CHAPTER 7. HYDROELECTRIC DEVELOPMENT

SOURCES OF MORTALITY AND EFFECTIVENESS OF MITIGATION ACTIVITIES

Introduction

The development of the hydroelectric system, dating to the late nineteenth century, has had profound effects on the ecosystems of the Columbia River basin, and it has been especially adverse to the existence of the anadromous salmonids. In this section, we examine what is known about the fate of the anadromous salmonids in the hydroelectric system, including the outcomes of the attempts which have been made to improve the survival of the migrants within the hydroelectric system. Although each dam is different from all others, the reader is first offered an explanation of how fish move through a typical big river hydrolectric dam, as background to the information presented in this section.

The typical large river hydroelectric dam presents challenges to the migrations of both juveniles and adults (Figure 7.1) Juvenile emigrants, moving down the river in the direction from left to right in Figure 7.1, may pass the project by one of three basic routes; the spillway (Point A; blown-up in inset B), the powerhouse (Right of Point A) or the powerhouse bypass system, if present (Enter powerhouse at right of Point A, exit vicinity of Point D). As seen in a cross section of the powerhouse (inset Circle, Figure 7.1), 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 entrance to the turbine gallery. If the project has a bypass, the juvenile may encounter a screen which sends it up into the body of the powerhouse, (Up Arrow, below Point F) and on into a series of passages that will bring it out of the powerhouse it below the dam in the vicinity of Area D (Figure 7.1) If it misses the screen, the juvenile will continue on through the turbine, exiting near the downstream side of the powerhouse in the vicinity of point D. Note that point D describes the same basic area in both the circular inset and the main drawing. Adult immigrants moving up the river from right to left in Figure 7.1 may enter the adult powerhouse bypass along the bank to the right of the powerhouse(enter near downstream Point E, exit upstream of powerhouse, Figure 7.1). Adults may also enter the navigational lock to the left of the spillway, exiting at the left-most point E)

A. WATER BUDGETING 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. Water budgeting to flush juveniles is a complex process involving monitoring of fish passage from one dam to the next and selective releases and/or bypass spills of water from the dams. An equally complex consultation process for forecasting runoff and planning annual water budgets has eventuated and is authorized in the Council's FWP (Northwest Power Planning Council, 1994).

Also, potentially lethal high temperatures associated with low flows in late summer in the mid and lower reaches of the Snake and Columbia Rivers and some of the arid land tributaries have been documented. Hence, recovery efforts recently have focused on elevated flows in late summer drawn from headwater storage reservoirs (National Marine Fisheries Service, 1995).

We noted above (Chapter 6) that an incremental, empirical relation between flow and survival has not been demonstrated, even though it is likely that survival is higher on high runoff (wet) years. We also suggested (Chapter 6) that using non-seasonal flow augmentation to force underyearlings out of the Snake and Columbia Rivers (smolt flushing flows) may do more harm than good because they may not have accumulated necessary growth and energy reserves for successful emigration. Underscoring these substantial uncertainties in flow augmentation rationale is the fact that summer drawdowns in upstream storage reservoirs, for example at Hungry Horse Reservoir in Montana, to accomplish summer smolt flushing flows in the lower Columbia River has direct and potentially negative implications for nutrient mass balance and food web productivity in Flathead Lake, located downstream from Hungry Horse. Indeed, integrated rule curves (IRCs) developed for regulating releases from Hungry Horse and Libby Reservoirs in Montana to minimize impacts on reservoir food webs apparently are compromised by flow augmentation during late summer in the lower Columbia River (Marotz et al., 1996). Owing to uncertainties associated with water budgeting and flow augmentation, considerable debate and at least one Congressional hearing has ensued (Senate Subcomittee on Science, Technology and Space, June 18, 1996), with upriver interests noting lack of a flow survival relation associated with flow augmentation in the lower river and lower river interests citing need for elevated flows to improve late summer travel time and potentially reduce high temperatures.

We concur with Stanford et al. (1992) that nonseasonal flow augmentation in the lower Columbia will have food web effects in headwater reservoirs and regulated lakes, like Flathead, although research to clarify influences of mass fluxes of water and nutrients, as influenced by natural and regulated flow dynamics, specifically on growth, behavior and populations dynamics of resident salmonids is needed. We also note that the IRCs developed for Libby and Hungry Horse Reservoirs (Marotz et al., 1996) provide seasonality of flow in downstream reaches as

called for under our normative river concept. 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 spawning habitat and stabilized 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.

Occurrence of high temperatures in the lower Columbia and Snake Rivers will remain problematic under either a normative river or flow augmentation strategy. 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 because the reservoirs are too far upstream. However, restoration and enhancement of interstitial flow pathways and discharge of ground water into channel and floodplain habitats of the alluvial reaches (Figure 2.5) likely will 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 abstraction for irrigation has 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% 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 propensity for temperature increases. Limiting grazing in the riparian zone of key reaches also seems logical. We believe that restoring function to the alluvial reaches could have significant buffering effect on mainstem temperatures or at least provide thermal refuges. Note here that we explicitly distinguish reregulation to elevate base flows of abstracted reaches of tributaries from flow augmentation to flush smolts through mainstem reaches. These are two very different concepts. The former is based on documented ecological processes (Stanford et al., *in press*); whereas the latter is purely technological and largely unsubstantiated.

Conclusions (level of proof)

1. Establishment of normative river condtions will make the process of designing a water budget specifically to move fish unecessary, as the new hydrograph will more closely match historic hydrographs to which the fish were adapted. (1)

2. Development and application of integrated rule curves for reservior operations throughout the basin may be a mechanism for achieving a reregualted hydrograph that is consistent with our normative ecosystem concept. (2)

3. Restoration of ecologically functional flood plains in the arid land (Columbia Plateau) tributaries likely will moderate high summer temperatures, as well as other habitat problems in the arid land tributaries and may moderate mainstem temperatures in late summer. (3)

Uncertainties

1. Human mediated changes in mass fluxes of water and nutrients may not significantly influence salmonid and other top consumers in food webs in headwater reserviors and regulated lakes (e.g., oligotrophic Flathead and Pend Orielle Lakes), because population dynamics are controlled more by physical habitat variables, harvest and non-native predators. For example, cascading food web effects associated with nutrient supply (bottom-up effects) are moderated by continual, extreme nutrient limitation thereby accelerating effects of overharvest, non-native predator invasions and other cascading effects that occur at higher trophic levels (top-down effects).

2. Food webs and hence food supply for juvenile salmonids in the laucustrine reaches of the lower Snake River and Columbia River downstream from Grand Coulee Dam may be very unstable owing to high rates of mass flux related to low storage capacity and loss of riverine habitat characteristics.

3. The interaction between normative flows and flood plain function may be insufficent to moderate high summer temperatures in the mainstem river, especially on dry years.

Recommendations

1. Implement food web research in relation to water and nutrient mass flux throughout the basin.
2. Develop integrated rule curves for all reserviors to help facilitate implementation of normative flows and integrate implications for flow management derived from food web research.

B. EFFICACY OF MAINSTEM RESERVOIR DRAWDOWN

Seasonal drawdown of lower Snake and Columbia River reservoirs has been examined as a mitigation tool. Rationale for temporary drawdown focuses primarily on the potential to increase travel time for emigrants. However, this has not been clearly demonstrated. Also, we point out in Chapter 6 that concentration of salmonid juveniles with predators and loss of shallow water habitats are potential problems with drawdown scenarios.

However, permanent drawdown to expose and revitalize drowned alluvial reaches to create riverine habitat for salmonids similar to the Hanford Reach likely is warranted in view of our normative river concept. 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, probably 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, significantly increasing the size of the river reach at Hanford containing both surface and ground water habitat components. Similarly, the flood plain functions of the Yakima River delta might also be significantly restored.

Restoration of a historically productive and complex riverine segment might also occur through drawdown of John Day pool to spillway crest (Figure 7.2). 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 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.

It is logical to note that if normative conditions can be enhanced through drawdown of selected reservoirs to spillway crest, then the “natural river option”, which requires breaching or

bypassing dams would be likely to yield normative conditions beyond that achieved by drawdown. These options to increase normative conditions and salmon production in the Basin need to be discussed in an open forum and evaluated with respect to their biological, as well as social and cultural, benefits and costs.

Conclusion (level of proof)

1. Drawdown of mainstem Snake and Columbia Reservoirs to restore drowned alluvial river reaches that were historic salmon producing areas is consistant with our normative ecosystem concept. (1)

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 normative flow recommendations for restoration.

Recommendation/ Implications

1. Discuss permanent drawdown and natural river options in an open forum that evaluates their biological, as well as social and cultural, benefits and costs.

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

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

C. BYPASS: Mortality Of Salmonid Smolts At Dams And Development Of Bypass Systems In The Columbia Basin

The emphasis in this section is on studies and development of bypass within the Columbia Basin. However, we wish to stress that these did not occur in isolation from studies and developments that have occurred elsewhere in the world.

As the nearest large river to the north, the Fraser River stands as an example where experience with salmon is useful for comparison with experience in the Columbia. We discuss this in some detail in another section of our report, but the application of the example merits some attention in this section. At the behest of the International Pacific Salmon Fisheries Commission, Andrew and Geen in 1960 undertook an analysis of the probable effects of hydroelectric development in the Fraser River, British Columbia on salmon production in the Fraser system. The proposed development would have involved construction of 18 dams on the mainstem and 44 on tributaries. They concluded that,

> *"Dam construction presents a serious threat to the continued expansion - and indeed the very existence - of the commercial and recreational value of the Fraser River fisheries resource.....Although the fish-dam problem has existed for centuries in many countries, no practical solutions have yet been found that afford complete protection for anadromous fish in rivers obstructed and altered by large dams."* (Andrew and Geen, 1960).

Largely on the basis of their conclusions, the Fraser River mainstem remains undammed to this date. Although their study was completed in 1960, their conclusion that no practical solution to the fish-dam problem has yet been found, still applies, as borne out by experience in the Columbia River which is summarized below.

INTRODUCTION

The need for development of bypass systems for salmonid smolts in the United States has its origin in 1906 with Public law 262, which gave the Secretary of Commerce responsibility for fish passage facilities at federally licensed projects (Office of Technology Assessment, 1995). Later the Federal Power Act of 1920 (U.S.C. § 791a, § 811), provided that the Secretary of Interior may require fishways at all federally licensed projects.[1]

[1] With the transfer in 1970 of the Bureau of Commercial Fisheries, now NMFS/NOAA into the Department of Commerce, leaving the Fish and Wildlife Service in the Department of Interior, the authority is now shared by those departments.

Accordingly, passage for adult salmon was provided at the FERC licensed dams in the Columbia Basin. In addition, when Congress authorized the non-federally licensed projects, i.e. the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation projects, they required fishways at all except Grand Coulee Dam and Chief Joseph Dam.[2] Hells Canyon Dam, constructed by Idaho Power Company on the Snake River included fishways that were not successful, (Petersen, 1995). By the time even the earliest of these projects were constructed, Rock Island Dam in 1933, Bonneville Dam in 1938, and Grand Coulee Dam in 1941, studies of salmon

Box 1. Success of fish ladders. The need to provide for fish passage at dams is a worldwide problem that has been studied since before the turn of the century, (Andrew and Geen, 1960; Bell, 1991) {Clay, 1995}. Andrew and Geen note that the earliest known record of the need to provide for free passage of fish in rivers dates from the Magna Carta in the year 1215. The constitution of the State of Oregon, which entered the union in 1859 included a requirement for fish passage at all dams on Oregon rivers. Criteria for the earliest ladders at the Columbia River projects were largely derived from experience elsewhere on smaller rivers. Initial problems with adult passage at Rock Island Dam, the first dam on the mainstem, were soon overcome. Criteria for design and operation have been developed (Bell, 1991; Bates, 1992). Milo Bell, as engineer, and Harlan Homes, as biologist were involved in the design of fish ladders at Bonneville Dam, the next to be built on the mainstem (Mighetto and Ebel, 1994). Refinements in design and operation of fish ladders resulted from the work of Collins and Elling at a laboratory constructed in 1955 by the COE at Bonneville Dam (Mighetto and Ebel, 1994). While in general adult passage facilities are effective in design and operation (Mighetto and Ebel, 1995), questions remain about possible delays in movement of adults approaching and passing through the ladders. And declines in counts at succeeding dams have been explained as losses of fish in transit due to their inability to locate entrances or similar causes. However, part of the explanation is due to turnoff into tributaries, harvest, and mainstem spawning, as well as to fall back of adults that are thus counted twice, and other factors. A recent review of the available information led Chapman et al (1994) to conclude that the best estimate is a 5% loss of adult chinook between dams, resulting from all of the factors listed above. Recent advancements in the technology of following radio tagged adults has made it possible to closely track individual adult salmon as they make their approach to the dams and fishways, and as they transit {Steuhrenberg, 1994, Bjornn, 1993, 1994} This tool has moved the science of adult passage to the point where it is possible to identify locations virtually anywhere in the river where fish may encounter delays or difficulties finding their way past the projects, and to design corrective measures, where they may be called for. Those studies are still_under way, or in process of interpretation.

[2] Since 1888, the Secretary of the Army has had the authority from Congress to "... in his discretion direct and cause to be constructed practical and sufficient fishways, to be paid for out of the general appropriations for the streams on which such fishways may be constructed." (33 U.S.C. 608).

behavior in laboratory settings and observations in the field had developed criteria for design of fish ladders that were generally successful in passing adults uptream {Clay 1995} (Andrew and Geen, 1960; Bell, 1991; Mighetto and Ebel, 1995).

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On the other hand, while the need for adult passage was obvious, the need to provide downstream passage for juvenile salmon, although it was suspected by many, (Mighetto and Ebel, 1995), was denied by others (Office of Technology Assessment, 1995; Petersen, 1995), and was not clearly documented until Harlan Holmes conducted a set of experiments at Bonneville Dam from 1938 to 1948 that showed a loss of 11% to 14% of juveniles in passing through turbines {Bell, et al 1967}.

Box 2. Andrew and Geen (1960) and Bell et al, {1967} state that downstream migrant bypass facilities were provided at Bonneville Dam when it was built in 1938. There were four such facilities at Bonneville. Although no description is given, they were apparently surface collection devices placed at the north end of the spillway and south end of the powerhouse (Mighetto and Ebel, 1995), in conjunction with screened water intakes, where it was hoped they would attract juvenile migrants away from the turbines or spillway. They were found to be inneffective for that purpose, as they were sampled by the COE biologist, Ivan Donaldson; and by the 1950's were being used primarily to obtain samples of fish moving past the project (Anas and Gauley, 1956), but their presence demonstrates that biologists were aware of the potential need for juvenile bypass prior to the construction of Bonneville Dam.

Holmes' experiment followed a procedure suggested by Rich (1940), as noted by (Schoeneman et al., 1961). It involved the release of several sets of marked fish, each set consisting of two groups of juvenile chinook salmon, a control group released in the tailrace and a second group released so they would pass through the turbines. He then allowed his marked fish free access to the river. His conclusions were then based on the recovery of marked adults as they returned in subsequent years. Holmes never published the results of his study, though they were known by those working in the field. They continue to be cited as a memorandum in his files, e.g.

(Schoeneman et al., 1961) {Bell et al, 1967}[3]. Bell and Holmes worked closely together for years, for example in the design of the fish ladders at Bonneville Dam (Mighetto and Ebel, 1995).

Box 3. Recently, it was brought to light that Holmes was prevented from publishing his results by his employing agency, the U.S. Bureau of Fisheries (later named the U.S. Fish and Wildlife Service), (Mighetto and Ebel, 1995). Upper level officials ordered that the report be kept confidential. They were concerned about the potential use or misuse of such information in a pending lawsuit brought by the Yakima Indian Nation, in which the Yakimas had asked for compensation for damage to their fishery caused by Bonneville Dam. Furthermore, COE officials remained skeptical of the results of the study **(Petersen, 1995**, p. 110).

Along with the work of Holmes, other studies attempted to measure losses by releasing fish upstream of the turbines and recovering them in the tailrace with a net equipped with a live box at the cod end where the fish would have sanctuary {Bell et al., 1967}. Initially, there were differences of opinion within the scientific community as to the validity of these studies. They were criticized on the basis that mortality and injury induced by capture in the net itself could not be separated from effects of turbine passage. Once Holmes had established a reference point that was acceptable, it was then possible to proceed with methods using recovery nets in the tailrace that did not require waiting years for the adults to return. Verification by other investigators soon followed, {Schoeneman and Junge 1954, 1959; Schoeneman, 1956} (Schoeneman et al., 1961). Bell et al (1981) summarized the mainstem Columbia and Snake River studies up to 1967. They showed a range of loss from 6% to 20% of juveniles as they passed through the turbines. Iwamoto and Williams (1993) summarized studies conducted since then. A generally accepted figure now is 15%, (Northwest Power Planning Council, 1987) although it is recognized that turbine mortality varies depending on a number of factors, which will be discussed below.

[3] Mighetto and Ebel (1995) note that Holmes' papers are available at the University of Washington Library, Seattle, WA.

Box 4. Estimated mortality of juvenile salmon and steelhead associated with passage through turbines at hydroelectric projects in the Columbia River

(Sources: {Bell et al, 1967}; (DeHart, 1987): Others, more recent, are named in the table.

Dam	Mortality	Year / Author	Species
Bonneville I	11% to 15%	1938-1948 /Holmes {1952}, (Mighetto and Ebel, 1995)	Chinook Subyearlings
	4%	1954 / Weber {1954}, See (Iwamoto and Williams, 1993)	Chinook Subyearlings
Bonneville II	2.3% or 9.5%*	1988-90/ Gilbreath et al {1993}	Chinook Subyearlings
John Day	13%	1980/ Raymond and Sims (1980)	Chinook Yearlings
McNary	11% **	1955; 1956/ Schoeneman et al (1961)	Chinook Subyearlings
Ice Harbor	10% to 19%	1968/ Long {1968}	Coho “Fingerlings”
Lower Monumental	16%	1975/ Long et al (1975)	Coho (20-22/ lb)
	(20% in turbine without perforated plate in gatewell. Not current standard.)		
	3.5%	1994/ Muir et al {1995a}	Chinook Yearlings
Lower Granite	16.9% ***	1987/ Giorgi and Stuehrenberg, {1988}	Chinook Yearlings
Little Goose	8%	1993/ Iwamoto et al (1994)	Chinook Yearlings
Wells	16%	1981/ Weitkamp et al {1981}	Steelhead
Rock Island No. 2 (Bulb Turbines)			
	5.7% or 13%****	1979/ Olson and Kaczynski (1980)	Coho and Steelhead
Big Cliff (North Santiam R. ; Tributary to the Willamette River)			
	11% **	1957/ Schoeneman et al (1961)	Chinook Yearlings and Subyearlings
	13.5%	1957/ Oligher and Donaldson {1965}	Chinook Yearlings
	11.8%	1964/ Oligher and Donaldson {1966}	Chinook Yearlings
	8.6%	1966/ Oligher and Donaldson {1966}	Chinook Yearlings

*Gilbreath et al {1993} provide data that produce a weighted average estimate of 2.3% mortality over three years of study, if fish released in the tailrace are used as reference controls. If fish released near the Hamilton Island Boat Launch downstream are used as the reference controls, the estimate is 9.5%. Their data show that, in the two years for which there are comparisons, fish released in the tailrace experienced an additional 6.8% mortality relative to the downstream release. In 1989, fish were released in the spillway. They survived at a higher rate than the fish released in the tailrace and at the same rate as the fish released donwstream. Therefore, the difference between the two estimtes of mortality in turbines can be explained by the fact that the hgher estimate includes an element of mortality in the tailrace. Fish passing through the spillway were not exposed to this source of mortality. It appears that in the tailrace at Bonneville Dam there are peculiar back eddies or shore areas where there may be concentrations of predators (Ledgerwood et al., 1994).

**Schoeneman et al (1961) found no significant difference between the 1955 estimate of 13% and the 1956 estimate of 8% mortality at McNary Dam, and combined them to get the 11% estimate. Similarly, they combined estimates at Big Cliff for yearlings and sub-yearlings.

***Giorgi and Stuehrenberg (1988) felt that their estimate was on the high side due to failure of test and control fish to mix at recovery sites, as required by the experimental protocol. However, their estimate agrees with the later one of Iwamoto et al (1994).

****There was a dispute over the results of this study at Rock Island. The point estimate was 5.7% mortality, but an ad hoc committee appointed to review the study found that there was no significant difference between that estimate and the estimates at Big Cliff and McNary dams, (Chapman and McKenzie, 1980). Nevertheless, the Administrative Law Judge for FERC found in favor of the 5.7% estimate, but ordered development of a bypass system, (Rock Island Project, 34 FERC 63,044 at 665, 167.)

Estimates using HI-Z Turb'n Tag {Heisey et al, 1992}

Rocky Reach Dam

Variable blades	7%	1994/RMC Env. Serv. and Skalski {1994}	Chinook Yearlings
Fixed blades	3.9%	1994/RMC Env. Serv. and Skalski {1994}	Chinook Yearlings
Lower Granite Dam	5.2%	1995 /RMC Env. Serv., mid-Col. Consulting, and Skalski {1995}	Chinook Yearlings

MORTALITY OF JUVENILE SALMON IN RIVER REACHES

It was recognized that the design of some of the turbine mortality studies left open the possibility that the estimates may have included mortality due to other factors, or may have omitted some causes indirectly associated with turbine passage. In addition to losses of smolts 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). The HI-Z Turb'n Tag {Heisey et al, 1992} makes it possible to recover test fish in the tailrace immediately after they have passed through the turbines or after they have been released in the tailrace as controls, thereby more effectively isolating estimates of mortality directly due to passage through the turbines. The resulting studies have produced estimates in the range of 3.9 to 7%, compared to estimates from other methods that range from 8 to 32%. It must be noted that there is considerable variability from one project to another, and with the exception of recent studies at Lower Granite Dam, that the new technology has not yet been employed at a project where estimates from another method have been obtained.

As another approach to estimating mortality associated with the dams, there have been studies designed to measure total mortality in passing through particular segments of the river, as distinguished from those intended to focus on mortality in turbines. A set of studies conducted over three different years in the mid-Columbia Reach, found an average of about 15% to 16% mortality per project, including mortality in the turbines and reservoirs, for chinook salmon smolts passing the five projects in the mid-Columbia reach (Chapman and McKenzie, 1980; McKenzie et al., 1982; McKenzie et al., 1983)[4]. Similar system-wide mortality estimates of 20 to 25% per project were derived for the Snake River and lower Columbia, (Raymond, 1979; Sims et al., 1984). However, the latter estimates are no doubt higher than in todays system with improved bypasses in place at all of the dams (Steward, 1994; Williams and Mathews, 1994; National Marine Fisheries Service, 1995; National Research Council, 1996).

[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, D.W. and D. McKenzie. 1980. Mid-Columbia River System Mortality Study. East Wenatchee, Douglas County Public Utility District No. 1. Washington**:** 23..

Box 5. Estimated Mortality of Smolts in Passing Through Reaches of River (Sources: Originals as cited, and **Bevan et al, 1994)**

River Reaches	*Mortalities*	*Years / Author*
For Hatchery Chinook		
Mid-Columbia	15%-16% per project (five proj.)	1980/Chapman and McKenzie (1980)
		1982/McKenzie et al (1982)
		1983/McKenzie et al (1983)
Through Lower Granite Reservoir from Asotin		
	18%	1988/Giorgi and Stuehrenberg {1978}
		(Probably an overestimate per the authors)
Lower Granite Reservoir from Asotin to Various Downstream Locations		
To tailrace at Lower Granite	10%	1993/Iwamoto, et al (1994) *
From Lower Granite to tailrace Little Goose	14%	1993/Iwamoto et al (1994) *
To tailrace at Lower Granite	8%	1994/Muir et al {1995}
From Lower Granite to tailrace Little Goose	21%	1994/Muir et al {1995}
From L. Goose to tailrace L. Monu.	11%	1994/Muir et al {1995}
For Hatchery Steelhead		
Lower Granite Reservoir from Asotin to various downstream locations		

To tailrace at Lower Granite	10%	1994/Muir et al {1995}
From Lower Granite to tailrace Little Goose	22%	1994/ Muir et al {1995}
From L. Goose to tailrace L. Monu.	17%	1994/Muir et al {1995}

For Naturally Produced Chinook

From Lower Granite Reservoir to Lower Monumental tailrace	27%	1994/Muir et al, {1995}

For Naturally Produced and Hatchery Chinook.

(The following figures are taken from the Draft Snake River Salmon Recovery Plan (National Marine Fisheries Service, 1995). They have been criticized by Steward (1994), and Williams and Mathews (1994), who concluded that system and average project mortalities were overestimated (National Research Council, 1995, p. 201). For the purposes of the Recovery Plan and our purposes here, they should be viewed as relative values that provide a comparison of survival before and after Little Goose and Lower Monumental dams were added to the system. In any case they are not relevant to the system as it now exists, as explained in the text below.)

From Salmon River to Ice Harbor Dam: Before and after Little Goose and Lower Monumental Dams Were Built.

Before 1970	11%	Before 1970/Raymond {1979}
After 1970	67%	1970-1978/Raymond {1979}

From Lower Granite to The Dalles Before and After Little Goose, Lower Monumental and Ice Harbor Were Built

Before	37%	Before 1970/Raymond {1979}
After	80%	1970-1978/Raymond {1979}; Sims et al (1994)

This study was designed to test the method and associated assumptions, not to produce survival estimates. Nevertheless, the resulting estimates are close to those in the later study.

According to the Proposed Recovery Plan for Snake River Salmon, conditions have improved considerably since the Snake River studies of Raymond were conducted, (National Marine Fisheries Service, 1995). These improvements have resulted from construction and modification of bypass facilities at some of the dams (construction at Lower Granite and Ice Harbor dams, and modifications 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, and implementation of the water budget. Their conclusion is supported by the studies of Iwamoto et al (1993) and Muir et al (1995). Although the proposed explanation for the differences in survival rates between those of Raymond and those of Iwamoto et al and Muir et al seems reasonable to some, the new estimates of survival have not achieved universal acceptance. The "PIT Tag" (Prentice, 1990) is a new technology that has made possible studies such as these that can provide estimates of survivals through given "reaches" or segments of the river, where detectors are located at both ends. The proposed procedure for developing such estimates in the Columbia Basin, based on a concept referred to as the Cormack-Jolly-Seber concept (Burnham et al., 1987), was first outlined in a document prepared by Skalski and Giorgi, (1992). This resulted in the Snake River studies by NMFS and the University of Washington in 1993 and 1994, (Iwamoto et al., 1994; Muir et al., 1995). The estimation method employed by Iwamoto et al and Muir et al had been questioned, but at the request of the Council, the ISG supervised a review (Independent Scientific Group, 1996). The ISG issued a report, concluding that the procedure was the best method available for estimating the survival rate in reaches, but methods for determining the variance of the estimates could be improved.

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 projects have added spill amounts as bypass routes for smolts (see Findings of the mid-Columbia Coordinating Committee 1984 to 1993). These factors are discussed in more detail below.

The new estimates of mortality in turbines, along with the estimates of survival in reaches of the river have brought into focus the need to be able to separate turbine induced mortality from mortality from other sources, because the solutions will differ. There have been a few attempts to separate mortality estimates into components for the reservoir and tailrace. Iwamoto et al (1994) produced an estimate of zero mortality for yearling chinook in the reservoir above Lower Granite Dam in 1993, based on a reach survival estimate applying from a point above Lower Granite Dam to the tailrace at little Goose Dam, and an estimate of survival in turbines at Little Goose Dam. Muir et al., (1995) developed an estimate of steelhead smolt mortality from the forebay at Lower Monumental Dam to the tailrace, amounting to 42%. Unfortunately, there seems to be no

estimate of mortality of steelhead in turbines for Lower Monumental Dam. However, even assuming the worst, say 20% mortality in the turbines, the result indicates a high loss of smolts 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% (Dawley et al., 1989). The data of Johnsen and Dawley (1974) can be used to estimate a 54.5% loss of smolts from the tailrace at Bonneville Dam to Rainier Beach Oregon.

The discussion on bypass systems that follows, focuses on measures that may be taken at the dams to divert salmonid smolts away from the turbine intakes, such as spill, turbine intake screens, surface collectors, conduits to carry diverted smolts for release into the tailrace, and similar measures. While transportation of smolts by barge or truck may be viewed as a type of conduit that depends for its source of fish upon intake screens or surface collectors, we view the focus of transportation as being toward amelioration of mortality in river reaches. In any case, it merits fuller discussion than would be appropriate here, and is discussed at greater length in another section.

SOURCES OF MORTALITY IN TURBINES

The early findings stimulated engineering studies designed to identify factors responsible for the mortalities in turbines and to seek engineering solutions. Existing models of turbine facilities were used in studies designed to explore the factors responsible for the smolt mortality, such as those of Cramer, (1965), Cramer and Oligher (1960; Cramer and Oligher, 1961). Further extensive, pertinent literature on the subject is summarized by Bell et al (1981), Turbak et al (1981), Lucas (1981) and Bell (1991).

Bell et al. (1981) and (Bell, 1991) summarized the findings as follows: Fish survival is related to the efficiency curve of propellor type turbines, highest survival occurring at highest efficiency. All of the Columbia River and Snake River Powerhouses on the portion of the river passable by salmon are equipped with propellor type turbines. Turbines with negative pressure within the draft tube have a higher kill rate than those with positive pressure, pointing to the importance of maintaining an optimum tailwater elevation; in the prototype dimensions it was not possible to establish an effect due to clearances between the runners and wicket gates (as they state - or clearances at other points, such as the hub or the draft tube), though this was suspected to be a potential source of mortality, since larger fish suffered greater mortalities.

They also stimulated studies of behavior of salmonids, as biologists sought to find a clue that might lead to directing juveniles away from the intakes, summarized by (Andrew and Geen, 1960): Examples are (Brett and MacKinnon, 1953; Brett, 1957; Brett and Alderdice, 1958;

Collins and Elling, 1964). They investigated batteries of lights, bubble curtains, electric fields, and sound, among other things. 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, (Ebel, 1981); Mighetto, 1994 #16682; Office of Technology Assessment, 1995 #16818]. More information on these is provided in a later section.

Remedies to the turbine passage problem were sought through the decades of the 1960's and 1970's (Mighetto and Ebel, 1995). Best turbine operating criteria were defined - operate at the upper end of the turbine efficiency curve: And design characteristics were analyzed - minimize negative pressures in the draft tube, and avoid clearances around runner blades that could impact fish (Bell, 1967). At the same time, efforts were continued to develop methods for diverting fish away from the turbine intakes.

SPILL AS A MEANS OF BYPASS FOR SMOLTS

NORMAL SPILL

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 number of salmonid smolts are moving downstream. Spill provides an avenue by means of which smolts may avoid turbine intakes. Studies of passage through spill are in agreement that mortality of smolts through this route is low or negligible, generally in the range of 0% to 2% in spill, with a potential for added mortality from predation below.[5] Spillway design affects the rate of injury and survival, with freefall being the least injurious {Bell and DeLacy, 1972; Stone and Webster, 1986}. 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, 1986}.

[5] Some references state that mortality of smolts in spill ranges from 0% to 4% (Fish Passage Center, 1994), or 0% to 3% (NMFS/NOAA Proposed Recovery Plan, 1995). However, close scrutiny of the studies upon which these numbers are based leads us to conclude that 0% to 2% 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 numbers (e.g. such as those Muir et al (1995) suggested may have occurred below Little Goose Dam in 1994.)

Box 6. Estimates of Mortality in spill.

Mortality	*Species*	*Location*	*Reference*
2%	chinook	McNary Dam	Schoeneman et al (1961)
2.2%	steelhead	Lower Monumental Dam	Long et al (1975) (For spill bays with deflectors)
27.5%*	steelhead	Lower Monumental Dam	Long et al (1975) (For spill bays without deflectors)
4%**	chinook	Lower Monumental Dam	Muir et al (1995) (For combined bays)
1.5%	chinook	Lower Monumental Dam	Muir et al (1995) (For spill bay without deflector.)
7%	chinook	Lower Monumental Dam	Muir et al (1995) (For spill bay with deflector.)
0%	steelhead	Wells Dam	Weitkamp et al. (1980) (Confidence interval included 0)
		(See Findings of the mid-Columbia Coordinating Committee for the Period 1979-84)	
1%	coho	Rocky Reach Dam	Heinle and Olson {1981}
0%	chinook	Bonneville Dam	Ledgerwood et al (1990)
0%	chinook	Bonneville Dam	Johnsen and Dawley (1974) (For spill bay with deflector)
0%	chinook	Bonneville Dam	Johnsen and Dawley (1974) (For spill bay without deflector)
1%	chinook	John Day Dam	Raymond and Sims (1980) (point estimate did not differ from 0)
0%	chinook	Little Goose Dam	Iwamoto et al (1994)

- This unusually high estimate at Lower Granite Dam was probably associated either with high predation by sqauwfish or other adverse conditions below the dam, such as were described for Little Goose Dam in 1994 (Muir et al., 1995). See footnote below.
- +* Muir et al (Muir et al., 1995) found no statistically significant difference between the survival estimates for spill bays with and without deflectors, in spite of what the point estimates might suggest
- While the relationship of survival of smolts with flow reported by Sims and Ossiander, (Sims and Ossiander, 1981) now appears to have been an artifact, (Steward, 1994) {Williams and Mathews, 1995} it should not be overlooked that they reported that spill increases survival more than flow. Their analysis suggested that the first 10% of spill increased survival by 28%, while the first 10% increase in flow only added 13%survival.. On the other hand, safe passage may not guarantee survival downstream. (See footnote 5.)

By 1976, the Columbia River was "fully developed" for hydroelectric power generation, as a result of the provision of storage capacity in the upper basin, through construction of Duncan, Keenleyside, and Mica dams in Canada, and Libby and Hungry Horse dams in Montana, {Bonneville Power Administration 1980}. Flood control was an additional benefit identified by the U. S. Army Corps of Engineers and the Bureau of Reclamation (Logie, 1993). The implications for smolt passage were that high river flows previously experienced in the spring during the peak of smolt emigration were reduced such that there was less spill and a higher percentage of the fish had to pass through the turbines.

One early result of reduced flow in the spring from this development was reflected by a complaint filed before the FERC in 1976 by the State of Washington Department of Fisheries, later joined by the Oregon Department of Fish and Wildlife, certain Columbia River Treaty Tribes, and the United States National Marine Fisheries Service against the three mid-Columbia Public Utility Districts, requesting provision of minimum flows for fish at the five projects operated by the PUD's in the mid-Columbia reach, (FERC mid-Columbia Proceeding, Docket # E-9569).

While the primary objective of this petition was to stabilize flows for spawning fall chinook in the Hanford Reach below Priest Rapids Dam, and especially to establish minimum flows to prevent exposure of their redds, the result was a Settlement Agreement, reached among the parties in 1979, that among other things provided for studies over a five-year period to find ways to measure the effects of the projects on the downstream migration of juvenile salmonids in the mid-Columbia reach, to find ways of improving production of salmonids, and as an interim measure provided for spill of 10% of the river flow at each of the projects during the period in the spring when the middle 80% of the migrating smolts were determined to be present. This spill program, which began in the spring of 1980, was the first formal application of spill as a bypass measure for smolts in the Columbia Basin.

In 1989, in response to a measure in the NPPC's FWP, the fishery agencies and tribes, and BPA reached a Memorandum of Agreement on spill to be used as an interim measure at COE projects pending the installation of bypass systems {FPC, 1990}. More information on this subject appears in Parts II and III of this review found in the Appendix.

EFFECTIVENESS OF SPILL

Negotiators felt that a small amount of spill would probably attract and pass a high percentage of the smolts. Subsequent studies using hydroacoustic technology at each of the mid-Columbia projects, revealed that the relationship between the percentage of smolts passed in spill and the spill volume relative to total river flow is complex and varies from project to project. For each of the mid-Columbia projects, studies were conducted to define the relationships between spill volume relative to river flow and the resulting percentages of juvenile fish passed in spill, {Raemhild et al 1984}

(Biosonics, 1983; Biosonics, 1983; Biosonics, 1984). For the studies, spill volume was varied in the range of 20% to 85% spill relative to total river flow. Curves were developed that describe the relationship between spill volume and the percentage of fish passed in spill for each of the projects.

Box 7. As an example of the non-linear relationship often found, at Wanapum Dam in the spring of 1983, night-time spill of 20% of the instantaneous flow passed, on the average about 45% of the fish, while spill of 50% passed 60% of the fish {Biosonics, 1983 d}. On the other hand, at Rocky Reach Dam during the spring of 1983, night time spill amounting to 20% of the instantaneous river flow was estimated to pass about 16% of the fish, spill of 50% passed about 30% of the fish, and spill of 80% passed about 55% of the fish (Biosonics, 1984).

Experience in 1995 at Priest Rapids and Wanapum Dams showed that maintaining spill over a 24 hour period as compared to spill for 12 hours at night doubled the effectiveness of spill in terms of the percentage of fish passed in a given volume of water spilled (see Box 8).

Box 8. In fact, as an example, at Priest Rapids in 1995 using 17% spill for 24 hours a day for 60 days during the summer achieved 62% fish passage, whereas in 1994 spill of 40% for 12 hours per night for 34 nights in the summer only achieved an estimated 33% fish passage **{Hammond, 1995}**.

As for the COE projects, in the late 1970's NMFS/NOAA investigators were seeking ways to increase the smolt passage rate over the spillways (Giorgi and Stevenson, 1995). Spill effectiveness has been intensively studied, using hydroacoustic technology at John Day Dam annually since 1983 (Kuehl and 1986, 1986; Johnson and Wright, 1987; Magne et al., 1987; Ouellette, 1988; McFadden and Hedgepeth, 1990); all as summarized by Giorgi and Stevenson (1995). Magne et al (1987) produced a data set from 1983 that shows a relationship between the percentage of fish passage and percentage of spill in the range from 37% to about 66% spill. The authors focused on developing an overall ratio of percentage fish passage to percentage spill for the whole range of spill values, 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. Giorgi and Stevenson concluded that visual inspection of the scattergram of data from the 1983 study showed a ratio that was close to 1.0.

Giorgi and Stevenson combined the data for spring and summer, which seems reasonable in the absence of an expectation of a seasonal difference. When they are plotted separately it becomes apparent that analysis of the spring observations is hampered by a paucity of observations at spill

levels other than around 50%. In the spring there were only three observations below 45% spill (four counting the intercept), which leads to caution in drawing inferences. Although our analysis suggests there is a difference between spring and summer, we believe it best to combine the data for spring and summer that are in hand, until a wider range of spill values may be available from the spring period. If the two are combined, the relationship falls short of 1.0. The combined data would estimate 50% fish passage in 60% spill. (Obviously, spill effectiveness must improve at some spill level beyond the observations, since 100% spill must include 100% of the fish.)

The approach used by the authors, using a ratio over the season, assumes a linear relationship between fish passed and relative spill volume, and it must connect that point to the origin (i.e. with zero spill there must be zero fish in spill). That simple model is susceptable to large error at low or high spill levels. It does not fit the experience in the mid-Columbia, as described above. Whether the relationship is linear or curvilinear within the range of the observations (logic would suggest a curvilinear relationship), a regression equation would provide a means for describing a confidence interval about the line.

A study of sluiceway efficiency at The Dalles produced an estimate of spill effectiveness in the process (Willis and Hendricks, 1992). Willis used marked coho that were released in the reservoir above the dam, and released marked coho within the ice and trash sluiceway, then was able, using recovery rates in a trap in the sluiceway, to estimate sluiceway effectiveness at various levels of spill from about 10% to about 60%. The result is a sharply rising curve, showing high spill effectiveness at low spill levels. This result is not surprising, considering the configuration of The Dalles 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.

Box 9. Willis developed an equation to describe the relationship between fish passage in the sluiceway and the percentage of river flow that was spilled. He projected the resulting curve through the origin to estimate sluiceway effectiveness at zero spill, arriving at an estimate of 40%. Then, assuming that this 40% estimate of the percentage of fish at the powerhouse would apply for all levels of abundance of fish at the powerhouse (which seems reasonable), he was able to calculate the percentage of fish that must pass through spill at the given flow levels at The Dalles. The equation estimates spill effectiveness of about 30% fish passage at 10% spill, and 75% fish passage at 40% spill. (Willis, 1982). Further details are provided in the appendix.

SURFACE SPILL

On the basis of a study at John Day Dam, Raymond and Sims (Raymond and Sims, 1980) suggested that surface spill would be more effective than standard spill. 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). Raymond and Sims (1980) placed stop logs in the spillbay to create surface spill. They found that smolts passing through the bays with surface spill were as likely to pass in the day time as at night, whereas samples of smolts 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 smolts approaching the dam delayed sounding to the intakes until after dark, and that they were more readily passed through surface spill.

Box 10. Giorgi and Stevenson (1995) observed that surface spill remains to be adequately evaluated at COE projects. The COE has begun studies on effectiveness of surface spill. This is discussed further in the Appendix C, Parts 2 and 3.

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, (Figure 7.3). They are smaller spill bays, being designed for passage of debris rather than control of water elevation in the forebay. It was thought that spill at these sluiceways might be especially effective in passing smolts because of their proximity to the powerhouse, where flow is normally concentrated. Hydroacoustic evaluations confirmed this hypothesis {Ransom and Malone, 1990; Ransom 1995} (McFadden et al., 1992).

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. Hydroacoustic studies also found the shallower gates to be more effective in passing fish, per unit volume of water used, than the deeper gates (Ransom et al., 1988).

Box 11. Sluiceway (Surface Spill) Effectiveness in Passing Fish.

Project	*Season*	*Percentage of Fish Passed*	*Percentage of River Flow Spilled*	*Duration of Spill*
Priest Rapids Dam				
	Spring	3.0%	1.3%	12h (night)
		1.6%	0.3%	24h
	Summer	4%	2%	12h (night)
		2.1%	0.6%	24h

Spill in the sluiceway was judged to be twice as effective as spill in the spillway.

Wanapum Dam				
	Spring	4%	0.5%	24h

At Rock island Dam, when spill was split 50:50 between deep and shallow spill gates, the shallow spill gates passed 87% of the fish passing in spill (Ransom et al., 1988).

EFFECTIVENESS OF SURFACE SPILL

Current thinking is that these sluiceways at Wanapum and Priest Rapids dams are more effective than the standard spill gates, not simply because they are located closest to the powerhouse, but because they operate in the upper portion of the water column where the fish prefer to be (see Box 19.) It is now thought that in cases where spill is necessary to accomplish safe passage of a given percentage of smolts, surface spill will be more effective, requiring less water to achieve the objective. Grant County P.U.D. modified a standard spill gate at Wanapum Dam in 1996 to evaluate surface spill. Tests will be conducted in 1996 at The Dalles, and Lower Granite dams to determine whether an overflow weir improves passage at the spillway and to determine at what location and under what conditions an overflow weir will operate most efficiently at those projects. (Source of information - Bill Hevlin, NMFS/NOAA.)

Gas supersaturation, brought about by large volumes of spill remains a problem, which will be discussed in more detail below and in another section. Another complication is that under some powerhouse and spill operations at certain projects, eddies may be created that favor predators and

lead to reduced survival below the spillway, as suggested by Muir et al (1995) for Little Goose Dam. They estimated a 7% higher mortality rate of chinook smolts in 1994 compared to 1993, which they thought was brought about by this eddy and the resulting predation by squawfish (see Box 6).

MECHANICAL BYPASS SYSTEMS

INTRODUCTION

A review of development of bypass systems for juvenile salmonids necessarily will include summaries of methods that were tried that failed. The following section briefly reviews the failures and successes. As with all such efforts, the failures ought to shed some light on the path to success.

IMPROVED TURBINE EFFICIENCY

As a result of studies summarized above, showing 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. One example is Wells Dam where installation began in 1987 and was completed in 1990, (personal communication Ken Pflueger, Douglas County P.U.D.) At Rocky Reach Dam, planning for installation of such improved turbines began in 1993, and is underway in 1995 with a schedule for completion in the year 2001, (personal communication Bill Christman, Chelan County P.U.D.). At Rocky Reach the schedule for installation of new runners was expedited, and improvements incorporated designs suggested by turbine mortality studies indicating that improvements in fish survival (1.7%) might be obtained thereby {RMC Environmental Services and Skalski 1993}. Ledgerwood et al, (Ledgerwood et al., 1994) suggest that their estimates of smolt mortality in passing through turbines at Bonneville's second powerhouse that are lower than most estimates elsewhere {2.3% or 9.5%, Ledgerwood et al, 1993} were due to higher efficiency of the turbines at that project and a deeper submergence of the blades. (Another explanation has to do with whether fish released in the tailrace are the proper control group to compare as the reference or whether fish released downstream are the proper group. If downstream, the estimate is 9.5% rather than 2.3% mortality. The COE is working to develop an advanced turbine design aimed at improving efficiency and reducing smolt mortality (Office of Technolgy Asessment, 1995)).

TURBINE INTAKE AS A PASSAGE ROUTE

Slotted bulkheads were installed by the COE in 27 of the empty turbine bays in the lower Snake River projects to provide a passage for juvenile fish in 1971 (Mighetto and Ebel, 1995). They induced high mortality on the fish as a result of high water velocities that were created against the bulkheads and they were abandoned.

Free wheeling, or locking of the runners of turbines was investigated at Rocky Reach Dam as a possible means of passing juvenile fish without harm, {Stone and Webster, 1982}. It was concluded that it would not be possible in this way to avoid problems of pressure changes in the scroll case, which would lead to cavitation, and it was not likely to reduce injuries caused by fish strikes in transit.

FLIP-LIP SPILLWAYS

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; Collins et al., 1975; Bouck, 1980). The condition of supersaturation is brought about by the plunging of water from the spillway, carrying air with it and putting it under pressure in the pool below. As the pressure is removed, the bubbles appear. 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 1974}.

Box 12. Effectiveness of Spill Deflectors. These spill deflectors at Little Goose Dam were shown to reduce gas saturation levels down stream by about 10%, relative to levels before the deflectors were installed, at flows of 123 to 169 kcfs (128% saturation with spill of 46% to 59% of 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% 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 they found gas saturation was lower by 16% to 20% with the spill deflectors in place than it had been before, (op. cit.). 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% and tailrace elevations of 24 feet, the deflectors generally reduced gas saturation levels by about 10% (130% compared to 120%). 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.

Flip lip spillways have been installed at five of the eight COE projects in the Snake River and lower Columbia River, and are being planned at Ice Harbor and John Day dams in 1997 and 1998 respectively {NMFS/NOAA, 1995; Fishery Agencies and Tribes, 1993} (Bruce, 1995). However, only Lower Granite Dam is fully equipped across the spillway, (See Appendix C, Part 2.)

DIVERSION BARRIERS UPSTREAM OF THE POWERHOUSE

Prior to the construction of Hells Canyon Dam in 1967, and following construction of Brownlee Dam in 1958 it was found that smolts experienced great difficulty in passing through the reservoir above Brownlee Dam, (Graban, 1964; Haas, 1965). As a consequence of the high storage volume relative to inflow and outflow, water velocities were judged to be too low to stimulate movement of the smolts. An additional difficulty was the fact that the turbine intakes were located at depths of over 200 feet, too deep for surface oriented smolts to readily use for passage. This difficulty was well documented elsewhere, as noted by Eicher, (1988). In the reservoir above Brownlee Dam, a barrier net was placed that extended completely across the river at a point 4800 feet upstream of the dam and reached to a depth of 120 feet. The barrier was equipped with a walkway to provide access to three inclined-plane fish traps located at the surface along its length. In addition, in order to attract fish, each of the traps was equipped with a pump to provide appropriate flow to attract smolts. (See "gulpers" described below.) It was found to be difficult to keep the equipment in place under adverse weather conditions and as a result of general accumulation of debris. Furthermore, efficiency of the net in guiding fish was poor as fish passed through or under it (Mighetto and Ebel, 1995).

At Wanapum Dam, a barrier net 12,000 feet long and 40 feet deep, was tested. The net extended laterally from a point on the left bank upstream of the powerhouse across the powerhouse to a point 800 feet west of the powerhouse, leading toward the spillway. In this case, the intention was to lead fish away from the turbine intakes toward the spillway (Tyler and Pock, 1989). Problems that had to be overcome were strong currents that required heavy anchoring systems, accumulation of debris that required deployment of the net with its cork line below the surface, accumulation of periphyton requiring regular cleaning, and the fact that the net only briefly affected migration of smolts that encountered it. After three years, further testing was abandoned when it was concluded the net was not effective at diverting smolts away from the power house.

In 1989, a “forebay wedge screen” was tested at Priest Rapids Dam {Ramsom and Malone 1989}. It consisted of a wedge wire barrier mounted on a framework in the forebay in front of turbine unit 9. Unacceptable head loss occurred due to periphyton growth.

If availability of funds had permitted, the COE planned to test a floating guidance curtain in the forebay of Ice Harbor Dam in 1996. However, this test has been postponed. The intention was

to place the curtain so as to divert the downstream migrants away from the powerhouse and toward the spillway. The design was for a net 60 feet in depth. It would leave an opening near the south shore for upstream passage of adult salmon. Evaluation would be by hydroacoustics and by radiotelemetry of juveniles as well as adults to determine their response to the curtain.

FISH "GULPERS"

While the barrier net concept has used nets stretched across the migration path, a related concept has been 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 emigrants, 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, OR, where the device is built into the upstream face of the dam (Wagner and Ingram, 1973). At Baker Lake, WA, a surface collection device of this type was found to be effective at collecting sockeye smolts for transportation below the powerhouse, (Wayne, 1961; Quistorff, 1966). It became a viable solution to the problem of collecting smolts in the reservoir when a lead net was added to the "gulper", (Cary Feldmann, Puget Sound Power and Light, personal communication).

The NMFS Recovery Plan, (National Marine Fisheries Service, 1995) calls for the IPC to evaluate the efficacy of reintroducing Snake River fall chinook into habitat above the Hells Canyon complex, i.e. Hells Canyon, Brownlee, and Oxbow Dams, as suggested by Armour, (1990). Evaluating the efficacy of that measure would require addressing adult passage over the 300 foot high Hells Canyon Dam, as well as addressing juvenile passage through the slow moving water in the reservoir, and the reluctance of juveniles to sound to the depths where turbine intakes are located. Some of the experience with gulpers suggests possibilities.

GATEWELL SALVAGE

It was early observed that smolts accumulate in turbine intake gatewell slots, a reflection of their tendency to pass through the intakes near the ceiling, This was first observed by C.W. Long, and G. Schneider, according to (Mighetto and Ebel, 1995). Bentley and Raymond, {1969} describe the salvage of juvenile salmonids from gatewells at dams in the Columbia River. A dip basket was developed for use in removing smolts from the gatewells.

A fish salvage operation was undertaken at John Day Dam in 1977, in anticipation of low flows that were expected to lead to accumulation of fish in the gatewells (Johnsen, 1978). The

numbers removed from the gatewells were disappointingly low, about 21,000 juvenile salmonids, mostly chinook yearlings.

On the other hand, marked juveniles that were released in the Wanapum reservoir were recovered in the gatewells at Priest Rapids Dam at the rate of 5% for coho, 2.1% for chinook yearlings and 3.6% for steelhead, {CH2M Hill and Wash. Dept. Fish., 1980}. During the initial five years of the mid-Columbia Settlement Agreement, the gatewells at Wanapum and Priest Rapids dams were emptied regularly and enumerated to obtain an index of fish passage. Following the Stipulation of 1985, Grant County P.U.D. has salvaged fish from the gatewells at Wanapum and Priest Rapids dams on a daily basis, weather permitting. Specially designed nets deployed by mobile cranes from the deck of the powerhouse are used to remove fish that have accumulated in the gatewells. Captured fish are placed into tank trucks and transported to below the dam where they are released into the tailrace. In the neighborhood of 200,000 fish are salvaged at each of the two projects each year.

Box 13. As an example of the numbers of fish involved, in 1991, during the spring emigration, there were 142,019 smolts collected from the gatewells at Wanapum Dam that were released in the tailrace below, and 173,273 smolts from the gatewells at Priest Rapids Dam. During the summer emigration there were 31, 218 smolts collected from the gatewells at Wanapum Dam and 46,423 from Priest Rapids Dam. (Personal communication, Stuart Hammond, Grant County P.U.D. No. 2)

AIRLIFT

A gatewell airlift system was tested at McNary Dam in 1981 as part of the study of a proposed intake screen configuration at John Day Dam. While the airlift did not affect the guidance of fish, the turbulence it created in the gatewell made it difficult for the fish to exit through the orifices, leading to unnacceptably low orifice passage efficiency {Swan et al, 1982} (Krcma et al., 1983). An airlift installed at John Day Dam is used to sample fish diverted into the gatewell by intake screens [Brege, 1990 #16587; (Wood, 1993).

At Rocky Reach Dam, in 1980, an airlift was investigated as a means of drawing fish out of the gatewells. It was concluded that the airlift was not effective in drawing a significant number of fish up the gatewell, although it could be used to remove some fish from the gatewell (Hill, 1982).

GATEWELL CONDUIT

When the second powerhouse at Rock Island Dam went into service in 1979 it included provision for orifices between the gatewells and a conduit leading from there to the tailrace. It also included a feature allowing for diversion of a portion of the fish thus collected, into a bypass sampler

(Olson, 1981). The effectiveness of the system in diverting fish from the turbine intakes varies among species and from year to year depending upon levels of spill relative to river flow, and ranges around 5 to 15%, being higher in years with low spill.

Box 14. In a 1981 test at Rock Island Dam, average recovery rate of six test lots of coho released in the forebay was 15%. In 1982 four lots each of chinook, steelhead and coho were released in the forebay and brought average recovery rates of 4.1%, 2.2%, and 9.8% respectively. Olson concluded that the difference in recovery rate between the two years was probably due to differences in relative volumes of spill in the two years, more fish passing in spill in 1982, lowering the recovery rate in the gatewells. He felt that many fish sounded out of the gatewells, and that efficiency could be improved by providing a screen (possibly a VBS?) to encourage upward movement of the fish toward the orifices.

OTHER

The Office of Technology Assessment refers to all other devices as "Alternative Behavioral Guidance Devices" (Office of Technology Assessment 1995). 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, (Office of Technology Assessment 1995, p. 87). Stone and Webster {1987} concluded that, up to the time of their review for EPRI, such devices had not offered much promise of meeting agency goals.

Nevertheless, from time to time, there is a revival of interest in these methods, as investigators either have a new perspective on the method, {e.g. Carlson, 1995} or are unaware that it has been tried. 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).

As mentioned previously, in the 1950s and 1960s the Fish Passage Program of the then Bureau of Commercial Fisheries (BCF, now NMFS/NOAA), under the direction of Gerald B. Collins investigated a number of potential methods for their efficacy in directing movements of fish, such as banks of lights, bubble curtains, sound, and electric fields, none of which proved to be practical for application in the field, (Mighetto and Ebel, 1995). Andrew and Geen (1960) reviewed the studies beyond those of BCF and came to the same conclusion. Some other pertinent studies are summarized below.

Electric Fields

Effectiveness of electrical barriers at power plant intakes has been generally poor {Stone and Webster, 1987}. Collins and his colleagues found that successful application of this technology would be limited to situations where velocity of flow was less than one fps (summarized by (Mighetto and Ebel, 1995). This would represent a serious limitation at the turbine intakes in the Columbia Basin. For example, Odgaard et al (Odgaard et al., 1990) determined that the approach velocity measured immediately upstream from the intake screen at Wanapum and Priest Rapids dams was on the order of 1.1-1.2 m/s. (3.6-3.9 fps). There are other serious drawbacks with the application of electricity. Electric fields are potentially dangerous to other fish that may be present. Susceptibility to dangerous shock is a function of fish size, making adult fish more vulnerable than juveniles (Office of Technology Assessment 1995).

Sound

Recently, Carlson, (Carlson, 1994) reviewed the extensive literature base, regarding studies that have been conducted to direct fish by means of sound. He concluded that sound deterrence for salmonids is possible only at short ranges using very low frequencies. Significant challenges remain in the possible application of sound to address problems of systems intended to modify fish behavior. Dolat et al (1995) reported success in using sound to divert from the intake, a portion of the smolts approaching the irrigation diversion at Dryden Dam on the Wenatchee River. Although a clear effect of sound was established, it was not as effective as the screen that is in place (Mueller et al., 1995).

Light

Mighetto and Ebel, (1995) report that Paul Fields was able, using lights, to divert smolts away from the turbine intakes and toward the spillway, but was unable to sustain that response over a 24 hour period. Fields {e.g., 1966} developed a large body of information on the effects of light on migration of salmonids, most of which fits the summary in the previous sentence.

In 1986, strobe lights, mounted on the trash racks in the turbine intakes were investigated at Rocky Reach Dam as a possible means of guiding fish away from the intakes, (Hays and Truscott, 1986). Although the lights affected the vertical distribution of smolts entering the gatewell, it was concluded that there was no way to use them effectively to assist fish in avoiding the intake. Mercury vapor lights attached to the frame of a guidance device at Bonneville Dam in tests over several years did not significantly increase guidance or decrease descaling of subyearling chinook (Gessel et al., 1990).

Louvers

Angled louvers have been used effectively at pump intakes and irrigation diversions to divert smolts into alternate channels {Stone and Webster, 1986} (Office of Technology Assessment 1995). They are considered to be standard technologies for turbine intakes in the Northeast but not in the Northwest (Office of Technology Assessment 1995). The difference is apparently due to the high water volumes and velocities present in Northwest river applications. Louvers have been widely applied in the Sacramento River system as fish protection devices {Stone and Webster, 1986}. In the Columbia Basin the primary application has been at irrigation diversions in conjunction with screens. Collins' group found that louvers would only be effective in diverting a high enough percentage of smolts in situations where flows were carefully regulated at low levels and floating debris was sparse (summarized in (Mighetto and Ebel, 1995). However, 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, 1986}. Best estimates of effectiveness ranged from about 40% for subyearling chinook to 80% for yearling chinook approaching the project (Clark and Cramer, 1977, as cited in Stone and Webster, 1986).

Vertical louvers were located behind each screen panel at the Dryden Reclamation District Canal on the Wenatchee River, for the purpose of balancing the flow across the set of screen panels, and were placed to facilitate the working of the screens, but were not completely successful in balancing the flow (Mueller et al., 1995).

TURBINE INTAKE SCREENS

Submerged Traveling Screens (STS)

In the early 1960's, studies by Bureau of Commercial Fisheries investigators showed that smolts tended to be concentrated near the ceiling of the turbine intakes, and a portion of them were drawn into the gatewells above (Long, 1968). This led to the idea that fish might be screened or deflected from the upper portion of the intake, with minimal effect on the generating capacity of the unit. The concept was first tested at model facilities at Washington State University, where initial studies, conducted under the aegis of BCF, also identified optimum screen porosities and deflection angles to mimimize impingement of fish on the screen. The model studies led to predictions of a unit head loss of less than 10% resulting from placement of the screen at the intake, which seemed acceptable. A cleaning mechanism was recommended in order to avoid violation of the operating criteria (Mueller and Osborn, 1969). The first test of a prototype device in the field took place in 1970 at projects on the lower Snake River (Long et al., 1970). The first design incorporated a traveling screen as a self-cleaning feature, leading to the name submerged traveling screen (STS) for

the device. Mighetto and Ebel (1995) summarized the decades of work by BCF (later NMFS/NOAA) and the COE to develop a satisfactory intake screen, Figure 7.4.

Criteria for success of intake screens are high fish guidance efficiency (FGE), low impingement, and low injury rates to guided fish. Using these criteria, numerous improvements in the design and deployment of intake screens have been made over the years. An evaluation of screen effectiveness is provided later in the text. Because improvements in designs have been made over the years, the early evaluations of effectiveness are mainly of historic interest, while the most recent estimates are the ones that should be applied in estiating diversion rates at the projects. More information on this subject follows below.

Box 15. The first screen tested in prototype was approximately 24 feet in length, which corresponded with dimensions in the model, and could be deployed at angles of 45 to 60 degrees, (Marquett et al., 1970). It was tested at Ice Harbor Dam in 1969 and 1970, where it was found that by using the screen, the relative number of smolts in the gatewell could be increased by a factor of three. Over the next several years, devices were also tested at Little Goose and Lower Granite dams, and improvements were made in the design. Details are to be found in Ebel, et al (1974), and Park et al (1977). Addition of a porosity plate behind the screen reduced impingement of fish to acceptable levels. Perforated steel panels, referred to as a vertical barrier screen (VBS) split the gatewell, distributing the flow upward, and discouraging fish from sounding out of the gatewell and back into the intake.

Fixed Bar Screens

In the mid-1970's planning for addition of a second powerhouse at Bonneville Dam led to testing of an intake screen at that project (Ruehle et al., 1978). Experience with the traveling screens had shown them to be costly to build and maintain. These Bonneville tests used a fixed screen concept that would be less complex and less costly. It was five feet wide and extended across the full width of one intake slot. Results were promising, leading to testing of a full-scale device at McNary Dam in 1978 that had somewhat different features (Krcma et al., 1978). Rather than flat steel bars used in the test at Bonneville, the McNary test used extremely smooth steel bars, triangular in cross section (wedge wire). 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 NMFS/NOAA test of the bar screen design at Bonneville and McNary dams {mid-Columbia Coordinating Committee, 1988}. 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 COE projects (Gessel et al., 1991).

Extended-length Screens

Initial tests in 1983 of an STS at Bonneville Dam's second powerhouse showed surprisingly poor effectiveness in guiding fish, with FGE less than 25% for chinook and coho. Therefore efforts were directed at improving fish guidance {Gessel, et al, 1992}. 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 sufficiently to justify further tests.

Similarly, at Lower Granite Dam, initial tests in 1982 of the STS indicated poor effectiveness (about 50%) 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. Increases of about 15% in guidance efficiency were measured. Descaling of guided fish was estimated to be 1.7%. Impingment that had ranged from 0.04% to 3% was reduced to less than 1% by design changes in 1990 (Wik and Barila, 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. The results of the simulated extended screen tests were not directly transferable to the design of the new units due to differences in hydraulic characteristics as shown by model studies, and appropriate modifications were made (Swan et al., 1990), Appendix B). Tests of full extended screens were also initiated at The Dalles and Little Goose Dams in 1993 {Gessel, et al, 1994}. At McNary Dam extended length screens, either bar screens or STS's have produced estimates of FGE of over 80% for yearling chinook (81% for the extended bar screen and 88% for the extended STS), {McComas et al, 1993}. No significant increase in descaling of guided fish was observed with the extended screen. For sub yearling chinook FGE of 67% was measured with the extended STS and 52% with the extended bar screen, while descaling was not significantly higher for either of the extended screens than for a standard STS used as a control.

At Little Goose Dam, tests of the full prototype in 1993 and 1994 brought FGE's of greater than 80% and 77% respectively, for yearling chinook (Gessel et al., 1995). For steelhead, FGE averaged 90% in the best configuration. No significant increases in descaling were observed in comparisons with a standard STS.

Plans for installation of extended length screens at COE projects are discussed in the Appendix, Parts 2 and 3 of this report.

Summary

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. Projects not yet equipped with turbine intake screens (not including Wells Dam, which has a different type of bypass, as explained elsewhere) are The Dalles, Priest Rapids, Wanapum, Rock Island, and Rocky Reach dams. This will be discussed further in the Appendix C, Parts 2 and 3. Prototypes have been tested with success at The Dalles, Priest Rapids and Wanapum dams, and schedules for installation are shown in the Appendix C, Part 3. At Rocky Reach Dam, prototype tests of intake screens have not yet produced satisfactory results. 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, test have shown some promise and are continuing.

Although it is not associated with a dam, the hydroelectric 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, 1987}. Average survival of chinook yearlings encountering the screen was found to be 97.9% {Page et al, 1975}.

SURFACE COLLECTION DEVICES

Ice and Trash Sluiceways

Being located at the surface, directly above the turbine intakes, the ice and trash sluiceways, that were included at the time of construction at some projects, are in good position to attract fish that are approaching the powerhouse. Smolts were observed in the sluiceways at Bonneville and The Dalles, leading to initial testing of the concept, (Michimoto and Korn, 1969). It was found that the efficiency of the sluiceways in diverting smolts from the turbine intakes was generally in the neighborhood of 20% to 40%, (Nichols et al., 1978; Willis and Hendricks, 1992) and {Willis, 1982, 1983}. 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 1980's, it is doubtful that those estimates would apply under current condtions. In 1987, at the Bonneville Dam second powerhouse, the ice and trash sluiceway was shown to pass an estimated 81% of smolts passing the powerhouse in the daytime and 30% at night (Magne et al., 1987).

At The Dalles Dam, as previously discussed under the subject of spill effectiveness, a study using marked fish provided an estimate of 40% sluiceway passage efficiency at zero spill {Willis, 1982}. Willis provided equations describing the relationships for spill effectiveness and sluiceway effectiveness. 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% of the migrants in the daytime in 4% of the water, and pass 21% of the migrants at night in 6% of the water (Ransom and Ouellette, 1991)

Box 16. Raymond and Sims (1980) found that smolts passing through the gates with surface spill were as likely to pass in the day time as at night, whereas samples of smolts 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 smolts approaching the dam delayed sounding to the intakes until after dark, and that they more readily passed through surface spill. The number of smolts in the ice and trash sluiceway at The Dalles Dam, peaked around mid-day {Nichols, 1979} (Nichols and Ransom, 1980; Nichols and Ransom, 1981; Steig and Johnson, 1986; Johnson and Wright, 1987); and at Bonneville Dam in 1981, the number also peaked at mid-day (Willis and Uremovich, 1981); all as summarized by (Giorgi and Stevenson, 1995). This is in contrast to turbine intakes where the number of smolts reaches a peak at night (Giorgi and Stevenson, 1995) summarize (Long, 1968; Steig and Johnson, 1986; Johnson and Wright, 1987).

There is much current interest in surface collection devices, including ice and trash sluiceways for passing smolts, Investigations that are underway, will be described in a later section.

Wells Dam

The unique design of the hydrocombine at Wells Dam, 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. The FERC Stipulation of 1985 called for spill to bypass 50% of the juvenile salmonids approaching the project.

Two-dimensional model studies were undertaken that were designed to determine the feasibility of altering the approach flow to direct the juvenile salmonids away from the turbine intakes, see (Sverdrup and Parcel and Associates, 1982; Johnson et al., 1992). The design included placement of solid covers on the turbine intake emergency gate slots, opening the flap gate in the top leaf of the spillway gate (surface spill), and installing solid panels in front of the spillway to a point 30 to 40 feet below the surface, (Figure 7.5). Testing of a prototype began in 1983 {Biosonics 1983}. The results were encouraging from the outset. 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 one of three spillbay baffles was most effective at diverting fish (Sullivan and Johnson, 1986). Following successful tests in 1987 of an enlarged set of diversion baffles encompassing most of the intakes, the mid-Columbia Coordinating Committee agreed that the

bypass was expected to perform satisfactorily, so no additional evaluations were undertaken until the system was fully installed in 1989. A sufficient array was in place across the powerhouse by 1987 that it was operated as though it were complete, and spill beyond the amount necessary to operate the bypass has not been required since then {Kudera and Sullivan, 1993}. The volume of water required for operation varies somewhat depending on river flow and the powerhouse load. In 1995 it ranged between 1.2 and 7.5% of the daily average river flow.

In January, 1991, a long-term Settlement Agreement among the parties to the mid-Columbia Proceeding, with respect to issues at Wells Dam was approved by FERC. It calls for operation of the juvenile fish bypass during the spring and summer emigrations, at times to be determined by representatives of the parties. Among other things, that agreement called for a three-year study to measure the effectiveness of the bypass. It established a criterion of at least 80% bypass for the spring period and at least 70% for the summer. From the resulting studies, the three year average bypass during both the spring and summer emigrations was estimated to be 89% (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 NPPC, or NMFS/NOAA, without adding spill. (The NMFS standard does not apply in the mid-Columbia.)

Rocky Reach Dam

The success at Wells Dam has stimulated studies of the possibility of applications elsewhere. The FERC Stipulation for Rocky Reach Dam in 1993 called for evaluation of a possible sluiceway for passage of juveniles. 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, with the spillway located directly above the turbine intakes, unlike any of the others.[6] The failure of conventional intake screens that had been tested to that time at Rocky Reach Dam was a factor in the decision to study a surface attraction device. A prototype surface collection device was prepared for testing at Rocky Reach Dam in 1995 (Peven et al., 1995). It consisted of a housing with a 15 foot wide and 56 foot deep opening located downstream of the unit 1 intakes in the corner of the cul-de-sac that is present where the powerhouse meets the forebay wall at nearly a 90 degree angle. Guidewalls extended from the opening upstream to the lower end of the unit 2 intake and downstream to the forebay wall.

A further difficulty arising from the surface collection concept is that it requires a different method of evaluation than the approach used to measure FGE with the turbine intake screens. With the intake screens, an array of fyke nets in place below the screen in the intake is used to capture fish not guided by the screens. Guided fish are removed from the gatewell and counted, thereby providing

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

an estimate of fish guidance efficiency. With a surface collection device in prototype, investigators are faced with the practical problem of not being able to directly associate a fyke net catch in an intake with an assignable number of guided fish that may be drawn from a wide area across the powerhouse. At Wells Dam, hydroacoustic estimates of relative fish passage were developed, in the beginning for a set of spillbays and the associated turbine intakes directly below them, and later across the entire hydrocombine. The hydroacoustic method has been employed in general for evaluation of surface collectors.

The method is also being investigated for possible use in evaluating intake screens because of present 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, e.g., (Magne et al., 1989; Thorne and Kuehl, 1989; Stansell et al., 1990; Thorne and Kuehl, 1990; Stansell et al., 1991).

At Rocky Reach Dam, it was estimated that over 725,000 juvenile salmon and steelhead passed through the prototype device during the spring emigration, April 26-June 15, 1995 (Peven et al., 1995). Future development of the concept in 1996 involves installation of a “floor” to assist in guiding fish into the opening. Radio-tagged and other marked fish will be released in the forebay to make possible an estimate of guidance efficiency (Peven, 1996). Surface attraction is also being investigated for juvenile fish bypass at Rock Island Dam.

Wanapum Dam

A parallel effort to develop a surface oriented juvenile bypass system began at Wanapum Dam in 1995 {Ransom et al, 1995}. The physical conditions at Wanapum Dam are much different from conditions at either Rocky Reach or Wells dams. At Wanapum Dam, the spillway portion of the dam is downstream of the powerhouse, and the reservoir is much wider. The prototype tested consisted of a 12 foot wide by 60 foot deep channel attached to the upstream face of the dam in front of units 7 to 10. A single entrance 15 feet wide by 60 feet deep, centered over unit 8, provided access for juvenile migrants. Hydroacoustic evaluation brought estimates of fish passage efficiency in relation to unit 8, of 12.2% to 68.8% and averaged 35% for the spring migration season. Grant County P.U.D. plans to enlarge the prototype for testing in 1996. (Personal communication Stuart Hammond, Grant County P.U.D.)

Ice Harbor and other Corps of Engineers Projects

NMFS/NOAA Proposed Recovery Plan (1994) refer to the success at Wells Dam and call upon the COE to investigate potential applications at COE projects. Accordingly, in 1995 the COE 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 smolts was greatest in the sluiceway, although more total fish passed in spill because of the high volume of spill (Biosonics, 1995). Further tests are scheduled for 1996 at Lower Granite and The Dalles dams, as discussed further below.

EFFECTIVENESS OF MECHANICAL BYPASS SYSTEMS

Fish Guidance Efficiency

The primary criterion in evaluating the effectiveness of mechanical bypass systems is their fish guidance efficiency (FGE), the percentage of fish approaching the powerhouse that are diverted unharmed from the turbine intakes into the system. In the case of turbine intake screens, impingement 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. In one early set of NMFS studies at Bonneville Dam (first powerhouse), FGE for chinook, steelhead and sockeye ranged from 70% to a little over 80% (Krcma et al., 1982). These were judged to be acceptable levels at the time, and installation at a number of COE projects proceeded on that basis.

It has been found that estimates of FGE are variable from one test to another. They differ from project to project, differ among fish species, differ according to the degree of smoltification of the fish, differ with the design and configuration of the apparatus, differ according to time of day (particularly day versus night), and differ as the season progresses (Swan et al., 1985; Hays and Truscott, 1986; 1986; 1987; 1987; Giorgi et al., 1988; Peven and Keesee, 1992).

Box 17. Measurements of FGE at the Bonneville Dam first powerhouse in 1981 brought estimates of 76% for yearling chinook and 72% for subyearling chinook (Krcma et al., 1982). Following installation of an approach channel for a new navigation lock that involved removal of part of Bradford Island (Gessel et al., 1991), FGE was measured again and found to be substantially reduced - to 21% for yearling chinook and 24% for subyearling chinook {Krcma et al. 1984}. Modifications to the screen and its deployment brought FGE up to 26-44% for yearlings and 20-32% for subyearlings {Krcma et al. 1984}. Fish guidance efficiency at Bonneville's second powerhouse was poor at the outset, 19% for yearling chinook and 24% for subyearling chinook {Williams et al. 1988}. Modifications of the apparatus, and eventually extensions of the turbine intakes into the forebay brought improvements by 1986 to around 60% for chinook yearlings, 55% for subyearlings, and 46% for steelhead (Gessel et al., 1991). Further tests were conducted each year through 1989. Best observed FGE was 78% for chinook yearlings and coho, 69% for steelhead, and 25% for subyearling chinook (Gessel et al., 1991). On the basis of these studies, a configuration was recommended for full installation across the second power house. {Gessel et al, 1992}.

More information on FGE measurements is provided in Table 7.1 and later in the Appendix in Part II, the section on requirements for fish passage by FERC, the NPPC, and NMFS/NOAA.

Information on FGE is shown in Table 7.1. In most cases the FGE measured applies to a prototype tested at the project. Usually, these estimates are projections for the particular project based on samples. Ordinarily, the sample is taken from one of three intake slots at a sample turbine, where fyke nets in the intake behind the screen capture, fish that are not guided, while guided fish rise in the gatewell where they are removed and counted. 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. In many instances the sample came from one slot, where the adjacent slots were not equipped with screens. Studies at Wanapum Dam verified the fact that although flow patterns were affected by screens in the adjacent slots, the resulting measurements of FGE showed little or no effect {mid-Columbia Coordinating Committee, 1995}.

With extended screens significant increases in FGE have been measured, for example at Lower Granite Dam, 66% for yearling chinook with the extended screen compared to 57% with the standard STS, and 83% for steelhead with the extended screen compared to 77% with a standard STS (Swan et al., 1990)..

At Wells Dam, the final measurement of 89% fish passage effectiveness was made in a three year study after the project was fully equipped with the bypass. Hydroacoustic technology was used at sample locations across the hydrocombine that were subsampled on a timed schedule (Biosonics, 1983; Skalski, 1993) {Kudera et al, 1990}.

Survival at the Screen

Another factor in evaluating the effectiveness of intake screens is mortality of fish caused by striking the screen. A percentage of the approaching fish may strike the screen in passing and lose some scales, while others, particularly the small sub-yearling chinook, may become impinged on the screen (Wik and Barila, 1990). Impingement rate on extended-length screens at Lower Granite Dam was reduced to less than 1% by design changes. Impingement rates of yearling chinook are negligible in properly tuned systems, but of subyearling chinook may be "high" e.g. (Peven, 1993).

Descaling occurs as a result of fish striking the screen or other objects in the bypass system. Standards defining descaling have been developed, and set a threshold level of a percentage of missing scales 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. Descaling of 1.7% of all species, representing 2.4% of chinook, and 1.4% of steelhead was observed in the bypass sampler at Lower Granite Dam in 1988, which was an improvement over 1987, when the total was 3.3% (Koski and al., 1989). As a result of improvements in the system and its operation, descaling rates declined to those levels after 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, 198}). At Little Goose Dam the combined rate in 1988 was 3.4%. At McNary Dam the figure was 10.4%. Muir et al (1995)estimated 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% descaling rate of hatchery origin steelhead observed after passing through the bypass was not excessive.

Concerns have been expressed about levels of stress induced on the juveniles as they encounter the screens and associated bypass systems (Schreck et al., 1984). Bjornn (1992) found no difference in survival rates of marked chinook that were subjected to high stress prior to release as smolts, compared to those that were not stressed.

Conduit to the Tailrace

As the tests of intake screens proceeded with promising results, appropriate means were sought for encouraging movement of the fish upward in the gatewells, for removing the guided fish from the gatewells on a mass scale, and providing an exit for them to the tailrace below the dam (Mighetto and Ebel, 1995). At Bonneville Dam, at the 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.

Box 18. Orifice Passage Efficiency (OPE) is a measure of the percentage of fish that leave the gatewell during a specified time period, normally 24 hours. OPE of 70% is considered satisfactory, (National Research Council, 1995), p. 191). At Wanapum Dam, two baffle systems in the gatewell were tested for their effects on OPE. The best system produced an OPE of near 90% (mid-Columbia Coordinating Committee, 1993).

A dewatering system was provided at the end of the 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 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., 1982; 1983; 1984; 1985; 1986; Swan et al., 1986).

Effectiveness of Bypass Systems

Performance of the part of the bypass system downstream of the screen itself has come under study. Dead fish are observed in the sampling systems in the bypasses. 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 smolt mortality 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 and al., 1989) {FTOT, 1994}.

At McNary Dam in 1983 mortality of marked yearling chinook in passing from the gatewells to the bypass sampler ranged from 2% to 4%, depending upon the location of the gatewell (Park et al., 1984). In the years 1989 to 1993, annual facility mortality at McNary ranged from 0.4% to 1.9% for chinook yearlings, from 1.2% to 5.0% for chinook sub-yearlings, from 0.2% to 1.5% for steelhead, and from 0.5% to 4.1% for sockeye {FTOT, 1994}.

Gilbreath et al., {1992} state that in the first years of evaluation in the 1980s, the bypass facilities at both power houses at Bonneville Dam had a number of internal mechanical problems, which the COE subsequently corrected, so that the resulting systems, internally, now have a minimum impact on fish. For example, in 1983, excessive delay and exhaustion of fish was documented at the Bonneville second powerhouse bypass system (Krcma et al., 1984). Now, at Bonneville Dam, juvenile mortality within the bypass system, as measured at the bypass sampler, generally ranges from less than 1% to 4% (Ceballos et al., 1993). Survival rate in bypass systems is given by the COE as 97-98% {COE Salmon Passage Notes, 1992}.

An additional source of mortality to guided fish is 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).

At Lower Granite Dam, studies of delayed mortality due to effects of passage through the entire bypass produced estimated losses of 7.6% , 4.4% and 5.1% in 1984, 1985 and 1986 (Mathews et al., 1987), as summarized by (Chapman et al., 1991).

Results of studies at Bonneville Dam have been surprising {Ferguson 1993; Gilbreath et al, 1993} (Ledgerwood et al., 1990; Ledgerwood et al., 1991; Dawley et al., 1992). During 1987 and 1988, the first two years of the study at Bonneville's second powerhouse, reported by Ledgerwood et al (1991), rates of recovery in the estuary of marked subyearling chinook that had transitted the bypass were significantly lower than fish that had passed through the turbines, indicating higher mortality of smolts in the bypass than in the turbines. 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}. It was found that the conduit itself contributed an estimated 3% mortality to smolts diverted by the intake screens (Dawley et al., 1992). Dawley et al (1992) and Gilbreath et al, {1993} therefore 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 smolt mortality associated with the bypass that was 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 smolts that passed through the bypass was lower than for smolts that passed through the turbines. Again, predation at the outfall was thought to be the principal source of mortality. They reported that Tom Poe of the U.S. Fish and Wildlife Service communicated to them the information that a higher proportion of marked smolts released into the bypass were consumed by northern squawfish in the tailrace than were other groups of smolts released at the same time.

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.

Summary

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) {NMFS/NOAA, 1990}.

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 COE projects. NMFS has adopted a policy statement that provides for development and evaluation of new technology under controlled conditions (Office of Technology Assessment, Appendix B.).

SUMMARY OF BYPASS FINDINGS

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

Box 19. The preponderance of evidence accumulated in these and other studies demonstrates that smolts migrating downstream are oriented to the upper portion of the water column. Giorgi and Stevenson, (Giorgi and Stevenson, 1995) reviewed much of the evidence at COE projects. Johnson, (1995) reviewed the evidence from salmon literature world-wide. When they encounter a dam, smolts prefer surface outlets when they are available and are reluctant to sound. Further evidence of their surface orientation comes from the fact that smolts 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); that they generally do not sound to significant depths unless no alternative is presented, (Wagner and Ingram, 1973; Dunn, 1978). Numerous hydroacoustic studies that were undertaken at each of the five mid-Columbia projects showed that smolts were concentrated in the upper portion of the water column, generally in the upper one-third. (Biosonics, numerous - see references. e.g. Ransom et al (Ransom et al., 1988) found that fish approaching Rock Island Dam were surface oriented.) Smolts have been sampled in the Wells forebay with purse seines, a fishing method that operates at the surface {Findings of the mid-Columbia Coordinating Committee, 1989}. In the forebay at lower Granite Dam, 92% of the smolts were found to be in the upper 36 feet of the water column {Smith, 1976}. The turbine intake screen technology depends upon the fact that smolts are concentrated near the ceiling of the intake as they pass through. Numerous examples exist, e.g. Long, (1968); fyke net sampling at each of the mid-Columbia projects showed that 75-80% of the smolts were in the upper portion of the intakes, (Hays, 1984), etc. Eicher, (Eicher, 1988) reviewed studies of passage efficiency at deep intakes. The studies of Regenthal and Rees, {1957} were particularly informative. They showed 55% of chinook would exit the reservoir when the only route was 118 feet deep or less, 48% when it was at 146 feet, and 8% when it was 160 feet (as summarized in (Eicher, 1988). Eicher concluded that "it has been accepted that fish (Salmonids et al.,) 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." (op. cit.).

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 atmospheric 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. 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. Effectiveness of spill differs among the projects. More information is needed at most of the COE projects. In addition, effectiveness of surface spill needs to 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.

Effectiveness of turbine intake screens seems to have reached an upper limit that is less than the surface collector at Wells Dam. Intake screens are unlikely to prove 100% effective in diverting salmon smolts (Office of Technology Assessment, p.127). Although some measurements of screen effectiveness have shown values as high as 90% for steelhead, and near that for chinook yearlings, none of the screens tested to date approach that value for subyearling chinook or sockeye, both of which are in the neighborhood of 50%, Table 7.1. Although extended screens have demonstrated improvements over standard length screens, their FGE's for subyearlings, ranging from 4% to 63.7%, are still below criteria set for fish passage by the NPPC or NMFS in the Snake River Salmon Recovery Plan. 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 pass. Therefore, the Council's goal of 90% FGE can not be achieved universally with present technology. Further discussion of this problem is presented in Appendix C, Parts 2 and 3.

The NPPC 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 FWP, appears to be attainable. However, losses due to predation at the outfalls and in the tailraces can be substantial in some situations.

Surface collectors are the most promising devices for attaining the fish passage goals established by the council in the FWP or NMFS/NOAA in the Snake River Salmon Recovery Plan.

Current developments are moving toward surface spill and surface collection, as opposed to turbine intake screens. The attractiveness of surface spill and surface collection over standard spill comes from the possibility of passing a high percentage of the smolts in a smaller volume of water by taking advantage of the natural behavior of the fish (Office of Technology Assessment., p. 130). Modification of ice and trash sluiceways offers a potentially effective means of providing a surface exit for smolts.

Table 7.1. Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

- The Fish and Wildlife Program of the Northwest Power Planning Council sets a Standard of 90% FGE for Turbine Intake Bypass Systems. Sources: NPPC (1994) {COE Salmon Passage Notes 1992; FERC orders and agreements of the parties; Progress Reports mid-Columbia Studies. Data for Rocky Reach and Rock Island dams, personal communication C. Peven, Chelan County P.U.D.}

PROJECT	FGE	NOTES
Mid-Columbia Projects.		
Wells (Fully equipped)	89%	Skalski, (1993). Spring and Summer. Surface attraction device. Hydroacoustic estimate provides no species separation.
Rocky Reach	30.8% 38.9%;	Combined species. Highest achieved for yearling chinook for subyearling chinook 21.9%; for steelhead 40.2%; and sockeye 24.1%. None of the prototype screens tested 1985-1992 and 1994 met criteria. Surface collector device being evaluated, 1995.
Rock Island		
Second Powerhouse	-	Prototype screens tested at Powerhouse No. 2 determined to be unfeasible.
First Powerhouse (1994)	85.7%	Yearling chinook
	29.6%	Subyearling chinook during the spring emigration
	63.7%	Subyearling Chinook during the summer
	60.9%	Steelhead
	64.4%	Sockeye

Table 7.1 (continued). Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

PROJECT	FGE	NOTES
Wanapum	75%	Yearling chinook in 1992
	50%	Subyearling chinook in 1992
	26%	Sockeye, Hammond (1991)
Priest Rapids	84%	Average for chinook yearlings
	52%	Average for sockeye,
	76-90%	Range for steelhead, Hammond (1991).
SNAKE RIVER PROJECTS		
Lower Granite		
(Standard STS)	57.3%	Yearling chinook (Swan et al., 1990)**
	77.3%	Steelhead (Swan et al., 1990)
(Extended Screen - Simulated)		
	66%	Yearling chinook (Swan et al., 1990)
	82.4%	Steelhead (Swan et al., 1990)
Little Goose		
(Standard STS)	73%	Yearling chinook - with raised gate (Swan et al., 1986)
(Extended Screen)	77.3%	Yearling chinook (Gessel et al., 1995)
	89.6%	Steelhead (Gessel et al., 1995)

Table 7.1 (continued). Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

PROJECT	FGE	NOTES
Lower Monumental	69%	Yearling chinook (Gessel et al., 1993)
	85.3%	Steelhead (Gessel et al., 1993)
	35.2%	Subyearling chinook (Ledgerwood et al., 1987)
Ice Harbor	78%	Yearling chinook (Brege et al., 1988)
	92%	Steelhead (Brege et al., 1988)
LOWER COLUMBIA RIVER PROJECTS		
McNary		
(Standard STS)	83%	Yearling chinook (Krcma et al., 1982)
	76%	Steelhead (Krcma et al., 1982)
	34-46%	Sub yearling chinook {Swan et al, 1984}
(Extended STS)		
	88%	Yearling chinook (McComas et al., 1994)
	67%	Sub yearling chinook (McComas et al., 1994)
	93%	Steelhead (McComas et al., 1994)
	73%	Sockeye (McComas et al., 1994)
	98%	Coho (McComas et al., 1994)

Table 7.1 (continued). Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

PROJECT	FGE	NOTES
John Day	75%	Yearling chinook {Swan et al, 1982}
(Tests of John Day configuration conducted at McNary Dam)		
	79%	Steelhead {Swan et al, 1982}. (Tests at McNary Dam)
	88%	Yearling chinook (Krcma et al., 1983). (Tests at McNary)
	87%	Steelhead (Krcma et al., 1983) (Tests at McNary Dam)
	72%	Yearling chinook (Krcma et al., 1985; Brege et al., 1992)
		Test at John Day Dam)
	20%	Subyearling chinook (Krcma et al., 1985; Krcma et al., 1986)
		(Test at John Day Dam)
	35%	Subyearling chinook (Brege et al., 1987; Brege et al., 1988)
	41%	Sockeye (Krcma et al., 1986; Brege et al., 1992)
	86%	Steelhead (Krcma et al., 1986)
The Dalles		
Standard STS	44-56%	Yearling chinook (Krcma, 1985)
	71-80%	Steelhead (Krcma, 1985)
	40-60%	Sockeye (Monk et al., 1987)
(Extended-length screens)		
	69%	Yearling chinook (Absolon et al., 1995)
	54%	Subyearling chinook (Absolon et al, 1995)
	83%	Steelhead (Brege et al., 1994)

Table 7.1 (continued). Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

PROJECT	FGE	NOTES
The Dalles continued		
	53%	Sockeye (Brege et al., 1994)
	93%	Coho (Brege et al., 1994)
	Scheduled for installation in 1998	
Bonneville		
Powerhouse number 1 (1981)		
	76%	Yearling chinook (Krcma et al., 1982)
	72%	Subyearling chinook (Krcma et al., 1982)
	Measurements following modification of navigation channel	
	21%	Yearling chinook (Krcma et al., 1984)
	24%	Subyearling chinook (Krcma et al., 1984)
	14%	Sockeye (Krcma et al., 1984)
	34%	Steelhead (Krcma et al., 1984)
	26-44%	Yearling chinook (Krcma and al., 1984)
	20-32%	Subyearling chinook (Krcma and al., 1984)
Powerhouse number 2		
	32-46%	Yearling chinook (Monk et al., 1992)
	11%	Subyearling chinook (Gessel et al., 1989)
	4%	Subyearling chinook (Gessel et al., 1990).
	Measurements following full installation of turbine intake extensions	
	36-57%	Yearling chinook (Monk et al., 1995)
	23-42	Subyearling chinook {Monk et al, 1994}

Table 7.1 (continued). Fish guidance efficiency measured at Columbia basin projects. Most recent data.*

Bonneville Dam is below criteria. NPPC calls for shutdown of second powerhouse and provision of spill during smolt migration.

- Because over the years improvements have been made in configurations of screens at the projects, early measurements in most cases are mostly of historic interest and do not apply to the existing bypass systems. Some historic information from Bonneville Dam is provided as an example, showing improvement in FGE as turbine intake extensions were provided and flows around the screen were modified in other ways.

- ** Park et al, (1978) measured FGE (actually recovery rate) at Lower Granite Dam by releasing marked fish at the mouth and near the top of the turbine intake in front of the screen, then measured the rate of recovery in the gatewell. While adequate for the purpose of that study, to evaluate relative effectiveness of various screen configurations and deployment angles, the estimates are probably not representative of fish freely migrating downstream. In 12 tests, recovery rates of the marked chinook “fingerlings” ranged from 48 to 90%, depending upon screen angle and porosity of the perforated plate in the intake bulkead slot, and the angle at which the screen was deployed. Similar tests in 1977 had shown lower recovery rates (46% to 87%), as experience was being gained with screen angles and various perforated plates, (Park et al., 1977).

D. Gas Bubble Trauma

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 Chapter 7 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). Survival of spilled fish has been measured at 98-100% compared to about 85% for turbine passage. Thus, use of spill has been recommended by state fisheries agencies, the Tribes, the Federal Energy Regulatory Commission, and the Council's Program. A spill management program for benefit of juvenile salmon has been in effect at non-federal dams in the mid-Columbia since the mid 1980s and in 1994-95 in the federal hydropower system in the Snake and lower Columbia rivers. 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 very 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 the 1994 Fish and Wildlife Program. The introduction to Chapter 6, Juvenile Salmon Migration, 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% 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).

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) and {Boyer 1974}. 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%, 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% 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 et al. 1975; Dawley and Ebel 1975; Fickeisen and Schneider 1975; Fidler and Miller 1994} (Bouck, 1980; Weitkamp and Katz, 1980). 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% can cause eventual direct mortality {NAS-NAE 1973; USEPA 1986}. There are additional concerns that sublethal exposures (either to gas saturation levels below 110% 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 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 (see Section 7C above, on dam passage). Because spill itself inflicts <2% mortality to downstream migrants at a dam compared to 10-15% mortality during turbine passage, spill has seemed to be a relatively benign route of dam passage {Fish Passage Center 1995}. 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, however.

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 U. S. Army Corps of Engineers has monitored levels of total dissolved gas saturation at near-surface monitoring stations downstream of dams for many years (Engineers, 1993) {Ruffing et al. 1995} 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 {**S**molt Monitoring Program 1995; McCann 1995}. An expert panel convened by the National Marine Fisheries Service has given advice on gas bubble disease and monitoring of clinical signs {Coutant et al. 1994, 1995, 1996 draft}. 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 recommended that monitoring for signs be augmented by estimates of in-river survival ("reach survival estimates," now possible with PIT-tag technology; Coutant et al. 1994), field research to obtain such estimates is still being developed (Muir et al., 1995). 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% saturation during controlled spill (the maximum physical criteria) but up to about 140% during uncontrolled spill (such as below Ice Harbor Dam in 1995). 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% 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 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 {Coutant et al. 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 bullets 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.

Gas bubble disease in laboratory fish

- 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; reviews by (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% saturation, but that debilitating trauma does not usually appear until about 110%. 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 (Chapter 6), saturation levels {Ruffing et al. 1996}, and temperatures (Chapter 5). 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. If so, then data on their normal behavior without supersaturation may not be relevant to estimating exposures.

Alternatively, life-stage-specific behavioral patterns (such as feeding by subyearlings in shallow waters on a daily cycle during emigration) may ensure some exposure to elevated gas saturations. 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 are not known. More field research is needed to understand what happens in the real world, but it may be long-term. 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 **{Coutant et al. 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 1995; Coutant et al. 1996}. The most critical assumptions are that :

(a) signs are not altered in passage through the fish bypass, consisting of a sequence of holding in dam forebay, descent to the turbine intake, screening, ascent in the gatewell, passage through pipes or troughs, separation from water flows in the Smolt Monitoring Program's separator, and holding before examination, evidence from simulator tests suggests that it does; {Montgomery and Watson 1995};

(b) fish at the dam bypasses are representative of fish in the river-reservoir system. Sampling at McNary Dam appears to under sample juveniles of Snake River origin (Coutant et al. 1996);

(c) there is no significant mortality between sample sites (i.e., the dam-sampled fish do not just represent the survivors after direct mortality, predation, etc.);

(d) the relationship between monitored signs and survival is known; and

(e) the dam bypasses represent adequately the highest risk reaches where the most damage may occur.

- 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 (Coutant et al. 1996). If the survival benefit from using spill is small, say 5-7% system wide, as suggested by the National Marine Fisheries Service's analyses of transportation (this chapter), 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.

- There may be early-detection methods for identifying the development of bubbles in fish that could be used to signal a potential problem in the river, but these have not yet been developed. Optical (reflectance or transmission of light) and acoustic (passing sound waves through fish) methods are examples of "high tech" approaches that might be fruitful for the monitoring program {Coutant et al. 1995}. Such techniques could avoid mortalities from excessive handling or dissection of fish. It may take considerable research to develop these techniques.

- Sampling of fish from the river (through nets, traps, etc.) may provide a more representative sample of riverine fish, and can be directed toward high-risk sites, but collecting fish in a large river-reservoir system is arduous, examinations on a boat are difficult, and there are untested sampling assumptions such as there being no gear selectivity for debilitated fish. Gear selection for debilitated fish could skew the results toward high incidence of signs.

- Biological monitoring of signs in fish as a means for managing spills requires an agreed-upon criterion for action (e.g., cessation of spill when the incidence of signs becomes too high). The relationship between signs and survival is inadequately known to substantiate the current 15% incidence criterion for juveniles and 0% incidence criterion for adults, or any alternative criteria.

- 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% 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 (1995). 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 }Coutant et al. 1996}.

Risk management

- Gas bubble disease is but one consideration among many for management of flow and fish passage in the Columbia and Snake rivers to minimize mortality. Risk management among the many sources of biological damage is important and it depends on having reasonably complete understanding of each source of mortality, including gas bubble disease. A recent risk analysis concluded that the risk of fish loss from gas supersaturation caused by managed spills was less than that expected from turbine passage and other damages (Center, 1995). This analysis, although extensive, has been criticized as not being sufficiently comprehensive.

Reduction in total dissolved gas saturation

- Realizing that the debate over adequacy of relevant biological knowledge from research or monitoring is unlikely to end soon, and entail extensive and expensive 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.

CONCLUSIONS (AND LEVEL OF PROOF) FOR GAS BUBBLE DISEASE

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 development of bubbles and associated mortalities differs between long exposures to low saturation values and short exposures to high values. 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 (e.g., fish can descend in the water to compensate with water pressure, supersaturation values differ across and down the river as fish migrate) and these variable exposures are not easily related to laboratory dose-response experiments (which have generally not sought to mimic field exposure histories), 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 (usually underestimate effects) because of changes in signs in bypasses, loss of debilitated fish in reservoirs between dams, and other untested critical assumptions. (2)

5. Managed spill, used as a means of passing fish at dams with low mortality, can induce supersaturation, as can uncontrolled spill caused by excess runoff. 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. Spill, unless supplanted by surface fish bypasses (this chapter), is the passage route that most closely approximates juvenile passage in the normative river, and thus should be the closest match to the normal behavior patterns of migrants. (1)

7. 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)

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.

CRITICAL UNCERTAINTIES FOR GAS BUBBLE DISEASE

1. Relationships of signs of gas bubble trauma to fish mortality.
2. Exposure histories of in-river fish to supersaturated conditions in a river-reservoir environment of varying total dissolved gas supersaturation, depth of migration, and temperature.
3. Unsubstantiated assumptions behind the monitoring of signs at dam bypass monitoring stations.
4. Ability to monitor in-river fish for signs or survival.
5. Relative risks and benefits of spill compared to other means of dam passage.

RECOMMENDATIONS FOR GAS BUBBLE DISEASE

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. Unless data can be collected inexpensively in conjuction with an integrated program of mainstem monitoring, much research would be necessary, likely beyond our capacity. Spill has a demonstrated lower level of fish mortality at dams than turbine passage and it more closely approximates the normative river system to which migrant behavior has evolved than either passage through turbines or gatewell fish bypasses. 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.

E. EFFICACY OF TRANSPORTATION

Transportation of juvenile salmon down river in barges and trucks is one of the techniques employed in the 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 reservoirs 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 7.1). Fish are collected out of the turbine intake bypass system (Figure 7.4). Screens at the intake divert fish into collection channels (bypass flume, Figure 7.4) that take the fish through the dams. At some of the projects there are facilities where fish can either be removed for transportation or allowed to continue down the river. Effectiveness in collecting fish for transportation therefore depends on the fish guidance efficiency of the intake screens (FGE), which varies among projects according to flow, species and life history type, among other factors. 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 (see preceding sections of this chapter). In any event,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 state of maturity within a life history type, and with respect to 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 (Figure 2.6). 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 general experimental approach is to collect actively migrating juveniles at one or more upstream dams, divide a portion of the fish collected into transported and untransported (control) groups, mark fish in each group with distinctive freeze brands and coded wire tags, and then either transport the fish around the remaining dams or return them to the river to continue their downstream journey. The experimental fish rejoin the unmarked population and 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, 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 adults under the assumption that the probability of recapture is the same for all marked fish.

For each transport-control group, the rate of return (R_T or R_C, the subscript denoting the experimental treatment) is defined as the observed number of marked adults (n_T, n_C) in a sample divided by the number of juveniles originally marked and released (N_T, N_C). A Transport/Control (T/C) ratio (or the equivalent Transport Benefit Ratio (TBR) is calculated as R_T / R_C. T/C ratios are determined either for a paired Transport/Control subsample (i.e., a within-season replicate) or, more commonly, for all Transport/Control fish marked at a given site over one season. An "annual" T/C 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.

Transportation appears to have increased the survival of fish to the point of release in about half of the experiments conducted during 1968-1990 (Table 7.2).

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 hydroelectric system survival for untransported juveniles were not made, nor were estimates of survival to release for transported juveniles 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), 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. Since much of the research by NMFS has been focused on the ability of transportation to increase the rate of return of adults to the point of release[i] that were transported as juveniles, compared to the rate of return to the point of release of adults not transported as juveniles,

the NMFS defines the effect of transportation as a change in the relative rate of adult return to the point of release between transported and untransported juveniles. Hence the null hypothesis is that there is no difference in rate of adult return to the point of release (see footnote 1) between transported and untransported juveniles.

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 (see footnote, Chapter 1 of this report), 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 {FWS Technical Staff 1993}, such as the ability of transported fish to find their way back to their natal spawning grounds.

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. (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. Park (1985) observed that transported fish tended to spend more time than untransported fish in the lower river as adults.

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 {FWS Technical Staff 1993}. 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 (Northwest Power Planning Council, 1992) {DFOP 1993}.

Does transportation reduce mortality and result in greater returns?

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 clearly 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. 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, and sometimes negative, in conjunction with overall higher survivals for both transported and untransported salmon. In order to understand the 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.

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 flow conditions, it removes only part of the mortalities attendant to passage through the hydroelectric system.

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. Hence, 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.

Research results to date are not conclusive regarding the ability of transportation to improve returns to the spawning grounds due to problems associated with experimental design and lack of wild fish. In the Snake River, relative survivals have been measured by returns of adults back to the point of transportation, so the research conclusions do not apply in terms of actual returns to upriver locations such as the spawning grounds.

Stock specific information on the effects of transportation is not at hand. The number of experimental fish does not permit evaluation of the effects of transportation for particular stocks of salmon originating from individual hatcheries and watersheds.

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 lesser degree the yearling-migrant stream type chinook salmon designated as "spring/summer chinook" by the National Marine Fisheries Service. With respect to Snake Basin fall (subyearling emigrant, ocean type) chinook, the time sequenced progression of fish quality and state of maturation may not be conducive to transportation from a locality such as Lower Granite Dam. 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.

Since information collected on fall chinook and sockeye salmon in places outside the Snake River Basin may not be applicable inside that basin, there is insufficient information to determine how transportation may affect the survivals of these two federally listed species.

Conclusions

1. Evidence exists that for certain life history types of certain species that transportation can provide increases in survival measured in terms of adult returns to the point where tagged smolts were released.

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

3. Transportation is stock (life history) selective and may be unnecessary under normative river conditions where all life history types and species would benefit, rather than just those with biological characteristics which lend themselves to transport.

4. In specific instances where normative river conditions cannot be restored, transporation may have a role in smolt migration.

Table 7.2. Percentage of yearling chinook returning as adults after having been either transported or released as controls from dams on the Snake River as yearling juvenile salmon during the emigration seasons of 1968 - 1990, and the ratio of transport to control, T/C. Data and commentary provided by Dr. John Williams, Coastal Zone and Estuarine Studies Division, NMFS, January 6, 1995.

			Percent return			NMFS
Species	Dam	Year	Trans	Contr	T/C	comments
Yr. Chin	IHR	1968	0.30	0.15	2.1*	
Yr. Chin	IHR	1968	0.16	0.15	1.1	A.
Yr. Chin	IHR	1969	0.24	0.19	1.3*	
Yr. Chin	IHR	1969	0.13	0.19	0.7	A.
Yr. Chin	IHR	1970	0.29	0.20	1.5*	
Yr. Chin	IHR	1970	0.07	0.20	0.4	A.
Yr. Chin	LGO	1971	0.38	0.25	1.6*	
Yr. Chin	LGO	1971	0.42	0.25	1.7*	B.
Yr. Chin	LGO	1972	0.08	0.08	1.1	
Yr. Chin	LGO	1972	0.09	0.08	1.1	B.
Yr. Chin	LGO	1973	0.31	0.02	13.8*	
Yr. Chin	LGO	1973	0.42	0.02	18.4*	B.
Yr. Chin	LGO	1976	0.04	0.02	1.8	C.
Yr. Chin	LGO	1976	0.03	0.02	1.2	C.; D.
Yr. Chin	LGO	1976	0.02	0.03	0.9	E.; D.
Yr. Chin	LGO	1976	0.03	0.01	3.9	D.; F.
Yr. Chin	LGO	1976	0.03	0.03	1.0	E.
Yr. Chin	LGO	1976	0.05	0.01	6.1	F.
Yr. Chin	LGO	1978	0.01	0.01	0.7	
Yr. Chin	LGO	1978	0.00	0.01	0.2	
Yr. Chin	LGR	1975	0.64	0.31	2.0*	
Yr. Chin	LGR	1976	0.02	0.04	0.6	C.
Yr. Chin	LGR	1976	0.04	0.04	1.0	C.; D.
Yr. Chin	LGR	1976	0.03	0.04	0.8	E.; D.
Yr. Chin	LGR	1976	0.08	0.04	2.1	D.; F.
Yr. Chin	LGR	1976	0.02	0.04	0.4	E.

Table 7.2. continued.

Species	Dam	Year	Percent return Trans	Contr	T/C	NMFS comments
Yr. Chin	LGR	1976	0.04	0.04	1.0	F.
Yr. Chin	LGR	1977	13 total returns to all recovery sites from transported fish --- no controls recovered			
Yr. Chin	LGR	1978	0.12	0.01	8.5*	Barge
Yr. Chin	LGR	1978	0.07	0.01	5.3*	Truck
Yr. Chin	LGR	1979	0.04	0.01	3.4*	Barge
Yr. Chin	LGR	1980	none	none	---	
Yr. Chin	LGR	1980	0.00	none	---	
Yr. Chin	LGR	1983	0.28	no controls released		
Yr. Chin	LGR	1984	0.16	no controls released		
Yr. Chin	LGR	1985	0.22	no controls released		
Yr. Chin	LGR	1986	0.16	0.10	1.6*	
Yr. Chin	LGR	1987	0.18	no controls released		
Yr. Chin	LGR	1989	0.06	0.02	2.4*	
Yr. Chin	LGR	1990	0.37	no controls released		

* Statistically significant difference between adult return rates of transported versus inriver migrants.

IHR is Ice Harbor Dam; LGO is Little Goose Dam; and LGR is Lower Granite Dam.

A. Released transported fish at John Day Dam. These fish had much lower return rates than transported fish released below Bonneville Dam. It is highly unlikely that the difference was due to mortalities between John Day Dam and Bonneville Dam as control fish which transited the same area had overall return rates equal to the transported fish.

B. Fish released at Dalton Point rather than the normal release site into the tailrace of Bonneville Dam downstream from the frontroll.

C. These numbers represent data that was combine from releases made at the Washington shore boat launch in April with releases at the normal Bonneville Dam tailrace release site in May and June.

D. These fish were hauled in a 10ppt salt-water solution. The solution was made by adding normal table salt to the water in the tank truck. This is not a procedure in use at this time.

E. Releases were made at the Washington shore boat launch in April. Because of wave action and the location of the ramp, the release hose did not go very far into the tailrace. Fish were washed up on the shore as they were released. (The same thing occurred with the 1987 releases for the Bonneville II survival studies.)

F. These were releases from fish marked in May and June only.

F. PREDATORS AND PREDATOR CONTROL

Predation by other fish species and birds, especially gulls on the mainstem, is a well documented source of mortality for emigrant juvenile salmon in the Columbia River Basin {Ruggerone and Mathews 1984}. 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 1993}. 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 to increase survivals of emigrants which is now underway in the Columbia River Basin was extensively discussed over a two year period 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 in 1988 and 1989 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; see Poe and Rieman {1988}**;** (Collis et al., 1995)), as well as by prior research, i.e., 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 Squawfish *Ptychocheilus oregonensis* (hereafter NSF) was chosen to be the object of control as one of the best known predators on juvenile salmonids. NSF was the target of the program not only because research indicated it to be responsible for the majority of predation on juvenile salmonids in the reservoir behind John Day Dam {Poe and Rieman 1988}, but also because other predators were the objects of sports harvesting effort, while NSF 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 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 NSF advantages in reproduction and opportunities for predation on juvenile salmonids which did not exist 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 NSF to juvenile salmon in the hydroelectric system, as well as more traditional means of removal by fishing and other lethal means {see Poe et al. 1988**}**. Modeling studies indicated that annual exploitation of NSF of approximately 15% could reduce the losses of juvenile salmonids by as much as half {Rieman and Beamesderfer 1988}. The control program was also seen by the Working Group not as a short term effort to eradicate NSF, 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 NSF age structure might be altered without substantially diminishing the reproductive capacity of the population. With sustained NSF reproduction, other species of predators, which normally target juvenile NSF, would not be forced to switch to juvenile salmonids by declining availability of NSF juveniles.

The Working Group also discussed the need to reduce populations of NSF in the immediate vicinity of the hydroelectric dams. Very large NSF 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 {see Young 1996}. The pilot approaches to reduction of NSF 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 NSF 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 NSF as of 1995. Angling by all means is estimated to have reduced predaceous populations of NSF to levels which should provide a 36% reduction in potential predation on juvenile salmonids by NSF in 1996, as measured relative to the time period prior to 1990. Reductions in NSF populations are not uniformly geographically distributed, with some areas showing decreases, while others do not.

Northern Squawfish 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 numbers of Northern Squawfish available to angling 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. Annual catches and catch per unit effort by technicians angling below Snake and Columbia River dams have declined by about 80% 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 squawfish 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 squawfish are now experiencing the higher feeding rates available at the dams, it is possible that the program has been instrumental in lowering the rate of NSF predation, which would have otherwise been experienced by the juvenile salmon. The extent to which the predator control program may have changed the total annual rate of predation by all piscivorous species in the hydroelectric system is not known.

CONCLUSIONS FOR PREDATORS AND PREDATOR CONTROL

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

2. Rates of predation by NSF 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 NSF 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 NSF 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 squawfish of predaceous size in the vicinities of the dams where the higher feeding rates are experienced. The overall rate of predation of squawfish on juvenile salmon has been lowered since 1990. (3)

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 NSF and other predators, since spill appears to reduce the total amount of habitat suitable for piscivorous Northern Squawfish 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 NSF, 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)

GENERAL 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 squawfish 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 squawfish 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 NSF on juvenile salmon.

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[i] Unlike steelhead, *Oncorhynchus mykiss*, and spring chinook, *O. tshawytscha*, approximately half of the fall chinook salmon, *O. tshawytscha*, are harvested before they have the opportunity to return to the point of release. In the case of fall chinook, the effects are measured as the relative rates of tag recoveries from transported and untransported juveniles. Fall chinook are transported almost entirely from McNary Dam, having originated from the area below Priest Rapids Dam.