Return to Table of Contents
Go to Next Chapter

CHAPTER 7. SOURCES OF SALMON MORTALITY AND EFFECTIVENESS OF MITIGATION

"Our experience with these adult returns has made us believe we can work wonders with this transportation system. We believe that... combining the traveling screens...expanding the transportation effort on schedule, and adding spillway deflectors at the dams to reduce nitrogen concentration, we can restore adult steelhead trout to their former levels within two or three years. After the Snake River Mitigation Plan is approved by Congress, it seems possible that we can establish adult runs of both steelhead trout and salmon in far greater numbers than ever existed before."

Wes Ebel, 1977, presenting the National Marine Fisheries Service's perspective on major fish passage problems and their solutions in Columbia River salmon and steelhead, American Fisheries Society.

"Never have so many capable people labored so hard for so long to produce so little."

Al Wright, 1997, independent consultant, referring to Columbia River restoration efforts at a conference titled "Columbia River Management – Time to Rewire the System" held 15 December 1997 in Seattle, Washington.

In this chapter we discuss efforts that have been made to mitigate for adverse effects on salmon and steelhead created by development and operation of the hydroelectric system.

Habitat Restoration Mitigation Effects

The Council's FWP devotes a significant amount of attention to habitat improvement measures in Section 7.6 - 7.9, and others. NMFS has opened up the possibility of developing Habitat Conservation Plans (HCPs) jointly with affected parties as a measure to avoid or delay listing of endangered fishes or to incorporate them as an element in a recovery plan. Parties in the mid-Columbia recently signed such an agreement with NMFS.

In our review of habitat problems in the basin (Chapter 5), we described how quality habitat for each life history stage is essential to conservation and enhancement of Columbia Basin salmonids. Numerous studies have demonstrated that habitat for fish can be improved and that fish populations will respond to those improvements (Rhodes et al. 1994; Rhodes 1995; Belsky et al. 1999). Habitat restoration may have lagged as a mitigation priority for lack of a clear understanding of the specific biophysical conditions that exemplify quality habitat.

Tributary Habitat Restoration

We have often heard the argument that large amounts of pristine habitat remain in the headwater reaches of the river system, especially in designated wilderness areas (see Table 7.1). However, headwater reaches are predominantly high gradient within constrained channels and are generally unproductive owing to low concentrations of plant growth nutrients. Food web fertility derived from decaying carcasses of spent adult spawners may have been an essential feature that is now missing from these reaches (Bilby et al. 1996; Gresh et al. 2000). In some areas of the basin, habitat degradation of headwater reaches is pervasive from mining, logging and road building (see Chapter 5).

Table 7.1. Chinook salmon habitat in the Columbia River basin as length of spawning and rearing habitat accessible in kilometers. Source NPPC (1986).

Type	*Original*	*1975*	*Percent of Original*
Spring	17088	8718	49
Summer	8002	3650	54
Fall	3961	2749	31
Average			45

It is generally assumed that recent use of best management practices (e.g., selective timber harvest prescriptions, larger riparian buffer strips, better road construction and maintenance guidelines) and the use of audits to enforce them has improved instream habitats in managed landscapes. However, empirical demonstrations of real influences of best management practices on habitat variables (e.g., sedimentation, temperature, riparian vegetation, woody debris) are rare in the basin (Hunter 1991; Rhodes et al. 1994, D. Whitney, personal observation).

Because of the vast spatial scale of human activities that have caused degradation of habitats in tributary streams (especially including grazing, cropland and irrigated agriculture, and logging), it is unlikely that site-specific in-stream interventions can successfully offset the adverse ecological effects of land use activities. Instead, significant modification of land use patterns and practices, which if correctly implemented could result in the re-establishment of key natural biophysical processes over large areas, will be necessary for restoration at appropriate ecological scales (Doppelt et al. 1993; Frissell 1993b; 1993; Rhodes et al. 1994). This has been termed "passive restoration" in recent discussion of ecosystem restoration (Kauffman et al. 1995). The first principle of tributary restoration is to identify and fully protect from future human disturbance existing areas where high ecological integrity and largely natural ecosystem processes persist (Reeves and Sedell 1992; Doppelt et al. 1993; Frissell 1993b; 1993). Such areas might include intact headwater tributary catchments, as well as downstream alluvial reaches where human activities have been relatively limited in their scope and ecological effects (Doppelt et al. 1993; Frissell 1993b; 1993). The most urgent priority for active intervention is to implement selected restoration measures necessary to prevent further ecological damage in these relatively intact areas. Such interventions do not include projects intended to re-create habitat that has been destroyed, but rather to de-fuse processes of impact that discourage the natural re-development of habitat diversity (Doppelt et al. 1993; Frissell 1993b; 1993). Examples of such interventions include obliteration or hydrologic decommissioning of existing road networks, removal and exclosure of domestic livestock from key areas, modification of irrigation practices (Table 7.2), removal or modification of selected dams diversion structures and re-establishment of instream flows in key reaches, and perhaps re-introduction of locally-adapted propagules of native riparian plant species (e.g., willows) that have been extirpated from certain tributary drainages. Comprehensive ecological assessment is necessary to successfully identify and establish priorities (among sites and activities) for such interventions, and such assessments must be a principle objective in watershed analysis projects of state and federal agencies (Frissell and Bayles 1996, critique of).

Table 7.2. Acres under irrigation, and acre-feet of water delivered to agricultural enterprises by the Bureau of Reclamation, Columbia River Basin (Northwest Power Planning Council 1986).

Year	*Acres*	*Acre-ft*	*Source*
1889	400000		App. D. p. 178
1900	500000		App. D. p. 178
1910	2300000		App. D. p. 178
1925	2900000		App. D. p. 178
1947	---------	2639000	App. D. p. 181
1966	6600000		App. D. p. 178
1967	---------	8385500	App. D. p. 181
1979	---------	11653000	App. D. p. 181
1980	7600000		App. D. p. 178
1981	---------	10723200	App. D. p. 181

Mainstem Habitat Restoration

Our ecologically based conceptual foundation (Chapter 3) emphasizes the importance of channel to floodplain connectivity and seasonality of flooding to create and maintain habitat. Restoration and enhancement of habitat forming processes on the large flood plains that are accessible to salmonids through reregulation of flows to produce flood peaks and to stabilize baseflows, elimination of pollution loads (sediments, toxic compounds) and protection of riparian vegetation from logging and grazing are key elements of maintaining a productive river. (Stanford et al. 1996). These actions contrast with current habitat projects in the Fish and Wildlife Program and are more inclusive of the processes that the fish, especially juveniles, require.

In the mainstem Snake and Columbia Rivers, improving habitat conditions may be more problematic than for the riverine flood plains primarily because so many reservoirs are present that riverine characteristics are largely replaced by laucustrine conditions throughout the mainstems. Freshet flows will not produce habitat within the laucustrine reaches, although high flows associated with spring runoff may be beneficial to juvenile emigration via spill over the dams.

Habitat Mitigation Conclusions (and Level of Proof)

1. Habitat restoration in the normative river context has not been emphasized to date in the Fish and Wildlife Program as a primary mitigation need and it should be. (1)

2. Research to clarify habitat conditions in all of the mainstem reservoirs is needed. (1)

Mainstem Mitigation Efforts

In the previous chapter, we reviewed the development of the hydroelectric system in the context of the life histories of salmon and steelhead, particularly with regard to their requirements for spawning, rearing, and migration. Dams and their reservoirs now occupy all of the available river on the mainstem except the Hanford Reach, where about 55 miles of mainstem riverine habitat remain out of the original 1200 miles available to salmon and steelhead. In the Snake River mainstem, dams now block or have inundated all but about 100 miles of the 500 miles formerly accessible to them (Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife 1999). In this chapter, although we review dam construction and operation in the context of development and operation of the hydroelectric system, it must be recognized that many of the projects, such as Grand Coulee Dam, were justified for their benefits to flood control, irrigation, and other uses besides hydroelectric production. Particularly in the tributaries, water removals for irrigation have had significant adverse effects on salmon and steelhead. In the Snake River, for example, irrigation presently removes about 20 percent of the river flow, with more planned for the future (National Research Council (NRC) 1996).

While dams themselves are an obstacle to passage of adult and juvenile salmon, their reservoirs have slowed the movement of water to the ocean. Juvenile salmon and steelhead migrating out of the system are affected by the volume of flow presumably as it affects water velocity. Yearling chinook, steelhead, and coho have a life history that moves them downstream rapidly in the spring at a time corresponding with the normal spring freshet. Subyearling chinook, move more slowly through the spring and summer, feeding, and resting on the way downstream.

In the Snake River, the reduced water velocities created by the reservoirs have added to the average transit time of juvenile fall chinook (ocean type) salmon to the mouth of the Columbia River to the extent that they now migrate primarily in late June to early August, where formerly they migrated in May and June (National Marine Fisheries Service 1999). On the other hand, subyearlings from the Snake River tend to be larger than those from the mid-Columbia, suggesting that the stock might have adapted to these conditions, as we noted in the previous chapter.

In the chapter that follows, we discuss mitigation measures that have been undertaken in an attempt to counteract the effects of the development and operation of the hydroelectric system on salmon and steelhead abundance, productivity, and diversity.

Flow Provisions of the NPPC Fish and Wildlife Program

Water Budget and Flow Augmentation

A primary mitigative activity in the mainstem is the use of water stored in upstream reservoirs to decrease the travel time of juveniles through the mainstem. The 1982 FWP established a "water budget", to be used annually in the spring months, April 15 to June 15, by the fish and wildlife agencies and tribes to *"…implement any flow schedule that provides maximum juvenile salmon survival, within the limits of firm non-power requirements, physical conditions, and flow required for firm loads."* (NPPC 1982; NPPC 1987, Section 303(a)(1)). Note that the stated purpose of the water budget, and later flow augmentation, is to improve survival of juvenile salmon. We will return to the question of whether that goal was achieved after we describe what the actions consisted of and how they were implemented. The water budget consisted of 4.64 million acre feet (Maf), divided into two portions, 3.45 Maf at Priest Rapids Dam and 1.19 Maf at Lower Granite Dam. Average annual runoff of the Columbia River at its mouth is about 198 Maf. The 1982 Fish and Wildlife Program referred to the water budget provision as an experiment, and called upon BPA to fund a study to gather information on the relationships among flow, spill, travel time and smolt survival (NPPC 1982).

In 1992, the Council in its Fish and Wildlife Program, called for increased volumes of water for flow augmentation (replacing the “water budget” terminology) in the spring months. The NPPC called for an independent scientific evaluation of the available information on effects of flow on survival of juvenile salmon. Noting that in the 1980's there had been unsatisfactory progress in refining this relationship, the Council "insisted" that this relationship immediately receive the highest priority in the region's research efforts (McConnaha 1993).

The Fish and Wildlife Program of 1994, in discussing operational and biological objectives of fish passage, flow augmentation, and temperature control in the rivers, specifies that,

> *"….the NPPC accepts the agencies' and tribes' judgement on the expected biological value of these operational objectives. This is not to say that the NPPC accepts these judgements conclusively. The scientific data are not clear, and there are genuine disagreements among capable scientists on these matters."* (NPPC 1994a, p.5-4).

The Fish and Wildlife Program went on to specify a hypothesis as to a relationship to be tested experimentally between flow, water velocity, fish travel time, and survival, and assigned the ISG (now the ISAB) a responsibility for "directing" development of technical aspects of a study design (NPPC 1994, p.5-6 and 5-9).[1] Because of the simultaneous need for action and better scientific information, the Council believes that the relationships can best be clarified through an adaptive management approach. This approach would involve the simultaneous use of in-river passage and transportation (by truck and/or barge) as management experiments to address specific hypotheses. The Council believed that experiments would include a combination of management actions, research, monitoring, and evaluation.

Implementation of the water budget or flow augmentation is a complex process that involves close monitoring of sequential passage of juvenile fish from one dam to the next and selective releases of stored water from upstream sites. The Fish Passage Center was established to implement the monitoring portion and to coordinate the necessary releases of water with the responsible federal agencies. Availability of water for the purpose is arranged through a consultation process for forecasting runoff and planning for flood control, irrigation, and power, along with the flow for fish (NPPC 1994a). The water for implementation comes from the storage reservoirs upstream, principally in Montana and Canada, and its withdrawal requires drawdown of those reservoirs. This in turn leads to adverse effects on resident fishes in those

[1] The hypothesis reads as follows: "The Council accepts that there is a relationship between flow, water velocity, fish travel time and survival such that increasing water velocity increases the survival of salmon and steelhead from the onset of active downstream migration to adult spawner." (NPPC 1994; FWP, p. 5-9)

systems (Independent Scientific Advisory Board 1997). For example, loss of the spawning cue associated with the spring freshet is a primary problem for recovery of endangered species of sturgeon downstream from Libby Dam (Marotz et al. 1996). Reregulation to produce freshet flows in the spring for creation of spawning habitat and stabilization of daily fluctuations in flows to provide shallow water habitat for larval recruits likely will be beneficial to all native fishes in headwater rivers like the Flathead, Kootenai, Clearwater, Clark Fork, Pend Orielle, Upper Columbia, Owyhee, Boise, Deschutes, Willamette, and others that are regulated by large storage reservoirs. Recognizing that there are trade-offs between benefits to the numerous water users in the basin, i.e. flood control, irrigation, hydroelectric power generation, navigation, fish and wildlife, and others, the NPPC in 1994 adopted Integrated Rule Curves (IRCs) developed by the Montana Department of Fish and Wildlife that were designed to balance the conflict over water between anadromous and resident fish requirements (NPPC 1994a; Marotz et al. 1996). However, the IRCs were never implemented because in 1995 responsibility for management of flows in the basin was assumed by NMFS/NOAA under the Biological Opinion (BiOP) for Endangered Snake River salmon. The NMFS/NOAA operations focus on improvement of survival of endangered Snake River chinook and sockeye salmon (National Marine Fisheries Service 1995a), which is the scope of authority of NMFS.

Recovery efforts by NMFS recently have focused on flow augmentation in spring and late summer in the mid- and lower reaches of the Snake and Columbia Rivers in an effort to provide flows to reduce travel time of juvenile salmon and to counteract potentially lethal temperatures associated with low flows (National Marine Fisheries Service (NMFS) 1995). This is accomplished by two strategies, first by limiting winter/spring drawdown in the storage reservoirs to increase spring flow and to increase the probability of achieving full reservoirs, then by drafting water releases from these reservoirs during the summer to increase summer flows. Releases from Dworshak Dam, a large storage dam on the Clearwater River, are intended to provide cooler water in the Snake River during the summer.

Effects of Flow Augmentation on Travel Time of Juvenile Salmon

In the Snake River, for spring chinook and steelhead, there is a clear relationship of travel time with flow; higher flows leading to reduced travel time (discussed in Chapter 6). The question is to what degree the amount of flow augmentation provided can be expected to counteract the effects of impoundment. Berggren and Filardo (1993) included in their analysis, points depicting flows before (1981-1983) and after (1984 and beyond) the water budget was implemented. That approach did not turn out to be particularly revealing with respect to the question whether travel time is lower and by how much thanks to flow augmentation. However, the curves they developed to predict the effects of flow on travel time out of the Snake River could be used to estimate how much reduction in travel time can be expected with given increments of flow augmentation.

Experience in practice showed that base power flows assumed by the Council were not available in the Snake River in low water years, thus compromising the ability to implement the water budget (Wood 1993). Wood concluded that up to the time of his report, execution of the water budget had been difficult due to lack of an authoritative management strategy, limited scope, and the absence of firm implementation guidelines. These problems made judging the efficacy of the program difficult. These problems were, at that time, further complicated by the lack of adequate documentation on the effects on fish travel time and survival. Since that time, there have been numerous studies on travel time (summarized in Chapter 6). Taking these into account, Giorgi et al. (1997b) concluded that during the years 1991-1995, the water management strategy changed from predominantly targeting spring migrants to emphasizing summer-migrating fall chinook salmon. In 1991, 74 percent of the flow augmentation was released prior to 21 June. By 1995, only 3 percent of the augmentation occurred during that same period, with the remainder released during the summer period extending through August. Typically, flow augmentation was insufficient to sustain the flow targets specified by NMFS in the Biological Opinion. Nevertheless, during the spring, flow augmentation increased estimated average water velocities through Lower Granite pool by 3-13 percent, and during the summer by an estimated 5-38 percent in the years 1991-1995. Using data from Berggren and Filardo (1993), the estimated reduction in travel time attributable to flow augmentation was 5-16 percent for spring/summer chinook and 6-17 percent for steelhead. (Note: We believe the CriSP model underestimates the effect.) No relationship of flow with travel time has been established for subyearling chinook. Most likely this is because of the natural behavior of these ocean-type salmon in alternately resting in near-shore areas, and moving out into the current to continue downstream (zigzagging or spiraling, as described in the previous chapter).

Thus, the data provided by Giorgi et al. (1997b) show that flow augmentation can reduce travel time for yearling chinook and steelhead out of the Snake River, but not for subyearling fall chinook. However, the data for Snake River subyearling fall chinook were limited until recently to observations in the lower Columbia River, from McNary Dam to John Day Dam (Berggren and Filardo 1993). Recent information from PIT tag studies of NMFS show that there is a weak, but significant relationship of travel time with flow for subyearling fall chinook within the Snake River (Data supplied by W. Muir, NMFS, personal communication, 1999). These data show that among individual fish there is a highly variable response to flow except at flows above about 120 kcfs and below about 60kcfs, when the response is more uniform, slowing below 60 kcfs and speeding above 120 kcfs.

The nature of the curves developed by Berggren and Filardo (1993) suggests that significant effects on yearling chinook and steelhead are most likely to be measurable at flows below 100 KCFS. At flows between 50 KCFS and 100 KCFS, the curve for Snake River yearling chinook suggests that travel time from Lower Granite Dam to McNary Dam may be reduced from 16 days to 11 days, roughly a one day reduction in travel time for each 10 KCFS of additional flow. For steelhead, it appears that the effect would be about the same, a reduction in travel time from 14 days to 9 days, or about one day for each 10 KCFS of additional water.

Effects of Flow on Survival of Juvenile Salmon

Owing to uncertainties associated with water budgeting and flow augmentation, considerable debate and at least one Congressional hearing has ensued (Senate Subcomitee on Science, Technology, and Space, June 18, 1996). Upriver interests noted the lack of a flow survival relation associated with flow augmentation in the lower river, while lower river interests cited a need for elevated flows to improve late summer travel time and potentially reduce high temperatures for the benefit of migrating juvenile salmon and steelhead.

Chapman et al. (1994a) in a review of the information available on effects of flow on survival of juvenile salmon, concluded:

> *"The goal of increasing migration speed is to increase survival through the reservoirs, and perhaps to and after ocean entry. However, the relationship between speed of migration and reservoir mortality has never been measured for any species, in any reach of river. The relationship has been inferred from system survival estimates reported by NMFS during the 1970s and early 1980s, for both yearling chinook and steelhead.".*

The system survival estimates of NMFS to which Chapman et al. (1994a) referred are contained in the work by Sims and Ossiander (1981) which used estimates of survival of juvenile chinook and steelhead through the Snake River over the period 1973 to 1979 to develop a mathematical relationship between flow and survival. On the basis of this work, it was logical for the Council to proceed, using it as a basis for action to improve survival of juvenile salmon (McConnaha 1993). According to McConnaha (1993), the Council's initial determination in the 1982 Fish and Wildlife Program arose from recommendations of the fishery agencies and tribes that were based on the analyses by Sims and Ossiander (1981), Raymond (1979), and Raymond (1968). Significantly, these recommendations recognized there were limitations in the flow-survival analyses and recommended further research to refine the flow requirements (McConnaha 1993).

Flow Provisions of NMFS Proposed Recovery Plan for Snake River Salmon

The NMFS Proposed Recovery Plan for Endangered Snake River Salmon describes a direct relationship between juvenile fish survival and flow citing Cada et al. (1993), Petrosky and

Schaller (1992), and Hilborn (1993). The reference to Cada et al. (1993) in the proposed Recovery Plan pertains to a review by Cada et al. (1993) of the Sims and Ossiander study (1981). We review these papers in detail below. Suffice it to say at this point, that the Plan uses these papers as a basis for requirements for flow augmentation, as it says, for two purposes, to increase the probability that flows would be available for migrating fish when they need it and to manage the available water through a real-time, flexible management process that ensures maximum benefits for both juvenile and adult migrating fish. Flow targets or flow objectives were a component of this approach (Snake River Salmon Recovery Team 1993).

In addition to the Council's flow augmentation, which is aimed at provision of spring flows, the NMFS BiOp calls for summer (mainly August) releases of water from headwater reservoirs, particularly Hungry Horse and Libby reservoirs. A Steering Committee appointed by NMFS/NOAA and BPA in 1994 to attempt to develop an agreement among affected water users on flow provisions that would be acceptable, found that the need for and level of August flow requirements to be one of the region's top salmon monitoring and evaluation priorities (Wright 1996).

Evaluation of the Council's Flow/Survival Hypothesis

As mentioned previously, the Council specified a working hypothesis regarding a relationship between volume of flow and survival of juvenile salmon migrating downstream, and "insisted" that a study be developed to test the hypothesis. Skalski et al. (1989) developed a suggested work plan for evaluation of flow, in the context of the water budget and smolt survival. However, a full-scale study plan has yet to be designed and executed. In the meantime, the region continues to depend upon the early work of Sims and Ossiander, and upon monitoring by NMFS of survival of Snake River salmon and steelhead accompanied by attempts to correlate those survival estimates with flow and other factors. We will have more to say on those studies later.

Discussion of Potential for Effects of Flow on Juvenile Salmon

There are many avenues, by which volume of river flow could affect juvenile salmon survival (Figure 7.1). These avenues are discussed below and elsewhere in this report.

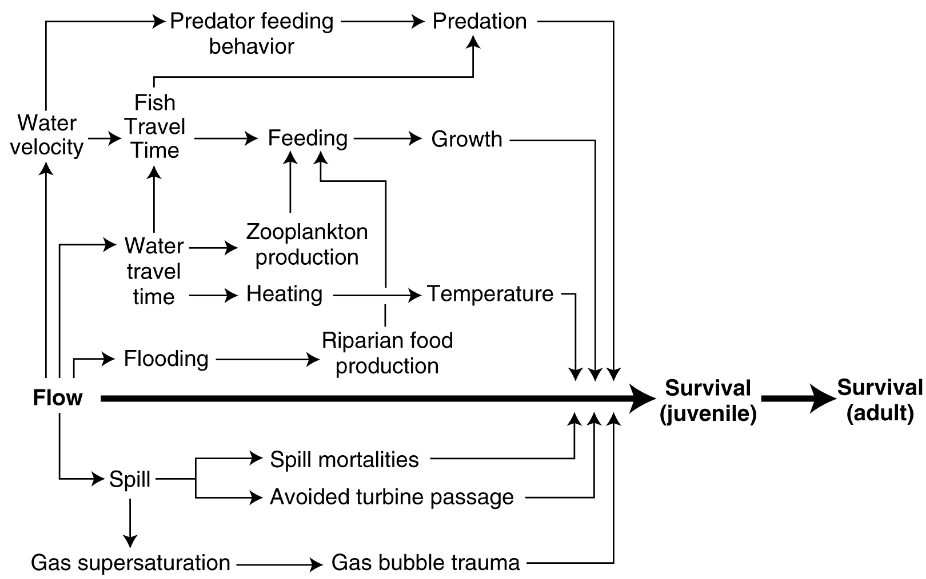

Figure 7.1. Alternative causal relationships that may affect any link between river discharge (flow) and survival of juvenile salmonids.

They include spill of water at dams during flows that exceed plant capacity (*leading to higher survival of smolts*), flooding of riparian zones (*stimulating food production for juveniles and providing refugia from predators*), reduced summer temperatures (*reducing stress induced by high temperatures*), reduced effectiveness of predators in high velocities and water volumes (*leading to higher survival of juveniles*), and effects on the aggregate energy budget of migrating fish (*better growth and survival*). Thus, simplification of a relationship between flow and survival that centers on water velocities and travel times for juveniles in reservoirs is probably inappropriate for the full range of life history types of salmon, nor does it provide a holistic view of measures needed for recovery and re-establishment of salmonid populations.

Improvement of in-river survival of juvenile salmonids depends upon the specific needs of fish that go beyond simply moving them downstream as though they were passive objects. River flow occurs in the context of a total river environment, one that historically provided a number of diverse habitats for use by different salmon species and stocks as they moved downstream as juveniles and upstream as adults. We have already pointed out that there needs to be a distinction between the needs for flow by spawning adults, the incubation of eggs, and the rearing of juveniles, as distinguished from the mainstem flows encountered by the juveniles as they move toward the sea. Here, we are discussing mainstem flows as they might affect that migration. Hydropower production has changed these riverine habitats, but the basic needs of the fish remain the same. There are several relevant details of the life history requirements of salmonid fishes. To begin, it must be recognized 1) that there are different life history patterns that interact with mainstem flows in different ways, 2) that emigration is not a passive riding of currents straight to the sea, 3) that good quality mainstem habitat for the resting and feeding stages is necessary (also, see discussions of habitat in Chapter 5 and 6), 4) that juvenile salmonids are generally surface oriented when moving downstream, and 5) that they probably use the complex unsteady and turbulent flow of river environments as migration guides and assists, rather than relying upon either mass water movement or their swimming abilities alone.

Review of Relevant Studies on Effects of Flow on Survival of Juvenile Salmon

Sims and Ossiander (1981)

The review of available information that was called for in 1992 by the Council was provided in the report by Cada, et al. (1993). They reviewed the methods employed by NMFS to estimate juvenile salmon survival (Raymond 1968; Raymond 1979) and the use of those estimates to develop the relationship of flow and survival by Sims and Ossiander (1981). Although Cada and colleagues were critical of the experimental design of the Sims and Ossiander study and the imprecise results obtained, they concluded that the relationship of increasing survival with increasing flow "appeared to be reasonable".

In a subsequent, more detailed analysis of the basic data, Steward (1994) noted several difficulties that are present both in the development of the survival estimates used in the analysis and their use in the method of analysis itself. Principal among these are the low recovery rates of marked fish in some years, and the different methods used for estimating survival in some years and at some locations. The use of different approaches for estimating survival led in some cases to different values reported for the same year in different publications. In one series of years a flow-efficiency curve was used to estimate the population size reaching the sampling station, while in later years a direct population estimate was made from recovery of control groups of fish. Further, an analytical problem arises from use of regression analysis where flow is both the independent variable and was used in some years as a basis for the "collection efficiency" number that was used to expand sample counts of treatment fish (Steward 1994). Steward (1994) concluded that sampling conditions were too variable, the methods employed to collect and analyze the data were too unreliable, and the statistical model used to describe the relationship was too simplistic to justify its use as a predictive tool. Steward's assessment led him to conclude that the flow-survival relationship should not be generalized to existing populations and settings. New field studies and analytical approaches will be needed to clarify the relation between survival and flow within the context of current management needs (Steward 1994, p.75).

Further questions were raised by Williams and Mathews (1995) who concluded that low survival of juvenile salmonids certainly occurred in 1973 and 1977, the two years with lowest flow included in the analysis by Sims and Ossiander (1981), but the low survival in those two years probably resulted more from fish encounters with debris at dams (encounters which were increased because of low flows and exacerbated by sporadic turbine operations) than from river discharge (Williams and Mathews 1995, p. 738).

As a follow-up of Williams and Mathews' observation that turbine operations were sporadic during those low flow years, we examined the records of hourly operations of Lower Granite, Little Goose, and Ice Harbor dams during the spring outmigration periods of 1973 and 1977. We chose the same dates identified by Sims and Ossiander as the 15-day period centered on the time of peak fish passage at the given project (as summarized by Steward, 1994). The daily average flows used by Sims and Ossiander were 71 kcfs in 1973 and 40 kcfs in 1977 (Sims and Ossiander 1981). The effects of load following during these years of water shortage are evident. In 1973 at Little Goose Dam, the uppermost dam at that time, there were five episodes during the May outmigration period when outflows were reduced by about one-half during a period from one hour to the next (in the range of 40 kcfs down to 20 kcfs). Reduced flows were held there for as long as seven hours (three episodes), then resumed to their former volume. At Lower Granite Dam in 1977, there were 17 episodes where outflow was reduced by half or less in the space of an hour, held for periods up to seven hours (7 cases), then resumed. In three episodes, outflow was reduced to less than 1 kcfs and held for as long as six hours (2 cases) before being resumed. In 1977, at Ice Harbor Dam there were 22 episodes in which flow was reduced to half suddenly for periods from 1 to 8 hours and then resumed. Among these were 7 episodes when flow was reduced to less than 1 kcfs for periods of 2 to 6 hours, and 4 episodes when flow was reduced to between 1 and 2 kcfs for periods of 1 to 3 hours.[2] We believe the potential for stranding of juveniles between the Snake River projects and below Ice Harbor Dam was significant at such times. Studies of fall chinook in the Hanford Reach have established beyond doubt that sudden changes in flow lead to stranding of juvenile salmonids (Independent Scientific Advisory Board 1998a). The effects of flow on survival reported by Sims and Ossiander (1981) were probably not caused by the low river flow per se, but by the operation of the hydroelectric system that artificially left fish high and dry during periods of reduced demand

[2] It seems highly likely that these patterns of load following reflect outflow from Hells Canyon Dam, since storage capacity in the four lower Snake River projects is quite small. However, we have not confirmed this.

for power. Daily average flow is not an appropriate measure of biological significance in a regulated river.

Without these two data points, 1973 and 1977, there is no relationship between flow and survival (Chapman et al. 1991). Of course, the idea of discarding data is controversial. However, we find justification in standard statistical practice in treating "outliers", and in treating contaminated samples. The two samples from 1973 and 1977 can be viewed as "contaminated" in the sense that the effects observed were clearly due to factors other than flow, as demonstrated by Williams and Mathews (1995) in particular and Steward (1994) secondarily.

Of relevance in this connection are data from studies conducted by NMFS and the University of Washington since 1993, using the PIT tag technology in the single release multiple recapture model (Burnham et al. 1987). The estimates are added to those of earllier studies and are shown in Figure 7.2. While none of the recent estimates were made at flows as low as those in 1973 and 1977, it is apparent from the figure that those two years are outliers.

The statistical model to which Steward (1994) referred as forming the basis of Sims and Ossiander's data, employed paired releases of marked fish; one released upstream (above Little Goose Dam in 1973-1975 and above Lower Granite Dam from 1974-1979) and the other released just above the point of recovery of the marked fish (The Dalles Dam from 1973-1975 and John Day Dam from 1977-1979). Recovery rates of the latter group were used to estimate the rate at which the upstream release group was recovered at that point, thus making possible an estimate of the total number of upstream fish that reached that point. Recoveries of marked fish were adjusted in some years for the estimated sampling efficiency at the particular project, which depended upon the relative amount of water spilled at the project, the reasoning being that fish included in spill were not available for sampling.

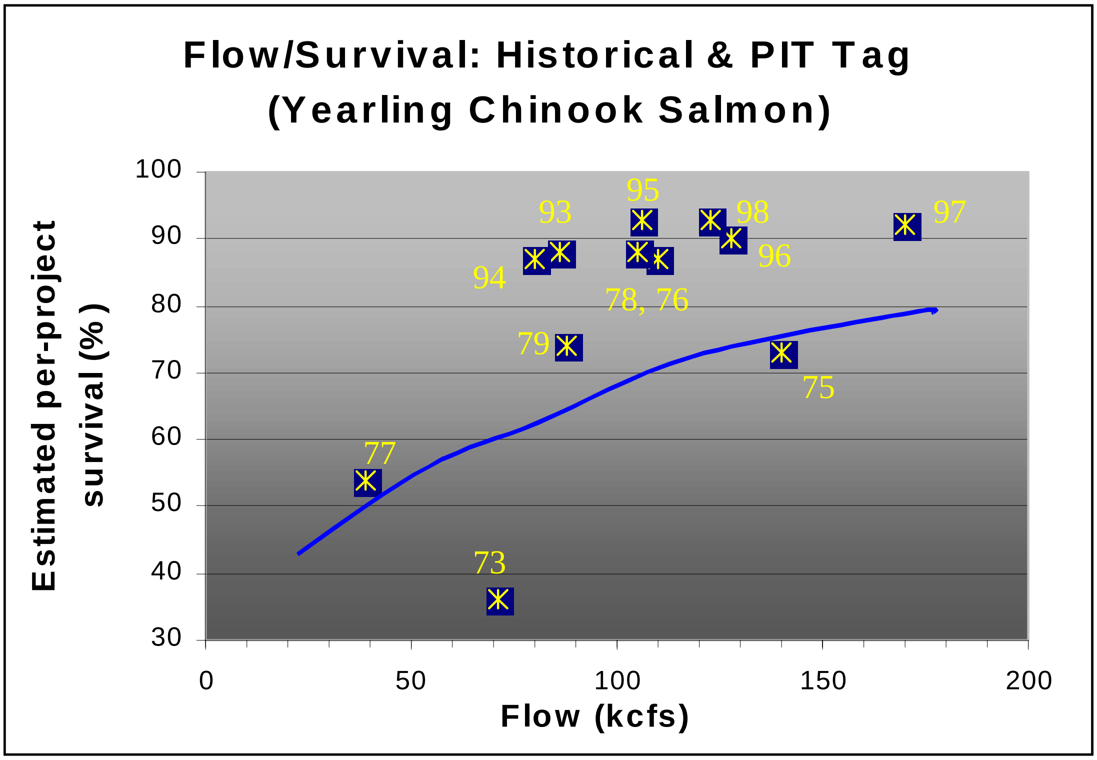

Figure 7.2. Relationship between flow and survival. Data points 1973-1979 from Sims and Ossiander, (1981). Subsequent data from PIT tag studies of NMFS (courtesy of Bill Muir, NMFS, 1999).

The method involved assuming a 1:1 relationship between percentage of river volume spilled and percentage of total fish diverted in spill. An estimate of per project survival was calculated from the estimate of total survival arising from the adjusted numbers of fish in the samples (i.e., the ratio of adjusted upstream recoveries divided by adjusted downstream recoveries reduced to the n^{th} root, where n is the number of projects present in the river in that year). The use of that model came under scrutiny by a team of statisticians assembled by the Smolt Monitoring Program not long after the Sims and Ossiander study (McKenzie et al. 1985). The idea of paired releases used for estimation of survival began to be discredited (McKenzie et al. 1985). There are many logistical and theoretical difficulties with application of the method. In practice, in the case of the estimates used to develop the flow survival relationship, it sometimes happened that fish passing the longest river reach were recovered at rates higher than those released just above the point of recovery, leading to survival estimates over 100% (Steward 1994). Those data were discarded and not included in the final analysis. In general, the paired release model requires assumptions about the routes, times of arrival at the sampling point by both groups, and other factors which may not be realistic (McKenzie et al. 1985). As a result of the McKenzie et al. report, estimation of reach survival was eliminated from the Smolt Monitoring Program in 1987 (McConnaha 1993).

Detailed Critique by the ISG of the Sims and Ossiander (1981) Study.

While reviews of Sims and Ossiander (1981) have already been provided by Cada et al. (1993) and Steward (1994), as noted above, we felt a responsibility to examine the analysis for ourselves. Sims and Ossiander themselves had included an analysis of effects both of flow and of spill on survival of chinook and steelhead. They developed separate correlations of survival with flow and with spill, and a third multiple regression analysis, that used both flow and spill. A more revealing analysis can be conducted using a step-wise regression analysis, which can be used to decide whether one or the other of flow or spill is more important in affecting survival. In addition, we observed that the values for spill they used were volumetric measures. We feel that a more appropriate indication of effectiveness of spill can be obtained by using spill as a percentage of river flow, rather than the volume of spill. For a more complete explanation see the section on Bypass in this report, or Whitney et al. (1997).

We conducted step-wise regression analyses of the effects of flow and spill on survival of chinook and steelhead, using the survival values and flow from 1973 to 1979 reported in Sims and Ossiander, and conversions of their spill volumes to percentages of river flow.[3] The analysis is complicated by the fact that flow and spill are themselves obviously correlated – at least at some level of flow. The result of our analysis reveals that if either variable (flow or spill) is forced into the model as an independent variable, the other variable never enters significantly for either chinook or steelhead (Table 7.3). In other words, there is a choice of whether to use flow or spill to improve survival of chinook and steelhead in the Snake River, but using both would not be justified by the data in Sims and Ossiander. In fact, Sims and Ossiander (1981) themselves concluded that spill is more effective than flow in improving survival, based on the slope of the two regression equations they developed in their analysis.

[3] We are indebted to Lyman McDonald of the Independent Scientific Advisory Board for preparation of the statistical analysis shown in Table 7.3, and the conclusions associated with it.

Table 7.3. Results of step-wise regression analysis of data From Sims and Ossiander (1981) on survival with flow and with spill for chinook and steelhead

A. Log Survival*Log Flow	***Equation***	R^2	***P***
Chinook	Log S = 0.3221 + 2.238(Log flow)	0.833	0.004
Steelhead	Log S = -0.4137 + 2.654(Log flow)	0.98	0.011
B. Log Survival*Log Spill %			
Chinook	Log S = 0.023 + 0.837(Log Spill %)	0.60	0.034
Steelhead	Log S = -0.25 + 0.958(Log Spill %)	0.89	0.011
C. Log Survival*Log Spill%*Log Flow			
Chinook	Log S = -4.511 -0.453(Log Spill%) + 3.213(Log Flow)		
	P (Spill%) = 0.45;		
	P (Flow) = 0.06;		
Steelhead	Log S = -2.671 + 0.41(Log Spill%) + 1.618(Log Flow)		
	R^2 = 0.94		

Conclusion: The R^2 values are, for practical purposes, not different using flow or spill% one variable at a time. When both variables are forced into the equations, predictions from the model for chinook become unreliable (i.e. the coefficient of Log Spill% is negative for chinook), because of multiple colinearity in the two predictor variables. Flow and spill are themselves highly correlated and use of a model with both variables may be very unreliable without larger sample sizes.

Review of Other Approaches

Other approaches have been used in attempts to arrive at a test of the hypothesis that river flow affects survival of downstream migrating juvenile salmon. These studies have some faults in common, i.e., in attempting to correlate survival with flow they have failed or been unable to consider concomitant effects of spill as well as effects on survival of other factors that are correlated with flow. They also suffer from the fact that correlation studies do not necessarily establish cause and effect relationships among factors, as Skalski et al. (1997) point out. For example, most of the factors, flow, survival, temperature, spill, and so on, are themselves correlated with time. The need is for an experiment designed to either randomize the effects of some of the factors or to incorporate them in some other way into the design.

Skalski et al. (1997)

Skalski et al. (1997) summarize an attempt to use recovery information from fall chinook originating in the hatchery at Priest Rapids that were marked with coded wire tags prior to release to determine whether flows during the year of release affected their survival. (This report is the final version of the draft by Hilborn et al. (1993) to which the NMFS Proposed Recovery Plan referred, as noted above). Skalski et al. (1997) summarized their conclusions as follows, "*This analysis of the 24 years of Priest Rapids hatchery returns yielded little insight into key in-river factors that may be influencing hatchery return rates*." They pointed to the difficulties in interpreting correlation studies such as theirs, where cause and effect cannot be identified. They felt that their study did shed some light on probable relationships, and recommended that these should be the subject of future controlled experiments.

Petrosky (1993) and Petrosky and Schaller (1993)

Petrosky (1993) and Petrosky and Schaller (1993) provided what they believed to be a flow-survival relationship for spring chinook from Idaho and Oregon tributaries. They examined the rate of return as adults of spring chinook smolts that were reared in the tributaries, and found a relationship of return rate with flows in the Snake River measured at Lower Granite Dam during the main emigration period. They detected a trend in the highly variable data, suggesting better smolt to adult returns when flows were high. Their analysis suffers from the problems discussed above of simultaneous effects of degree of smoltification, temperature and other factors affecting survival, all of which show trends with time through the season. The presence of a declining trend in abundance of chinook through the y ears, along with a declining trend in flow further complicates interpretation.

NMFS/UW PIT Tag Studies

In the 1987 Fish and Wildlife Program, the Council created technical work groups (TWGs) to develop research work plans for various areas of emphasis. A technical work group on reservoir mortality was appointed. The Reservoir Mortality Work Group was unable to agree on a plan and went out of existence in 1989 (McConnaha 1993). As an outgrowth of the Council's continued interest in the issue, a group of experts was appointed to develop a research work plan (Skalski et al. 1989). The resulting report included a plan for further investigation of the relationship between flow and survival. In particular, the plan called for employment of PIT tags for the studies. The PIT tag technology made possible a statistical model that depends upon multiple recaptures of a single release of marked fish, a method advocated by Burnham et al. (1987) in preference to the paired release model for the survival estimates used by Sims and

Ossiander (1981). Dauble et al. (1993), agreeing with McKenzie et al. (1985), identified the primary problem with the "paired release" method used in the analysis by Sims and Ossiander (1981) as the difficulty in estimating collection efficiency of treatment groups at downstream locations, because it requires an assumption that both groups will experience the same hazards in arriving at the sample location. In general this requires them to arrive at the same time, to avoid differences in river or project conditions.

This new model, a single release model with multiple recoveries of marked fish, using the PIT tag technology, has been employed since 1993 by NMFS and the University of Washington to develop survival estimates in reaches of the Snake River (Iwamoto et al. 1993; Iwamoto et al. 1994; Muir et al. 1995b; Muir 1996; Williams and Bjornn 1997). These studies are summarized below and in somewhat more detail in the Bypass section of this chapter. These must be considered to be monitoring studies, since they are not associated with a specific experiment designed to isolate a relationship between flow and survival. However, neither were the monitoring studies reported by Sims and Ossiander (1981), which may have created another difficulty with their interpretation, e.g. if treatments had been randomized, it would have been less likely that there would have been confounding of effects of flow with effects of trash on survival.

Using this new model to estimate survival, Smith et al. (1997a) concluded that when data were adjusted for annual means, no environmental exposure (including flow, spill%, and/or temperature) had a significant correlation with survival of primary release groups of yearling chinook salmon in the lower Snake River reach that was studied. Without adjusting for annual means, spill percent and temperature resulted in the model with the greatest explanatory power for survival estimates. If spill percent was replaced with flow in the model, flow was significant but not as highly significant as spill percent. With respect to subyearling chinook Smith et al., (1997b) noted that determining the relationship between survival, flow, and water temperature for subyearling fall chinook would be difficult because of their protracted migration. They recommended that future studies release more fish from a single location over time. Additional years of data will help to define these relationships. A primary difficulty with such analyses is the fact that survival was also found to be correlated with travel time and fish size, both of which showed a trend with time through the season, as did flow. It is separating the effects of these variables that presents the problem.

Upstream (National Research Council, 1996)

After analyzing the Council's requirement for a water budget and NMFS's requirement for flow augmentation, the National Research Council (1996) concluded the effectiveness of flow augmentation alternatives had not been demonstrated. They cited a Systems Operation Review

(SOR) which found that flow augmentation alternatives provided negligible survival benefits for in-river migrants. The SOR pointed out that spill, which may be associated with provision of flow levels, does provide measurable survival benefits.

Effects of Flow on Transportation of Juvenile Salmon

Both the Council's Fish and Wildlife Program and NMFS/NOAA's Recovery Plan for Snake River salmon recognize that transportation of juvenile salmon is affected by flow provisions. Higher flows and higher levels of spill reduce the collection efficiency of the turbine intake bypass systems that provide the fish for transportation. Neither agency is yet prepared to decide on one mode of protection over the other. The reason for this is that there are uncertainties with respect to transportation that are yet to be addressed. In the 1994 Fish and Wildlife Program, the Council stated two mainstem passage hypotheses which are to be addressed by an experimental program using adaptive management (1994 FWP, Section 5.0E). One having to do with survival of juvenile salmon passage in-river, and the other having to do with survival in the transportation mode. We provide a more complete description and analysis of the transportation program in another section of this chapter. The Council's Fish and Wildlife Program of 1994 notes that much disagreement remains about the efficacy of transportation, which is similar to the disagreement about the benefits of flow augmentation. These uncertainties form the basis of the Council's mainstem passage experiment, which includes elements of in-river survival and of survival by transportation. In short, the Council calls for substantial reduction in the number of fish transported.

The NMFS/NOAA Recovery Plan specifies flow levels above, which spill is to be enhanced for in-river migration of juvenile salmonids and below which transportation is to be emphasized. When flow is equal to or greater than 85 kcfs at Little Goose and Lower Monumental Dams and greater than or equal to 100 kcfs at Lower Granite Dam, then spill should occur, resulting in fewer fish being collected for transportation. The Plan notes that, "*Ideally, these interconnected programs would be founded on a rule curve that establishes the relationship between flow conditions, in-river survivals, and the relative benefits of transportation*." (Snake River Salmon Recovery Team 1993).

Effects of Flow on Water Temperature in the Mainstem

Storage and release of water from upstream reservoirs, specifically Lake Roosevelt above Grand Coulee Dam, has delayed the timing of peak summer temperatures since 1941 (Ebel et al., 1989). The delay has amounted to about 30 days at Rock Island Dam and the effects could be detected to a lesser extent at Bonneville Dam (Jaske and Goebel 1967; Jaske and Synoground 1970). Projects downstream of Grand Coulee have little storage capacity and show negligible effects on water temperature. Water temperatures at the mouth of the Snake River in August and September have historically been a few degrees higher than those in the mainstem Columbia (Roebeck et al. 1954). During late summer of some years, high water temperatures (20^{o} to 22^{o}C) and low dissolved oxygen levels (<6 mg/ L) make living conditions marginal for salmon and steelhead in the lower Snake River reservoirs (Bennett et al., 1983). The problem also occurs in a number of tributaries, such as the Okanogan River where sockeye adults are delayed in their upstream migration by warm water at the mouth of the river (Major and Mighell 1966; Allen and Meekin 1980; Mullan 1986; Mullan et al. 1986). Similar thermal blockages during summer and early fall months have been noted for the John Day and Yakima rivers.

Water temperatures in August at Ice Harbor Dam have shown a downward trend over the years 1962-1989, probably due to deep-water releases from Brownlee and Hells Canyon dams, whose reservoirs stratify during the summer (Chapman et al. 1991).

Occurrence of high temperatures in the lower Columbia and Snake Rivers will remain problematic. Heat storage in the mainstem reservoirs will occur, especially on dry, hot years. Release of deep, cold water from headwater storage reservoirs will not ameliorate high temperatures in the lower Columbia River because the reservoirs are too far upstream. Coldwater releases from upstream storage dams also cause ecological problems in the river systems immediately downstream of the storage projects due to negative (potentially lethal) effects of dramatically fluctuating temperatures on fish and the aquatic community (Stanford and Hauer 1992). However, restoration and enhancement of interstitial flow pathways and discharge of ground water into channel and floodplain habitats of the alluvial reaches likely could cool temperatures in the Hanford Reach and middle and lower reaches of the arid land tributaries.

Hiram Li and colleagues at Oregon State University (personal communication) have recently shown that salmon and steelhead move into discrete cold water zones associated with upwelling ground water during hot, low flow periods in the lower John Day River. Similar situations likely occurred on all tributaries draining the arid lands of the Columbia Plateau prior to regulation of these rivers. Today, flow abstractions for irrigation have dewatered the alluvial flood plains of the middle and lower reaches of these rivers. For example, the middle reach of the Yakima River has been completely dewatered for significant periods during dry years and over 50 percent depleted on average flow years; summer base flows increase downstream as a consequence of irrigation return flows mainly from shallow, often turbid drainage canals. On the Yakima and other tributaries on the arid Columbia Plateau, loss of baseflow very likely has significantly reduced the natural buffering effect on high summer temperatures formerly mediated by complex interstitial flow pathways of the expansive flood plains. Loss of riparian vegetation due to dewatering and grazing by cattle likely adds to the thermal loading of what water does flow through the impaired reaches. In such cases, the solution would be to increase and stabilize late summer flows to increase interstitial flow and decrease the propensity for temperature increases. Limiting grazing in the riparian zone of key reaches also seems logical.

Conclusions and Recommendations on Flow

Conclusions

1. We conclude that information presently available does not support the mainstem hypothesis raised by the Council. No relationship can be shown between mainstem river flow and survival of juvenile salmon migrating downstream. There is an effect of load following as it leads to stranding of juveniles.

2. Our analysis of available data indicates that the percentage of river flow that is spilled has a larger effect on survival of salmon than volume of flow, and that the two variables are correlated to the extent that no purpose is served by employing both of them. Requiring a spill percentage is readily justified from available information on effectiveness of spill in passing fish, and survival of fish in spill.

3. The importance of maintaining suitable flows for spawning and rearing of salmon in the tributaries and mainstem is clear. A problem is created with load following by the hydroelectric system, which leads to sharp fluctuations in flow during times when salmon are spawning, their eggs are incubating, and their fry are rearing. Chinook salmon have been observed to spawn in the tailraces of most of the projects in the mid-Columbia and Snake rivers. These fish are particularly vulnerable to fluctuations in flow. The experience in the Hanford Reach below Priest Rapids Dam demonstrates that maintaining suitable flows at critical times in the life history of salmon can lead to increases in salmon abundance.

Recommendations

1. The fish passage efficiency requirements can substitute for flow augmentation as a means of improving survival of juvenile salmon because they result in spill, which has been demonstrated to lead to improved survival. This would necessitate the development of more effective spill deflectors to eliminate the problem of gas supersaturation at high spill levels. This needs to be done in any case, because of the fact that the river flows periodically will exceed plant capacity requiring spill in amounts that presently lead to dangerous supersaturation levels.

2. Load following by hydroelectric projects should be limited within a range of fluctuating flows that can be tolerated by spawning, incubating, and rearing chinook below the particular project. This should apply to water releases from Hells Canyon Dam, below which there is significant spawning by chinook, as well as the other Snake River and mid-Columbia River projects where salmon spawning has been observed. The requirement should apply to projects on tributaries as well.

Bypass for Juvenile Salmon and Steelhead at the Dams

Development and operation of the hydroelectric system has added substantially to the mortality experienced by juvenile salmon and steelhead as they migrate downstream. This section describes and evaluates mitigation efforts undertaken at the dams to reduce adverse effects on survival of juvenile salmon and steelhead as they migrate to the sea and are affected by the dams and their operations.

We discussed this subject in detail in the prepublication issue of *Return to the River*. The development of bypass systems has a long history. Up to the time of our summary, there had not been a comprehensive summary and integration of information on the subject. Considering the importance of the subject and the lack of an existing summary, we felt a need to go into it in detail at that time. The result was that we felt our treatment was out of balance with the rest of *Return to the River*. Consequently, we decided to publish it separately. It was issued by the Council as Document 97-15, and is available on the Council's web page as Whitney et al. (1997). In addition to describing the process of development of apparatus designed to bypass juvenile salmon away from the turbine intakes, that report described studies that evaluated effectiveness of the bypass systems, and puts that information in the context of the requirements for bypass by the Council and NMFS as specified in the Fish and Wildlife Program and the BiOp. In the present report, we provide an overview of the subject, and refer the reader to Council Document 97-15 (Whitney et al. 1997) for further details.

In Chapter 6, we described the downstream migrations of juvenile salmon and steelhead. The typical dam in the Columbia Basin that is equipped with passage for adults is about 100 feet high. Juvenile emigrants, the product of their spawning, as they move downstream may pass the dam by one of four basic routes; the powerhouse, the spillway, the navigation channel, or the fish ladders. The fish ladders are designed for adult passage and are rarely used by juveniles because they are not designed, located, or operated in ways that will attract them. As the hydroelectric system was developed, the storage capacity that was added spread the flow over the year and reduced the volume of spill available in the spring for passage of juvenile salmon, forcing more of them to pass through the turbines.

Mortality of Juvenile Salmon in Turbines

When Rock Island and Bonneville dams were built in the 1930s, there was a difference of opinion as to whether there might be need to provide special passage routes for juvenile salmon at the dams. One school of thought held that the turbines were so large and the blades spaced so far apart that it was unlikely that small fish would be injured by passage through them (Petersen 1995, p. 110). Nevertheless, four surface outlets were provided for juvenile salmon at Bonneville Dam at the time of its construction. However, they proved to be inneffective and were used primarily to sample fish as they passed the dam.

The first record of juvenile salmon being killed in passing through turbines came in the early 1950's when Harlan Holmes recorded recovery of marked adult salmon that had been marked as juveniles and released in two groups. One that passed through the turbines and the other that was released in the tailrace below the turbines (Mighetto and Ebel 1995). Whitney et al., (1997) summarized 20 studies that have been conducted in the interim, up to 1997. Measurements of mortality associated with turbine passage ranged between 2.3 percent and 19 percent at various projects. It is apparent that mortality is project specific, as can be seen in the tables provided by Whitney et al., (1997). Another explanation for the wide range in estimates is that three of the studies (which produced low estimates in the range of 3.9 percent to 7 percent) were designed in such a way as to estimate direct mortality in turbine passage, while the remaining 17 (which produced estimates in the range of 2.3 percent to 19 percent) were designed in such a way that they included an additional element of mortality in the tailrace that was associated with subsequent effects of turbine passage. The first group of studies were conducted with fish that were marked with balloon tags, enabling their recapture immediately after they passed through the turbines into the tailrace, while the second group of studies generally depended upon recaptures further downstream. We interpret this to mean that a portion of the fish that have passed through the turbines and survived, are probably disoriented for a distance downstream and are more vulnerable to predation than fish released into the tailrace as controls. There have been no studies using both methods at the same project.

In addition to losses of juvenile salmon in direct turbine passage, losses have been identified in intake and discharge structures, the tailrace, or reservoir, and losses due to predation as an incidental effect of turbine passage or other losses not directly assignable to turbine effects, (Long et al. 1975). Mortality (both direct and indirect) of juvenile salmon and steelhead in passage through turbines is variable among projects, is dependent upon operating conditions, inherent efficiencies of the turbines and other factors.

Mortality of Juvenile Salmon in Mainstem River Reaches

A set of studies conducted over three different years in the mid-Columbia Reach found an average of about 15 - 16 percent mortality from one project to the next, including mortality in the turbine, tailrace, and reservoir for juvenile chinook salmon passing each of the five projects (Chapman and McKenzie 1980; McKenzie et al. 1982; McKenzie et al. 1983).[4] Similar system-wide mortality estimates of 20 to 25 percent per project (reservoir and dam) were derived for the Snake River and lower Columbia, (Raymond 1979; Sims et al. 1984). With these rates of loss in passing through the hydroelectric system, fewer than half of the fish migrating downstream from above the uppermost projects in the Snake River or upper Columbia River would survive to below Bonneville Dam without spill or other passage routes.

Mortality of Juvenile Salmon in Spill

Studies of mortality in spill had been conducted at six projects up to the time of Whitney et al. (1997), resulting in 13 estimates. Five of the thirteen separate estimates were of zero mortality in spill. Five others were of 2 percent or less. Studies revealed a potential for added mortality from predation below the spillway. One unusually high estimate of 27.5 percent at Lower Granite Dam was probably associated either with high predation by northern pikeminnow or other adverse conditions below the dam, such as were described for Little Goose Dam in 1994 (Muir et al. 1995b).

Some references state that mortality of juvenile salmon in spill ranges from 0% to 4% (Fish Passage Center 1994), or 0 - 3 percent (National Marine Fisheries Service (NMFS) 1995). However, close scrutiny of the studies upon which these numbers are based leads us to conclude that 0 - 2 percent is the more likely range for standard spill bays, but that local conditions, such as back eddies or other situations that may favor the presence of predators may lead to higher

[4] The 1980 study produced a higher estimate (20%), but there were difficulties in execution of the study design, which called for release groups to arrive at downstream recovery sites at near the same time, which they did not do (Chapman and McKenzie, 1980).

numbers such as those Muir et al. (1995b) suggested may have occurred below Little Goose Dam in 1994. The ISAB recently reviewed studies of survival in spill conducted by NMFS at The Dalles Dam in the years 1997 -1999 and concluded that at that project, survival of juvenile salmon in spill is variable from year to year, differs between night and day, and differs between spring and summer, probably being affected by a number of factors, not all of which are understood (Independent Scientific Advisory Board 2000).

Spillway design affects the rate of injury and survival, with freefall being the least injurious (Bell and DeLacy 1972; Stone and Webster Engineering Corp. 1982). Backroll may be created with certain designs and spill levels, which can trap fish in turbulence, adding to the potential for predation and other causes of mortality (Stone and Webster Engineering Corp. 1986).

A problem encountered with high spill amounts is gas supersaturation, leading to a condition in fish similar to the divers “bends”, in which gas bubbles appear in the blood stream and other tissues, which can lead to death (Ebel 1969; Bouck 1980) (Ebel et al., 1975). The subject is discussed in more detail later in this chapter.

Development of Bypass Systems in the Columbia Basin

Compensation for losses of adult salmon and steelhead due to construction and operation of the hydroelectric system has been attempted primarily by hatchery production and to some extent by habitat improvement. Meanwhile mitigation of mortalities experienced by juveniles migrating downstream has been attempted primarily by construction at the dams of bypass systems for juvenile salmon, by provision of specific spill requirements at each project, and by provision of the “water budget” or flow augmentation for facilitating movement of juvenile salmon downstream out of the system (NPPC 1984; 1994). Transportation of juvenile salmon by truck and by barge is in fact part of the bypass system since it depends upon the bypass system for collection of fish moving in the river. This section of the report deals with the subject of development and operation of bypass systems, including the provision of spill, which is part of the bypass system. The other subjects, including transportation of juveniles, and flow augmentation are dealt with in other sections.

The significance of bypass facilities for juvenile salmonids can perhaps be judged by the fact that the Corps of Engineers budgeted $32 million in 1992 for development and installation of bypass facilities, a program that has been ongoing since the 1960's (US Army Corps of Engineers 1992).

Adult Fish Passage

Federal law, dating from 1906, authorizes the United States Departments of Commerce (and/or Interior now) to require fishways at all federally licensed dams (Office of Technology Assessment 1995). Accordingly, passage for adult salmon was provided at the time of their construction at the five dams licensed by the FERC in the mid-Columbia reach. In addition, when Congress authorized the non-federally licensed dams, i.e. those constructed and operated by federal agencies (U.S. Army Corps of Engineers and U.S. Bureau of Reclamation), they required adult fish ladders at the time of construction at all except Grand Coulee Dam and Chief Joseph Dam, which were thought to be too high for effective ladders. We discussed the subject of adult passage in more detail in Chapter 6.

Juvenile Fish (Smolt) Passage

The preponderance of evidence demonstrates that juvenile salmon migrating downstream are oriented to the upper portion of the water column. Coutant and Whitney (2000) summarize the effects of fish behavior on turbine passage and the ability to divert fish from the intakes. Giorgi and Stevenson (1995) reviewed much of the evidence at COE projects and Johnson (1995) reviewed the evidence from salmon literature worldwide.

When they encounter a dam, juvenile salmon prefer surface outlets when they are available and are reluctant to sound into deeper water. As seen in a cross section of the powerhouse (inset Circle, Figure 2 in Chapter 6), on following the flow of the water onto the upstream face of the powerhouse, the juveniles are forced to dive in order to follow the water flow (arrows below point F in the inset) into the turbine intakes. Some projects, such as The Dalles Dam, have an ice and trash sluiceway adjacent to the powerhouse and above the intakes, which passes some juveniles. If the project has a bypass, some of the juveniles encounter a screen which sends them upward into gatewells toward the upper deck of the powerhouse, (Up arrow, below Point F) and from there into a series of passages connecting the gatewells that will bring them out of the powerhouse to below the dam in the vicinity of Area D. Juveniles that miss the screen continue on through the turbine, exiting near the downstream side of the powerhouse in the vicinity of Point D (the Tailrace). Note that point D describes the same basic area in both the circular inset and the main drawing. The spillway offers an alternate route, which again in most cases requires the juveniles to dive to follow the water flow because the tainter gates normally open from the bottom at a depth near 50 feet. The five projects in the mid-Columbia reach generally fit this diagramatic representation except that they do not have navigation channels, as do the other mainstem Columbia and Snake river projects, and Wells Dam has the spillway located directly above the powerhouse.

As a result of their surface orientation, juvenile salmon are observed to accumulate in gatewells of unscreened turbine intakes, as first noted in the early 1960's by Cliff Long and George Snyder (Mighetto and Ebel 1995). Eicher (1988) reviewed studies of passage efficiency at deep intakes. The studies of Regenthal and Rees (1957; cited in Eicher 1988) were particularly informative. They showed 55 percent of chinook would exit the reservoir when the only route was 118 feet deep or less, 48 percent when it was at 146 feet, and 8 percent when it was 160 feet (as summarized in Eicher 1988). Eicher (1988) concluded that *"…it has been accepted that fish sound to great depths as a last resort, and if an alternative, such as an artificial outlet, is available, they will use it preferentially and can be collected in that way."*.

Effectiveness of Bypass Measures for Juvenile Salmon and Steelhead

In evaluating the effectiveness of various passage routes for juvenile salmon migrating downstream, reference to Figure 6.1 is useful for explaining several terms that will appear later in the text. Fish passage efficiency (FPE) is the percentage of total fish approaching a project that pass by routes other than the turbines. Fish Guidance Efficiency (FGE) is the percentage of fish approaching a turbine intake that is successfully diverted by screens into a bypass system. Similarly, spill effectiveness and effectiveness of the ice and trash sluiceways are evaluated in terms of the percentages of total fish that are diverted into spill or the sluiceways respectively. Fish passage efficiency, as the term is used, includes all the fish except those that continue their passage through the turbines. Thus, FPE includes FGE as well as spill effectiveness and effectiveness of any ice and trash sluiceway. In each route, there may be associated injury or mortality of fish. An additional standard for fish survival is therefore applied to those fish that are successfully passed away from the turbines.

Application of Spill as a Means of Smolt Bypass

The following discussion is an overview of spill as it has been implemented for passage of juvenile salmon at projects in the mainstem Columbia and Snake rivers. More detail is provided in Appendix A of Whitney et al. (1997) as to requirements by FERC, the Council, and NMFS/NOAA for spill and other bypass measures.

Depending upon the hydraulic capacity of the individual projects and the river flow in the particular year, there will normally be spill during the spring freshet when the largest numbers of juvenile salmon are moving downstream. As previously mentioned, added storage capacity in the Columbia River hydroelectric system made possible reduction in the spring runoff, resulting in less spill and forcing more juvenile salmon through the turbines where rates of mortality are much higher. The first formal application of spill as a bypass measure for juvenile salmon in the Columbia Basin came in the spring of 1980 as a result of a Settlement Agreement, reached among the parties to the mid-Columbia Proceeding. The agreement provided, among other things, for spill of 10 percent of the river flow at each of the five mid-Columbia projects during the period in the spring when the middle 80 percent of the migrating juvenile salmon were determined to be present. Spill continues to be a primary method for bypass of juvenile salmon at four of the mid-Columbia projects. The fifth, Wells Dam, the one exception, is equipped with a mechanical bypass system, which will be described below.

Subsequently, in 1994, the Federal Energy Regulatory Commission (FERC) ordered Grant County P.U.D. to provide sufficient spill at Wanapum and Priest Rapids dams to pass 70 percent of outmigrating juvenile salmon during 80 percent of the migration in the spring and 50 percent during 80 percent of the migration in the summer (FERC Docket No. E-9569-003, Grant County Phase. Order of May 24, 1994). Those spill levels are to be interim measures pending installation of mechanical bypass systems or a contrary order of the Commission. Production of gas supersaturation by these spill amounts has prevented full implementation of the order. Consequently spill has been limited to 17 percent in spring and 14 percent in summer, which in 1994 provided passage for an estimated 50 percent of the fish in spring and 25 percent in summer at Wanapum Dam. At Priest Rapids Dam, 50 percent were passed in the spring and 62 percent in the summer (Hammond 1994).

With respect to the COE projects, in 1989, in response to a measure in the NPPC's FWP of 1984, the fishery agencies and tribes, and BPA reached a Memorandum of Agreement on spill to be used in spring and summer as an interim measure at Lower Monumental, Ice Harbor, The Dalles, and John Day dams, pending the development of solutions to fish passage problems (Fish Passage Managers 1990). However, this agreement has been superseded at the U.S. Army Corps of Engineers projects by requirements of the NMFS/NOAA Biological Opinion for endangered Snake River salmon, which requires a standard of 80 percent fish passage during time periods set for spring and summer migrants (National Marine Fisheries Service 1995a). Implementation of this standard requires spill as a supplement to operation of the turbine intake bypass systems. Determination of the spill amounts required is a complex process. We discuss this further in evaluating the effectiveness of bypass measures below.

<u>Spill Effectiveness</u>

A long-standing assumption in the region has held that there is a 1:1 relationship between the percentage of river flow that is spilled and the percentage of fish that will be bypassed in spill. The assumption has not held up at any project under close scrutiny, but is still employed at times, for lack of better information. Studies in the 1980s, using hydroacoustic technology at each of the mid-Columbia projects, revealed that the relationship between the percentage of juvenile salmon passed in spill and the spill volume relative to total river flow is complex and varies from project to project (Biosonics 1983a; Biosonics 1983b; Raemhild et al. 1983; Biosonics 1984). For the studies, spill percentage relative to river flow was maintained for a week at each of four levels, varying in the range of 20 percent to 85 percent of total instantaneous river flow. Curves were developed that describe the relationship for each project. As an example of the non-linear relationship often found, at Wanapum Dam in the spring of 1983, night-time spill of 20 percent of the instantaneous flow passed, on the average about 45 percent of the fish, while spill of 50 percent passed 60 percent of the fish (Biosonics 1983b). On the other hand at Rocky Reach Dam during the spring of 1983, night time spill amounting to 20 percent of the instantaneous river flow was estimated to pass about 16 percent of the fish; spill of 50 percent passed about 30 percent of the fish; and spill of 80 percent passed about 55 percent of the fish (Biosonics 1984).

As for the U.S. Army Corps of Engineers projects, in the late 1970s NMFS/NOAA investigators were seeking ways to increase the passage rate of juvenile salmon over the spillways (Giorgi and Stevenson 1995). Spill effectiveness has been studied, using hydroacoustic technology, at John Day Dam annually since 1983 (Kuehl 1986; Johnson and Wright 1987; Magne et al. 1987a; Magne et al. 1987b; Ouellette 1988; McFadden and Hedgepeth 1990). These are most accurately described as monitoring studies, because they involve no control or manipulation of spill, but take the spill levels as they come, in contrast with the mid-Columbia studies described above wherein spill levels were deliberately manipulated. Magne et al. (1987a) focused on developing an overall ratio of percentage fish passage to percentage spill for a range of values from 37 to 66 percent spill for the spring and summer seasons, arriving thus at spill effectiveness ratios of 1.3 in 1987, 1.4 in 1989, and 1.1 in summer 1988. Analysis of the spring observations is hampered by a paucity of observations at spill levels other than around 50 percent, only three observations being below 45 percent spill (four counting the intercept), which leads to caution in drawing inferences. The combined data would estimate 50 percent fish passage in 60 percent spill at John Day Dam. Obviously, spill effectiveness must improve at some spill level beyond the observations, since 100 percent spill must include 100 percent of the fish. Therefore, a curve would be more appropriate for describing spill effectiveness than a ratio.

Measures to Improve Spill Effectiveness

Surface Spill

Spill effectiveness can be improved by several means. The standard spill gates in the Columbia River projects are designed to open from the bottom of the spillbay, typically at depths near 50 feet; (47-58 feet below normal operating pool at John Day Dam, for example, according to Giorgi and Stevenson 1995). From a study at John Day Dam, Raymond and Sims (1980) suggested that surface spill would be more effective in passing fish than standard spill. They placed stop logs in the spillbay opening to create surface spill. They found that juvenile salmon passing through the bays with surface spill were as likely to pass in the day time as at night, whereas samples of juvenile salmon from the turbine intakes, the ceilings of which were located at about the same depth as the bottoms of the unlogged spill bays, showed a strong peak at night, suggesting that juvenile salmon approaching the dam delayed sounding to the intakes until after dark, and that they more readily passed through surface spill. Giorgi and Stevenson (1995) observed that surface spill remains to be adequately evaluated at US Army Corps of Engineers' projects. The Corps has begun studies on effectiveness of surface spill.

Some projects are fitted with sluiceway spill gates that open from the top. Wanapum and Priest Rapids dams are each equipped with one such gate that is located closest to the powerhouse in the array of spill gates. They are smaller spill bays, being designed for passage of debris rather than control of water elevation in the forebay. It was found that with a given volume of water, spill in the sluiceway at Priest Rapids Dam was twice as effective in passing fish as spill in the spillway (Ransom and Malone 1990; McFadden et al. 1992; Ransom and Steig 1995).

The spillway at Rock Island Dam is equipped with several gates that open from below, but at a depth of about 35 feet, as compared to another set of gates that opens from a depth of about 55 feet. There, when spill was split 50:50 between deep and shallow spill gates, the shallow spill gates passed 87 percent of the fish passing in spill and the deep gates only 13 percent (Ransom et al. 1988).

Spreading Spill Volume

Experience in 1995 at Priest Rapids and Wanapum Dams showed that spreading the spill of a given total volume of water (a certain number of acre feet) over a 24 hour period doubled the percentage of fish passed in spill, as compared to spilling the same number of acre feet over a 12 hour period at night, where it might have been expected to pass the same percentage of fish, given the volume for volume comparison. In fact, at Priest Rapids Dam in 1995 using 17 percent spill for 24 hours a day for 60 days during the summer achieved 62% fish passage, whereas in the summer of 1994, spill of 40 percent for 12 hours per night for 34 nights only achieved an estimated 33 percent fish passage (Hammond 1994).

Grant County P.U.D. modified a standard spill gate at Wanapum Dam in 1996 to evaluate surface spill. Tests were scheduled in 1996 at The Dalles, and Lower Granite dams to determine whether an overflow weir improves passage for juvenile salmon.

Spill Deflectors –"Flip-Lip" Spillway

The problem of gas supersaturation that occurs at high spill levels and can lead to fish mortalities, as mentioned above. A remedy that has been adopted is a spill deflector ("flip lip") design for the spillway, which directs the spill in a horizontal direction, rather than vertical (Smith 1974b). At flows of 123 to 169 kcfs, spill deflectors at Little Goose Dam were shown to reduce gas saturation levels down stream by about 10 percent, relative to levels before the deflectors were installed (pre-installation gas saturation of 128 percent with spill of 46 to 59 percent of river flow) (Park et al. 1977). At Lower Monumental and Lower Granite dams, also equipped with spill deflectors, they found gas saturation levels to be 2 to 8 percent lower than at Little Goose, under the same flow conditions, probably due to the greater depth of the stilling basin below Little Goose Dam and smaller deflectors there, 8 feet in length compared to 12 feet at the others. At McNary Dam, gas saturation was lowered 16 to 20 percent by installation of spill deflectors (Park et al. 1977).

In a more thorough analysis, Johnsen and Dawley (1974) developed curves showing the relationship of gas saturation levels below the spillway with forebay gas levels, spill discharges, water temperatures, tailwater elevations, and effects of deflectors at Bonneville Dam. With forebay gas levels of 110 percent and tailrace elevations of 24 feet, the deflectors generally reduced gas saturation levels by about 10 percent (130 percent reduced to 120 percent). But at higher discharge rates (thus tailrace elevations), the difference lessened to the extent that it appeared the deflectors might be disadvantageous at spill discharges above 14 kcfs per bay.

Application of Flip-Lip Spillway Design

The demonstrated success of spill deflectors in reducing levels of gas saturation led to installation by the US Army Corps of Engineers at some projects and to a call by NMFS/NOAA for improved devices at Ice Harbor and John Day dams. Additional information on installation at specific projects is provided in Appendix A of Whitney et al. (Whitney et al. 1997). In 1996, only Lower Granite Dam was fully equipped with flip-lip spillbays across the spillway, however, at present, seven of the eight Corps projects in the Snake River and lower Columbia River are equipped with spill deflectors (Bruce 1995; National Marine Fisheries Service 1995a). Only The Dalles Dam does not have spill deflectors installed as juvenile fish passage efforts there have concentrated on passage associated with the ice and trash sluiceway.

<u>Ice and Trash Sluiceway – Effectiveness in Passing Juvenile Salmonids</u>

Willis (1982) using marked coho, estimated effectiveness of the sluiceway at The Dalles Dam in passing fish at various levels of spill from about 10 percent to about 60 percent of the river flow. Using equations developed from regression analysis of the data, he was able to calculate the percentage of fish that must pass through spill at given flow levels. The method estimates spill effectiveness of about 30 percent fish passage at 10 percent spill, and 75 percent fish passage at 40 percent spill (Willis 1982). This high effectiveness of spill and of the ice and trash sluiceway is not surprising, considering the configuration of The Dalles Dam where the spillway is at right angles to the natural course of the river and the powerhouse is nearly parallel to the natural course of the river, with the sluiceway at the downstream end of the powerhouse (see Giorgi and Stevenson 1995; their Figure 11). The Corps has conducted further studies of spill efficiency and efficiency of the ice and trash sluiceway at The Dalles Dam since 1995 with radiotelemetry and 1996 with hydroacoustics (Independent Scientific Advisory Board 2000). They appear to be in general agreement with Willis' (1982) findings. All of the Corps of Engineers projects on the lower Columbia and Snake rivers are equipped with ice and trash sluiceways.

Turbine Intake Screens

Submerged Traveling Screens (STS)

Mighetto and Ebel (1995) summarized the decades of work by NMFS/NOAA and the Corps of Engineers to develop a satisfactory turbine intake screen. The basic principle of operation is that fish, normally oriented toward the surface are drawn downward toward the ceiling of the turbine intake. The screens are lowered through the gatewell into position to divert fish headed for the turbine intake upward into the gatewell instead. The first prototype was tested in the field at Ice Harbor Dam in 1969 (Long et al. 1975). While the frame itself was fixed once it was in place, the screen rotated along a track in order to continually flush debris off its face. Over the next several years devices were also tested at Little Goose and Lower Granite dams. Many modifications had to be tested to identify a screen that would divert the juveniles without harming them (Park et al. 1977).

Fixed Bar Screens

Experience with the traveling screens had shown them to be costly to build and maintain. Tests at Bonneville Dam in the 1970s used a fixed screen concept that would be less complex and less costly. Results were promising, leading to testing of a full-scale device at McNary Dam in 1978 (Krcma et al. 1978). Cleaning could be accomplished by periodically raising the angle of the screen to create a backflush through the mesh. Results were favorable (Ruehle et al. 1978; Krcma et al. 1980). Tests of a bar screen design in prototype at Priest Rapids and Wanapum dams later confirmed the favorable results of the tests at Bonneville and McNary dams (Mid-Columbia Coordinating Committee 1989). On the other hand, problems with accumulation of trash in tests of bar screens at the Bonneville second powerhouse, led to a recommendation to proceed with traveling screens there and at other Corps of Engineers projects (Gessel et al. 1991).

Extended-length Screens

Initial tests in 1983 of a submersible traveling screen (STS) at Bonneville Dam's second powerhouse showed surprisingly poor effectiveness in guiding fish, with FGE less than 25 percent for chinook and coho. It was also observed that effectiveness of the intake screens at the first powerhouse had declined substantially since tests in 1981, from about 75 percent for yearling and subyearling chinook to about 20 percent in 1983 (Krcma et al. 1982; Krcma et al. 1984). The probable cause was modification of the navigation lock during construction of the second powerhouse, which involved removal of part of Bradford Island (Gessel et al. 1991). Efforts were thus directed at improving fish guidance of the screens (Gessel et al. 1993). In 1994, a frame with bar screen was attached to the trashrack in a position where it would simulate an extension of the STS - an extended screen. The FGE improved as a result of the extended screen.

Similarly, at Lower Granite Dam, initial tests in 1982 of the STS indicated poor effectiveness (about 50 percent) in guiding yearling chinook. From 1984 to 1989, NMFS investigators sought ways to increase FGE (Swan et al. 1992). A fixed bar screen was tested in conjunction with a standard STS in a configuration that simulated an extended screen, forty feet in length compared to the standard screen of 24 feet. With extended screens significant increases in FGE were measured, 66 percent for yearling chinook compared to 57 percent with the standard STS, and 83 percent for steelhead compared to 77 percent with a standard STS (Swan et al. 1990).

Encouraging results at Lower Granite Dam, led to the design of two types of prototype extended-length screens, a bar screen, and an STS that were tested at McNary Dam in 1991 to 1994. Tests of full extended screens were also initiated at The Dalles and Little Goose Dams in 1993 (Gessel et al. 1995).

Effectiveness of Turbine Intake Screens for Bypass of Juvenile Salmon

As previously noted, the measure of effectiveness of turbine intake screens is their fish guidance efficiency. Values of FGE measured in tests of prototype devices at various projects are shown in Whitney et al. (1997). Estimates of FGE are variable from one test to another. They differ from project to project, and differ with respect to other factors, the design and configuration of the apparatus, the fish species, their degree of smoltification, time of day (particularly day versus night), and progress of the season (Swan et al. 1985; Hays and Truscott 1986; Swan et al. 1986; Swan et al. 1987; Swan and Norman 1987; Giorgi and Stuehrenberg 1988; Peven and Keesee 1992; Peven 1995). Information on FGE included in Whitney et al.,

(1997) must be interpreted in that context. FGE estimates have improved with time, due to improvement of the screens. Since 1995, with the ESA listing of Snake River stocks, hydroacoustic methods have been employed for measurement at the Snake River and lower Columbia River dams, rather than fyke nets previously used, because the fyke nets kill fish.

An example of variability of FGE measurements was mentioned above, with respect to studies at Bonneville Dam, where installation of an approach channel for a new navigation lock brought about a reduction in FGE measured at the first powerhouse (Krcma et al. 1984; Gessel et al. 1991). Modifications to the screen and its deployment brought FGE up to 26-44 percent for yearlings and 20-32 percent for subyearlings (Krcma et al. 1984). At the second powerhouse, FGE was poor at the outset, less than 25 percent for yearling and subyearling chinook (Gessel et al. 1993). Modifications of the apparatus, and eventually, extensions of the turbine intakes into the forebay brought improvements by 1986 to around 60 percent for chinook yearlings, 55 percent for subyearlings, and 46 percent for steelhead (Gessel et al. 1991). Further tests were conducted each year through 1989. Best observed FGE was 78 percent for chinook yearlings and coho, 69 percent for steelhead, and 25 percent for subyearling chinook (Gessel et al. 1991). On the basis of these studies, a new configuration was recommended for full installation across the second powerhouse (Gessel et al. 1993).

Extended length screens generally show higher FGE's than the standard screens, by variable amounts depending upon fish species and stock (ocean-type versus stream-type chinook) and features of the specific project. For example, at The Dalles Dam extended length screens tested, produced estimates of FGE for yearling chinook of 69 percent, compared to 44-56 percent for the standard screens tested; 83 percent for steelhead compared to 71-80 percent for standard screens (Krcma 1985; Absolon et al. 1995, see also Whitney et al. 1997). At McNary Dam, FGE for subyearling chinook was measured as 67 percent with the extended screen and 34-46 percent with the standard screen (Krcma et al. 1982; McComas et al. 1994, see also Whitney et al. 1997).

In summary, estimated FGE in prototypes of presently installed systems or scheduled for installation, range from 26 percent (Bonneville first powerhouse) to 88 percent for yearling chinook, with most (6 of 11) in the range of 65 to 80 percent. For steelhead, FGE ranges from 76 to 93 percent, with most (6 of 8) above 80 percent. For coho salmon, FGE estimates were 93 percent and 98 percent for the two studies that were able to include them. For sockeye salmon, FGE ranged from 14 to 73 percent in 6 studies, with only 1 estimate above 53 percent.

Conduit to the Tailrace

Once diverted into the gatewells, the juvenile salmon and steelhead are led into a conduit to the tailrace below the dam. At Bonneville Dam’s first powerhouse, orifices were cut from the gatewells to the ice and trash sluiceway to provide an exit for fish. A vertical barrier screen

(VBS) was installed in the gatewell to create an upward flow to encourage movement of the fish toward the orifices near the surface. A dewatering system was provided at the end of the ice and trash sluiceway, where water was pumped back into the forebay in order to reduce the volume of water that entered a 20-inch conduit leading to the tailrace. At McNary Dam and other Corps of Engineers' projects, a separate bypass flume was constructed within the ice and trash sluiceway. Evaluations of effectiveness of the systems led to improvements in designs (Krcma et al. 1984; Krcma 1985; Krcma et al. 1985; Krcma et al. 1986; Swan et al. 1987; Swan and Norman 1987; Swan et al. 1990; Swan et al. 1992).

Mortality, Descaling, and Stress in Bypass Systems

As noted previously, the primary criterion in evaluating the effectiveness of mechanical bypass systems is their fish guidance efficiency (FGE), i.e. the percentage of fish approaching the powerhouse that are diverted from the turbine intakes into the bypass system. The bypass system itself can be a source of mortality for juveniles at each stage beginning with encounter with the flow pattern created by the screen or encounter with the screen itself, or within the gatewells, within the conduit, within the sampling system that is present at most facilities, or at the outfall and below where predators may concentrate. Impingement on the screens and injury of diverted fish are problems that have had to be addressed by manipulations of screen openings, angle of deployment of the screen, velocity at the screen, and other factors.

A percentage of the approaching fish may strike the screen in passing and lose some scales, while others, particularly small sub-yearling chinook, may become impinged on the screen. These fish are observed during prototype tests of the screens, when they are raised for inspection. While these numbers are collected at the time of the tests and are useful in evaluating the performance of the prototypes, for our purposes here, the pertinent numbers are the percentages of dead and descaled fish in the bypass system as a whole, which reflect the total effects of the screen after the final design was adopted.

Impingement rates of yearling chinook are negligible in properly tuned systems, but of subyearling chinook may be "high" in prototypes (Peven 1993). At Lower Granite Dam, impingement that had ranged from 0.04% to 3% was reduced to less than 1 percent by design changes to the extended length screen being tested in 1990 (Wik and Barila 1990).

Descaling resulting from contact with the screen may be observed with fish diverted into the gatewells during prototype tests. Standards defining descaling have been developed, and a threshold level of a percentage of missing scales set to meet the criteria of the definition (Koski et al. 1986). Implications of descaling are not clear, since no direct relationship with survival has yet been established. As an example, descaling of guided fish at Lower Granite Dam during prototype testing was estimated to be 1.7 percent (Wik and Barila 1990). No significant increase in descaling of guided fish at McNary Dam was observed with the extended screen (McComas et al. 1994), compared to a standard STS used as a control.

Performance of the bypass system as a whole is monitored daily at those projects equipped with sampling systems in the bypasses. Dead fish are observed in the samples. These deaths may have occurred at any location within the bypass facility, from the screen to the sampler. At Little Goose Dam in the years from 1981 to 1993, average annual mortality of juvenile salmon observed in the facility amounted to from 0.9% to 6.2%, for chinook, 0.1% to 0.8% for steelhead, and 0.6% to 6.3% for sockeye; and at Lower Granite Dam from 0.3% to 1.2% for chinook, and 0.1% to 0.4% for steelhead (Koski et al. 1986; Koski et al. 1989).

Descaling is monitored daily in the samplers located in the COE bypass system and summarized in annual reports (e.g. Koski et al. 1989). As observed at that point, descaling may have occurred at any point in the system from the screen downstream. The following are examples of numbers observed: As a result of improvements in the system and its operation, descaling rates at Lower Granite Dam declined in 1988 to 1.7 percent of the total sample. Of these, 2.4% of the chinook were defined as descaled, and 1.4% of the steelhead; an improvement over 1987, when the total rate was 3.3% (Koski et al. 1989); and 1981 and 1982 when descaling had been recorded as 15.5% for chinook and 16.8% for steelhead in 1981, and 8.8% and 10.1% respectively in 1982 (Koski et al. 1986).

At Little Goose Dam the combined rate in 1988 was 3.4%. At McNary Dam, the figure was 10.4%. Muir et al (1995A) estimated there was addition of 2.8% to the rate of descaling of river-run steelhead as a result of passage through the bypass conduit at Lower Granite Dam. They felt that the 7 percent descaling rate of hatchery origin steelhead observed after passing through the bypass was not excessive.

<u>Mortality of Juvenile Salmon in the System Below the Screen</u>

A number of studies have been designed to measure mortality at particular points within the bypass system, particularly from the gatewells to the sampler (Park et al. 1984; Ceballos et al. 1993). Survival rate in bypass systems is given by the Corps of Engineers as 97-98 percent (US Army Corps of Engineers 1992).

An additional source of mortality to guided fish is the portion of the conduit leading from the dewatering screens at the sampler to the tailrace. Marked fish released out of the north shore outfall at McNary Dam were recovered at half the rate of other release groups, suggesting that predation in the vicinity of the outfall was responsible for added mortality (Sims and Johnson 1977).

A set of studies that attracted considerable attention, due to their surprising outcome was conducted at Bonneville Dam second powerhouse in the early 1990s. First studies suggested that survival in the bypass system as a whole, from gatewells to a point downstream of the outfall, was no better than survival in passing through the turbines (Ledgerwood et al. 1990a; Dawley et al. 1992; Gilbreath et al. 1992; Ferguson 1993). During 1987 and 1988, rates of recovery in the estuary of marked subyearling chinook that had transited the bypass were significantly lower than for fish that had passed through the turbines, suggesting higher mortality of juvenile salmon in the bypass than in the turbines (Ledgerwood et al. 1991). Likewise, in the following two years there was no significant difference in recovery rates, suggesting that the bypass was not accomplishing any reduction in mortality compared to the turbines (Ferguson 1993). However, it was then found that the conduit itself contributed only an estimated 3 percent mortality to juvenile salmon diverted by the intake screens (Dawley et al. 1992). Therefore, Dawley et al. (1992) and Gilbreath et al. (1992) concluded that the primary source of mortality was outside of the bypass itself. The location of the outfall, in a place where predators could congregate, was identified as the most likely source of the high mortality that had been measured by Ledgerwood et al. (1991).

Ledgerwood et al., (1994) have begun a similar study of survival in the bypass and turbines at Bonneville's first powerhouse. Results of the first year of study indicated, as with the bypass at the second powerhouse, that survival of juvenile salmon that passed through the bypass was lower than for juvenile salmon that passed through the turbines. Again, predation at the outfall was thought to be the principal source of mortality, rather than caused within the system itself. The ISAB conducted a review of a proposal to relocate the outfall from the bypass system at Bonneville Dam and concluded that high predation rates by northern pikeminow had been demonstrated. The ISAB recommended that the outfall be relocated to a place with higher water velocities where the predators would be less able to maintain themselves in the current (Independent Scientific Advisory Board 1998c).

Ferguson (1993) observed that bypass evaluations at other mainstem hydroelectric projects have been limited to assessing survival at a collection point within the system, and not below the tailrace. Chapman, et al. (1991) recommended further research to evaluate mortality associated with bypass.

Stress is not thought to be a significant factor in contributing to mortality within the bypass systems (summarized in Whitney et al. 1997).

Summary of Effectiveness of Turbine Intake Bypass Systems

Following studies by NMFS/NOAA and others, a set of criteria for successful bypass systems has been developed. These establish maximum velocities, advise open conduit rather than closed, in order to avoid pressurization, set appropriate angles for curves and changes in elevation, set standards for dewatering, and other factors in the design (Bates 1992; Rainey

1995). These are being used in the design of bypass systems at Rocky Reach, Wanapum, and Priest Rapids dams, and in the improvement of systems at the Corps of Engineers' projects. NMFS has adopted a policy statement that provides for development and evaluation of new technology under controlled conditions (Office of Technology Assessment 1995, Appendix B).

In the final analysis, effectiveness of bypass systems must be evaluated in terms of their ability to achieve performance goals established by FERC, the Council, and NMFFS/NOAA. Whitney et al. (1997) provide a detailed evaluation in their Appendix B. In summary, the goals of Council and NMFS/NOAA are stated as 80 percent fish passage at each project. The NMFS/NOAA goals apply to the Snake River and lower Columbia River, while the Council goals apply to the basin as a whole. The Council goals apply to time periods that are different from the NMFS/NOA time periods. FERC requirements for the mid-Columbia projects differ from project to project and do not correspond with the Council goals.

None of the turbine intake screens tested can achieve the 80 percent fish passage goal for all species and stocks at all seasons. Therefore, it has been necessary to supplement the bypass provided by screens with bypass in spill.

<u>Application of Turbine Intake Screens for Bypass of Juveniles</u>

Success with tests of prototype screens has led either to their installation or to schedules for installation at most of the projects in the mid-Columbia, Snake and lower Columbia rivers. Appendix A of Whitney et al. (1997) includes specific information on installations at each of the mainstem Columbia and Snake River projects. The Corps of Engineers has installed standard STS's at all of their projects except The Dalles Dam. Now, in response to NMFS requirements in the BiOp, installation of extended length screens has proceeded, being scheduled by the Corps of Engineers for 1996 at Lower Granite, and Little Goose dams, for 1997 at McNary Dam, and for 1998 at John Day dams (US Army Corps of Engineers 1993). The bar screen design is being used in these installations, rather than the STS. Projects not yet equipped with turbine intake screens (not including Wells Dam, which has a different type of bypass, as explained below) are The Dalles, Priest Rapids, Wanapum, Rock Island, and Rocky Reach dams (US Army Corps of Engineers 1992; Mid-Columbia Coordinating Committee 1995). Prototypes have been tested with success and schedules set for installation at The Dalles (1998), Priest Rapids, and Wanapum dams. At Rocky Reach Dam, prototype tests of intake screens annually from 1985 to 1994 did not produce satisfactory results (Peven et al. 1995). At Rock Island Dam, the idea of screening powerhouse number 2 has been abandoned, based on poor performance of prototypes tested, while at powerhouse number 1, tests have shown some promise and are continuing (Peven 1995).

Although it is not associated with a dam, the steam electric facility at Hanford (Hanford Generating Plant) should be mentioned here, as it has a cooling water intake with six bays, each equipped with a traveling screen designed to protect juvenile fish (Stone and Webster Engineering Corp. 1982). Average survival of chinook yearlings encountering the screen was found to be 97.9 percent (Page et al. 1976).

Surface Collection Devices

Ice and Trash Sluiceways

Being located at the surface, directly above the turbine intakes, the ice and trash sluiceways, included at the time of construction at some projects, are in good position to attract fish approaching the powerhouse. Juvenile salmon were observed in the sluiceways at Bonneville (first powerhouse) and The Dalles dams, leading to initial testing of the concept (Michimoto and Korn 1969). Efficiency of the sluiceways in diverting juvenile salmon from the turbine intakes was generally in the neighborhood of 20 to 40 percent, (Nichols et al. 1978; Willis and Uremovich 1981; Willis 1982). However, Giorgi and Stevenson (1995) point out that because major modifications were made to the bypass system at the Bonneville Dam first powerhouse in the early 1980s, it is doubtful that those estimates would apply under current conditions there. In 1987, at the Bonneville Dam second powerhouse, the ice and trash sluiceway was shown to pass an estimated 81 percent of juvenile salmon passing the powerhouse in the daytime and 30 percent at night (Magne 1987).

At The Dalles Dam, as previously discussed under the subject of spill effectiveness, the ice and trash sluiceway passed an estimated 40 percent of the fish approaching the project when there was no spill (Willis 1982). Confirming Willis' results at The Dalles Dam, hydroacoustic studies showed fish were more concentrated in the volume of water entering the ice and trash sluiceway than in water entering the turbines (Nichols and Ransom 1980; Nichols and Ransom 1981; Steig and Johnson 1986). At Ice Harbor Dam, the sluiceway was estimated to pass 48 percent of the migrants in the daytime in 4 percent of the water, and pass 21 percent of the migrants at night in 6 percent of the water (Ransom and Ouellette 1991).

Wells Dam Hydrocombine

The unique design of the hydrocombine at Wells Dam (Figure 7.3), in which the spillway is located directly above the turbine intakes, provided a situation in which it was thought that juvenile salmonids, observed to enter the turbines near the ceiling, might be diverted into the spillbays above. Testing of a prototype began in 1983 (Biosonics 1983a). Alternative dimensions and configurations of openings in the intake baffles were tested in prototype in the next several years during which it was found that a vertical slot configuration in the center baffle of three spillbay baffles was most effective at diverting fish (Sullivan and Johnson 1986). The volume of water required for operation of the bypass varies somewhat depending on river flow and the powerhouse load. In 1995, it ranged between 1.2 and 7.5 percent of the daily average river flow.

Figure 7.3. Wells Dam, which uses a unique hydrocombine configuration that is thought to contribute to its success in passing juvenile salmonids with low associated mortality. Photo from the US Army Corps of Engineers' Digital Virtual Library.

Effectiveness of the Bypass System at Wells Dam

The hydroacoustic method was used at Wells Dam in evaluating the performance of the surface collector. Currently, the hydroacoustic method is being employed in general for evaluation of intake screens as well because of concerns about the impact of sampling with fyke nets where Snake River stocks are present, and a question whether the presence of the fyke net array may itself affect measurement of FGE through influence on water movement (Magne et al. 1989; Thorne and Kuehl 1989; Stansell et al. 1990; Thorne and Kuehl 1990; Stansell et al. 1991). A major disadvantage of the hydroacoustic method is that it is not possible to estimate the FGE's separately for each species of salmon. This is particularly important for fall chinook and sockeye, which have shown low FGE's.

Early results of hydroacoustic evaluation were promising, and development of the design proceeded rapidly. The final measurements of fish passage effectiveness at Wells Dam were based on timed samples across the entire hydrocombine after the project was fully equipped with the bypass (Biosonics 1983c; Kudera and Sullivan 1993; Skalski 1993).

Application of Surface Collection at Wells Dam

The Wells Dam bypass system was fully installed in 1989. In January 1991, a long-term Settlement Agreement approved by FERC established a criterion at Wells Dam for bypass of at least 80 percent of the juvenile salmon for the spring period and at least 70 percent for the summer. From the resulting studies, the three year average bypass effectiveness during both the spring and summer outmigrations was estimated to be 89 percent (Skalski 1993). It is currently the most effective bypass system in the basin, and the only one that can meet the standards for fish passage set by FERC, the Council, or NMFS without adding spill (however, the NMFS/NOAA standard does not apply in the mid-Columbia).

Application of Surface Collection at Other Projects

<u>Mid-Columbia P.U.D. Projects.</u>

The success at Wells Dam has stimulated studies of the possibility of applications elsewhere, as recommended by the Snake River Salmon Recovery Team (1993). The technology used at Wells Dam is not directly transferable to any other mainstem or Snake River project in the basin because Wells Dam is a hydrocombine (Figure 7.3), with the spillway located directly above the turbine intakes, unlike any of the others.[5]

The failure of conventional intake screens that had been tested in prototype from 1985 to 1992 at Rocky Reach Dam was a factor in the decision to study a surface collection device, which was prepared for testing in 1995 (Peven et al. 1995). Development of the concept is proceeding (Peven 1996). Surface collection is also being investigated for juvenile fish bypass at Rock Island Dam.

A parallel effort to develop a surface oriented juvenile bypass system began at Wanapum Dam in 1995 (Ransom and Steig 1995). Grant County P.U.D. enlarged the prototype for testing in 1996 (personal communication, Stuart Hammond, Grant County P.U.D.)

<u>Ice Harbor and Other Corps of Engineers Projects.</u>

The Snake River Salmon Recovery Team (1993) in the NMFS Proposed Recovery Plan refer to the success at Wells Dam and call upon the Corps of Engineers to investigate potential applications at Corps projects. Accordingly, in 1995 the Corps conducted several studies of prototype surface collection configurations at Ice Harbor Dam. Three types of surface collectors were installed: vertical slots in front of two turbine intake slots (in conjunction with the ice and trash sluiceway), a sluiceway surface skimming gate, and stop logs that allowed surface spill at two spillbays (Swan et al. 1995). The effectiveness was evaluated by radiotelemetry of juveniles and by hydroacoustics. The hydroacoustic study showed that the density of juvenile salmon was greatest in the sluiceway, although more total fish passed in spill because of the high volume of spill (Biosonics 1995). Further tests were scheduled for 1996 at Lower Granite and The Dalles dams. Tests were suspended in 1998.

Can the Region's Goals for Bypass be Achieved?

Because none of the intake screens in place at the Snake River or lower Columbia River projects achieves FGE's high enough to reach the 80 percent fish passage goal, when all species and times are included, it is necessary to add spill in sufficient quantities to make up the

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5 The Cowlitz Falls Project on the Cowlitz River is a hydrocombine design where the Wells concept is being tested (Solonsky et al. 1995).

difference between a "standard" FGE and the 80 percent fish passage goal. The “standard” FGE represents a compromise among the FGEs for the different species and stocks. Spill amounts are different from project to project because of project specific differences in FGE, and different in spring than in summer because of the change in mix of species that are present. The result is a complex situation that is explained in detail in Whitney et al. (1997, Appendix B). Spill effectiveness curves are lacking for most of the Corps of Engineers projects, requiring an assumption of a 1:1 relationship between percentage of flow that is spilled and the percentage of fish passed. This assumption has not been supported in any case where adequate data are available. Furthermore, the calculated spill amounts in the Detailed Fishery Operating Plan (DFOP) depend upon an assumption (or conclusion) that there is an advantage to spilling 12 hours at night versus 24 hours a day as a benefit to power production. We question this assumption. We believe a more detailed analysis of costs and benefits to fish and power would be warranted. In any case, the spill amounts calculated for use by NMFS can not be provided in practice due to limitations on gas saturation levels.

Analysis by the Fish Passage Center in 1995 (Fish Passage Center 1995) showed that the NMFS/NOAA or Council goals for 80 percent fish passage were not met at any of the Snake River or lower Columbia River projects in 1995, except at Ice Harbor Dam. The “success” at Ice Harbor Dam occurred only because turbines were out of operation there, which necessitated spill in amounts that led to production of gas saturation levels that went beyond permitted levels. At none of the other projects were the fish passage goals achieved, because spill amounts required to supplement the FGE's to reach the goals could not be provided. The spill amounts were limited in practice because of gas saturation levels that were specified in permits issued by the states under provisions of the Clean Water Act.[6] (See Whitney et al., 1997, Appendix B). Under the NMFS requirements, highest fish passage, 78 percent, was achieved at The Dalles Dam (Fish Passage Center 1995). With the exception of Bonneville Dam at 55-62 percent, all of the lower river projects achieved fish passages in the 70 percent range. Snake River projects, with the exception of Ice Harbor Dam, achieved fish passages in the 50-60 percent range. Ice Harbor Dam achieved an estimated 79-84 percent fish passage, but with excessive spill.

With respect to FERC requirements, which apply in the mid-Columbia reach, the fish passage requirements at Wells Dam of 70 percent in spring and 50 percent in summer were exceeded by the 89 percent measured. The FERC requirement of 50 percent fish passage at Priest

[6] NMFS specifies gas saturation levels not to exceed 115% in the forebays of the projects, while the states issued special permits allowing 120% during the spring outmigration period.

Rapids Dam in summer was met (62 percent) by provision of spill alone, but not in the spring. Fish passage requirements by FERC at Wanapum Dam for spring and summer could not be met because of limitations on spill due to gas saturation limits for water quality. FERC requirements were met at Rocky Reach and Rock Island dams, as they are specified in terms of spill amounts, not fish passage criteria. The 80 percent fish passage requirement by the Council, which applies as well as those requirements of FERC in the mid-Columbia reach was met only at Wells Dam.

The experience in 1995 is not unique. It represents a good example of a year with flows that are average or below. As long as limits of gas saturation restrict the volume of spill permitted at Snake River or Columbia River projects, spill cannot be used as a supplement to turbine intake screens at levels required to achieve fish passage goals set either by FERC, the Council, or NMFS at any of the 13 projects on the Columbia mainstem and Snake rivers.

What has the Region Accomplished So Far?

The new estimates of direct mortality in turbines from the balloon tag studies, along with the estimates of survival in reaches of the river, have brought into focus the need to be able to separate direct mortality induced upon juvenile salmon in the turbines themselves from mortality experienced elsewhere either as an indirect result of turbine passage or other causes, because the solutions will differ. There have been several attempts to separate mortality estimates into components for the reservoir and tailrace. Iwamoto et al. (1993) developed a specific estimate for mortality in the reservoir above Lower Granite Dam in 1993, based on a series of reach survival estimates applying from a point above Lower Granite Dam to the tailrace at little Goose Dam, and estimates of survival in turbines at both dams. The study produced an estimate of zero mortality for yearling chinook in the reservoir above Lower Granite Dam in 1993. Muir et al. (1995a) developed an estimate of steelhead smolt mortality from the forebay at Lower Monumental Dam to the tailrace, amounting to 42 percent, a surprisingly large number. Unfortunately, there seems to be no estimate of mortality of steelhead in turbines for Lower Monumental Dam. However, even assuming the worst, say 20 percent mortality in the turbines, the result indicates a high loss of juvenile steelhead in the forebay. At Bonneville Dam, mortality of subyearling chinook in the tailrace downstream to the Hamilton Island Boat Launch was estimated to be 10.5 percent (Dawley et al. 1989). The data of Johnsen and Dawley (1974) can be used to estimate a 54.5 percent loss of juvenile salmon from the tailrace at Bonneville Dam to Rainier Beach Oregon. These studies indicate that in some instances losses of juvenile salmon in the forebay and tailrace exceed the losses in turbines.

The Council has set a goal of 95 percent survival of juvenile salmon and steelhead at each project. Based on information currently available, this goal can probably be achieved if the 80 percent fish passage goal can be achieved without concentrating the fish in the forebays, or at outfalls where predators concentrate. Concentration in the forebay can occur if the fish are delayed in their migration as a result of power operations. Experience has shown that the effects of predation at bypass outfalls and in the forebays at some projects under certain operating conditions may lead to survival rates lower than 95 percent even with 80 percent fish passage.

The estimates of reach survival in the mid-Columbia by Chapman et al. (1980) and in the 1970s in the Snake River by Raymond and others (Raymond 1968; Raymond et al. 1975; Raymond 1979) are no doubt lower than we observe in today's system with improved bypass provisions (including turbine intake diversions and enhanced spill) in place at all of the 13 dams (National Marine Fisheries Service and Center for Quantitative Science 1992; National Research Council (NRC) 1996). These improvements have resulted from construction of turbine intake bypass facilities at Lower Granite and Ice Harbor dams, and modifications of those at Little Goose and Lower Monumental dams, removal of debris from collection systems, installation of flip-lips in spillways to reduce gas supersaturation, changes in turbine operations, requirements for spill, and implementation of the water budget. The conclusion that survival is now higher in the Snake River is supported by the studies of Iwamoto et al. (1993; 1993) and Muir et al. (1992; 1995a; 1995b; 1996; 1999). Their estimates of mortality of juvenile chinook in passing through reservoir to tailrace of three projects in the Snake River in 1993 and 1994 ranged from 8 - 22 percent per project and are most likely site specific. In 1994, mortality of naturally produced chinook in passing through the full length of the reach from the reservoir at Lower Granite to the tailrace at Lower Monumental Dam was estimated to be 27 percent (Muir et al. 1995a). On a per project basis that would amount to a little less than 10 percent mortality, which is in the range of the other recent estimates. This compares with Raymond’s estimate of about 20 percent per project in the 1970s.

Conditions in the mid-Columbia reach have also improved since the studies of Chapman and McKenzie (1980) and McKenzie et al. (1982; 1983) were conducted. Wells Dam has a fully functioning bypass system, as well as new turbines with higher efficiency ratings, and the other mid-Columbia projects have added spill amounts as bypass routes for juvenile salmon. These are substantial amounts at Wanapum and Priest Rapids dams. Chelan and Douglas County PUDs are currently undertaking studies to measure survival of juvenile salmon in the upper reaches of the mid-Columbia. Results should be available soon. It would be premature to attempt to assess the degree of improvement in survival in the mid-Columbia Reach until those studies are completed.

Alternative Methods for Bypass of Juveniles

Spill, turbine intake diversion screens, surface collectors (Wells Dam), and ice and trash sluiceways are the only bypass systems that have proven to be effective for juvenile salmon in the Columbia Basin. Numerous alternatives have been investigated for their potential in directing juvenile salmonids at the dams, including diversion barriers upstream of the dams, a "forebay wedge screen," batteries of lights, bubble curtains, electric fields, sound, air lifts to remove fish from gatewells, a gatewell conduit without intake screens, and others. These alternative methods were reviewed by OTA (Office of Technology Assessment 1995) and Stone and Webster (Stone and Webster Engineering Corp. 1986). They concluded that for the most part, these devices have not been accepted by the resource agencies because they have not been shown to divert a high enough percentage of the fish. Up to the time of their review for EPRI, such devices had not offered much promise of meeting agency goals (Stone and Webster Engineering Corp. 1986). None of these methods was found to be sufficiently effective in directing fish movements to justify full-scale or prototype testing in the field, for application at large hydroelectric projects. These are summarized in Whitney et al. (1997). Some of these methods have met with varying degrees of success for other species in different applications elsewhere, such as at pump intake diversions or irrigation diversions (Office of Technology Assessment 1995). For example, angled louvers have been used effectively at pump intakes and irrigation diversions to divert juvenile salmon and other small fish into alternate channels. Louvers have been widely applied in the Sacramento River system as fish protection devices (Stone and Webster Engineering Corp. 1986). They are considered standard technologies for turbine intakes in the Northeast, but not in the Northwest. This is due to the high water volumes and velocities present in Northwest river applications. In the Columbia Basin, the primary application has been at irrigation diversions in conjunction with screens. Louvers appear to be effective in diverting a high enough percentage of juvenile salmon only in situations where flows were carefully regulated at low levels and floating debris was sparse (Mighetto and Ebel 1995). At Sullivan Dam on the Willamette River, louvers, consisting of modified trash racks guide fish from intakes at units 1 through 12 into the intake for unit 13 where an inclined screen diverts them away from the turbines (Stone and Webster Engineering Corp. 1986). Best estimates of effectiveness ranged from about 40 percent for subyearling chinook to 80 percent for yearling chinook approaching the project.

Juvenile Traps with Pumped Attraction Flows

While the barrier net concept used nets stretched across the migration path, a related concept has been successfully employed, built around the idea that migrating fish could be attracted or directed to a collection device without completely blocking their path. In some of these, pumps were used to create attraction flows for outmigrants, bringing them into an enclosure of some kind (e.g. “Merwin” Trap). Such devices were tested at Pelton Dam on the Deschutes River, Mud Mountain Dam, and Merwin Dam on the Lewis River (Stockley 1959; DeHart 1987). A device with much higher attraction flows was used with some success at Green Peter Dam on the Middle Fork Santiam River, Oregon, where the device is built into the upstream face of the dam (Wagner and Ingram 1973). At Baker Lake, Washington, a surface collection device of this type was found to be effective at collecting sockeye juvenile salmon for transportation below the powerhouse (Wayne 1961; Quistorff 1966). It became a viable solution to the problem of collecting juvenile salmon in the reservoir when a lead net was added to the "gulper" (Cary Feldmann, Puget Sound Power and Light, personal communication).

Gatewell Salvage

Salvage of fish from gatewells in some situations has proven to be a worthwhile exercise. Marked juveniles that were released in the Wanapum reservoir were recovered downstream in the gatewells at Priest Rapids Dam at the rate of 5 percent for coho, 2.1 percent for chinook yearlings and 3.6 percent for steelhead (CH2M Hill and Washington Department of Fisheries 1980). Since 1980, Grant County PUD has salvaged fish from the gatewells at Wanapum and Priest Rapids dams on a daily basis during the outmigration, weather permitting. Specially designed nets deployed by mobile cranes from the deck of the powerhouse are used to remove fish that have accumulated. Captured fish are placed into tank trucks and transported to below the dam where they are released into the tailrace. In the neighborhood of 150,000 to 200,000 fish are salvaged at each of the two projects each year in the spring and an additional 30,000 to 50,000 in the summer (Stuart Hammond, Grant County PUD No.2, personal communication).

Improved Turbine Efficiency

Studies have shown higher survival of fish in passing through turbines when turbine efficiency is higher, and because damage to the machinery is least at high efficiencies, both factors are incentives to operate the machines in the region of their highest efficiency. Furthermore, improvements have been made in the design of turbines to increase their efficiency, and these have been fitted at a number of projects as replacement occurs. The Corps of Engineers has underway a study to develop more efficient turbines, which are expected to result in designs that will be more "fish friendly." However, none of these designs can reasonably be expected to be as benign in effects as diversion by spill, intake screens, or surface collectors, so they would be used in conjunction with other measures.

Conclusions for Juvenile Bypass

1. Mortality of juvenile salmon in passing through turbines, measured at between 2.3% and 19%, has led to the development, construction, and operation of mechanical bypass systems at all of the projects on the mainstem Columbia River and in the Snake River, except The Dalles, Rocky Reach, Rock Island, Wanapum and Priest Rapids dams. The Dalles Dam has used the ice and trash sluiceway to pass at least 40% of the juvenile salmon approaching the dam.

2. Only turbine intake screens, surface collectors, and spill have been found to be sufficiently successful in bypassing adequate percentages of juvenile salmon at the dams to justify full installation. Ice and trash sluiceways can pass significant percentages of the fish approaching the powerhouse. Many other approaches have been tried without success.

3. Turbine intake screens have been installed at all of the Corps projects, except The Dalles Dam. The Corps has a schedule for replacement of standard screens and installation of extended-length screens at all eight of their projects, including The Dalles Dam.

4. Whether it be through spill, intake screens, or surface collection, the most successful bypass systems, have taken advantage of a surface orientation of juvenile salmon as they move downstream.

5. Effectiveness of turbine intake screens seems to have reached an upper limit that is less than the surface collector at Wells Dam, which passes 89% of the fish approaching the dam. Intake screens are unlikely to prove 100% effective in diverting salmon juvenile salmon (Office of Technology Assessment 1995, p.127). Although some measurements of effectiveness of extended screens have shown values as high as 93% for steelhead and coho, and 88% for chinook yearlings, none of the screens tested to date approach that value for subyearling chinook or sockeye, most of which are less than 50%.

6. Although extended length screens have demonstrated improvements over standard length screens, their FGE's for subyearlings chinook, are still below criteria set for fish passage by the Council (80% fish passage at each Snake River project from April 15 to July 31, and at each Columbia River project from May 1 to August 31) or NMFS/NOAA in the Snake River Salmon Recovery Plan (80% fish passage at each Snake River project from April 10 through June 20, and at each Columbia River project from April 20 through June 30). This presents a particularly difficult problem in the Snake River, where these fish are listed as threatened or endangered, and in the lower Columbia River through which these fish must pass.

7. The Council and NMFS goals of 80% fish passage cannot be achieved at any project except Wells Dam without the addition of spill for bypass of juveniles.

8. Spill is effective as an interim measure, or a supplement to mechanical bypasses, that has been shown to offer high survival of fish up to the point where supersaturation of at-

mospheric gas becomes a problem. Further studies in the open river are needed in order to establish the appropriate upper limit for gas saturation that can be tolerated by salmon in the natural situation.

9. The most effective spill is surface spill. Spill spread over 24 hours a day was more than twice as effective per unit volume of water used than night-time spill for 12 hours at Priest Rapids Dam.

10. Effectiveness of spill differs among the projects. More information is needed at the US Army Corps of Engineers projects. In addition, effectiveness of surface spill should be defined at each project, along with determination of the effects of spilling for different time intervals, such as spilling for 24 hours per day versus 12 hours.

11. Fish Guidance Efficiency (FGE) of turbine intake screens varies widely from project to project and as a result of many other factors, particularly the species of fish. And because spill effectiveness also varies, particularly among projects and has not been measured at Corps projects, the determination of spill levels that are set each year to attain the passage goals set by the Council or NMFS, is complex, requiring assumptions that go considerably beyond available information.

12. The Council's criterion of 98% smolt survival within bypass and collection systems from the screen to the end of the outfall that is specified in the 1994 Fish and Wildlife Program appears to be attainable. However, losses due to predation at the outfalls and in the tailraces can be substantial in some situations.

13. Surface collectors are the most promising devices for attaining the fish passage goals established by the Council in the Fish and Wildlife Program or NMFS in the Snake River Salmon Recovery Plan.

14. Current developments are shifting toward provision of surface spill and surface collection, as opposed to turbine intake screens for bypass of juvenile salmon. The attractiveness of surface spill and surface collection over standard spill comes from the possibility of passing a high percentage of the juveniles of all species and sizes in a relatively small volume of water by taking advantage of the natural behavior of the fish.

15. Modification of ice and trash sluiceways offers a potentially effective means of providing a surface exit for juvenile salmon.

Proposed Mitigation Measures – Not Implemented

Reservoir Drawdowns

In the early 1990s, seasonal drawdown of lower Snake and Columbia River reservoirs was proposed as a mitigation tool. The rationale for temporary drawdown focuses primarily on the potential to reduce travel time for emigrants. However, this mitigaiton measure has not been demonstrated. Since that time, scientists within and outside the region have rejected this approach (National Research Council (NRC) 1996). Concentration of salmonid juveniles with predators and loss of shallow water habitats are potential problems with drawdown scenarios.

However, permanent drawdown may have potential value as it would expose and revitalize drowned shoreline areas and alluvial reaches to create riverine habitat for salmonids similar to the Hanford Reach. The Hanford Reach is the only mainstem area that consistently continues to produce salmonids and it is one of only a few river reaches in the entire Columbia River system that provides riverine habitat for a "healthy" salmon stock. However, the Hanford fall chinook spawn only in the upper two thirds of the reach, perhaps because interstitial flow pathways are nonfunctional in the lower third of the reach due to the elevated water table created by virtual continual maintenance of the full pool elevation of McNary Reservoir. Lowering the McNary pool likely would lower the water table in the alluvial reaches upstream, increasing the size of the river reach at Hanford containing both surface and ground water habitat components. Similarly, lowering the McNary pool might also restore the flood plain functions of the Yakima River delta.

Restoration of a historically productive and complex riverine segment might also occur through drawdown of John Day pool to spillway crest. The upper portion of John Day pool, which lies immediately below the confluence of the Snake and Columbia Rivers, contains what was formerly a large alluvial reach (Figure 7.4) that served as a highly productive area for mainstem spawning chinook populations. Populations in this area, may have functioned as a metapopulation, and served as a core to stabilize chinook salmon production in the region. Restoration and revitalization of the upper John Day pool as a free-flowing river segment might assist in the reestablishment of chinook salmon production and metapopulation structure through straying and dispersal from the adjacent Hanford Reach chinook.

The "natural river option", which calls for breaching or bypassing dams would likely yield conditions and benefits beyond those achieved by drawdown. These options to improve ecological conditions and salmon production in the basin are being discussed throughout the region and evaluated with respect to their biological, as well as social and cultural, benefits and costs. There is insufficient information available to predict with certainty the magnitude of responses to drawdown or breaching that might occur in salmon populations.

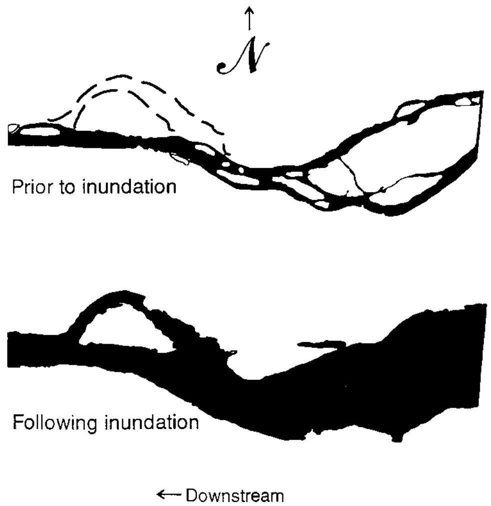

Figure 7.4. Silhouettes of the area upstream of John Day dam on the Columbia River prior to and after impoundment.

Nevertheless, virtually all attempts at analysis predict the greatest and most rapid response by depressed upper basin salmon and steelhead stocks to management scenarios that restore natural river conditions via the breaching or bypassing of the four lower Snake River dams (PATH Scientific Review Panel 1998). See also the NMFS *Works in Progress* – Anadromous Fish Appendix (AFA), and the Cumulative Risk Initiative (CRI), NMFS, Northwest Fisheries Science Center. Information may be obtained from Dr. Peter Kareiva, Northwest Fisheries Science Center, 2725 Montlake Blvd., Seattle, WA 98112.

Conclusions and Recommendations

Conclusion

Permanent drawdown of mainstem Snake and Columbia Reservoirs to restore drowned alluvial river reaches that were historic salmon producing areas may have potential for establishing new populations of salmon that could assist in repopulating depressed stocks.

Uncertainties

1. Fine sediments stored on the bottom of mainstem reserviors may be problematic for restoration of drowned flood plains owing to extreme turbidity resulting from flushing of fines downstream after drawdown.

2. Fluvial geomorphic responses of dewatered flood plains are difficult to predict and relate to specific flow recommendations for restoration.

Recommendation/ Implications

1. Identify one or more reservoirs in the Columbia or Snake River where biological and social/cultural considerations suggest that drawdown or natural river options might enhance ecological conditions and salmon production.

2. Develop protocols to implement drawdown or natural river options, including the necessary monitoring and evalution to assess improvement in conditions and responses by salmon populations.

Gas Bubble Disease: Mitigation and Monitoring

Spilling water at dams is a way to improve survival of migrating juvenile salmon as they pass, compared to turbine passage or passage through conventional fish bypasses (see section above on fish bypass). Spill is a route of passage at dams that most closely resembles the natural migration route (a spillway can be viewed as analogous to a natural waterfall). Because of high survival rates measured in passage through spill, use of spill has been recommended by state fisheries agencies, the Tribes, the Federal Energy Regulatory Commission, the Council's Program, and NMFS BiOp. A drawback to spill, however, is that it can increase total dissolved gas levels in the river downstream of the dams. High gas levels can cause serious injury and mortality to the salmon the spill is intended to protect. Salmonid recovery efforts using spill, therefore, have been constrained by gas saturation levels in the rivers and the best understanding of their biological effects.

Spill and gas supersaturation are addressed specifically in Chapter 6 (Juvenile Salmon Migration) of the 1994 Fish and Wildlife Program. The chapter’s introduction refers to actions to (a) improve fish bypass at mainstem dams through spill that does not exceed state-defined levels of nitrogen gas supersaturation and (b) reduce dissolved gas levels (page 5-4). There are measures for spill (5.6C1), in which the Corps of Engineers, Bonneville Power Administration, and other parties are directed to: (a) provide spill with 80 percent passage efficiency within total dissolved gas guidelines established by federal and state water quality agencies; (b) manage spill in close cooperation with the National Marine Fisheries Service and fish managers to respond to monitoring information on gas bubble trauma; and (c) recommend exceptions to the state standards for total dissolved gas saturation by showing that the risk of fish mortality from exposure to higher levels of dissolved gas is less than the risk of failure to provide the spill regime that may result in such levels. BPA and the NMFS are directed to fund a study of dissolved gas saturation and its effects on salmon and steelhead (5.6E.1). NMFS BiOp calls for operating the Federal Columbia River Hydroelectric System to maintain gas supersaturation levels below 115 percent saturation.

Supersaturation of atmospheric gases in waters of the Columbia and Snake rivers occurs when water is discharged through spillways in dams into deep plunge pools (Ebel 1969; Ebel et al. 1971). Water released through gates from near the tops of the dams falls into pools where water pressure at depth forces entrained air bubbles into solution. The water can be supersaturated to near 140 percent, relative to atmospheric pressures at the water surface. This supersaturation tends to equilibrate with the atmosphere by gas exchange at the water surface and by formation of small bubbles that rise to the surface and burst. Supersaturation to levels of 110-115 percent also occurs naturally by warming of air-saturated water and high rates of photosynthesis by aquatic plants (both usually in shoreline shallows).

Bubble formation occurs in fish tissues as well as in environmental water. These bubbles (similar to the "bends" in human divers) can disrupt blood flow in capillary nets such as gills and fins and fill connective tissue spaces with large and physically disruptive bubbles that affect function (such as causing "popeye" blindness) (Dawley and Ebel 1975; Fickeisen and Montgomery 1978; Bouck 1980; Weitkamp and Katz 1980; Fidler and Miller 1993). Gas bubble trauma can be directly lethal if there is sufficient tissue disruption or blood vessel blockage. National water quality criteria indicate that continuous levels of supersaturation above 110 percent can cause eventual direct mortality (National Academy of Sciences/National Academy of Engineering 1973). There are additional concerns that sublethal exposures (either to gas saturation levels below 110 percent or to higher saturation values for periods of time less than would be directly lethal) can induce debilitation sufficient to cause "ecological death" through increased susceptibility to predation because of performance or behavior changes, increased susceptibility to microbial infections through tissue trauma, loss of stamina and orientation needed for migrations, and reduced growth rates through both impaired feeding and reduced physiological performance. Supersaturation at atmospheric pressure near the water surface can be counteracted when a fish descends to depths where water pressure is sufficient to prevent bubble formation, although many fish functions (feeding, migration) that normally occur near the water surface may be impaired by change in location. Because the Columbia and Snake rivers are migratory corridors for salmon and steelhead (both of which are showing marked population declines and sockeye and chinook salmon in the Snake River are listed as threatened or endangered), there is special concern for the well-being of these migratory stocks. Natural sources of supersaturation are rarely a problem for fish, although occasional fish kills have been reported elsewhere (Weitkamp and Katz 1980).

Spill and gas supersaturation have occurred in the Columbia River for different reasons over the past 35 years. In the 1960s and 1970s, they occurred most often in spring when snowmelt swelled rivers beyond the capacity of upstream reservoirs to store water and when downstream reservoirs were not fully equipped with hydropower turbines that pass water in a way that does not supersaturate it. Large numbers of fish were believed killed in the river system during these high-spill years (Ebel et al. 1971). Subsequent completion of hydropower projects and addition of more upstream storage reservoirs reduced the incidence of uncontrolled spills. Concern for gas bubble effects then subsided. Concern has revived recently, however, as spill has gained favor as a management tool for passing downstream-migrating juvenile salmonids past dams without going through turbines, which physically damage and kill fish. An unknown amount of gas bubble trauma caused by spill and its potentially damaging in-river effects can potentially shift the overall survival balance between dam-passage routes.

To achieve the survival benefits of spill during dam passage with minimal in-river damage from gas bubble disease, a physical and biological monitoring program has been in place, which includes both physical and biological criteria for cessation of spill. The US Army Corps of Engineers has monitored levels of total dissolved gas saturation at near-surface monitoring stations downstream of dams for many years (US Army Corps of Engineers 1993; Ruffing et al. 1996) and the Smolt Monitoring Program and the National Biological Service have monitored downstream migrants for biological signs of gas bubble trauma at smolt monitoring stations in dam bypasses since 1994 (McCann 1995; Smolt Monitoring Program 1995). An expert panel convened by the National Marine Fisheries Service has given advice on gas bubble disease and monitoring of clinical signs (Panel on Gas Bubble Disease 1994; Panel on Gas Bubble Disease 1996). A limited program of in-river monitoring for gas-bubble signs has been undertaken recently by the National Marine Fisheries Service (Schrank and Dawley 1996) and the Columbia River Inter-Tribal Fish Commission (Backman et al. 1996). Although the Expert Panel (Panel on Gas Bubble Disease 1994) recommended that monitoring for signs be augmented by estimates of in-river survival ("reach survival estimates," now possible with PIT-tag technology), field research to obtain such estimates is still being developed (Muir et al. 1995a). There have been few attempts to decipher changed survival due to gas-bubble effects from PIT-tag data (Cramer 1996).

The monitoring results have been controversial. Physical monitoring has shown that spill increases gas saturation, both when controlled by the management program and when uncontrolled during major runoff events or unavailability of turbines. Values at short distances (usually one mile or less) downstream of dams range to about 115-120 percent saturation during controlled spill, but upt to about 140 percent during uncontrolled spill. Even during uncontrolled spill, however, biological monitoring of bubbles in fish at dam bypasses has shown low incidence and severity, much below the biological criterion of 15 percent incidence in juveniles that would trigger cessation of spill. On the basis of these monitoring results, risk analyses favoring spill have been prepared by the Fish Passage Center (1995). However, the biological monitoring results seem inconsistent with the biological effects that would be expected on the basis of the published literature. The monitoring program has been peer reviewed by a special panel (Montgomery Watson Inc. 1994). Based on this review, an interagency (U. S. Environmental Protection Agency and National Marine Fisheries Service) technical work group evaluated the gas bubble monitoring at dam bypasses and found seven critical assumptions for validity of the monitoring that were apparently not met and which they recommended be the focus of immediate research (BMIT (Biological Monitoring Inspection Team) 1995). The Expert Panel concurred with the BMIT's critical assumptions and advised that 1996 research focus on testing the assumptions of monitoring at dam bypasses and on better relating signs to mortality (Panel on Gas Bubble Disease 1996). It also recommended that increased effort be placed on in-river monitoring of signs and development of reach survival estimates.

Status of Science for Gas Bubble Disease

The following sections outline our level of understanding, the usefulness of the information, and a judgment of what science on this topic (both existing and reasonably attainable) can contribute to the restoration effort.

<u>Gas bubble disease in laboratory fish</u>

Much is known about mortality of fish exposed to supersaturated water in captivity in shallow tanks, for certain gas levels, physiological conditions, and selected species (Bouck 1980; Weitkamp and Katz 1980; Fidler and Miller 1993).

Debilitating trauma has been related to gas levels and gas composition (largely for mortality and a few other selected indices of trauma). Physiological research and theoretical analyses have helped define that gas bubbles can begin to form in some tissues from as low as 105 percent saturation, but that debilitating trauma does not usually appear until about 110 percent. The biophysics of bubble formation and coalescence (the essence of gas bubble disease induction) is understood in principle (Fidler and Miller 1993), but not enough is known about its variability between species, under different conditions, such as changing temperatures (Coutant and Genoway 1968) and in systems other than the controlled laboratory.

Responses of adult and juvenile salmon to gas supersaturation are similar, but relative sensitivities, detailed differences in responses, and their significance must be quantified differently because fish function differently at different ages and sizes. Less work has been done on adults than juveniles to evaluate relationships among exposures, signs, and mortality.

Laboratory studies have not adequately simulated exposures of fish under riverine conditions, which entail fish migrating in varying depths, saturation levels (Ruffing et al. 1996), and temperatures. There is little consensus among biologists about how much laboratory-based dose-response information is needed to establish protective levels for in-river fish. Further research to relate gas exposure to mortality (and secondary effects such as increased predation) will increase the knowledge base but probably not quickly improve consensus.

Gas bubble disease in river fish

How information from controlled experiments relates to fish in the river is unclear. Much less is known about how gas bubble disease develops in the river system than in the laboratory or artificial field enclosures. Free-swimming fish may avoid supersaturation by swimming in deeper levels where water pressure compensates for high gas concentrations. Recent data on the spatial variability of total dissolved gas levels downstream of dams (Ruffing et al. 1996) suggests that migrating salmonids must receive fluctuating exposures. Whether and how these fluctuating exposures accumulate to a debilitating level is not known. More field research is needed to understand what happens in the real world. A fully definitive set of experimental information that mimics conditions in the field may not be attainable.

We know little about sublethal and behavioral effects of exposures to gas supersaturation both in the laboratory and the river system, although there are suggestive observations of both the occurrence and importance of these effects for fish survival in their ecological context (such as increased susceptibility of sublethally exposed juveniles to predation; National Biological Service, Cook, Washington, unpublished). Not enough attention has been given to the ecological context of debilitating exposures; this avenue deserves further research and analysis if we are to relate gas saturation exposures to survival.

Monitoring for gas bubble disease

Standard methods for measuring and quantifying bubble signs in fish that are clearly related to mortality (or other debilitation) should be useful for routine monitoring. Because a monitoring program for juvenile migrants has been in place at dams for several years (Fish Passage Center, Portland, Oregon, annual reports), the agencies decided to use these facilities for routine monitoring. Although certain measures have been implemented in laboratory testing and field monitoring (bubbles in the lateral line, fins, buccal cavity, and gill lamellae) the link to changes in survival is still unclear. We can not reliably relate severity of damage or probability of death (survivability) to the presence or absence of specific signs used in monitoring today across a full range of possible effects. This deficiency has led some observers to view the use of signs as unproductive and possibly misleading. More perspective is needed linking identifiable signs and survival of fish in the river (Panel on Gas Bubble Disease 1996).

Monitoring of juvenile salmonids for gas bubble disease signs in the bypasses of dams is based upon assumptions that have not been substantiated and thus the results may be skewed toward underestimation of effects (BMIT (Biological Monitoring Inspection Team) 1995; Panel on Gas Bubble Disease 1996).

The level of accuracy needed in biological monitoring of gas bubble disease signs as an index of survival depends, in part, on the amount of survival benefit derived from using spill rather than turbines for passing fish at dams (Panel on Gas Bubble Disease 1996). If the survival benefit from using spill is small, say 5-7 percent system wide, as suggested by the National Marine Fisheries Service's analyses of transportation, then a high level of monitoring accuracy is needed to ensure that in-river mortalities from gas bubble disease do not exceed this value. If, however, the survival benefit from spill is large, then there is more margin for error in the estimates of gas bubble disease effects on survival. Because the benefit of spill is still uncertain, so is the needed accuracy in biological monitoring of indices of survival from gas bubble disease.

Monitoring of fish from the dams or river for signs of gas bubble disease as a means to regulate concurrent spills is fraught with so many uncertainties that using established physical-chemical criteria may be the better way. This is the historical approach to water quality management. Although simplifying in some respects, such a decision shifts the argument to the level of supersaturation selected. Uncertainties about actual exposures in the river and their relationships to mortality (noted above) make selection of an allowable level difficult. Unless some conservative saturation value for biological effects is agreed upon as a matter of principle, this approach is equally uncertain. Preliminary analyses of 1994-95 PIT-tag survival data by NMFS and the Fish Passage Center (presentation to Council, January 10, 1996) suggested that managed spill yielding gas saturation values generally under 115 percent did not lower survival.

Because high in-river survival of fish is the recovery goal, direct measurement of survival under varying conditions of gas supersaturation would appear to be the most useful source of information for managing total dissolved gas saturation and spill. Methods for obtaining reach survival estimates being developed by Muir et al. (1995a). Analysis techniques initiated by Cramer (1996) call for further examination.

A research program has been proposed by the National Marine Fisheries Service that tests the critical assumptions of the monitoring program, tests in-river survival of juveniles under controlled conditions of enclosures augmented with capture of in-river migrants, and study of alternative methods for monitoring gas bubble signs. The Expert Panel recommended that this program be pursued while the conventional monitoring program is continued for comparison (Panel on Gas Bubble Disease 1996).

<u>Reduction in total dissolved gas saturation</u>

Realizing that the debate over adequacy of relevant biological knowledge from research or monitoring is unlikely to end soon, and entail expensive and extensive research and monitoring, which may not be feasible, an alternative course would be to search for mechanisms to lower levels of total dissolved gas during fish emigration. Carefully evaluated, innovative engineering and water management projects might be identified and implemented to limit the springtime increases in gas saturation while providing adequate fish passage.

Modification of spillways with "flip lips" was an active program by the Corps of Engineers in the 1970s, but was largely abandoned when spill became less common. Provision of these modifications on the basis of current scientific knowledge about both the probable biological need and engineering feasibility might be more fruitful than further attempts to eliminate all uncertainties in biological monitoring.

Overall reduction in risk may require water managers to consider plans that spread the effects of high, uncontrolled flows (in flood years) over longer time periods in order to minimize exceptionally high spill (and gas supersaturation) during the peak fish migration season.

General Conclusion for Gas Bubble Disease

Gas bubble disease from supersaturation of water with atmospheric gases is a poorly defined but highly plausible (based on much science) risk to in-river fish, a risk that would need to be better defined to quantitatively establish the net value of spill as a mechanism to reduce mortalities during dam passage. This definition would require a large amount of research and monitoring to achieve desired levels of confidence, and may not be feasible or necessary if means can be found to mechanically reduce supersaturation.

<u>Conclusions (and Level of Proof)</u>

1. Salmonids in water supersaturated with atmospheric gases in laboratory experiments (usually shallow tanks) can develop bubbles in tissues at levels as low as 105% saturation although debilitating trauma does not usually occur until about 110% saturation, the USEPA-recommended water quality standard. The severity of debilitating trauma is greater the higher the saturation. Mortalities within 24 hours are common at saturation values of 130% or more. The relationships between signs and mortality for different exposures and species are not fully described, but work is underway. (1)

2. The cause and persistence of supersaturation in waters of the Columbia River basin are known to be the spilling of water at dams with deep plunge pools followed by slow equilibration with air in downstream rivers or reservoirs. There is complex in-river mixing of supersaturated water from spill and water from turbines and tributaries not enriched with gases that is not fully described, but research is underway. (1)

3. The relationship between in-river gas supersaturation levels and salmonid in-river survival is not well understood because (a) the supersaturation-exposure histories of in-river fish are not well understood and these variable exposures are not easily related to laboratory dose-response experiments, and (b) sublethally debilitated fish can be lost through predation, disease, or other ecological factors not well quantified. (1)

4. Monitoring of gas bubble disease signs at the bypasses of dams as part of the Smolt Monitoring Program as an index of the incidence and severity of gas bubble trauma in river fish may be inadequate as they usually underestimate effects. (2)

5. Managed spill, used as a means of passing fish at dams with low mortality, can induce supersaturation. The relative benefits of managed spill when counteracted by any in-river mortalities from gas bubble disease are not well established. Uncontrolled spill at levels of the 1970s is well demonstrated to cause high risk of fish mortalities. Managed spill resulting in levels generally below 115% did not appear to cause mortalities. (2-3)

6. Given the unresolved scientific aspects of estimating the risks from gas bubble disease relative to the benefits of spill for passing fish at dams, it seems more fruitful to modify dam spillways to allow spill with minimal supersaturation of gases. Solution of the gas saturation problem at the source would solve gas bubble disease problems of both managed and uncontrolled spill. (1)

<u>Recommendations</u>

The ISG recommends that dams be modified structurally to avoid or minimize gas supersaturation under conditions of both managed and uncontrolled spill rather than expanding gas-bubble disease research to adequately define the risk of gas bubble disease in river fish. In-river monitoring, whether for trauma signs or for reach-specific survival, is being developed and needs further use to establish a more reliable estimate of survival of migrants under differing levels of gas supersaturation than is provided by monitoring at dam bypasses.

Juvenile Transportation

Transportation of juvenile salmon downstream in barges and trucks is one of the techniques employed in an attempt to protect salmon from the harmful effects of the federal Columbia River hydroelectric system. A portion of the juvenile salmon emigrants is removed from the turbine intake bypass systems when they arrive at the federally owned and operated hydroelectric dams of the Snake and Columbia Rivers during their annual migration down the river (Point F, Figure 6.1). Effectiveness in collecting fish for transportation therefore depends on the fish guidance efficiency (FGE) of the intake screens, which varies among projects according to flow, species, and life history type, as well as their state of maturity, among other factors, as previously described. In general, FGE is higher for life history types with large juvenile emigrants, such as spring chinook, and lower for life history types with small juvenile emigrants, such as sockeye and fall chinook. As a consequence, without considering any other factors, the efficacy of transport depends heavily on the FGE, and the FGE varies on a dam-by-dam basis with respect to life history type, and with respect to state of maturity within a life history type

The captured fish are placed into water-filled barges or tank trucks, and transported down river to be released into the unimpounded portion of the Columbia River below Bonneville Dam. As noted above, methods of collection do not permit all of the juveniles to be collected at any one dam, however collections are made at several dams, so that only a fraction of the migrants is expected to transit the full federal hydroelectric system of eight reservoirs and dams. Not all species and life history types are equally easy to collect, so that the proportion remaining in the river will vary by species and life history type within species.

Determination of effectiveness of transportation

The original experimental approach was to collect actively migrating juveniles at one or more upstream dams, divide a portion of the fish collected into transported and untransported (i.e., control) groups, mark fish in each group with distinctive freeze brands and coded wire tags, and then transport one group of fish around the remaining dams and return the other to the river to continue their downstream journey. The experimental fish spend one to four years in the ocean before returning to freshwater to spawn. The number of adults bearing treatment and control marks is recorded in samples obtained from commercial and recreational catches, returning adults passing mainstem dams, and fish returning to upriver hatcheries and spawning grounds. Evaluation of the transport program is based on comparative rates of return of transported and untransported (i.e., "in-river") adults under the assumption that the probability of recapture is the same for all marked fish. Recently, the PIT tag technology has made it possible to use a somewhat different approach. PIT tagged fish are released above Lower Granite Dam. A portion is collected at the bypass system there, along with additional portions at Little Goose, Lower Monumental, and McNary dams and transported to below Bonneville Dam. Another portion of the released fish consists of fish that are not intercepted at any of the dams so they pass in-river undetected in the PIT tag detection systems, and their identity and total numbers are known by subtraction of detected fish from the original numbers released.

For each transport-control group, or transport- in-river group, the rate of return (R_T or R_I, the subscript denoting transported or in-river treatment group) is defined as the observed number of marked adults (n_T, n_i) in a sample divided by the number of juveniles originally marked and released (N_T, N_i). A Transport/ In-river (T/I) ratio (or the equivalent Transport Benefit Ratio (TBR)) is calculated as R_T/ R_i. T/I ratios are determined either for a paired Transport/In-river subsample (i.e., a within-season replicate) or, more commonly, for all Transport/In-river fish marked at a given site over one season. An "annual" T/I ratio is obtained by combining (not averaging) mark/recapture data across all within-season replicates. Reported values are typically based on the number of adults observed (not estimated) to return to the point of origin rather than to all recovery sites.

Problems in estimating reduced mortality of transported versus untransported fish

The central thesis of transportation is that transportation removes the mortality that would otherwise have been inflicted by the hydroelectric system. According to this thesis, the maximum expected benefit resulting from transportation would be removal of the mortality experienced in the hydroelectric system by untransported juveniles. But, estimates of survival for untransported juveniles through the full length of the system have not been made, nor have adequate estimates of survival to release for transported juveniles been made. However, by assuming that mortalities are equal for both groups after exit from the hydroelectric system and transportation until they return as adults, the difference in the release to recapture survivals of the two groups may be attributed to the effects of the hydroelectric system and transportation.

Park's (1985) statement of the fundamental thesis with respect to effectiveness of transportation focuses on an objective to increase smolt survival. However, the impracticality of recapturing sufficient numbers of treatment smolts below the point of release of transported fish (Ebel et al. 1973), led to the necessity of measuring effectiveness in terms of differences in return rates of adults. With the advent of new tagging technology, PIT's (passive integrated transponders), new experiments are now well under way at the National Marine Fisheries Service's Coastal Zone and Estuarine Studies Division Seattle, Washington. Such results should permit revisiting the question of measuring the effects of transportation at different points in the life cycle, as well as for routes of passage other than the turbine intake bypass

The question of fixing the lower bound on the effects of transportation on mortalities of juvenile salmonids is most challenging, and no small part of the challenge derives from multiple definitions of the effects. In 1993, in response to new considerations, such as the Endangered Species Act and the recent federal court ruling on the shortcomings of the Biological Opinion on the hydroelectric system, the interest in effectiveness of transportation was enlarged from a question of whether transportation can improve the survival of downstream migrating smolts, which is the question addressed by the NMFS research, to a question relating to the effectiveness of transportation in increasing adult returns of individual populations or stocks to particular points of natal origin (Ad Hoc Transportation Review Group 1992). These questions have led to other questions about the basic assumptions needed for future use in transportation work such as the ability of transported fish to find their way back to their natal spawning grounds, and questions about the possibility of delayed mortality of one group or the other.

National Marine Fisheries Service investigators have addressed questions regarding the survivals and homing behaviors of juvenile salmon from the inception of their studies. For example, Ebel et al. (1973) reported results of a study designed to determine whether transportation affected homing of Snake River chinook and steelhead, concluding that homing ability was not affected, based on the opinion that returns of transported juvenile salmon at Ice Harbor Dam and at the Rapid River hatchery on the Snake River were virtually the same. Slatick et al. (1975, 1988) focused on the question of whether transportation affects homing, and if so, how might the effects be overcome. In attempting to explain high recapture rates of transported fish in the lower river compared to groups that transited the river, Park (1985) speculated that transported fish might have tended to spend more time than untransported fish in the lower river as adults. This would suggest possible homing impairment. From an experiment with transportation of sockeye and chinook smolts from Wanapum and Priest Rapids dams to below Bonneville Dam, Chapman et al., (1997) concluded that transportation of sockeye salmon impaired their homing ability as they returned between Bonneville and Priest Rapids dams. They observed migration delays and differences in recovery rates between groups that were transported compared to those that migrated in-river as smolts.

Since the publications of Ebel (1973); 1980) and Slatick et al. (1975; 1988), questions concerning the degree to which homing abilities may be impaired, the degree to which the act of transportation inflicts mortality on the transported fish, the degree to which the act of gathering the fish for transportation inflicts mortality, and the degree to which the treatment effects of transportation may be measured and understood have become more and more prominent. Although the degree to which collection for transportation inflicts injuries and mortalities should not affect the perception of the relative rates of return of transported and untransported adults, collection mortality is a factor which prevents comparison of rates of return of transported fish to rates of return of fish that passed by spill and turbines. The need to evaluate alternative mitigative measures such as spill is pressing (NPPC 1992a).

Does transportation reduce mortality and result in greater returns?

In cases where sufficient numbers of adult recoveries were made to make a judgement possible, transportation increased (to varying degrees) the survival of yearling spring chinook to the point of release in 26 out of 36 studies (i.e. T/I was greater than 1) over the years from 1968 to 1995. In four of the remaining ten studies, T/I was equal to 1, while only six were less than 1 (Table 7.4). The results with steelhead more uniformly indicate improved survival of transported juveniles.

Snake Basin spring/summer chinook have shown a response to transportation that is best explained in terms of conditions within the hydroelectric system at the time of transportation.

Clearly adverse conditions associated with low flows in the hydroelectric system, such as those of 1973, have shown strongly positive relative rates of adult returns for transported spring/summer chinook to the point of transportation, with extremely low overall survival of both transported and untransported salmon. In another low flow year, 1977, the effects of transportation could not be measured because nearly all of the juvenile salmon marked for the experiment, both transport and control, died before returning as adults (see the section on Flow for an analysis and explanation for this loss of fish). However, under passage conditions associated with higher river flows than those of 1973 and 1977, the responses of relative survivals of spring/summer chinook to transportation may be equivocal. It is to be expected that as in-river survival continues to improve as a result of improved bypass systems and provision of spill, the T/I ratio would approach a value of 1. Similarly, the benefits of transportation would be expected to be smaller during years of high flow, when spill amounts are high, at least a long as gas supersaturation does not become a problem. In order to understand the full effects of transportation it is essential to have information on survival by route of passage.

There is presently no standard for hydroelectric project (dam plus reservoir) and system (the sum of dams and reservoirs) survival for listed species that is based upon the rebuilding schedule for the species. With the listing of Snake River salmon under the Endangered Species Act, NMFS issued a Biological Opinion that called for consultations among the federal entities responsible for operation of the Columbia River Hydroelectric System (National Marine Fisheries Service 1995b). NMFS then began an analysis of options that might lead to recovery of the endangered salmon and steelhead. The first effort was through development of the Anadromous Fish Appendix (AFA), followed by the Cumulative Risk Initiative (CRI) (NMFS, Northwest Fisheries Science Center. *Works in Progress*. Information may be obtained from Dr. Peter Kareiva, Northwest Fisheries Science Center, 2725 Montlake Blvd., Seattle, WA 98112).

Transportation is one of the measures being evaluated in those processes, along with breaching of the lower Snake River dams, and other alternatives. The ISAB reviewed both of those steps in the process (Independent Scientific Advisory Board 1999b; Independent Scientific Advisory Board 1999c) arriving at two principal conclusions: That the AFA process underestimated the probability of extinction of the fish, and agreed with the CRI analysis concluding that no single measure, such as transportation, taken alone is likely to reverse the downward trend in abundance of Snake River salmon and steelhead. In spite of the favorable adult return rate of transported chinook and steelhead, the stocks in the Snake River have continued to decline.

In the Anadromous Fish Appendix, NMFS suggested that transportation effectiveness for spring/summer chinook might have improved in recent years. This suggestion arose from modeling analysis of survival estimates in which an element “D” was specified as the difference between the expected improvement in survival due to transportation (i.e. due to avoiding in-river mortality) compared to the improvement measured by the ratios of relative return rates of the adults, which was hypothesized to represent an element of delayed mortality.

Table 7.4. Percentage of yearling chinook returning as adults after having been either transported or having transited in-river from the uppermost dam in the Snake River, and comparison of the return rates, i.e. the ratio of T/I.*

YEAR	TRANSPORTED	IN-RIVER	T/I	NOTES
1968	0.30	0.15	2.1	Statistically significant
1968	0.16	0.15	1.1	A.
1969	0.24	0.19	1.3	Statistically significant
1969	0.13	0.19	0.7	A.
1970	0.29	0.20	1.5	Statistically significant
1970	0.07	0.20	0.4	A
1971	0.38	0.25	1.6	Statistically significant
1971	0.42	0.25	1.7	Statistically significant. B
1972	0.08	0.08	1.1	
1972	0.09	0.08	1.1	B
1973	0.31	0.02	13.8	Statistically significant
1973	0.42	0.02	18.4	Statistically significant. B
1976*	0.04	0.02	1.8	C
1976*	0.03	0.02	1.2	C, D
1976*	0.03	0.01	3.9	D, F
1976*	0.02	0.03	0.9	E, D
1976*	0.03	0.03	1.0	E
1976*	0.05	0.01	6.1	F
1978*	0.01	0.01	1.0	
1978*	None		-	Controls returned 0.01%
1975	0.64	0.31	2.0	Statistically significant
1976	0.02	0.04	0.5	C
1976	0.04	0.04	1.0	C, D
1976	0.03	0.04	0.8	E, D
1976	0.08	0.04	2.1	D, F
1976	0.02	0.04	0.5	E
1976	0.04	0.04	1.0	F
1977		none	-	13 transported adults recovered
1978	0.12	0.01	8.5	Statistically significant. Barge
1978	0.07	0.01	5.3	Statistically significant. Truck
1979	0.04	0.01	3.4	Statistically significant. Barge
1980	None	None	-	
1980	0.0	None	-	
1983	0.28	No releases	-	
1984	0.16	No releases	-	
1985	0.22	No releases	-	
1986	0.16	0.10	1.6	Statistically significant
1987	0.18	No releases	-	
1989	0.06	0.02	2.4	Statistically significant
From PIT tag survival studies				
1990	0.18	0.08	2.3	
1991	0.16	0.04	4.5	
1992	0.03	none	-	
1993	0.08	0.06	1.3	
1994	0.29	0.14	2.0	
1995	0.59	0.40	1.5	

*Ice Harbor Dam was uppermost from 1968 through 1970, Little Goose Dam from 1971 through 1974 (but experiments with transportation continued at Little Goose Dam through 1978 – marked with an asterisk in the table), and Lower Granite Dam from 1975 through 1995. Data provided by Dr. John Williams, Coastal Zone and Estuarine Studies Division, NMFS. Data through 1989 were from paired release studies, one group transported and the other released to transit in-river. From 1990, the data are derived from PIT tag single release studies of survival taken from Sandford and Smith (*in press*). We combined hatchery, wild, and fish of unknown origin from their tables for our purposes.

The letter notes indicate deviations from experimental protocol that were observed as follows:

A. Transported fish were released at John Day Dam rather than below Bonneville Dam.
B. Fish were released at Dalton Point rather than the normal release site into the tailrace of Bonneveille Dam below the backroll.
C. These are combined data from releases made at the Washington shore boat launch in April with releases at the normal Bonneville Dam tailrace site in May and June.
D. These fish were hauled in a 10ppt salt-water solution made with table salt. This was a one-time experiment.
E. Releases were made at the Washington shore boat launch in April. Because of wave action and the limitations of the ramp, the release hose did not reach far into the tailrace, as a result of which some fish were observed to be washed up on the shore as they were released.
F. These numbers are from fish marked in May and June only.

The problem is that there is no direct estimate of in-river survival through the length of the system avoided by transportation. Therefore, the magnitude, in fact the existence of "D" depends upon the assumptions one is willing to make in the modeling exercise (Schaller et al. 1999). We do not believe that speculations over "D", nor of a related "extra mortality" assigned to factors in the ocean unaccounted for by "D" have contributed to our understanding of the merits of transportation.

Juvenile salmon die at rates related to physical conditions existing during the time of emigration in the river, including the hydroelectric system, despite the transportation effort. Given the apparent dependence of the survivals of both transported and untransported juvenile salmon on conditions in the hydroelectric system, transportation alone, as presently conceived and implemented, is unlikely to halt or prevent the continued decline and extirpation of listed species of salmon in the Snake River Basin. While transportation appears to improve the relative survivals of certain kinds of salmon from the Snake River Basin under certain combinations of dam operations and river flows, it is selective in its operations, as it removes the mortalities attendant to passage through the hydroelectric system for only a portion of the juvenile salmonids present and its effects are insufficient to reverse the downward trends in abundance even for those stocks that it favors..

Northwest Power Planning Council Mainstem Hypothesis

We earlier alluded to the Council's Mainstem Hypothesis which called for an evaluation of the relationship of flow and survival of juvenile salmon and called for an evaluation of transportation as a mitigation alternative.

Available evidence is not sufficient to identify transportation as either a primary or supporting method of choice for salmon recovery in the Snake River Basin. While juvenile salmon transportation may not be discounted as a recovery measure, the factual basis is insufficient to determine the relative efficacy of transportation as a mitigative measure for recovery of salmon populations listed as threatened and endangered in the Snake River Basin. Even if all juvenile salmon could be collected for transportation, there is not enough evidence from previous research to suggest that even the minimum survival rates necessary for maintenance of population levels could be achieved, let alone those survival rates necessary for rebuilding of salmon populations. Certainly, transportation is not normative.

The kinds of Snake River salmon for which transportation is likely to act to improve relative survival to the point of transportation are the steelhead and to a somewhat lesser degree the yearling-migrant stream type chinook salmon designated as "spring/summer chinook" by the National Marine Fisheries Service. The situation is different for fall chinook and sockeye salmon. In addition to the problem of collecting fall (subyearling emigrant, ocean type) chinook for transportation, the time sequenced progression of smolt quality and state of maturation may not be conducive to transportation from a locality such as Lower Granite Dam as it shortens the time of transit to the estuary. Facts are not in evidence to permit the assessment of the utility of transportation from Snake River Dams for the sockeye salmon. Steelhead appear to have the best relative survivals under transportation, as measured at the hydroelectric project from which they are transported. However, the facts regarding the role of transportation in returning steelhead to the spawning grounds are limited.

Managers are faced with a quandary with respect to in-season decisions on transportation. To maximize the benefits of transportation for those groups of fish that are most susceptible to diversion into the bypass systems and thus the barges, spill should be minimized. But minimizing spill is certain to emphasize the selective effects of transportation, because it is known that the bypass systems favor the yearling spring chinook, coho and steelhead, and are not as effective for sub-yearling fall chinook and sockeye. On the other hand, the relative benefits of spill for the different stocks of salmon are unknown, and it has to be assumed that spill is equally beneficial for all of them. In the face of this quandary, the ISAB recommended a "spread the risk" approach, involving the use of barges as well as in-river measures such as spill to improve survival of the entire spectrum of juvenile salmon and steelhead emigrants (Independent Scientific Advisory Board 1998b). The ISAB recommended against the use of trucks for transportation because the NMFS studies have not demonstrated favorable return rates for trucked fish.

Conclusions for Transportation

1. For certain life history types of certain salmon species and steelhead transportation can provide increases in survival measured in terms of adult returns to the point where tagged smolts were released. Thus, transportation is stock (or life history) selective.

2. Transportation alone is not sufficient to overcome the current negative effects of habitat loss, hydropower operations and other sources of mortality.

3. The relative benefit of transportation is expected to decrease as in-river survival is increased from improvement of bypass systems, provision of spill, predator reduction, and other measures to reduce in-river mortality of smolts.

Predation

Development and operation of the hydroelectric system has produced habitat more favorable to native and non-native predators and coolwater-adapted species than to the native coldwater-adapted salmonid species. Conspicuous among these species is the native piscivorous minnow, the northern pikeminnow *Ptychocheilus oregonensis*, known until recently as the northern squawfish. Predation by other fish species and by birds, especially gulls and terns on the mainstem, is a well-documented source of mortality for emigrant juvenile salmon in the Columbia River Basin. Upstream movement of gulls corresponding with the development of the system was observed. Gulls congregate below the dams during the spring outmigration of juvenile salmon and steelhead and are seen to pick fish from the surface in the tailrace (G. Bisbal, NWPPC, personal communication). Direct observations of rates of consumption, and conclusions derived from simulation models, established fish predation as a factor capable of removing a substantial fraction of the annual juvenile emigration (Willis and Ward 1995). It was therefore logical for the framers of the Northwest Power Planning Council's Fish and Wildlife Program to consider means of altering predation in ways beneficial to salmon survival.

The application of predator control as an action to increase survivals of emigrants in the Columbia River Basin was extensively discussed over a two year period (1988-89) by biologists employed by the fisheries agencies and tribes, the Northwest Power Planning Council and the hydroelectric industries prior to implementation. These scientists constituted a Technical Working Group (TWG). The discussions were conducted in the Reservoir Mortality and Water Budget Effectiveness Technical Working Group under the auspices of the Northwest Power Planning Council with written reports being presented to the NPPC. One of the primary agents of mortality in reservoirs of the Columbia River was postulated by the Working Group to be predation by piscivorous fishes. The extent to which predation is a documented agent of mortality in juvenile salmonids in the Columbia River system was established by an intensive program of research on predation on juvenile salmon conducted in John Day reservoir (Poe and Riemann 1988; Collis et al. 1995), as well as by prior research by Thompson and Moran (1959), which formed the basis for the John Day investigations. With a good deal of difficulty owing to the perceived failures of many past predator control programs elsewhere in fish and wildlife management, the Working Group identified predator control as one of the few measures within the Fish and Wildlife Program which might immediately reduce mortalities of emigrant and resident juvenile salmonids.

Northern Pikeminnow

Northern pikeminnow were chosen to be the object of control as they are one of the best known predators on juvenile salmonids. Northern pikeminnow were targeted not only because research indicated them to be responsible for the majority of predation on juvenile salmonids in the reservoir behind John Day Dam (Poe and Riemann 1988), but also because other predators were the objects of sports harvesting effort, while Northern pikeminnow were not. Exotic predators such as the members of the sunfish family, Smallmouth bass *Micropterus dolomieu*, bluegill and related species *Lepomis macrochirus* and other *Lepomis spp*., and the crappies *Pomoxis spp*. were obvious targets of opportunity, which were spared from the predator control program due to the concerns of the sports fisheries management agencies. The protection was also extended to other introduced predators such as walleye *Stizostedion vitreum* and channel catfish *Ictalurus punctatus* as the object of sports fisheries. As was the case with the decision to consider predator control as a mitigation tool, the decision to discuss limiting that tool to a predator species native to the ecosystem, while sparing exotic species of predators, was very difficult for the Working Group. The decision was made somewhat easier for the Working Group by the concept that the presence and operation of the hydroelectric dams had given the northern pikeminnow advantages in reproduction and opportunities for predation on juvenile salmonids which did not exist in the natural river prior to impoundment.

Due to the controversial nature of the predator control measures from the beginning, predator control was envisioned in its broad sense to include non-lethal means of reducing access of northern pikeminnow to juvenile salmon in the hydroelectric system, as well as more traditional means of removal by fishing and other lethal means (Poe and Riemann 1988). Modeling studies indicated that annual exploitation of northern pikeminnow of approximately 15 percent could reduce the losses of juvenile salmonids by as much as half (Beamesderfer and Rieman 1988; Beamesderfer et al. 1990; Rieman and Beamesderfer 1990). The control program was also seen by the Working Group not as a short term effort to eradicate northern pikeminnow, but as a long term, perhaps continuous, attempt to alter the age composition of the population in favor of the younger, smaller age classes which do not consume juvenile salmonids. Altering the age composition was seen as preferable to eradication efforts, because the northern pikeminnow age structure might be altered without substantially diminishing the reproductive capacity of the population. With sustained northern pikeminnow reproduction, other species of predators, which normally target juvenile northern pikeminnow, would not be forced to switch to juvenile salmonids by declining availability of northern pikeminnow juveniles.

The Working Group also discussed the need to reduce populations of northern pikeminnow in the immediate vicinity of the hydroelectric dams. Very large northern pikeminnow individuals congregate in the forebays and tailraces of the dams. The waters near the dams are also known as the boat restricted zone (BRZ), because the general public is prohibited from the area. Angling from the dams and operational procedures such as turbine operating sequences and spill were also identified as possible ways to disrupt intense predation at the dams.

The control program was implemented by the fisheries agencies and tribes starting with pilot studies in 1990 (Young 1996). The pilot approaches to reduction of northern pikeminnow predator populations to date have been: 1) paying bounty to members of the public for NSF of predaceous size (sport reward fishery); 2) employing net fishers to target northern pikeminnow in the reservoirs; 3) employing professional hook and line anglers to fish in waters adjacent to dams from which the general public is excluded; and 4) fishing with nets near a hatchery outfall. All approaches but the reservoir net fishing were initially highly productive. The sport reward and hatchery outfall fisheries have continued to be highly productive as of the 1995 season (Young 1996). The dam angling projects have seen a sharp drop in catches of northern pikeminnow as of 1995. Angling by all means is estimated to have reduced predaceous populations of northern pikeminnow to levels which should provide a 36 percent reduction in potential predation on juvenile salmonids by northern pikeminnow in 1996, as measured relative to the time period prior to 1990. Reductions in northern pikeminnow populations are not uniformly geographically distributed, with some areas showing decreases, while others do not.

Northern pikeminnow greater than eleven inches in length are known to be predators on juvenile emigrant salmon. The predator control program has demonstrated a sharp decline in the abundance indices of northern pikeminnow in the vicinity of Snake and lower Columbia River dams, and it has demonstrated a shift toward younger, smaller individuals available to private anglers outside the areas of dam influence (Friesen and Ward 1999; Zimmerman and Ward 1999). Annual catches and catch per unit effort by technicians angling below Snake and Columbia River dams have declined by about 80 percent during the four years of the program ending in 1995, however there has been no appreciable change in the average size of the individuals caught at dams. Annual catches of private anglers, who are paid for each northern pikeminnow over eleven inches long, have not declined during this period, however the average size of the individual fish in these catches has declined. Average size of the individuals caught by private anglers appears to be influenced by recruitment from strong year classes in unimpounded areas below Bonneville Dam, and below Priest Rapids Dam. Since fewer northern pikeminnow are now experiencing the higher feeding rates available at the dams, the program has been instrumental in lowering the rate of northern pikeminnow predation, which would have otherwise been experienced by the juvenile salmon. In the period from 1990 to 1996, the program removed about 1.1 million northern pikeminnow, leading to reduction in predation on juvenile salmonids by 14-38 percent relative to, that which occurred prior to implementation of the mitigation program (Friesen and Ward 1999).

Caspian Terns

Within the last few years, since the prepublication draft of *Return to the River* was issued, it has been discovered that a colony of Caspian terns, which nest on Sand Island below Bonneville Dam are significant predators on juvenile salmon and steelhead. The seriousness of the problem was first noted when scientists equipped with magnetic sensors detected large numbers of fish tags that had accumulated on the ground among the deposits of bird scat. The number of terns had increased dramatically as a result of new nesting area made available by disposition of dredge spoils by the US Army Corps of Engineers. The terns prefer bare sand and silt as nesting habitat and are discouraged by growth of grass or other vegetation. In 1997 it was estimated that Caspian terns consumed about 11 million salmon and steelhead smolts, amounting to an estimated 5.4 percent of the total production of the Columbia and Snake river systems (G. Bisbal, NWPPC staff, personal communication, 29 September 1999). Estimates for 1998 and 1999 are expected to be about the same. The Council has called for measures to remove the terns from this location and the Corps has developed an action plan for implementation in the spring of 2000.

Conclusions for Predators and Predator Control

As a consequence of the predator control program, the information is available to indicate that the overall rate of predation of northern pikeminnow on juvenile salmon has been lowered since 1990. The extent to which any single factor such as spill, or the predator control program, may have been a factor in lowering the rate of predation of northern pikeminnow on juvenile salmon is uncertain. Spill is a factor, which in some cases might lower the rate of predation by all fish predators in the vicinity of the dams. The change in the size composition of the catches in the sport reward fishery promises a reduced total rate of predation by northern pikeminnow on juvenile salmon.

<u>Conclusions (and Level of Proof)</u>

1. Individuals of northern pikeminnow greater than eleven inches in length are known to eat juvenile salmon in the Columbia River basin. Columbia River basin northern pikeminnow populations are capable of consuming on the order of several million juvenile salmon each year. (1)

2. Rates of predation by northern pikeminnow on juvenile salmon are known to be higher in the boat free zones of dams than in the reservoirs of the hydroelectric system. Boat free zones include the tailraces below, and the forebays above, where it not safe to operate recreational boats. (1)

3. Since 1990, total annual catches, and catch per unit effort of northern pikeminnow from professionals angling in the boat free zones of the Snake and lower Columbia River dams (dam angling) have shown a sharp decline, although the average size of the fish in the catches has not declined during this period (1)

4. Since 1991, total annual catch per unit effort from public angling outside the boat free zones above and below the Snake and lower Columbia River dams (i.e., non-sport reward fishing areas) has shown no apparent trend, although the average size of the fish in the catches has declined significantly during this period. (1)

5. Predaceous sized northern pikeminnow are attracted by hatchery releases of juvenile salmon as demonstrated by site specific net fisheries conducted at hatchery release localities. (1)

6. Since there are now fewer northern pikeminnow of predaceous size in the vicinities of the dams where the higher feeding rates are experienced. The overall rate of predation of Northern Pikeminnow on juvenile salmon has been lowered since 1990. (1)

7. The use of spill as a juvenile salmon passage measure has also been in effect between 1990-1995. Spill may be a factor in determining the effects of attempts to control northern pikeminnow and other predators, since spill appears to reduce the total amount of habitat suitable for piscivorous northern pikeminnow below dams to an extent which depends on the design of the dam (2).

8. When juvenile salmon pass the hydroelectric projects by the spillway, all predators, including northern pikeminnow, encounter lower prey densities of juvenile salmon in those areas where rates of predation are otherwise the highest, i.e. in the turbine tailraces, bypass outfalls and other areas immediately below the dam. (3)

9. Caspian tern predation on juvenile salmonid smolts is large (around 5% of the total smolt production in the basin) and needs to be reduced. (1)

Return to Table of Contents
Go to Next Chapter