relatively strong correlations reported by Berggren and Filardo (1993) and Giorgi et al. (1997). Secondly, water temperatures got hotter sooner, in 2001 than they had in the preceding three years (see DART web page for inspection of these data). This pattern was evident in both the lower Snake and Columbia Rivers. More importantly, water temperatures exceeded 12°C early in the steelhead migration. This, coupled with slow migration speed, can compromise the migratory process in steelhead. Increasing water temperature can disrupt the migratory behavior of steelhead. Steelhead smolts commonly remain in the system, and there is laboratory evidence that suggest temperatures in excess of 12°C may cause reversion from smolt to parr (Zaugg and Wagner 1973). It is plausible that if migration is slow as witnessed in 2001 (Zabel et al. in press), then steelhead smolts could be exposed to seasonally increasing water temperatures, and increased risk of residualization.

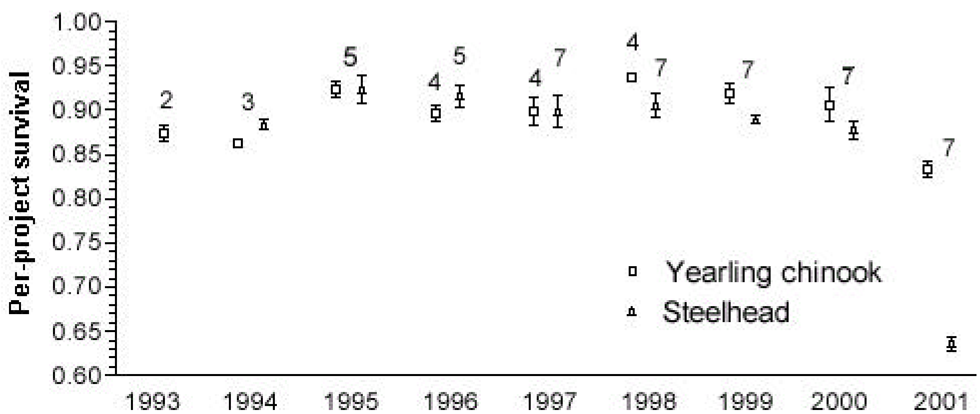

Figure 3.6 —Estimated per-project survival (i.e., per dam/reservoir combination) with standard errors for yearling chinook salmon and steelhead from 1993 through 2000. Number above bar is the number of projects over which survival was estimated (from Zabel et al. In press).

<u>Snake River Fall Chinook Salmon</u>--For fall chinook salmon, the best information has been reported by Muir et al. (1999). Using PIT-tagged juveniles from Lyons Ferry Hatchery, they estimated survival in the lower Snake River. From release sites upstream from Lower Granite Dam to that site they found significant correlations between survival and all three environmental variables they examined (flow, water temperature and turbidity). Over the course of the summer, survival decreased when flows and turbidity decreased and water temperature increased. Predictor variables were highly correlated, confounding the ability to identify the causative agents.

As fish migrated from Lower Granite Dam to Lower Monumental Dam, the range of environmental conditions encountered by juvenile fall chinook in 1995 and 1996 appeared to be narrow and may have obfuscated any relationships with survival. But in 1997, significant correlations between smolt survival and each of the three predictor variables were apparent, with temperature, then flow and turbidity showing the greatest r-squared values, respectively (Muir et al. 1999).

3.2 Premise 2–Lowering water temperature in the summer improves migratory and rearing conditions for juvenile and adult salmonids, ultimately improving survival.

Within the impounded lower Snake River, summer water temperatures can reach levels that impose risks to juvenile and adult salmonids. During the summer, juvenile fall chinook rear and migrate through that river segment, and adult steelhead and fall chinook migrate upstream. River temperatures can often exceed 20°C (Giorgi and Schlecte 1997). Temperature tolerance for juvenile fall chinook has been reported to range from 5.5 to 20°C (Groves 1993). This suggests that juvenile fall chinook can be at risk associated with inhospitable thermal conditions in the Snake River. If there were a means to reduce water temperature, particularly to below 20°C, this would minimize such risk.

Water temperature is also an important factor affecting predation-related mortality incurred by juvenile salmon. Reducing water temperatures below 20°C can be beneficial in decreasing the consumption rates of northern pikeminnow, (*Ptychocheilus oregonensis*), a primary predator of salmon smolts. Vigg and Burley (1991) developed a model that predicts that decreasing water temperature from 21.5 to 17°C could reduce the number of prey consumed by pikeminnow from 7.01 to 4.25 per day. This suggests that water temperature regulation in the Snake River could indirectly provide survival benefits to juvenile fall chinook.

Lower water temperatures in the summer can also be advantageous for adult salmonids as they migrate upstream. Both fall chinook and steelhead are migrating upstream in the late summer when temperatures are highest. Bjornn and Peery (1992) reviewed literature regarding adult passage in the lower Snake River. They reported that steelhead appear to delay migration when water temperatures exceed 21-22°C (although they did caveat that data were limited).

Overall, it appears that if water temperatures in the Snake River could be maintained below 20°C, this would minimize risk to adult and juvenile life stages. However, we have not encountered any analyses that would permit one to predict survival changes as related to water temperature.

3.3 Flow Augmentation Evaluations

None of the information presented thus far constitute analyses of the effectiveness of flow augmentation. Establishing general relationships between flow and either migration speed or survival certainly provides a rationale for entertaining flow augmentation as a strategy to improve survival. However, an evaluation of the biological benefits of providing additional water in any particular year has many facets and requires a more focused analysis. In 1996, BPA funded a flow augmentation evaluation study (Giorgi and Schlecte 1997) and directed the investigators to address four key objectives:

1. Determine the volume and timing of water that was drafted from storage reservoirs and provided above base flows, which could be identified as flow augmentation for anadromous fish.
2. Estimate the extent to which flow augmentation increased water velocity or decreased water temperature as compared to base conditions.
3. Predict the magnitude of fish responses in terms of smolt migration speed or survival, as attributable to that incremental change in environmental conditions (flow, temperature).
4. Identify the degree to which populations of interest (ESA-listed stocks) were exposed to FA events.

BPA felt these were fundamental issues that required resolution in the context of a comprehensive evaluation of flow augmentation effectiveness. Most of these objectives first emerged and were analytically treated in a comprehensive System Operation Review that was conducted by the Action Agencies and completed in 1994. Surprisingly, few, if any, comprehensive evaluations of flow augmentation have been published, which address all or even most of the issues identified above. Typically, the annual reports published by the FPC address objectives 1 and 4. Objectives 2 and 3 are not explicitly analyzed, except in terms of reporting general smolt travel time or survival estimates on an annual basis. The NMFS BO is deficient in this regard as well. BO specifies volumetric (in Maf) standards for flow augmentation, and prescribes seasonal flow (kcfs) targets. However, no quantitative analysis describing the change in water velocity, smolt speed or survival benefits is offered that can be attributed to providing the additional water through flow augmentation. Furthermore, the smolt passage model (SIMPAS) used in the BO lacks an explicit flow-survival function or any flow-related mechanisms to affect survival through reservoirs. As a consequence, that model, as currently configured, is incapable of predicting the change in survival attributable to flow augmentation.

Dreher (1998) provided a very general assessment of the effectiveness of flow augmentation in changing water velocity and meeting the flow targets specified in the BO. He concluded that the volumes of water in storage reservoirs currently earmarked for flow augmentation in the Snake River: 1) provide only small incremental increases in average water velocity through the hydrosystem, and 2) is insufficient to meet flow targets in all years. However, his analysis offered no insight with respect to the fish responses. Clearly it was quite limited in scope and thus offers little utility in terms of assessing benefits of flow augmentation. In fact, the author did not purport his analysis to be an evaluation of flow augmentation, but rather a treatment of some rather specific water issues.

Connor et al. (1998) conducted a study that had implications to summer flow augmentation in the Snake River. Using PIT-tagged juvenile fall chinook that reared upstream from Lower Granite Dam, they regressed tag detection rates at the dam (survival index), against flow and temperature separately. They found that over four years, the detection rate was positively correlated to mean summer flow (r-squared = 0.993, P = 0.003) and negatively correlated with maximum water temperature (r-squared = 0.984, P = 0.008). They acknowledged that the predictor variables were highly correlated, limiting specific inferences regarding the effects of the individual variables. They also graphically depicted the temperature changes coincidental with flow augmentation from Dworshak Dam and the Hell's Canyon Complex in 1993 and 1994. Water temperatures at Lower Granite Dam dropped approximately 5-6°C during the period of flow augmentation. They concluded that summer flow augmentation especially cooler water released from Dworshak Reservoir could improve survival of juvenile fall chinook, at least to arrival at Lower Granite Dam. This evaluation was one of the more well-rounded appearing in the literature. However, it would be advantageous if the geographic impact zone could be expanded beyond the single dam (LGR). Also, some indication of the change in water velocity attributable to the flow augmentation would be instructive. Nevertheless, their approach offers a model for future assessments, particularly if true survival estimates, rather than detection rates, can be used as the response variable.

In 1997, Giorgi and Schlecte (1997) conducted an evaluation of the effectiveness of flow augmentation in the Snake River for the years 1991-1995. The purpose of that BPA-funded study was to estimate the volumes and shape of flow augmentation water delivered to the Snake River, and to assess the biological consequences to ESA-listed stocks. There were four steps to the study:

1. Provide an independent estimate of the volume and shape of water drafted from storage reservoirs that could be classified as flow augmentation.
2. Estimate the incremental change in water velocity and temperature that was attributable to the water delivered as flow augmentation.
    a. Two physical models were used to estimate the changes in water velocity – HEC-2 and CRiSP
    b. Changes in water temperature attributable to flow augmentation were estimated with time series analysis.
3. Estimate the incremental change in smolt migration speed and survival (where possible) for yearling chinook, steelhead and fall chinook salmon associated with providing the flow augmentation water.
    a. Models included CRiSP, Berggren and Filardo (1993), and a fall chinook migration model by Connor et al. (1994).
4. Estimate to what extent ESA-listed salmonid populations encountered flow augmentation events.

They found that for the years 1991-1995, the Snake River flow augmentation volume ranged from an annual low of 1.35 to 2.56 Maf. Those volumes were insufficient to sustain the flow targets established by NMFS for the duration of the smolt migration period. However, over the five years, flow augmentation increased water velocity through Lower Granite Pool an average of 3-13% (Figure 3.7). During the summer, the increase was more pronounced with an increase of 5-38% change in water velocity attributable to providing flow augmentation water.

Correspondingly, the change in smolt travel time predicted by the different passage models varied considerably (Figure 3.8). For example, the decreases in travel time for yearling chinook ranged from 5-16% over five years, whereas CRiSP predicted a 0-5% decrease. Only the CRiSP model was readily available for application in predicting survival through Lower Granite Dam and through to Ice Harbor Dam. Those results are depicted in Figure 3.9.

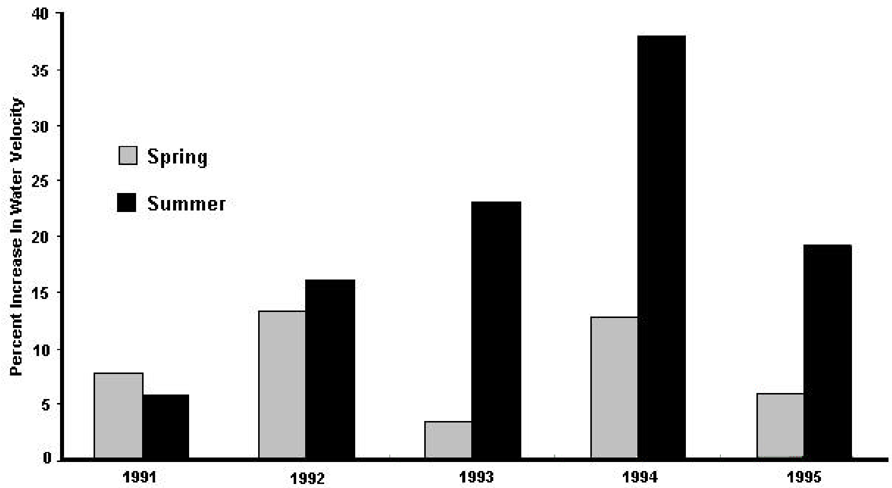

Figure 3.7 — Estimated increase in water velocity (as a percentage of total velocity) that is attributable to flow augmentation volumes as estimated by HDR during the springs (10 April – 20 June) and summers (21 June – 31 August) 1991-1995 (from Giorgi and Schlecte 1997).

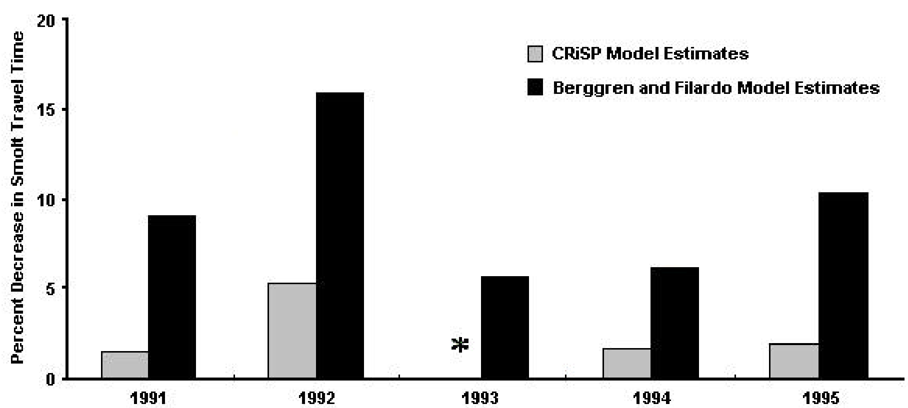

Figure 3.8 — Percent decrease (i.e., benefit attributable to flow augmentation) in estimated smolt travel times (average of the median travel times for each of the three release dates) for yearling chinook using base flows calculated by HDR. The asterisk in 1993 indicates that the CRiSP model predicted no change in travel time associated with flow augmentation (from Giorgi and Schlecte 1997).

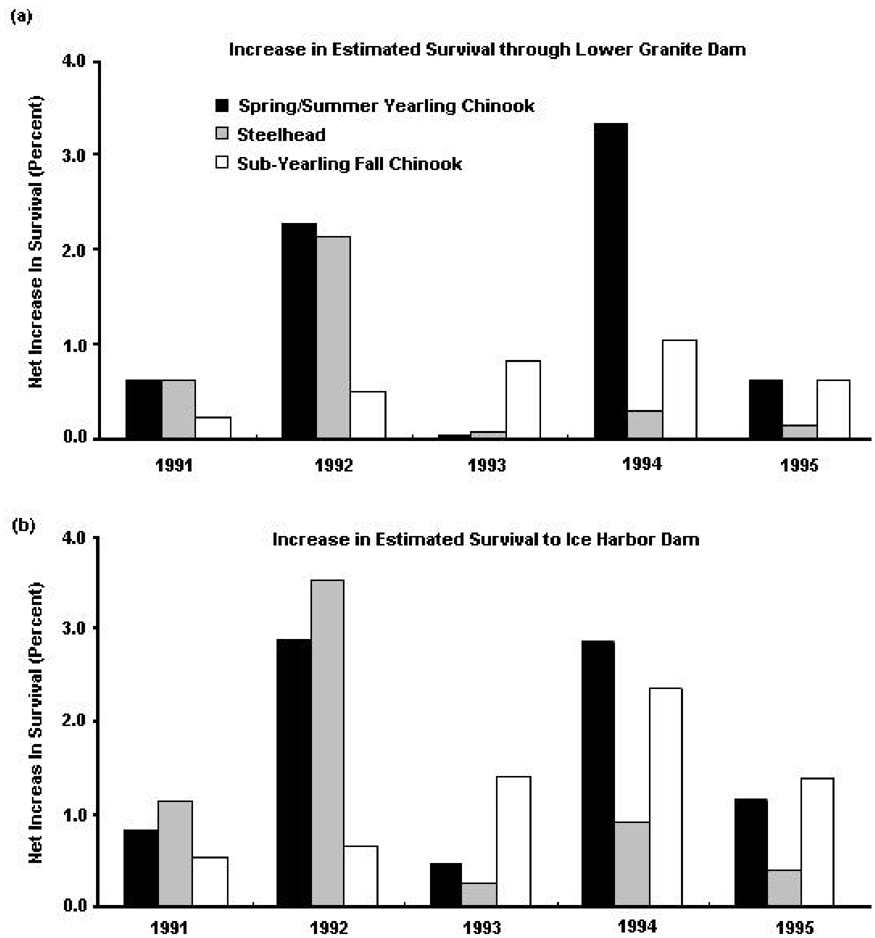

Figure 3.9— Average increase in survival attributable to flow augmentation for yearling chinook, steelhead, and sub-yearling chinook from release point at the head of Lower Granite Pool (a) through Lower Granite Dam and (b) to Ice Harbor Dam. Survival estimates were derived using the CRiSP model under three release scenarios (i.e., Early, Mid and Late) (from Giorgi and Schlecte 1997).

Since Giorgi and Schlecte (1997) conducted their analyses, the models have been updated. Furthermore, over the last five years, a variety of empirical passage-related estimates have been acquired and need to be incorporated into the passage models. No doubt some of their results would change to some extent if the same years were analyzed today with updated information. That is not important in the context of future assessments. We do, however, suggest that the approach used by these investigators, and that of Connor et al. (1998) offer tractable models for future flow augmentation evaluations.

Temperature Control Studies--Several investigations evaluated the effectiveness of Snake River FA in reducing summer water temperature in the Lower Snake River. Specifically, the use of Dworshak Reservoir as a coldwater source for decreasing water temperature in August and early September has been the focus of investigators (Karr et al.1992; Karr et al. 1998; Bennett et al. 1997). Karr et al. (1992) first provided results that indicated that strategic releases of outflow from Dworshak Reservoir could reduce water temperature in the Snake, at least to the vicinity of LGR Dam. Bennett et al. (1997) conducted a more comprehensive study involving water temperature model analysis and field monitoring for the years 1991-1993. They established that the Army Corps of Engineers model (COLTEMP) provided reliable predictions of changes in water temperature associated with flow augmentation releases upstream. The reduction in Snake River water temperature associated with coldwater releases from Dworshak Reservoir was greatest at LGR and diminished as water moved downstream to IH. Depending on the year and base flow characteristics, the change in temperature at LGR typically ranged from 1-4 °F. However, the model predicted differences as great as 6-8 °F, which extended for a period of several weeks. Here again, the prediction depended on base flows and the volume released for flow augmentation. At Ice Harbor Dam the decrease in temperature was typically small, on the order of 1-2 °F. They also reported that the cold water released upstream tended to sink toward the bottom of the reservoirs, and mixed at the dams. This suggests that deep cool water may be available as refugia, but cooling throughout the water column cannot be realized. Also the degree of cooling decreases in the lower reaches of the river. As yet, biological information has not been integrated with this or similar evaluations. The authors recommended that this is a necessary next step.

Benefits and Risks to other species--Drafting flow augmentation water from storage reservoirs alters conditions within the storage reservoirs and in the tributaries connecting with the Columbia and Snake rivers. These processes in turn have effects on resident fish inhabiting those waters. This introduces a broad and complex facet attending the implementation of flow augmentation. It is beyond the scope of this paper to treat this topic in detail, but we identify key issues. Risks associated with flow augmentation were broached by the Independent Scientific Group's publication "Return to the River". Therein they expressed uncertainty regarding the magnitude of a flow-survival, and the strategy to use non-seasonal flow augmentation in an attempt to force subyearling chinook from the mainstem (ISG 1996). In their words,

> "*Underscoring these substantial uncertainties in flow augmentation rationale is the fact that summer drawdowns in upstream storage reservoirs, for example Hungry Horse Reservoir in Montana, to accomplish summer smolt flushing in the lower Columbia river has direct and potentially negative implications for nutrient mass balance and food web productivity in Flathead Lake, located downstream from Hungry Horse*. "

The issue they raise involves balancing expected benefits to anadromous fish against ecosystem function and potential risk to other native species. The Kootenai River white sturgeon inhabit waters downstream from Libby Dam, and are listed under the ESA. Paragamian and Kruse (2001) found that river temperature and river stage (sensitive to flow) were the best predictors of female sturgeon migrating to spawning areas in the Kootenai River. Part of the recovery effort for this species involves drafting water from Libby reservoir at strategic times during the spring. Depending on the magnitude and timing of the water releases, these actions could compete against or enhance flow augmentation that targets anadromous salmonids in the Columbia River.

Clearly a complex array of water management activities has evolved in the Columbia Basin. The net balance among competing and complementary strategies is uncertain. Apart from the System Operation Review conducted in the early 1990s, we have not encountered a comprehensive multidisciplinary evaluation of flow augmentation, which attempts to assess and quantify the full suite of benefits and risks to anadromous and resident fish species and their habitat. The tendency has been for groups to focus on the species under their jurisdiction, or within their geographic zone.

3.5 Summary

Flow effects on smolt migration speed: For most species the evidence indicates that increased flow (water velocity) contributes to swifter migration speed. Information regarding fall chinook is equivocal. River discharge appears to be the most influential variable affecting migration speed of steelhead and sockeye salmon in the Snake and Mid-Columbia rivers. For yearling chinook salmon, flow, and the degree of smolt physiological development, explain the observed variation in the migration rate (except in the mid-Columbia where only smolt development has been identified as a predictor variable). At least four variables have been implicated as influencing the migration speed of sub-yearling (fall or summer/fall) chinook; flow, water temperature, turbidity, and fish size. However, strong correlations among these predictor variables confound the ability to identify causative agents.

Flow effects on smolt survival based on PIT-tag estimates acquired since 1993 provide the most relevant data set for characterizing smolt survival dynamics through the impounded mainstem Snake and Columbia rivers. Based on recent estimates there is little evidence supporting a flow-survival relationship across the water years experienced from 1993-2000, for yearling chinook or steelhead. However, in 2001 under the extreme low flow conditions, steelhead survival decreased dramatically to about 63% per project (typically it is near 90%). Slow migration speed and rapidly increasing water temperatures are implicated as causative factors affecting residualization and mortality. A complex of factors are implicated as influencing Snake River fall chinook survival, including flow, water temperature and turbidity. These environmental variables are strongly correlated during the summer migration, confounding the ability to identify the most influential one. Knowing if water velocity or temperature is the most influential could be important when the decision is to use Dworshak or Hell's Canyon for flow augmentation, since the temperature of those water sources differs greatly.

The premise for reducing summer water temperature, particularly in the Snake, to improve rearing and migratory conditions for juvenile fall chinook and adult salmonids appears sound. The literature indicates that maintaining river temperatures at or below 20°C is advantageous to both life stages of fall chinook, and adult steelhead, which are in the river in August and early September.

However, it is not clear that releasing cool water from Dworshak effectively alters the thermal structure of most of the Lower Snake River. The major effect is localized at two upper reservoirs (LGR, LGO). Based on results reported by Bennett et al. (1997), when cool water enters the reservoirs it sinks to the bottom. This can provide cool refugia in deeper waters, but not uniform cooling of reservoirs. The greatest change in temperature attributable to FA releases from

Dworshak are evident at LGR, where water temperatures with FA are predicted to be as much as 4-8° F lower than base conditions at certain times. At Ice Harbor the difference is on the order of 1-2° F.

Comprehensive flow augmentation evaluations are generally lacking. Only a handful of studies have attempted to quantify the volume and shape of water provided specifically as FA, and translate that incremental increase in flows to changes in water velocity and temperature. Certainly there is a need for a prediction of the change in smolt travel time and survival attributable to those increases and to identify whether populations of interest (e.g. ESA stocks) have sufficiently encountered flow augmentation events. The last such evaluation treated information through the 1995 water year, and only for the Snake River. Given the community's sensitivity to this controversial management action, a holistic comprehensive updated evaluation seems prudent, and long overdue. The scope of future evaluations need to more fully address the balance of benefits and risks between anadromous and resident fish resources.

3.6 Critical Uncertainties and Research Opportunities

Flow-survival relationships for spring-migrating species--In the Snake River, the NMFS PIT-tag-based smolt survival estimates acquired since 1993 form a strong foundation for examining and defining such relationships. It is our understanding those efforts will, and in our view should, continue to be expanded geographically to the lower and upper Columbia River, when and where possible. Radio telemetry, or some other device, may need to be employed in the upper Columbia because PIT detector installations are lacking and the opportunities to install them are not readily apparent.

Factors influencing fall chinook survival--Disentangling the complex of factors that are implicated as influencing Snake River fall chinook salmon survival is an important goal, because it may guide decisions regarding the most suitable water source for use in FA. To accomplish this may require well-designed experimental manipulation of Dworshak and Hell's Canyon dams. Established management practices and political considerations may limit opportunities in this regard. Absent a well-designed experiment, we will likely be left with the equivocal results we now have.

Holistic evaluations of FA effectiveness--A multi-faceted, comprehensive evaluation of the biological benefits and risks associated with flow augmentation is advisable. Wherever possible, quantitative analyses should be undertaken. The effort will require physical and smolt passage modeling. Updating certain tools will be required, given the abundance of passage and survival information collected since the models used in PATH were constructed and validated. To fully address concerns regarding anadromous fish and resident fish will require a significant effort. But without such an effort it is not clear how the region can determine if the status quo as prescribed in the FCRPS is an effective water management strategy for measurably improving salmon survival.

3.7 Literature Cited

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4.0 APPENDICES

Appendix A-1. Seasonal flow objectives prescribed for spring and summer on the Snake River at Lower Granite Dam and on the Columbia River at Priest Rapids, McNary, and Bonneville dams (NMFS 2000).

	Spring		Summer	
Location	**Dates**	**Flow (kcfs)**	**Dates**	**Flow (kcfs)**
Snake River at Lower Granite Dam	4/03-6/20	85-100	6/21-8/31	50-55
Columbia River at Priest Rapids Dam	4/10-6/30	135	NA	NA
Columbia River at McNary Dam	4/10-6/30	220-260	7/01-8/31	200
Columbia River at Bonneville Dam	11/1 - Emergence	125-160	NA	NA

Appendix A-2. Seasonal flow objectives at Lower Granite, Priest Rapids, and McNary dams based on different forecasts of runoff volumes (NMFS 2000).

		Flow Determination		
Location	**Season**	**Forecast**	**Volume Forecast (Maf)**	**Flow Objective (kcfs)**
Lower Granite Dam	Spring	Based on the April final runoff volume forecast at Lower Granite Dam for April to July.	< 16	85
			> 16 and ≤ 20	85-100
			> 20	100
Lower Granite Dam	Summer	Based on the June final runoff volume forecast at Lower Granite Dam for April to July.	< 80	220
			> 80 and ≤ 92	220-260
			> 28	55
Priest Rapids Dam	Spring	NA	NA	135
McNary Dam	Spring	Based on the April final runoff volume forecast at the Dalles dam for April to August	< 80	220
			> 80 and ≤ 92	220-260
			> 92	260
McNary Dam	Summer	NA	NA	200

Appendix A-3. Estimated spill levels and gas caps for FCRPS projects during spring (all) and summer (non-transport projects) (NMFS 2000).

Project[1]	Estimated Spill Level[2] (kcfs)	Hours (military)	Limiting Factor
	Snake River		
Lower Granite Dam	60	1800-0600	Gas cap
Little Goose Dam	45	1800-0600	Gas cap
Lower Monumental Dam	40	24 hours	Gas cap
Ice Harbor Dam	100 (night)	24 hours	Nighttime-gas cap
	45 (day)		Daytime-gas cap
	Columbia River		
McNary Dam	12-150	1800-0600	Gas cap
John Day Dam	85-160 /60%[3] (night)	1800-0600[4]	Gas cap/percentage
The Dalles Dam	40% of instant flow	24 hours	Tailrace flow pattern and survival concerns (ongoing studies)
Bonneville Dam	90-150 (night)	24 hours	Nighttime-gas cap
	75 (day)		Daytime-adult fallback

[1] Summer spill is curtailed beginning on or about June 20 at the four transport projects (Lower Granite, Little Goose, Lower Monumental, and McNary dams) due to concerns about low inriver survival rates.

[2] Estimated spill levels shown in the table will increase for some projects as spillway deflectors optimization measures are implemented.

[3] The TDG cap at John Day Dam is estimated at 85 to 160 kcfs, and the spill cap for tailrace hydraulics is 60%. At project flows up to 300 kcfs, spill discharges will be 60% of instantaneous project flow. Above 300 kcfs project flow, spill discharges will be at the gas cap (up to the hydraulic limit of the powerhouse).

[4] Spill at John Day Dam will be 7:00 p.m. to 6:00 a.m. (night and 6:00 a.m. to 7:00 p.m. (day) between May 15 and July 31.

Appendix B. Estimates for survival for various passage routes at Bonneville, The Dalles, Lower Monumental, Lower Granite, Wanapum, Rock Island, and Rocky Reach dams on the Columbia and Snake rivers. References to footnotes appear on the last page.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
					Bonneville Dam			
1995	Hatchery Chinook	Spill	1.0		0.991-1.0	BT	Normandeau et al. (1996c)	Spillbay with flow deflector (Spillbay 4); 12,000 cfs; 90% C.I.
1995	Hatchery Chinook	Spill	1.0		0.977-1.0	BT	Normandeau et al. (1996c)	Spillbay without flow deflector (Spillbay 2); 12,000 cfs; 90% C.I.
					The Dalles Dam			
1995	Hatchery Chinook	Spill	0.955		0.927-0.982	BT	Ploskey et al. (2001)[1]	Unmodified spillbay (Bay 3); 10,500 cfs; 90% C.I.
1995	Hatchery Chinook	Spill	0.993		0.972-1.02	BT	Ploskey et al. (2001)[1]	Spillbay 4; surface flow bypass vertical I-slot; 10,500 cfs; 90% C.I.
1995	Hatchery Chinook	Spill	0.990		0.951-1.00	BT	Ploskey et al. (2001)[1]	Spillbay 6; surface flow bypass overflow weir, 4,500 cfs; 90% C.I.
1997	coho	Spill	0.871		0.804-0.939	PT	Ploskey et al. (2001)[2]	64% spill, 95% C.I.
1997	subyearling chinook	Spill	0.921		0.855-0.987	PT	Ploskey et al. (2001)[2]	64% spill, 95% C.I.
1998	coho	Sluiceway	0.96		0.87-1.05	PT	Ploskey et al. (2001)[3]	30% spill, 95% C.I.
1998	subyearling chinook	Sluiceway	0.89		0.81-0.98	PT	Ploskey et al. (2001)[3]	30% spill, 95% C.I.
1998	coho	Spill	0.89		0.82-0.96	PT	Ploskey et al. (2001)[3]	64% spill, 95% C.I.
1998	subyearling chinook	Spill	0.75		0.68-0.83	PT	Ploskey et al. (2001)[3]	64% spill, 95% C.I.
1998	coho	Spill	0.97		0.88-1.07	PT	Ploskey et al. (2001)[3]	30% spill, 95% C.I.
1998	subyearling chinook	Spill	0.89		0.80-0.99	PT	Ploskey et al. (2001)[3]	30% spill, 95% C.I.
1999	Coho and chinook yearlings	Spill	0.94		0.90-0.97	PT	Ploskey et al. (2001)[4]	64% spill, 95% C.I.
1999	subyearling chinook	Spill	0.96		0.92-1.00	PT	Ploskey et al. (2001)[4]	64% spill, 95% C.I.

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
					The Dalles Dam			
1999	Coho and chinook yearlings	Spill	0.95		091-0.98	PT	Ploskey et al. (2001)[4]	30% spill, 95% C.I.
1999	subyearling chinook	Spill	1.00		0.96-1.04	PT	Ploskey et al. (2001)[4]	30% spill, 95% C.I.
2000	Coho and chinook yearlings	Sluiceway	0.95		0.92-0.98	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	subyearling chinook	Sluiceway	0.96		0.88-1.04	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	Coho and chinook yearlings	Sluiceway	0.976		NA	RT	Ploskey et al. (2001)[6]	Spill levels unknown
2000	Coho and chinook yearlings	Spill	0.95		0.92-0.99	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	subyearling chinook	Spill	0.92		0.83-1.01	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	Coho and chinook yearlings	Spill	0.929		NA	RT	Ploskey et al. (2001)[6]	Spill levels unknown
2000	Coho and chinook yearlings	Turbine	0.81		0.78-0.84	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	subyearling chinook	Turbine	0.84		0.76-0.92	PT	Ploskey et al. (2001)[5]	40% spill, 95% C.I.
2000	Coho and chinook yearlings	Turbine	0.856		NA	RT	Ploskey et al. (2001)[6]	Spill levels unknown
					Lower Monumental Dam			
1994	Yearling Chinook	Spill	0.984	0.033		PT	Muir et al. (2001)[7]	Spillbay 8 without deflector; Relative Recovery method (RR); 125-136 m^3/s
1994	Yearling Chinook	Spill	0.927	0.023		PT	Muir et al. (2001)[9]	Spillbay 7 with deflector; Relative Recovery method (RR); 125-136 m^3/s
1994	Yearling Chinook	Turbine	0.865	0.018		PT	Muir et al. (2001)[8]	Relative Recovery method (RR); Unit 6B, 135 MW
1995	Yearling Chinook	Bypass	0.954	0.034		PT	Muir et al. (2001)[9]	Relative Recovery method (RR); Unit 6C, collection channel
1995	Steelhead	Bypass	0.929	0.060		PT	Muir et al. (2001)[9]	Relative Recovery method (RR); Unit 6C, collection channel

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
							Lower Granite Dam	
1993	Yearling Chinook	Spill	1.021	0.026		PT	Muir et al. (2001)[10]	Spillway with deflector using relative recovery method (RR); Bay 3, 108 m^3/s
1993	Yearling Chinook	Turbine	0.920	0.025		PT	Muir et al. (2001)[10]	Estimates derived using relative recovery method (RR); Unit 6B, 135 MW
1994	Yearling Chinook	Bypass	0.994	0.023		PT	Muir et al. (2001)[8]	Estimates derived using relative survival method (RS); Unit 6C, collection channel
1995	Steelhead	Bypass	0.979	0.031		PT	Muir et al. (2001)[9]	Estimates derived using the relative survival method (RS); Unit 6C, collection channel
1997	Steelhead	Bypass	0.953	0.016		PT	Muir et al. (2001)[11]	Estimates derived using relative recovery method (RR); Unit 6B, trashrack
1997	Hatchery Steelhead	Spill	1.000	0.010		BT	Normandeau et al. (1997)	Spillbay 1 without deflector; 1,800 cfs
1997	Hatchery Steelhead	Spill	1.000	NA		BT	Normandeau et al. (1997)	Spillbay 1 without deflector; 5,600 cfs
1997	Hatchery Steelhead	Spill	1.000	NA		BT	Normandeau et al. (1997)	Spillbay 1 without deflector; 9,500 cfs
1997	Hatchery Steelhead	Spill	1.000	NA		BT	Normandeau et al. (1997)	Spillbay 1 without deflector; 5,600 cfs; released into vortice upstream of tainter gate
1997	Hatchery Steelhead	Spill	0.983	0.012		BT	Normandeau et al. (1997)	Spillbay 1 without deflector; 9,500 cfs; released into vortice upstream of tainter gate
1997	Hatchery Steelhead	Spill	0.990	0.017		BT	Normandeau et al. (1997)	Spillbay 3 with deflector; 1,800 cfs
1997	Hatchery Steelhead	Spill	0.980	0.011		BT	Normandeau et al. (1997)	Spillbay 3 with deflector; 5,600 cfs
1997	Hatchery Steelhead	Spill	1.000	NA		BT	Normandeau et al. (1997)	Spillbay 3 with deflector; 9,500 cfs
1997	Hatchery Steelhead	Spill	1.000	NA		BT	Normandeau et al. (1997)	Spillbay 3with deflector; 5,600 cfs; released into vortice upstream of tainter gate
1997	Hatchery Steelhead	Spill	0.992	0.008		BT	Normandeau et al. (1997)	Spillbay 3 with deflector; 9,500 cfs; released into vortice upstream of tainter gate
1997	Steelhead	Spill	1.004	0.015		PT	Muir et al. (2001)[11]	Spillbay 1 without deflector using relative recovery method (RR); 139-283 m^3/s
1997	Steelhead	Spill	0.972	0.015		PT	Muir et al. (2001)[11]	Spillway with deflector using relative recovery method (RR); Bay 3, 139-283 m^3/s
1997	Steelhead	Turbine	0.934	0.016		PT	Muir et al. (2001)[11]	Estimates derived using the relative recovery method (RR); Unit 6B, 135 MW
1993	Yearling Chinook	Spill	1.021	0.026		PT	Muir et al. (2001)[10]	Spillway with deflector using relative recovery method (RR); Bay 3, 108 m^3/s

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
Lower Granite Dam								
1994	Yearling Chinook	Bypass	0.994	0.030		PT	Muir et al. (2001)[8]	Relative survival method (RS); Unit 6A, collection channel
1995	Yearling Chinook	Bypass	0.976	0.036		PT	Muir et al. (2001)[9]	Relative survival method (RS); Unit 6A, collection channel
1995	Steelhead	Bypass	0.983	0.019		PT	Muir et al. (2001)[9]	Relative Survival method (RS); Unit 6A, collection channel
1995	Yearling Chinook	Turbine	0.927	0.027		PT	Muir et al. (2001)[9]	Relative Survival method (RS); Unit 4B, 135 MW
1996	Hatchery Chinook	SBC	0.958		0.928-0.988	BT	Normandeau et al. (1996d)	Surface Bypass Collector (SBC); 90% C.I.
1996	Hatchery Chinook	Spill	0.975		0.952-0.988	BT	Normandeau et al. (1996d)	Spillbay 2; 90% C.I.
1996	Steelhead	Spill	1.010	0.019		PT	Muir et al. (2001)[12]	Spillbay 1 without deflector;Relative Survival method (RS); 110 m^3/s
2000	Hatchery Chinook	SBC	0.970		0.945-0.994	BT	Normandeau et al. (2000)	Surface Bypass Collector (SBC); 90% C.I.
2000	Hatchery Chinook	Spill	0.976		0.954-0.999	BT	Normandeau et al. (2000)	Spillbay 2; 90% C.I.
Wanapum Dam								
1996	Hatchery Yearling Chinook	Overflow Weir	0.920	0.023		BT	Normandeau et al. (1996b)	Overflow weir; 2,000 cfs
1996	Hatchery Yearling Chinook	Overflow Weir	0.969	0.023		BT	Normandeau et al. (1996b)	Overflow weir; 4,000 cfs
1996	Hatchery Yearling Chinook	Sluiceway	0.974	0.014		BT	Normandeau et al. (1996b)	Sluiceway; 2,000 cfs
1996	Hatchery Yearling Chinook	Spill	0.957	0.014		BT	Normandeau et al. (1996b)	Spillbay with deflector (Spillbay 2); 4,300 cfs
1996	Hatchery Yearling Chinook	Spill	0.996	0.004		BT	Normandeau et al. (1996b)	Spillbay without deflector (Spillbay 3); 4,300 cfs
1996	Hatchery Yearling Coho	Turbine	0.897	0.027		BT	Normandeau et al. (1996a)[13]	Induction of fish 10' below turbine intake ceiling; 9,000 cfs
1996	Hatchery Yearling Coho	Turbine	0.924	0.023		BT	Normandeau et al. (1996a)[13]	Induction of fish 10' below turbine intake ceiling; 11,000 cfs
1996	Hatchery Yearling Coho	Turbine	0.948	0.022		BT	Normandeau et al. (1996a)[13]	Induction of fish 10' below turbine intake ceiling; 15,000 cfs
1996	Hatchery Yearling Coho	Turbine	0.885	0.026		BT	Normandeau et al. (1996a)[13]	Induction of fish 10' below turbine intake ceiling; 17,000 cfs

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
Wanapum Dam								
1996	Hatchery Yearling Coho	Turbine	0.949	0.020		BT	Normandeau et al. (1996a)[13]	Induction of fish 30' below turbine intake ceiling; 9,000 cfs
1996	Hatchery Yearling Coho	Turbine	0.968	0.017		BT	Normandeau et al. (1996a)[13]	Induction of fish 30' below turbine intake ceiling; 11,000 cfs
1996	Hatchery Yearling Coho	Turbine	1.000	0.013		BT	Normandeau et al. (1996a)[13]	Induction of fish 30' below turbine intake ceiling; 15,000 cfs
1996	Hatchery Yearling Coho	Turbine	0.968	0.014		BT	Normandeau et al. (1996a)[13]	Induction of fish 30' below turbine intake ceiling; 17,000 cfs
1998	Hatchery Yearling Chinook	Spill	1.000		± 0.026	BT	Normandeau and Skalski (1999)	Unmodified spillbay (Spillbay 3); 2,000 cfs; 90% C.I.
1998	Hatchery Yearling Chinook	Spill	0.993		± 0.031	BT	Normandeau and Skalski (1999)	Unmodified spillbay (Spillbay 3); 5,000 cfs; 90% C.I.
1998	Hatchery Yearling Chinook	Spill	0.945		± 0.061	BT	Normandeau and Skalski (1999)	Unmodified spillbay (Spillbay 3); 10,000 cfs; 90% C.I.
1998	Hatchery Yearling Chinook	Spill	0.990		± 0.022	BT	Normandeau and Skalski (1999)	Spillbay 4; 14° sloped flow deflector; 2,000 cfs; 90% C.I.
1998	Hatchery Yearling Chinook	Spill	0.976		± 0.041	BT	Normandeau and Skalski (1999)	Spillbay 4;14° sloped flow deflector; 5,000 cfs; 90% C.I.
1998	Hatchery Yearling Chinook	Spill	0.928		± 0.063	BT	Normandeau and Skalski (1999)	Spillbay 4; 14 °sloped flow deflector; 10,000 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.994		0.985-1.004	BT	Normandeau and Skalski (2000a)	Unmodified spillbay (Spillbay 3); 2,800 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.976		0.957-0.996	BT	Normandeau and Skalski (2000a)	Unmodified spillbay (Spillbay 3); 6,000 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.995		0.991-1.019	BT	Normandeau and Skalski (2000a)	Unmodified spillbay (Spillbay 3); 7,500 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.983		0.968-0.999	BT	Normandeau and Skalski (2000a)	Spillbay 5; shallow-flat flow deflector; 2,800 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.982		0.966-0.999	BT	Normandeau and Skalski (2000a)	Spillbay 5; shallow-flat flow deflector; 6,000 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.976		0.965-1.007	BT	Normandeau and Skalski (2000a)	Spillbay 5; shallow-flat flow deflector; 7,500 cfs; 90% C.I.

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
Rock Island Dam								
1997	ROR Yearling Chinook	Pool	0.949	0.303		RT	Skalski and Giorgi (1999)	
1997	ROR Steelhead	Pool	0.9897	0.055		RT	Skalski and Giorgi (1999)	
1997	Hatchery Yearling Chinook	Spill	0.951		0.920-0.979	BT	Normandeau and Skalski (1998)	Spillbay 21; slotted, 1,850 cfs; 90% C.I.
1999	ROR Steelhead	Project	0.9863	0.0474		RT	Lady et al. (2000)	Estimate from Route-Specific Survival Model (RSSM)
1999	ROR Steelhead	Project	0.9983	0.0467		RT	Stevenson et al. (2000)	Estimate from Paired-Release Recapture Model (PRRM)
1999	Hatchery Yearling Chinook	Spill	0.995		0.981-1.0	BT	Normandeau and Skalski (2000b)	Spillbay 31; 2,500 cfs; 90% C.I.
1999	Hatchery Yearling Chinook	Spill	0.995		0.997-1.0	BT	Normandeau and Skalski (2000b)	Spillbay 31; 10,000 cfs; 90% C.I.
1999	ROR Steelhead	Spill	1.0939	0.0654		RT	Lady et al. (2000)	
1999	ROR Steelhead	Turbine P.H. 1	0.7488	0.1816		RT	Lady et al. (2000)	
1999	ROR Steelhead	Turbine P.H. 2	1.0135	0.0547		RT	Lady et al. (2000)	
2000	ROR Steelhead	Project	0.9258	0.0183		RT	Skalski et al. (2000a)	Estimate from Route-Specific Survival Model (RSSM)
2000	ROR Steelhead	Project	0.9196	0.017		RT	Skalski et al. (2000b)	Estimate from Paired-Release Recapture Model (PRRM)
2000	Hatchery Yearling Chinook	Project	0.9476	0.0186		RT	Skalski et al. (In Press.)	Estimate from Route-Specific Survival Model (RSSM)
2000	Hatchery Yearling Chinook	Project	0.9475	0.0192		RT	Skalski et al. (In Press.)	Estimate from Paired-Release Recapture Model (PRRM)
2000	ROR Yearling Chinook	Project	0.9445	0.0190		RT	Skalski et al. (In Press.)	Estimate from Route-Specific Survival Model (RSSM)
2000	ROR Yearling Chinook	Project	0.9391	0.0156		RT	Skalski et al. (In Press.)	Estimate from Paired-Release Recapture Model (PRRM)
2000	Hatchery Yearling Chinook	Spill	1.000		1.00-1.00	BT	Normandeau and Skalski (2001)	Spillbay 29; notched with middle release; 2,500 cfs; 90% C.I.
2000	Hatchery Yearling Chinook	Spill	0.990		0.978-1.00	BT	Normandeau and Skalski (2001)	Spillbay 29; notched with periphrial release; 2,500 cfs; 90% C.I.
2000	ROR Steelhead	Spill	0.9668	0.0239		RT	Skalski et al. (2000a)	
2000	Hatchery Yearling Chinook	Spill	1.0150	0.0217		RT	Skalski et al. (In Press.)	
2000	ROR Yearling Chinook	Spill	0.9863	0.0305		RT	Skalski et al. (In Press.)	
2000	ROR Steelhead	Turbine P.H. 1	1.0000	0.0493		RT	Skalski et al. (2000a)	
2000	Hatchery Yearling Chinook	Turbine P.H. 1	0.9115	0.0711		RT	Skalski et al. (In Press.)	
2000	ROR Yearling Chinook	Turbine P.H. 1	0.9702	0.0520		RT	Skalski et al. (In Press.)	
2000	ROR Steelhead	Turbine P.H. 2	0.9420	0.0227		RT	Skalski et al. (2000a)	
2000	Hatchery Yearling Chinook	Turbine P.H. 2	0.9722	0.0237		RT	Skalski et al. (In Press.)	
2000	ROR Yearling Chinook	Turbine P.H. 2	0.9959	0.0212		RT	Skalski et al. (In Press.)	

Appendix B. Continued.

Year	Species	Passage Route	Survival	S.E.	C.I.	Method	Source	Comment
				Rocky Reach Dam				
1997	ROR Yearling Chinook	Bypass	0.9772	0.274		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Steelhead	Bypass	0.7756	0.138		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Yearling Chinook	Dam	0.926	0.283		RT	Skalski and Giorgi (1999)	
1997	ROR Steelhead	Dam	0.919	0.05		RT	Skalski and Giorgi (1999)	
1997	ROR Yearling Chinook	Pool	0.9474	0.022		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Yearling Chinook	Pool	0.934	0.025		RT	Skalski et al. (1998)	Estimate from Single Release-Recapture Model (SRM)
1997	ROR Steelhead	Pool	0.9562	0.017		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Steelhead	Pool	0.959	0.018		RT	Skalski et al. (1998)	Estimate from Single Release-Recapture Model (SRM)
1997	ROR Yearling Chinook	Spill	0.9408	0.3060		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Steelhead	Spill	0.8893	0.0860		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Yearling Chinook	Surface Coll. 1	0.8885	NA		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Steelhead	Surface Coll. 1	0.9932	0.051		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Yearling Chinook	Turbine	0.9175	0.297		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1997	ROR Steelhead	Turbine	0.9078	0.074		RT	Skalski et al. (1998)	Estimate from Route-Specific Survival Model (RSSM)
1999	ROR Steelhead	Project	0.9612	0.0376		RT	Lady et al. (2000)	Estimate from Route-Specific Survival Model (RSSM)
1999	ROR Steelhead	Project	0.9658	0.0375		RT	Stevenson et al. (2000)	Estimate from Paired-Release Recapture Model (PRRM)
1999	ROR Steelhead	Spill	1.0622	0.0759		RT	Lady et al. (2000)	
1999	ROR Steelhead	Surface Coll. 1	1.0926	0.0429		RT	Lady et al. (2000)	
1999	ROR Steelhead	Surface Coll. 2	1.0036	0.0596		RT	Lady et al. (2000)	
1999	ROR Steelhead	Turbine	0.8972	0.0675		RT	Lady et al. (2000)	

Appendix B. Concluded.

[1] Original work by Normandeau et al. (1996), and reported in Ploskey et al. (2001).
[2] Original work by Dawley et al. (1998), and reported in Ploskey et al. (2001).
[3] Original work by Dawley et al. (2000a), and reported in Ploskey et al. (2001).
[4] Original work by Dawley et al. (2000b), and reported in Ploskey et al. (2001).
[5] Original work by Dawley and Absolon (2000 Preliminary), and reported in Ploskey et al. (2001).
[6] Original work by Counihan et al. (In Prep.), and reported in Ploskey et al. (2001).
[7] Original work by Muir et al. (1995a), and reported in Muir et al. (2001).
[8] Original work by Muir et al. (1995b), and reported in Muir et al. (2001).
[9] Original work by Muir et al. (1996), and reported in Muir et al. (2001).
[10] Original work by Iwamoto et al. (1994), and reported in Muir et al. (2001).
[11] Original work by Muir et al. (1998), and reported in Muir et al. (2001).
[12] Original work by Smith et al. (1998), and reported in Muir et al. (2001).
[13] The work by Normandeau et al. (1996a) was a separate evaluation of turbine survival from other work conducted at Wanapum Dam in 1996, where spill survival was evaluated with yearling chinook.

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