Idaho Water Users Association, Inc.

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410 SOUTH ORCHARD, SUITE 144
BOISE, IDAHO 83705
208-344-6690 – OFFICE
208-344-2744 – FAX
iwua@rmci.net – E-MAIL

TO: Interested Parties

FROM: Sherl L. Chapman, Executive Director

DATE: March 23, 2000

SUBJECT: WATER USER COMMENTS ON THE NMFS ALL-H PAPER

Enclosed you will find the comments submitted in behalf of the Committee of Nine and the Idaho Water Users Association to the National Marine Fisheries Service regarding their recent release of the so-called All H Paper. These comments are designed to provide constructive criticism on the All-H Paper in an effort to represent the concerns and positions of Idaho's water users.

If you have any comments or questions, please feel free to contact the Association office.

COMMENTS BY IDAHO WATER USERS
ON
THE DRAFT ALL-H PAPER BY THE FEDERAL CAUCUS:
CONSERVATION OF COLUMBIA BASIN FISH-
BUILDING A CONCEPTUAL RECOVERY PLAN

SUBMITTED ON BEHALF OF

THE COMMITTEE OF NINE
AND
THE IDAHO WATER USERS ASSOCIATION

MARCH 16, 2000

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Comments by Idaho Water Users on The Draft All-H Paper by the Federal Caucus: *Conservation of Columbia Basin Fish-Building a Conceptual Recovery Plan*

These comments are submitted on behalf of the Committee of Nine and the Idaho Water Users Association (hereinafter "Idaho water users"). The Committee of Nine is the official advisory committee for Water District 1, the largest water district in the State of Idaho. Water District 1 is responsible for the distribution of water among appropriators within the water district from the natural flow of the Snake River and storage from U.S. Bureau of Reclamation reservoirs on the Snake River above Milner Dam. The Committee of Nine is also a designated rental pool committee that has facilitated the rental of stored water to the Bureau of Reclamation to provide water for flow augmentation pursuant to the 1995 Biological Opinion. The Idaho Water Users Association was formed in 1938 and represents about 300 canal companies, irrigation districts, water districts, agri-business and professional organizations, municipal and public water suppliers, and others. These comments have been prepared with the assistance of the scientists, biologists, and engineers who have been retained to address Snake River ESA issues.

Synopsis of Comments

Idaho water users support salmon recovery. However, development of water resources in the Upper Snake River basin did not cause the decline of fish populations and has not resulted in the destruction or adverse modification of critical habitat. Reducing Upper Snake River water uses to provide flow augmentation will not reverse the fish population decline, recover the populations, or mitigate the adverse modification of critical habitat caused by activities in the lower Snake and Columbia Rivers. Continued calls for ever-increasing amounts of water from southern Idaho ignore the fact that there is no significant biological benefit from an option that has enormous economic and social costs.

Idaho water users agree with the overall scope and purpose of the All-H Paper. A conceptual anadromous fish recovery plan that provides context for the many proposed federal and regional ESA actions is sorely needed. However, in order to be feasible, the plan must reflect and balance the biological, physical, economic, legal, and political realities in the region. In general, the water users also agree with the All-H goals and objectives and suggest that they be set in the following priority: 1) to conserve species and habitats; 2) to balance the needs of other species including minimizing the impacts on humans; and 3) to provide tribal harvests to the extent possible.

However, Idaho water users do not agree with the inclusion of existing or additional levels of flow augmentation in the conceptual recovery plan. Upper Snake River[1] flow augmentation is not a necessary or viable component of a conceptual recovery plan because it fails to meet the goals and objectives spelled out in the All-H Paper and it does not reflect and balance the realities of the region, i.e.:

- Flow augmentation does not provide significant biological or physical benefits;
- Flow augmentation has high economic cost and impact; and
- Flow augmentation must overcome huge political and legal hurdles.

The Upper Snake River basin has supplied over 3.5 million acre-feet (MAF) of water for flow augmentation over the past 10 years. Another 15 MAF have been provided from Brownlee and Dworshak Reservoirs. In spite of the enormous volume of water that has been released for flow augmentation, there is no evidence that this added water has significantly benefited Snake River spring and summer chinook, steelhead, or sockeye populations or contributed to their survival. Studies of fall chinook survival above Lower Granite Reservoir show a relationship to migration timing, temperature, turbidity, flow, and travel time (in that order), but the relationship between flow and adult survival is not statistically or biologically significant.

[1]Throughout these comments, the Upper Snake River means the portion of the basin above Brownlee Reservoir.

The existing level of flow augmentation from the Upper Snake River (427,000 AF/yr) should be discontinued since it provides no significant benefit to listed species or their habitat and impacts will occur on water users and local resources in dry years. Likewise, an aggressive program of additional flow augmentation, such as Hydropower Option 2 (taking up to another 1 MAF out of the Upper Snake River), should be eliminated from further consideration. Such a program would have devastating impacts on southern Idaho by drying up more than 600,000 acres of productive farmland, costing over $430 M per year, causing thousands of lost jobs, and severely impacting local fisheries, wildlife habitat, recreation, and the cultural and historical resources of the Upper Snake River (USBR, 1999).

Notably, four of the Federal Caucus members (Corps of Engineers, Bureau of Reclamation, Bonneville Power Administration, and Environmental Protection Agency) recently eliminated the 1 MAF alternative from the Draft Feasibility Report and Environmental Impact Statement ("EIS") for the Lower Snake River Juvenile Salmon Migration Study for a variety of reasons: 1) insufficient biological benefits; 2) high costs and impacts; 3) numerous implementation issues; 4) legal and water supply uncertainties; 5) inadequacy of study; and 6) lack of public acceptability (U.S. Army Corps of Engineers et al., 1999; pp. 3-15 and -16, 5.16-3 and -4).

In summary, Upper Snake River flow augmentation should be eliminated from consideration as part of any recovery plan. Instead, Idaho water users support more aggressive measures with respect to other hydrosystem components, habitat options, hatchery alternatives, and harvest reductions. These measures are far more biologically effective and cost effective than flow augmentation. The Idaho water users oppose dam breaching because it is not a viable alternative when all of the biological, physical, economic, legal, and political realities are considered.

All-H Purpose, Goals and Objectives

Idaho water users agree with the purpose of the All-H Paper outlined in the prefatory Note to Readers:

> *"The final paper, to be produced after a public comment period on this draft, will provide a conceptual anadromous fish recovery plan that provides context and linkages for other federal [and] regional efforts and actions within the four Hs (habitat, harvest, hatcheries and hydropower). It will also describe opportunities and relationships for restoration and recovery of listed resident fish and aquatic species."*

Idaho water users also agree with the general goals and objectives of the paper outlined on pages 23 and 24. However, the goals should be prioritized to help focus the difficult decisions that face the region. In order to reflect the overriding importance of actions needed under the ESA, the conservation of listed species and their habitats should have the highest priority. Balancing the needs of other species, including humans, should be the next priority to ensure that additional species do not become threatened or endangered as a result of actions to protect already-listed species. The minimization of adverse effects on humans should also be at this level of priority in order to reflect the political realities of efforts to recover listed species. Finally, assurance of tribal fish harvest should be given priority. Tribal harvest is listed as the lowest priority among these goals, not because it is unimportant, but because tribal harvest may have to be further limited or modified in the short-run in order to conserve and recover the species, especially with respect to fall chinook. As a semantic matter, the goal should be to assure tribal fish "harvest" not "rights" because tribal fishing rights (the rights to take fish in common with other citizens at usual and accustomed places) are assured by law and the objectives are:

1. *To manage fisheries in a manner that prevents overharvest and contributes to recovery;*
2. *To provide fishing opportunities* [higher harvests] *in a manner that comports with trust obligations to the tribes and complies with sustainable fisheries objectives to all citizens* (Federal Caucus, 1999, p. 48).

Principles and Tools

Idaho water users generally agree with the scientific principles listed on page 24 with one exception – technology and research should be used to achieve the best possible conditions for fish, not simply to "achieve natural ecosystem functions." In some instances, such as hydrosystem improvements (e.g., transportation or dam modifications), it is impossible to achieve "natural" conditions. However, these are areas where additional research and technology may be very beneficial.

Habitat Options

Idaho water users generally agree with Habitat Option 2 to the extent that actions are limited to areas that directly affect habitat for listed species. The final All-H Paper should clearly confine the scope of the habitat options to those areas that directly affect habitat. Inclusion of actions for areas outside of directly affected habitat will not provide significant benefits to the listed species but will result in strong legal and political opposition to the recovery plan. For example, the Upper Snake River basin should not be further regulated under the Clean Water Act in the name of salmon recovery. As to the two attributes of primary concern to downstream fish, changes in temperature and turbidity through and below Brownlee Reservoir and Hells Canyon overshadow any upstream water quality modifications. Thus, the Upper Snake River should be excluded from the geographic scope of the habitat options being considered in the recovery plan.

As discussed at length below, development of the Upper Snake did not contribute to the decline of the listed populations. It is not necessary to use Upper Snake River flow augmentation to "*mimic natural hydrographs*" with respect to the mainstem (Federal Caucus, 1999, p. 33) because upstream water use has not significantly altered the natural hydrograph.

Predator Control

The All-H Paper should include aggressive predator control programs in the suite of recovery measures as part of the habitat or hydropower options. An enormous number of salmonid smolts are consumed each year by predators. Predators include other fish, marine animals, and birds.

Northern pikeminnow (formerly northern squawfish) alone consume an estimated 16.4 million smolts annually (NMFS, 1999d, p. 14). The Predator Control Program has reduced predation by northern pikeminnow by an estimated 13 percent (Id., p. 15). Additional reductions in pikeminnow predation are "*probable*" (Id.).

Smallmouth bass, walleye, channel catfish, Pacific lamprey, yellow perch, largemouth bass, northern pike, and bull trout also prey on salmonid smolts (Id., pp. 18-31). Consumption of smolts by these fish species is significant but has not been studied as thoroughly as pikeminnow predation (Id.). The annual loss from these other fish predators is estimated to be in the hundreds of thousands or more (Id.). However, a predator control program for these species has not been implemented (Id., pp. 34, 35).

Avian predators such as Caspian terns, double-crested cormorants, and gulls consume millions of smolts each year (NMFS, 1999d, pp. 37-42). It is estimated that 10 to 30 percent (100,000 to 600,000) of ESA-listed smolts reaching the Columbia River estuary are consumed by predatory birds (Id., p 39). Although preliminary attempts at reducing predation by these avian predators have begun, much more can and should be done.

Although the total impact has not been determined yet, marine mammals injure and consume large numbers of salmon and steelhead (Id., pp 43-46). Importantly, marine mammal predation occurs on adults as well as juveniles (Id.). Protection of adults returning to spawn — fish that have survived the gauntlet of mortality in previous life stages — is obviously important to the recovery of threatened and endangered populations. Like avian predators, a reduction in marine mammal predation should be aggressively pursued.

Harvest Options

Idaho water users strongly support aggressive harvest strategies, options, and actions, i.e., Option 3, especially with respect to fall chinook. It is hard to think of a more perverse policy than to allow the harvest of substantial numbers of listed fish, particularly as they come upriver to spawn. These adults that are killed on their way upstream have survived the life stages with the two largest components of mortality — incubation/rearing and ocean feeding — only to be taken a short time before spawning.

Minimizing harvest is extremely cost-effective relative to the enormous investments and tremendous uncertainties associated with the hydropower (flow augmentation or breaching), habitat and hatchery options.

With respect to tribal fisheries, Idaho water users strongly support pursuit of "additional tributary and other selective harvest opportunities for tribes" (Federal Caucus, 1999, p. 51). We also agree that "selective fishing gear is a promising tool" (Id.).

A substantial number of salmonids continue to be harvested in the ocean and the mainstem Snake and Columbia Rivers. In-river harvest rates for Snake River spring/summer chinook have ranged from 3 to 8 percent in recent years (Marmorek et al., 1998, p. 14). Snake River fall chinook are subjected to heavy fishing pressure (NRC, 1995, p. 82; Marmorek et al., 1999, p. 15). Table 1 shows combined ocean and river harvest rates of up to 75 percent for fall chinook (Peters et al., 1999, p. 71; see also NRC, 1995, pp. 81, 82).

Table 1. Fall chinook exploitation (harvest).

Run Year	Mainstem (Columbia and Snake Rivers) Exploitation Rate		Ocean Exploitation Rate by Age				
	Jack	Adult	2	3	4	5	6
1986	0.055	0.469	0.015	0.106	0.170	0.169	0.303
1987	0.037	0.560	0.037	0.156	0.140	0.159	0.169
1988	0.046	0.524	0.027	0.060	0.288	0.172	0.159
1989	0.026	0.432	0.038	0.151	0.233	0.227	0.172
1990	0.028	0.452	0.042	0.059	0.271	0.252	0.227
1991	0.044	0.276	0.026	0.051	0.138	0.212	0.252
1992	0.051	0.166	0.020	0.095	0.242	0.204	0.212
1993	0.050	0.254	0.006	0.079	0.244	0.204	0.204
1994	0.033	0.155	0.015	0.014	0.229	0.204	0.204
1995	0.025	0.115	0.016	0.047	0.074	0.169	0.204
1996	0.039	0.171		0.046	0.000	0.158	0.169
Mean	0.039	0.325	0.024	0.079	0.184	0.194	0.207
Min	0.025	0.115	0.006	0.014	0.000	0.158	0.159
Max	0.055	0.560	0.042	0.156	0.288	0.252	0.303

Not surprisingly, reduced harvest rates can improve the probability of recovery for fall chinook by 100 percent or more (Peters et al., 1999, pp. 197, 198).

Hatchery Options

Idaho water users support the aggressive hatchery option (Option 3). Expanding conservation programs while reducing mitigation programs helps to ensure that the potential adverse impacts of mitigation programs (such as exceedance of carrying capacity) do not reduce the possible benefits of hatchery conservation programs.

Hydropower Options

As discussed below, the Idaho water users oppose flow augmentation from the Upper Snake River. However, Idaho water users support pursuit of the other aggressive hydropower options included in Option 2. Moreover, improved transportation should be considered as an additional management measure. Many studies have shown that the smolt-to-adult return (SAR) of transported fish is higher than the SAR of in-river migrants (NMFS, 1999e). Also, there may be opportunities to further improve transportation success such as with the use of towed net pens (McNeil et al., 1991). Further transportation research and improvements should be a part of any recovery plan.

In contrast to their support for other measures, Idaho water users strongly oppose continuation of existing levels of Upper Snake River flow augmentation or providing additional water from southern Idaho for such purposes. Flow augmentation is not a reasonable action to conserve or recover listed anadromous fish given that: 1) there are no significant biological benefits; 2) the water supply from the Upper Snake River has not changed and is insufficient to meet the flow targets; 3) there are enormous socioeconomic impacts from flow augmentation; 4) the MAF Alternative has been rejected by the Corps, Reclamation, BPA and the EPA in the Lower Snake Juvenile Migration EIS; and 5) there are numerous legal and institutional barriers to continued flow augmentation from Idaho, let alone additional augmentation. Recent research has not found substantial correlations, especially within years, between flow and 1) subyearling travel time or 2) yearling and subyearling juvenile survival through the impounded sections of the lower Snake River.

Moreover, recent research indicates that significant correlations between flow and yearling travel time through the reservoirs is flawed. With respect to fall chinook, date of migration, temperature and turbidity are all better predictors of survival than flow. Moreover, flow augmentation does not significantly affect these other variables (see Attachment 3, *The Effects of Flow Augmentation on Snake River Fall Chinook*). Finally, variation in flow is not statistically or biologically significant to fall chinook survival when the entire life history is considered.

RATIONALE FOR OPPOSITION TO UPPER SNAKE RIVER FLOW AUGMENTATION

Introduction

Flow augmentation has been suggested as a measure to help recover listed Snake River salmon and steelhead. The rationale for flow augmentation ranges from using augmentation water to "flush" juvenile fish through the reservoirs on the lower Snake and Columbia Rivers, to providing additional flow to operate the fish collection facilities more efficiently so greater numbers of fish will be transported, to using augmentation water for temperature control, to providing improved conditions in the estuary. However, despite years of research and experimentation, there is no evidence that Upper Snake River diversions of water caused the decline of anadromous fish populations or that flow augmentation provides significant biological benefits to any listed species.

The Hydropower Appendix to the All-H Paper (pp. 6-8) relies heavily on the subjective statements in the draft White Paper to support flow augmentation while ignoring or downplaying scientific evidence that there is no significant biological benefit from existing or proposed levels of additional flow. The premises of flow augmentation in the All-H Paper are set forth in the Hydropower Appendix (pp. 7, 8):

1. *"Flow augmentation from storage reservoirs is intended to reduce the fishes' travel time to more closely approximate that of pre-dam conditions. The hypothesis is that increased water velocities resulting from higher flow rates will decrease juvenile fish travel time, resulting in reduced freshwater residence and earlier arrival at the estuary."*
2. *"Research has shown that there is a strong relationship between river flow and fish travel time for spring migrants (e.g., yearling chinook*

and steelhead). Generally, spring migrants' rate of travel increases with increasing flow and increased smoltification."

3. There is a strong relationship between flow and survival for summer migrants (fall chinook) above Lower Granite Dam.

Each of these premises and conclusions are addressed in the following sections of these comments. The first premise is addressed in the next section, Hydrology of the Upper Snake River. The other two premises are addressed in the Biology of Upper Snake River Flow Augmentation section.

Hydrology of the Upper Snake River

Overview

Water is the backbone of Idaho's economy. Beginning in 1836 on the Nez Perce Reservation, irrigation expanded to encompass about 1.5 million acres in 1909 (Arrington, 1986; U.S. Census, 1910). Surface and ground water sources in the Snake River basin in Idaho now irrigate over 3 million acres (IWRB, 1996). Continued development of irrigation in the first half of the 20th century was possible principally through storage facilities constructed by the United States. About 6.5 MAF of storage space is available for use in the Snake River basin in Idaho as a result of federal projects (USBR, 1998). This storage is of sufficient size that water can be carried over from year-to-year, yet storage is already inadequate to supply all water uses after a series of dry years. Irrigation from wells increased significantly from the 1950s through the 1970s but has leveled off at about 1 million acres (IWRB, 1996).

In addition to irrigation, other water uses — including towns and cities, industries, hydropower generation, and recreation — depend on significant amounts of water. Combined, Idaho water uses consume about 5 MAF per year leaving 70 MAF to flow downstream to the Columbia River (IWRB, 1996). This outflow from Idaho into the Columbia River system is about one-third of the total flow of the Columbia River (Id.). Approximately one-half of this flow is provided by northern Idaho tributaries and one-half is from the Snake River. Average annual flow of the Snake River as it leaves the state at Lewiston is about 36 million af (Id.). In turn, roughly one-third of this amount comes from the Upper Snake River above Hells Canyon and about one-half is contributed by the Salmon and Clearwater River basins (Id.). The remainder is contributed from smaller tributaries in Oregon, Washington, and Idaho.

Stream flow records do not extend back to the beginning of irrigation in the mid-1800s. However, records do exist for roughly the second half of irrigation development in the Upper Snake River basin. Impacts to stream flow caused by the construction of reservoirs and development of irrigation on about 1.5 million acres would be expected to be reflected in the flow records for the Snake River at the Weiser gage, located just above Brownlee Reservoir. However, the historical record does not reflect a significant decrease in flow due to development in southern Idaho.

Figure 1 shows the actual mean annual flow at Weiser for the period 1911-1997. As can be seen from the trend line plotted on the graph, average annual flows have increased slightly over the past 85 years despite water development in the Upper Snake River basin. Figure 2 shows the actual mean summer flow for July 1 through August 31 for the period 1911-1997 without flow augmentation. This period was selected to match the time during which flow targets are usually not met and this is the time of concern for juvenile fall chinook migration. Again, the trend line plotted on the graph shows the measured flow of the Snake River at Weiser has increased during the past 85 years.

Similarly, the actual historical hydrology at Lower Granite does not reflect decreasing flows. Figures 3 and 4 show the same trend of increasing mean annual and summer (July 1 through August 31) flows at Lower Granite for the period 1911-1997 as shown for the Snake River at Weiser.

Figure 1

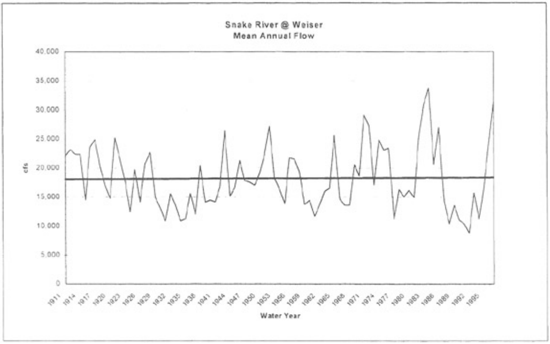


Figure 2

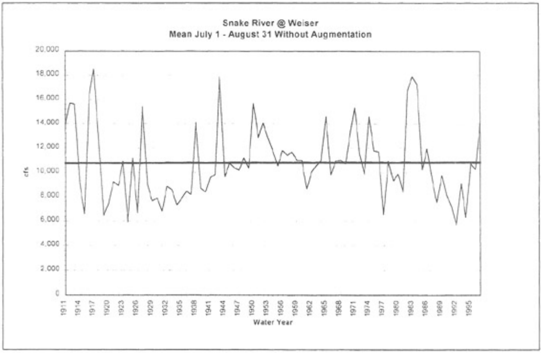


Figure 3

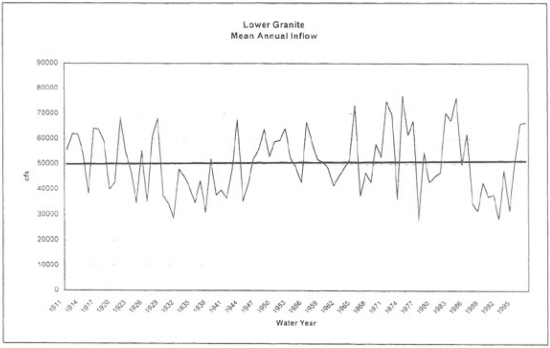
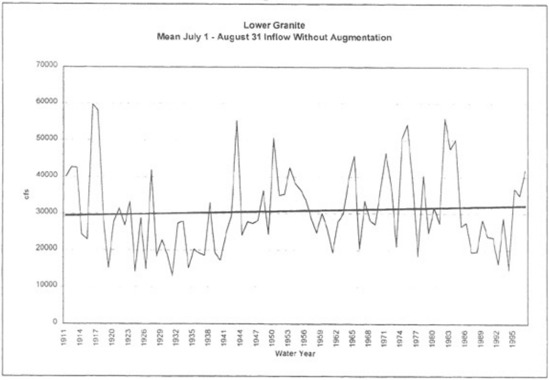


Figure 4



The fact that the quantity and timing of Snake River flow has not changed significantly is not new. In 1995, the National Research Council concluded:

> "*Because there has not been a major shift in the Snake River hydrograph, it is doubtful a priori that the declines in Snake River salmon stocks are due to or reversible by changes in the seasonality of the flow regime of the Snake River alone*" (NRC, 1995 at 193).

Flow Augmentation Efforts

Flow augmentation began in 1983 under a water budget recommended by the Northwest Power Planning Council (Olsen, 1998a). The budget steadily increased from less than 4 MAF (including about 300,000 af from Idaho) in the early years to over 10 MAF in 1994 (including about 2.7 MAF from Idaho) (Id.). Idaho's share comes from three sources: the Corps' Dworshak Reservoir (about 2 MAF), Idaho Power Company's Brownlee Reservoir, and Reclamation's Upper Snake reservoirs (Id.). Figure 5 shows the amount of flow augmentation from each source from 1987 through 1999 (1999 data from the Idaho Department of Water Resources). Figure 6 shows the combined adult returns of wild salmon and steelhead to the uppermost dam on the Snake River from 1964-1998. Obviously, there is no correlation between flow augmentation and adult returns of fish.

In recent years, the Bureau of Reclamation has augmented flows below Hells Canyon using 427,000 af of water per year made available from its own uncontracted reservoir space, powerhead space (1993 and 1994), and water purchased or rented from willing sellers in the Upper Snake River basin water. This flow augmentation was suggested in the 1995 Biological Opinion from the National Marine Fishery Service (NMFS) on operation of the federal Columbia River power system. However, Idaho's interim authority to use Idaho water for flow augmentation expired at the end of 1999.

Figure 5. Flow augmentation table and graph.

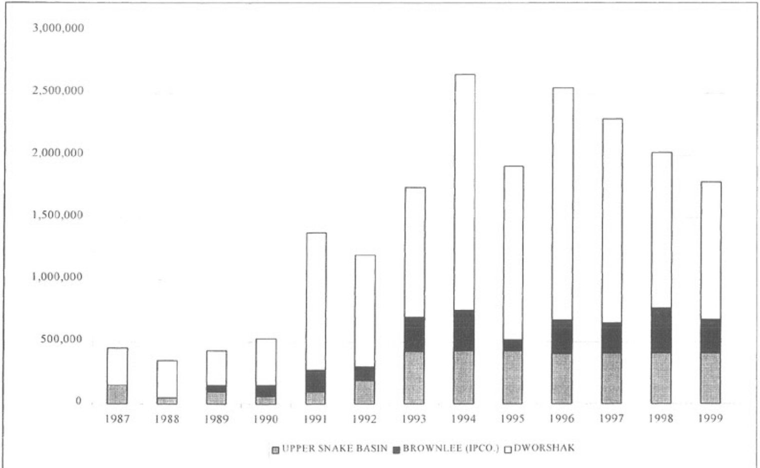
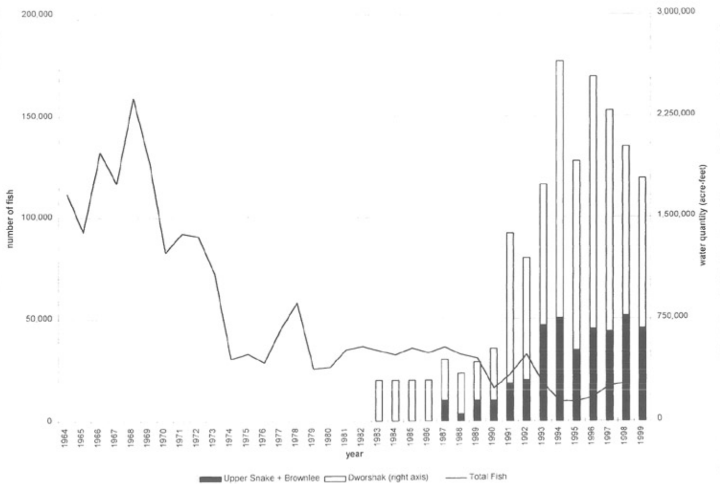


Figure 6. Snake River flow augmentation compared to adult returns of wild salmon and steelhead to the uppermost dam on the Snake River below Hells Canyon (Ice Harbor 1964-68; Lower Monumental Dam 1969; Little Goose Dam 1970-74; Lower Granite Dam 1975-98).



Recently, Reclamation completed an analysis of obtaining an additional 1 MAF of water from the Upper Snake River basin for flow augmentation (Reclamation, 1999). Reclamation's report concludes that providing an additional 1 MAF for flow augmentation will require purchase and retirement of 221,500 acres of land irrigated with natural flow water rights in Idaho, Wyoming, Nevada, and Oregon plus reacquisition of up to 3 MAF of contracted storage space in Reclamation reservoirs in Idaho and Oregon (Id., pp. 5-5, 6-24).

Reclamation also concludes that reacquisition of nearly 50 percent of the contracted storage space in the Upper Snake River would reduce irrigated acreage by only about 139,000 acres per year on average (Id., p. 6-19).[2] Idaho water users believe that Reclamation's analysis is flawed and the impacted acreage will be much larger if 3 MAF of storage space is acquired in the Upper Snake River basin (IWUA, 1999).

Recently, the Corps of Engineers, Bureau of Reclamation, Bonneville Power Administration, and Environmental Protection Agency released the Draft Feasibility Report/Environmental Impact Statement ("EIS") for the Lower Snake River Juvenile Salmon Migration Study (U.S. Army Corps of Engineers et al., 1999). This EIS eliminated the MAF alternative for a variety of reasons: 1) insufficient biological benefits; 2) high costs and impacts; 3) numerous implementation issues; 4) legal and water supply uncertainties; 5) inadequacy of study; and 6) lack of public acceptability (Id., pp. 3-15, 3-16, 5.16-3, 5.16-4).

Flow and Velocity

Some biologists and various groups suggest that downstream migration of juvenile salmon could be improved by increasing the rate of flow through the reservoirs along the lower Snake and Columbia Rivers to speed up migration. Flow augmentation is futile to mitigate the velocity reductions resulting from dams on the lower Snake River (Dreher, 1998, p. 12). For example, adding 1 MAF annually to existing flows results in less than $^{1}/_{10}{}^{th}$ of 1 mile per hour increase in velocity through the lower Snake River reservoirs (Id.,

[2]Total contracted storage space in Reclamation reservoirs in the Upper Snake River basin is about 6.3 MAF (Id., p. 2-6).

1998). Stated another way, more than 160 MAF (over 4 times the existing flow) would be required to restore pre-dam velocities (Id.). Clearly, existing and proposed levels of flow augmentation from the Upper Snake River have an insignificant effect on water velocity through the lower Snake River (Id.).

Estuary/Plume Effects

In a further attempt to find some basis for flow augmentation, NMFS has suggested that higher flows might improve conditions in the estuary and provide survival benefits to juvenile salmonids migrating through the estuary or the Columbia River plume (NMFS 1999c, p. 32).

As discussed in the previous section, the volume and pattern of flow in the Snake River upstream from Lower Granite Reservoir has not changed significantly over the past 85 years. Thus, any changes that may have occurred in the Columbia River estuary or plume are not the result of upstream development on the Snake River. Further, the flows required to make significant changes in the estuary or plume are so large that any attempt to use Snake River augmentation water for that purpose will be just as futile as trying to restore pre-development water velocity through the hydropower system using Snake River flow augmentation.

Table 2 compares maximum and minimum monthly discharges of the Columbia River at Beaver Army Terminal near Quincy, Oregon with the monthly discharge of the Snake River at Weiser during the same month. The Beaver Army Terminal gage is located at river mile 53.8 within the area of the river affected by tidal flow. Even though the gage record is short—10 years of records, some partial, from 1968 through 1997—it serves to show the wide variation in annual flow of the Columbia River. For example, the variation in monthly flow from high to low years (18.5 MAF in June) is more than the average entire annual flow of the Snake River at Weiser (13.2 MAF).

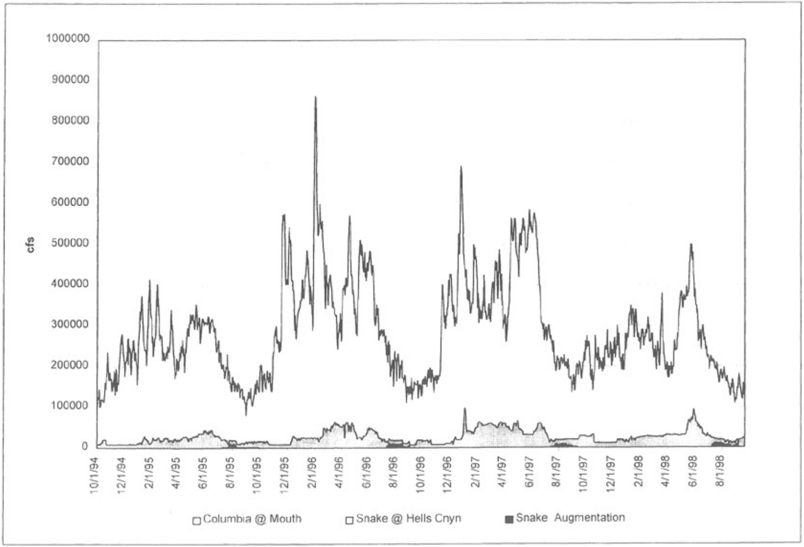
Table 2. Minimum and maximum monthly discharge of the Columbia River compared to Upper Snake River discharge in that month.

Month	Minimum Flow (MAF)			Maximum Flow (MAF)		
	Year	Lower Columbia River	Upper Snake River	Year	Lower Columbia River	Upper Snake River
April	1992	11.7	0.5	1969	24.2	2.3
May	1968	13.0	0.7	1997	31.2	2.5
June	1992	12.1	0.3	1997	30.6	2.9
July	1992	8.6	0.4	1997	17.2	1.1
August	1994	6.6	0.5	1997	12.8	0.9

Table 2 illustrates the flow of the Columbia River at the beginning of the estuary is at least 10 times greater than the flow of the Snake River at Weiser under both high and low flow conditions. It is impossible to try to restore the lower Columbia to pre-development conditions using augmentation from a source that provides less than 10 percent of the flow during the spring and summer.

Another way to consider the futility of using flow augmentation from the Upper Snake River is to compare the period of record average flow of the Columbia River at Beaver Army Terminal for July, a relatively low flow month during the period of flow objectives, to recent levels of Upper Snake River flow augmentation. The average monthly flow of the Columbia River for July at this location is 13.9 MAF for the period of record at the Beaver Army Terminal gage. If the entire 427,000 acre-feet of Upper Snake River flow augmentation were released in July it would be only 3 percent of the average monthly July flow of the Columbia River at Beaver Army Terminal. Figure 7 shows Upper Snake River flow augmentation from 1995-1998 in relation to the flow of the Columbia River at the mouth.

Figure 7. Snake River flow augmentation compared to the Columbia River at the mouth and the Snake River at Hells Canyon, 1995-1998.



Flow Targets

Table 3 contains the NMFS flow objectives for the Snake River at Lower Granite Dam.

Table 3. NMFS flow objectives, Snake River at Lower Granite Dam.

Spring (4/3 – 6/20)	85-100[a] kcfs
Summer (6/21 – 8/31)	50-55[a] kcfs

[a]Varies based on water volume forecasts.

As described above, it is not clear that flow objectives are necessary at this location because current flows are approximately equal to historical flows in both amount and timing. It is even less clear why the flow targets have been set at an unreasonable level that requires enormous volumes of flow augmentation from southern Idaho, especially in dry years—over 10 MAF would have been needed in 1977 and 1992, or nearly the total storage capacity of the largest 80 reservoirs in the Snake River basin (Dreher 1998, p. 13).

Flow and Turbidity

Idaho water users continue to evaluate the effect of flow augmentation on turbidity. Unfortunately, turbidity data on the Snake River is scarce. However, significant increases in turbidity as a result of flow augmentation are not expected. Most instances of high turbidity in the lower Snake River are the result of high tributary inflows due to storm events or snowmelt. Lower turbidity from Upper Snake River augmentation may result from suspended material settling out of the water in Brownlee Reservoir before the augmentation flow reaches the lower Snake River. The rocky nature of the channel in the Hells Canyon reach of the Snake River limits any increase in suspended material that could be caused by flow augmentation from Brownlee Reservoir.

Flow and Temperature

Cold water has been released from Dworshak Reservoir in the Clearwater basin to lower temperatures in the river for the benefit of salmon (NMFS, 1999b, pp. 29, 30). However, during low flow years (when temperature is even more significant), warm water released from the Upper Snake River counteracts the cooling effect of releases from Dworshak Reservoir (U.S. Army Corps of Engineers, 1995, pp. 4-61).

As discussed in *The Effects of Flow Augmentation on Snake River Fall Chinook* (Attachment 3), temperature is one of the most significant environmental variables that affect juvenile survival. However, Upper Snake River flow augmentation does not provide temperature improvement in the lower Snake River during the summer months. In fact, Upper Snake River flow augmentation may increase the water temperature downstream and negatively affect fall chinook.

Estuary Timing

Flow augmentation also is being hypothesized as a way to change the timing of the arrival of smolts at the estuary to pre-dam conditions (NMFS, 1999c, p. 45). The suggested use of flow is perplexing for two reasons. First, about 80 to 90 percent of Snake River chinook and steelhead passing through the estuary arrive through transportation (Marmorek et al., 1998). Transportation shortens the hydrosystem passage by two weeks for spring chinook and a month or more for fall chinook, resulting in estuary arrival times similar to the pre-dam conditions (Dr. James Anderson, pers. comm.). Furthermore, under the existing hydrosystem, augmentation can only change the arrival time of the remaining 10 to 20 percent of in-river migrating fish by a few hours for spring chinook and a few days for fall chinook (Id.). Using water to speed arrival timing at the estuary is a gross misuse of water resources that may affect only a small proportion of fish.

Water Conservation

Some fishery interests advocate water conservation through improved irrigation efficiency to increase the water available for instream flows in the lower Snake River (or mitigate the impact of a federal/tribal taking of water). However, on an annual basis, the flow of the lower Snake River would not be significantly increased by changes in irrigation efficiency because water losses from irrigation inefficiency already return to the river above Hells Canyon (USBR, 1999b, pp. 3-4). Moreover, increased efficiency is likely to reduce return flows during the summer months—a time when many advocate that additional flows are needed.

Biology of Upper Snake Flow Augmentation

Upper Snake River flow augmentation is not of significant biological benefit to any of the listed species. Nevertheless, the draft All-H Paper includes alternatives that continue to rely on the myth that existing levels of flow augmentation from the Upper Snake River have helped anadromous fish and includes an alternative that assumes that more water would be better yet.

The Origin and Perpetuation of the Myth

The theory that salmon survival is related to flow can be traced to a paper published in 1981 by Carl Sims and Frank Ossiander. These researchers developed a graph of annual values of juvenile salmon survival in relation to Snake River flows at Ice Harbor for 1973-1979. In recent years, this early research has been discounted as a result of problems with the data, assumptions, and analysis (Williams and Matthews, 1995; Steward, 1994). Moreover, some of the problems attributed to low flow may have been due to passage facilities at the dams, which have been significantly improved over the past 20 years (Williams and Matthews, 1995).

NMFS continues to perpetuate the myth that Upper Snake River flow augmentation will significantly benefit anadromous fish with casual, qualitative analysis and speculation. In the Biological Opinion on operation of Bureau of Reclamation reservoirs in the Upper Snake River basin, NMFS focuses on summer flow augmentation to benefit juvenile fall chinook (NMFS, 1999a). Even more recently, in the draft White Paper on which the All-H Paper currently relies,[3] NMFS reiterates the alleged benefit to fall

[3]It is not clear what revisions to the All-H Paper will be based upon since the following caveat is contained in the Hydropower Appendix: *Information in the following section concerning current conditions in the hydro corridor is based in part on a series of "white papers" prepared in draft by NMFS in October 1999. (NMFS, 1999)...Because the white papers are a work in progress and subject to revision, the following section summarizes the current drafts and does not reflect a consensus among the members of the hydro workgroup with regard to the papers' contents.* (p. 6).

chinook but also speculates that there may be qualitative benefits to other runs as well (NMFS, 1999c). Notably, NMFS is beginning to recognize: 1) that "*relationships between flow and survival and between travel time and survival through impounded sections of the lower Snake River*" are neither strong nor consistent; and 2) that another part of the flow augmentation myth—a previously supposed relationship between flow and smolt-to-adult returns (SAR)—is not supported by recent data and analysis (Id., pp. 32, 39, 41). However, as discussed in Attachment 1 to these comments, through reliance on dated research and selective use of studies, the draft White Paper still concludes that the flow targets are reasonable and that existing levels and additional levels of flow augmentation would be beneficial, especially to fall chinook (Id., pp. 45, 46).

The flow augmentation theory is a slippery fish. As the portion of the myth that flow augmentation benefits salmon through the hydrosystem has been exposed, proponents have turned to alleged benefits above and below the dams. As discussed in these comments, the data do not clearly support the purported benefits above Lower Granite Reservoir, there is no biological data to support flow augmentation benefits in the estuary or near-shore environment, and hydrological analysis concludes that little or no benefit from Upper Snake River flow augmentation is even possible due to the small magnitude of additional flow that can be made available under any scenario.

Yearling Migrants (spring/summer chinook and steelhead)

In the draft White Paper on which the All-H Paper relies, NMFS asserts:

> "*A strong and consistent relationship exists between flow and travel time. Increasing flow decreases travel time. Thus, although no relationship appears to exist within seasons between flow and yearling migrant survival through the impounded sections of the Snake River, by reducing travel times, higher flows <u>may</u> provide survival benefits in other portions of the salmonid life cycle and in free-flowing sections of the river both upstream and downstream from the hydropower system. For example, higher flows <u>might</u> improve conditions in the estuary (see above) and provide survival benefits to juvenile salmonids migrating through the estuary or the Columbia River plume (see below). By reducing the length of time the smolts are exposed to stressors in the reservoirs, higher flows also <u>likely</u> improve smolt condition upon arrival in the estuary*" (NMFS, 1999c, p. 32, emphasis added).

To speculate on the possible benefits of decreased travel time from flow management ("*may*," "*might*," "*likely*") in the face of weak and inconsistent data on any relationship between flow and survival or any relationship between travel time and flow is evidence of bias toward the benefits of flow augmentation. Any discussion of the mechanisms, uncertainties, and quantification of these speculative indirect impacts is conspicuously absent. Survival is the issue, not travel time.

NMFS, based on research by Smith et al., reports a strong association between travel time and flow and concludes that travel time is a function of flow (NMFS, 1999c, pp. 8,9). However, the correlation appears to be spurious due to a collinear relationship between flow and time (photoperiod). Flows measured by the U.S. Army Corps of Engineers at Lower Granite Dam at 15-day intervals in 1995 and 1996 (years of the Smith et al. study) are given in Table 4.

Table 4. Flow at Lower Granite Dam.

Date	1995	1996
April 1	46 kcfs	81 kcfs
April 15	78 kcfs	132 kcfs
April 30	84 kcfs	98 kcfs
May 15	96 kcfs	139 kcfs
May 30	111 kcfs	156 kcfs
June 14	120 kcfs	170 kcfs

As seen in Table 4, there was a consistent increase in flow over time during the downstream migration of smolts. Both flow and photoperiod increased synchronously over the period of study. Thus, conclusions concerning flow as the variable controlling travel time are highly speculative.

Attachment 2 of these comments contains an analysis of tagged juvenile hatchery chinook based on annual reports on smolt migration through Lower Granite Reservoir from 1987-1995. The conclusion from the analysis is that photoperiod provides a better basis to predict travel time than flow, and that travel time can be predicted by flow only because the relationship between flow and time is collinear.

In summary, NMFS and other agencies should further evaluate potential collinear effects among variables before arriving at firm conclusions for yearling migrants. As discussed below for sub-yearling migrants (fall chinook), confounding effects probably exist from collinearity between flow and other environmental variables such as water temperature and turbidity. In addition, the relationship of survival to other independent variables such as the physiological state of the juveniles, size of the juveniles, predation, competition, and ocean conditions should be explored.

Sub-Yearling Migrants (Fall Chinook)

A more scientific examination of the available data, including the recent research that is being used to support and defend flow augmentation for fall chinook, leads to the conclusion that Upper Snake River flow augmentation is not of significant benefit to survival. In summary, a close review results in the following findings:

1. Flow augmentation should be the focus of analysis, not natural variations in flow. Upper Snake River flow augmentation does not create changes in important environmental variables such as date of migration, temperature, and turbidity.
2. Flow is a poor predictor of survival and the effect of flow on survival cannot be reliably estimated. Other environmental variables such as time of migration, water temperature, and turbidity are more strongly correlated with survival.
3. Survival is also more likely related to other independent variables such as the physiological state of the juveniles, size of the juveniles, predation, competition, and other factors.
4. There is no statistically significant relationship between flow and spawner-recruit data for fall chinook over brood years 1964-1994.

Survival v. Flow Above Lower Granite Dam

As discussed in *The Effects of Flow Augmentation on Snake River Fall Chinook* by Dr. James Anderson, Dr. Rich Hinrichsen and Chris Van Holmes (Attachment 3), juvenile fall chinook mortality above Lower Granite Dam is affected by a number of critical environmental attributes, e.g., migration date, temperature, and turbidity. Most of these attributes vary significantly from year-to-year and over the course of the migration season and are closely related to each other and to flow. For example, years of high flows are associated with cooler temperatures and higher turbidity. The same is true of higher early season flows compared to lower summer flows. In the jargon of statistics, the close correlation of these variables means that they are "collinear." PIT-tag research for 1995-1998 found significant individual correlations between survival and date of migration, temperature, turbidity and flow (in that order), but not with travel time. However, due to the collinearity among the variables, it is not possible to statistically separate the individual effect of each parameter on survival (see Attachment 3). Further analysis of the PIT-tag data indicates that the date of migration, temperature, and turbidity are more significant than flow as a predictor of smolt survival above Lower Granite Dam (Id.). Date of migration and temperature are sufficient to fully explain the decline in survival during the course of the year. Including flow in the regression adds no new information and is unnecessary to predict survival.

Turning to the issue at hand—flow augmentation—the overwhelming evidence indicates that flow augmentation from the Upper Snake River does not beneficially affect temperature or turbidity. Because travel time is not significantly related to natural flow variation, it is not likely to be related to augmented flow. Finally, there is no evidence that migration timing is positively affected by Upper Snake River flow augmentation (and there is no reason to suspect such a relationship). Overall, summer flow augmentation from the Upper Snake with warm, clear water from Brownlee is highly likely to decrease survival of juvenile fall chinook migrants, not enhance recovery.

Adult Survival v. Flow

The flow augmentation analysis in Attachment 3 evaluates spawner-recruit data for several index stocks of fall chinook (Snake, Hanford, and Deschutes) for various brood year data sets extending back to the 1960s. No statistically significant relationship between natural variations in flow and recruits per spawner was found. Although not statistically significant, a small positive relationship was found. However, even if additional data proved the relationship to be valid, the impact on life cycle survival is miniscule, i.e., the effect of natural variations in flow is not biologically significant. Moreover, as discussed in the previous section, it must be emphasized that it is not clear that flow is the operative variable, and it is not apparent that flow augmentation provides any of the benefits of a naturally high-flow year.

Another perspective on life cycle implications of flow augmentation can be gained by assessing the relative mortality in various life stages resulting in smolt-to-adult returns (SAR). Smolt-to-adult survival, as expressed by SAR, encompasses life stages between juvenile seaward migration and adult spawning. High mortality during various life stages contributes to low SARs. For example, as set forth in Attachment 4 of these comments, optimistic survival levels for fall (ocean-type) chinook are: spawning to juvenile migrant ($\approx$ 0.115), juvenile migration ($\approx$ .610), marine feeding ($\approx$ .015), adult migration ($\approx$ .600), and pre-spawning ($\approx$ .950). Total life cycle survival contributing to SAR can be approximated by multiplying the survival fractions, i.e., SAR $\approx 0.115 \times 0.610 \times 0.015 \times 0.600 \times 0.950 \approx 0.0006$. Thus, survival for juvenile migration ($\approx$ 0.610) represents less than 1 percent of the total SAR. A similar example for spring/summer Snake River chinook also shows that the SAR for juvenile migrants ($\approx$ 0.60) is a tiny fraction of total SAR ($\approx$ 0.00014) (BPA et al., 1999, pp. 4-9 – 4-11). Thus, there is little prospect for associating SAR with environmental variables such as flow.

Economic and Social Impacts of Upper Snake Flow Augmentation

Economic Impacts of Taking Water for Salmon

Total annual income in Idaho generated by irrigated agriculture exceeds \$2 billion or about \$400/af of water consumption (Olsen, 1998b). The net annual economic value of water for irrigation consumption varies by crop but averages \$40 to \$70/af or more (Id.; Hamilton and Whittlesey, 1996; Huppert and Fluharty, 1996). Because there are a variety of transaction costs in moving water from irrigation to other uses, this range represents the lower bound of direct economic cost or impact of taking water from existing uses to satisfy the claims.

USBR Analysis

Although the Idaho water users believe that the Bureau of Reclamation (USBR) has underestimated the impacts, that agency analyzed the effects of providing an additional 1

MAF of flow augmentation to Lower Granite Reservoir (USBR, 1999). This augmentation is in addition to the 427,000 af that has been provided from the Upper Snake River since 1993 (Id., p. 5-9). Depending on whether storage reservoirs are operated to minimize the impact on recreation (1427r) or irrigation (1427i), the USBR estimates the impacts shown in Table 5.

Additional direct costs would be incurred by hydropower, recreation, and municipal interests. Although detailed estimates of the economic impact to these sectors are difficult to make due to uncertainties in the location, frequency and amount of water shortage from flow augmentation, indications are that the direct net costs may be tens of millions of dollars per year (USBR, 1999, pp. 6-27 to 6-52, 9-4). Moreover, as with irrigation, there would be additional secondary impacts resulting from changes in these sectors.

Table 5. USBR impacts, Million Acre Feet Study.

National Effects	1427i	1427r
Decrease in irrigation acres in average water-year	243,000	360,000
Decrease in irrigated acres in dry water-year	376,000	643,000
Decrease in value of production in average water-year	$90,204,000	$136,433,000
Decrease in value of production in dry water-year	$141,202,000	$243,737,000
Loss of proprietors income and other property income (annual)	$46,691,000	$81,357,000
Annual water acquisition cost		
Low estimate	$10,414,000	$31,128,000
High estimate	$31,243,000	$87,157,000
Regional Effects	1427i	1427r
Employment- annual jobs lost	2,543	3,612
Annual income lost	$44,700,000	$51,976,000
Annual sales lost	$95,200,000	$130,400,000

The USBR analysis of the MAF alternative was developed as part of the Lower Snake River Juvenile Salmon Migration Study (U.S. Army Corps of Engineers et al., 1999). However, the EIS eliminated the MAF alternative for a number of reasons: 1) insufficient biological benefits; 2) high costs and impacts; 3) numerous implementation issues; 4) legal and water supply uncertainties; 5) inadequacy of study; and 6) lack of public acceptability (Id., pp. 3-15, 3-16, 5.16-3, 5.16-4).

Conclusions

Idaho water users are caught between conflicting federal policies. For over 100 years, Idaho has built its economy on water development, fostered and encouraged by the federal government. Now, federal agencies and various flow augmentation advocates seek large blocks of Idaho water to increase downstream flows. The augmented flows are intended to help fish passage problems at downstream federal dams. Idaho water users are confident that changes in Idaho water use did not cause and cannot cure the decline of Snake River anadromous fish populations. Successful recovery of salmon runs must reflect a pragmatic assessment of the hydrologic, economic, biological, and political realities of Idaho and the Pacific Northwest.

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Attachment 1
Additional Issues With the NMFS' Draft White Paper

In the recent draft report, Salmonid Travel Time and Survival Related to Flow Management (hereinafter, "White Paper"), NMFS summarized and analyzed recent research on the relationship of flow (NMFS, 1999).

The Idaho water users agree with NMFS that "*[i]dentifying and quantifying relationships between environmental variables and travel times or survival of PIT-tagged migrant juvenile salmonid release groups in the Snake River present difficult challenges [due to confounding effects]*" (Id., p. 31). However, we strongly disagree that "*it is remarkable that survival and exposure indices have had any significant correlations*" (Id.). What is remarkable is that NMFS chose to ignore the collinearity between flow and other variables such as temperature and photoperiod. Conclusions by NMFS regarding direct correlations between flow and survival disregard: 1) the synchrony between the dependent (survival) and independent (flow) variables; 2) the relationship between migration distance and survival; and 3) limitations of experimental protocols.

Yearling Migrants

As discussed in the main body of the comments, the White Paper primarily relies upon speculation for assertions that flow augmentation will benefit the survival of yearling migrants (spring/summer chinook and steelhead). Moreover, the relationship between flow and travel time appears to suffer from collinearity between variables and there is no evidence presented of a travel time-survival relationship.

Subyearling Migrants

In the draft White Paper, NMFS admits that collinearity between flow and other environmental variables is an issue for subyearling migrants:

> "*Since the environmental variables were also highly correlated with each other, determining which variable was most important to subyearling fall chinook salmon survival is difficult*" (Id., pp. 32, 33).

Nevertheless, NMFS concludes that "*significant correlations exist among survival, flow, water temperature and turbidity*" (Id., p. 34) and "*[d]irect evidence for a survival* *management to fall chinook from flow management is strongly supported by research results*" (Id., p. 45).

In large part, the White Paper's conclusions are based on PIT-tag research plus studies by Connor et al., dated research, and selective use of research. The PIT-tag research is discussed in detail in *The Effects of Flow Augmentation on Snake River Fall Chinook* in Attachment 3. The reports by Connor et al., dated research, and selective use of research are discussed below. In summary, these studies are not adequate to support the conclusion that flow augmentation benefits juvenile fall chinook.

Studies by Connor et al.

The research by Connor et al. is inadequate as support for Upper Snake River flow augmentation. Connor et al. conclude that the primary benefits from summer flow augmentation result from cold water releases at Dworshak (Connor et al., 1998a). Moreover, Connor's paper relies on insufficient evidence to draw a relationship between flow augmentation and survival because it is based solely on four data points of detection rate, mean summer flow, and maximum summer water temperature. As noted in Connor's paper, the conclusions cannot be confirmed without further research. Subsequent work by Connor suffers from the same problem—insufficient data to evaluate statistical associations between survival and flow, especially within a given year (Connor et al., 1998b).

In addition, migration timing of natural juvenile fall chinook differed greatly between the two years of observations, being delayed in 1995 (the year of relatively high survival) and advanced in 1996 (the year of relatively low survival). In addition, flow augmentation from Dworshak and Brownlee Reservoirs was sequential in 1996 and overlapping in 1995. Thus, the experimental design was inconsistent between the two years, and the data cannot be pooled for analysis. Finally, large annual differences between survival and detection probabilities remain to be explained.

Reliance on Dated Research

In situations where there is lack of support from recent research for flow augmentation benefits, the White Paper frequently relies on dated research to support speculative conclusions. While some of this research is partially discounted due to recognition of changes and improvements in the hydropower system over time (p. 39) and reliance on between-year average annual flows (p. 32), the White Paper still appears to rely partially on studies that are dated and have been discounted, including some that are 20 years old (e.g., Raymond, 1979; Sims and Ossiander, 1981).

In recent years, the Raymond and Sims and Ossiander research has been discounted (even by NMFS' own scientists) as a result of problems with the data, assumptions and analysis as well as improvements of passage facilities at the dams (Williams and Matthews, 1995; Steward, 1994). However, the studies criticizing the dated research are not even discussed or cited in the White Paper.

Similarly, as discussed in the previous section, older research that does not consider changes in the hydropower system over time (e.g., more dams, different operations, and modified transportation programs) is still relied upon. For example, Petrosky's 1992 study is discounted in the White Paper by discussing the results if pre-dam data is removed (p. 39). However, similar studies (Petrosky, 1991; and Mundy et al., 1994) are not similarly re-evaluated although they suffer from the same weaknesses. Then, disregarding the problems with these research results, those studies are used to support the conclusion.

Use of Selected Research

In some instances, the White Paper provides selective, incomplete, and misleading summaries of reports. For example, the White Paper misleadingly cites Giorgi (1993) in support of the statement:

> "*A number of studies have found a positive relationship between migration rate of yearling chinook salmon and steelhead in the lower Snake and Columbia Rivers related to increases in flow*" (p. 8).

Giorgi's report reviews and summarizes investigations on migratory behavior of juvenile chinook migrants (including studies on flow/migration conducted in the mainstem Columbia River and reservoirs, the Rogue River, and the Snake River). The results of the studies are highly variable. Predicted associations between flow and migration rate range from no association between variables to a significant positive association.

In the same section, the White Paper states:

> "*Berggren and Filardo (1993) found a significant flow/travel time relationship for wild and hatchery subyearling chinook salmon in John Day reservoir (Lake Umatilla)*" (p. 9).

Later, the paper concludes:

> "*Giorgi et al. (1994) found that subyearling chinook salmon migrating through the John Day reservoir early in the summer contributed more adults than juveniles migrating later in the summer for all three years of the study (1981-83)*" (p. 39).

What NMFS fails to mention is that the Giorgi study evaluated a data set that included data used by Berggren and Filardo and found no significant flow/travel time relationship for fall chinook smolts in the lower Columbia River.

In another example, the White Paper summarizes two other studies as follows:

> "*Hilborne et al. (1993) found a significant relationship between flow and adult returns of Priest Rapids fall chinook salmon. However, Skalski et al. (1996), in further analysis, concluded that it was not possible to determine the key factors that influenced these hatchery return rates with the available data and statistical techniques*" (p. 39).

NMFS should also note that of all the in-river variables analyzed by Skalski, flow provided the least amount of predictive capability and that the choice of comparisons with other stocks significantly affected the outcome of the analysis.

In other cases, important research is omitted altogether. For example, Skalski (1998) found survival of yearling chinook between Lower Granite and Little Goose Dams to be "*Remarkably stable over the course of the season.*" Skalski found no association between survival and daily flow.

A substantial amount of research that finds no flow/survival relationship, or suggests that other factors dominate survival, is simply omitted from the White Paper. A list of some of this research and a summary of the findings are contained in the next section. Clearly, this omission skews "*the weight of the evidence*" considered and reported in the White Paper.

Research Omitted by the White Paper

The following 15 documents that are relevant to the flow augmentation issue were excluded from the White Paper.

1. Achord, et al. 1995, 1996, 1997. Monitoring the migrations of wild Snake River spring/summer chinook salmon smolts. Bonneville Power Admin. Proj. 91-028. September 1995, September 1996, and July 1997.

Wild fish were PIT-tagged as parr and released into Snake basin streams. Migrating PIT-tagged smolts were detected daily during passage of downstream dams. Peak detections were largely independent of river flows prior to mid May. Median passage dates at Lower Granite Dam occurred on May 4, (1994), May 10 (1995), and April 26 (1996). Well over 90 percent of detected smolts migrated past Lower Granite Dam prior to peak flows in June.

2. Dawley, E.M. et al. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. NMFS/NWAFC. Bonneville Power Admin. Proj. 81-102.

These authors marked groups of ocean type juvenile chinook salmon and released them at various locations in the lower Columbia River. Marked fish were recaptured at Jones Beach, which is 75 km from the ocean.

They found little evidence of a correlation between flow and migration speed. Some marked cohorts released during periods of high river flow moved downstream at a slower rate than cohorts released during lower flows.

Reach survival estimates are given of marked cohorts released at various locations upriver from Jones Beach and recaptured at Jones Beach. Reach survivals are converted to survival per km for 29 marked cohorts released over 4 years (1968, 1969, 1970, and 1979). The mean survival per km is calculated to be 0.996. Average survival per 100 km is calculated to be 0.670.

3. Giorgi, A.E. et al. 1997. An evaluation of the effectiveness of flow augmentation in the Snake River, 1991-1995. Bonneville Power Admin. Proj. 95-070-00. July 1997.

This report evaluates effects of flow augmentation in the Snake basin and assesses certain biological consequences. Models were used to assess changes in migration and survival of ocean type chinook juveniles. Predictions of survival during migration were possible only for the CRiSP model, which predicted inconsequential changes in survival with flow augmentation.

4. Giorgi, A.E. 1991. The migrational characteristics of chinook salmon emanating from the Snake River Basin. Don Chapman Consultants. Boise, ID. April 11, 1991.

This report reviews the literature on migration of ocean type juvenile chinook salmon in the Columbia basin into 1991. The author concludes, "*The collective information strongly suggests that factors other than flow may influence the migration dynamics of subyearling chinook, e.g., food availability, competition, predation pressure, or perhaps physiological development. Unfortunately, we have a poor understanding of this race's ecological requirements, and of its physiological development. As a consequence, we cannot make an informed assessment as to the importance of these factors. Research on these topics is desperately needed, if we are ever to understand the environmental requirements of these populations of chinook salmon.*"

5. Giorgi, A.E., D.R. Miller, and B.P. Sanford. 1990. Migratory behavior and adult contribution of summer outmigrating subyearling chinook salmon in John Day Reservoir, 1981-1983. Prepared for Bonneville Power Administration. Contract DE-A179-83BP39645.

This study investigates the effects of river flow volumes on the travel time of subyearling chinook salmon migrating through John Day Reservoir. Analysis of flow-travel time data was largely inconclusive due to poor marking and recovery capability coupled with the difficulty of isolating flow from other closely related variables.

6. Giorgi, A.E. 1990. Migratory behavior and adult contribution of summer outmigrating subyearling chinook salmon in John Day Reservoir, 1981-1983. Bonneville Power Admin. Proj. 81-1. April 1990.

Passage of marked ocean type chinook juveniles through John Day Dam and adult return rates are reported for 1980 through 1982 brood years.

There was no evidence of a relationship between river flow volumes during the 1981 through 1983 outmigrations and associated adult returns. Also, it was not feasible to define a relationship between flow and migration speed of ocean type chinook through the John Day Reservoir.

7. Kreeger, K.Y. and W.J. McNeil. 1992. A literature review of the factors associated with migration of juvenile salmonids. For Direct Service Industries Inc.

The authors review over 90 references and summarize that, "*...speed and time of migration are associated with age and size of juveniles as well as with time. Older and larger smolts tend to migrate faster and earlier than younger and smaller smolts. Smolts migrating earlier tend to move more slowly than smolts migrating late.*"*

8. Marsh, D.M. and S. Achord. 1992. A comparison of PIT-tagged spring and summer chinook salmon detection rates with Snake River flows at Lower Granite Dam. In: Passage and survival of juvenile chinook salmon migrating from the Snake River Basin. Proceedings of a technical workshop, University of Idaho, February 26-28, 1992. Pp. 88-90.

In 1989, 1990, and 1991, flows at LGD differed substantially during spring salmonid out-migration, "*...flow had little effect on the dynamics of the out-migration of hatchery or wild spring/summer chinook populations. There was virtually no difference in fish movement patterns for the three years in each of the three groups of chinook salmon. Since flow at Lower Granite Dam had little effect on the passage pattern of PIT-tagged fish, we believe that other environmental and physiological factors, in addition to flow, influenced the movement patterns of fish.*"*

9. McNeil, W.J. 1992. Relationship of time of migration of juvenile salmonids in the Columbia River to stream discharge and water temperature: Ocean type chinook. Direct Service Industries, Inc., Portland, OR. February 27, 1992.

Statistical associations between time of migration and stream discharge, and time of migration and water temperature are examined in this report in an attempt to evaluate the relative importance of stream discharge and water temperature on migration of juvenile ocean type chinook salmon. Two statistical approaches are used — linear correlation and the variance component model of ANOVA. Both approaches treat migration timing, stream discharge, and water temperature as independent variables.

Migration timing of juvenile ocean type chinook is estimated for seven preselected percentiles of the total number of fish passing two index locations, Rock Island and McNary Dams. The percentiles are 5, 10, 25, 75, 90, and 95 percent cumulative passage. Index counts include 6 years, thus each percentile includes six observations.

Water temperature was found to be statistically associated with time of downstream migration of juvenile ocean type chinook salmon in the Columbia River. Stream discharge was found to be statistically associated with time of migration in the early portion of the period of migration but not during the mid and late portions. It appears that water temperature exerts a much greater influence on downstream migration than stream discharge.

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*Summary taken from Olsen et al. (1998).

Results of this analysis support the hypothesis that migration of juvenile ocean type chinook salmon in the Columbia River is controlled largely by water temperature and/or photoperiod. Stream discharge may influence migration timing early in the migration period. The conclusion that discharge has limited influence on migration timing becomes intuitively obvious when one contrasts the consistent timing of the annual migration at each dam with highly variable annual patterns of discharge. The ANOVA test provides a quantitative verification of recurrent migratory patterns, which are largely fixed in time and which occur largely independently of variations in discharge.

10. McNeil, William J. 1995. Water velocity and migration of juvenile salmon: Is faster necessarily better? Hydro•Review, Vol. XIV, No. 2, April 1995.

"*Comparisons between dates corresponding to percentiles of cumulative dam passage and stream discharge gave no indication that dam passage was earlier in years of high flow than in years of low flow.*

As part of the study, three hypotheses related to the relationship between passage time and discharge were tested:

- *No association exists between passage time and stream discharge;*
- *Time of passage is advanced by low stream discharge and delayed by high stream discharge; and*
- *Time of passage is advanced by high stream discharge and delayed by low stream discharge (which would support the theory favored by NMFS).*

The analysis failed to support the third hypothesis—that dam passage is early in years of high flow and late in years of low flow...

[Some of] the data tend to favor an alternative hypothesis that migration is advanced by low flow and delayed by high flow. This is the antithesis of NMFS theory.

Overall, most of the linear correlation coefficients (104 of 117) supported the first hypothesis, that time of passage and stream discharge were not associated...

Proposals for flow management actions to improve survival of Columbia and Snake River salmon are based largely on a hypothesis that increased water velocity is necessary for increased survival. The key assumption is that high water velocity is necessary for normal migration of juveniles. Reduced survival from factors such as predation, physiological dysfunction, and disease is purported by some analysts to result from delayed migration associated with low water velocity. I conclude, however, that there is no compelling reason at this time to reject a hypothesis of no association between migration timing and flow."

11. Miller D.R. and C.W. Sims. 1984. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Prepared for Bonneville Power Administration. Contract DE-A179-83BP39645.

This study was conducted to refine flow/travel time relationships and distributional behavior of 0-aged chinook salmon. "*Regression analysis was used to develop a description of the relationship of river flow to the rate of downstream movement…The slope of this line and the correlation coefficient (R) were not significantly different from zero.*"*

12. Miller D.R. and C.W. Sims. 1983. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Prepared for Bonneville Power Administration. Contract DE-A179-81BP27602.

"*There was no statistical evidence to indicate that instream flows affected either the rate of movement or the residence time of 0-age chinook salmon in John Day Reservoir in 1981.*"*

13. Miller, D.R. and C.W. Sims. 1982. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Prepared for Bonneville Power Administration. Contract DE-A179-81BP27602.

See Miller and Sims, 1983.*

14. Skalski, J.R. 1998. Estimating season-wide survival rates of outmigrating salmon smolt in the Snake River, Washington. Can. J. Fish Aquat. Sci. 55:761-769.

Even though environmental variables fluctuate greatly, survival of cohorts of PIT-tagged juveniles released daily at Lower Granite Dam exhibit little change throughout the migration period. Skalski (1998) found survival between Lower Granite and Little Goose Dam tailraces to be "*…remarkably stable over the course of the season.*" Skalski observed no association between survival and daily flow or daily spill.

15. Tiffan, K.F. et al. 1996. Osmoregulatory performance, migration, behavior, and marking of subyearling chinook salmon at McNary Dam to estimate adult contribution. Pp. 99-128. In: D.W. Rondorf and K.F. Tiffan. Identification of the spawning, rearing, and migratory requirements of fall chinook in the Columbia River basin. Bonneville Power Admin. Proj. 91-029. August 1996.

This study examined possible associations between migration rate of ocean type juvenile migrants and physiological and environmental variables. Migration rate showed no obvious pattern or trend with time as well as with the several physiological and environmental variables examined.

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*Summary taken from Olsen et al. (1998).

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Attachment 2
Smolt Migration in the Snake River
Migration Time, Flow, and Photoperiod

Buettner et al. have produced a series of annual reports on smolt migrations through Lower Granite Reservoir, beginning with the 1987 migration (Buettner, 1988-1996). The most recent report that was reviewed for this analysis assesses the 1995 migration of chinook and steelhead smolts. The authors conclude that river discharge is the principal environmental variable influencing migration. The following quotation from their report on 1995 studies highlights their conclusions:

> "*...fish tagged at the Snake River trap...showed that a two-fold increase in discharge between 50 and 100 kcfs increased migration rate by 12-fold for hatchery chinook salmon...*"

Buettner et al. imply that correlations between flow and migration time are sufficient to establish a cause and effect relationship between these two variables. They ignore the possibility that variables other than flow may also correlate with time and potentially may influence migration behavior. One such variable is photoperiod, expressed as Julian date.

This analysis addresses two hypotheses:

1. Migration time is largely determined by flow (flow hypothesis); and
2. Migration time is largely determined by photoperiod (photoperiod hypothesis).

Datasets presented by Buettner et al. were evaluated for the 1987 through 1995 migrations of tagged juvenile hatchery chinook. Daily collections of juvenile migrants were marked with passive integrated transponder (PIT) tags and released at three locations—Snake River near Lewiston, Clearwater River near Lewiston, and Salmon River near White Bird. Although Buettner et al. also tagged wild chinook and wild and hatchery steelhead, this evaluation is limited to hatchery chinook since they provide the largest number of tagged cohorts.

Migration time is expressed as the number of days between release of a tagged cohort and the date on which the 50^{th} percentile (median) of cumulative total arrivals are detected at Lower Granite Dam. Buettner et al. label the elapsed time (days) between release and median arrival at a single downstream site as "travel time." For this analysis, this statistic is labeled as "migration time."

Each dataset presented by Buettner et al. consists of 12 to 52 cohorts of PIT-tagged juveniles. Date of release, date of recapture (interrogation) of the 50th percentile passing Lower Granite Dam, and daily discharge on each release date has been compiled by Buettner et al. in nine annual reports for the years 1987 through 1995. The reports are available from the Bonneville Power Administration, Portland. These data are used here to calculate two sets of correlation statistics comparing:

- Discharge and migration time (flow hypothesis); and
- Release date and migration time (photoperiod hypothesis).

Release date as expressed by the Julian calendar is used as a measure of photoperiod.

Acceptance of the flow hypothesis implies that migration time consistently decreases as discharge increases. Acceptance of the photoperiod hypothesis implies that migration time consistently decreases as photoperiod increases.

Below, the results of linear correlation analyses are summarized, beginning with the 1995 migration and continuing back year-by-year to the 1987 migration.

1995. Tagged cohorts were released from the Snake (n = 43), Clearwater (n = 30), and Salmon (n = 52) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.79	r = -0.89
Clearwater	r = -0.81	r = -0.88
Salmon	r = -0.98	r = -0.94

Inverse correlations between migration time and flow, and migration time and photoperiod are highly significant (Prob. <0.001) for all three release sites. Both flow and photoperiod increased synchronously over the period of observation. Conclusions concerning relative importance of flow and photoperiod as variables controlling migration time would be highly speculative based on 1995 datasets.

1994. Tagged cohorts were release from the Snake (n = 31), Clearwater (n = 16), and Salmon (n = 32) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.73	r = -0.70
Clearwater	r = -0.31	r = -0.61
Salmon	r = -0.60	r = -0.72

Inverse correlations between migration time and flow, and migration time and photoperiod are highly significant (Prob. <0.001) for Snake and Salmon River release sites. However, for the Clearwater release site, the inverse correlation between migration time and flow is not significant (Prob. >0.100); whereas, the inverse correlation between migration time and photoperiod is significant (Prob. ~ 0.010). Observations on tagged cohorts from the Clearwater River provide limited support for the photoperiod hypothesis. The flow hypothesis is not supported by these results.

1993. Tagged cohorts were released from the Snake (n = 33), Clearwater (n = 19), and the Salmon (n = 31) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.69	r = -0.73
Clearwater	r = -0.63	r = -0.90
Salmon	r = -0.80	r = -0.93

Inverse correlation between migration time and flow, and migration time and photoperiod are highly significant (Prob. <0.002) for all three release sites. Both flow and photoperiod increase synchronously over the periods of observation. Conclusions concerning relative importance of flow and photoperiod as variables controlling migration time would be highly speculative based on 1993 datasets.

1992. Tagged cohorts were released from the Snake (n = 12) and Clearwater (n = 50) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.76	r = -0.89
Clearwater	r = -0.53	r = -0.88

The inverse correlation between migration time and flow is weakly significant (Prob. ~0.050) for Clearwater River cohorts and highly significant (Prob. < 0.002) for Snake River cohorts. The inverse correlation between migration time and photoperiod is highly significant (Prob. <0.001) for both Snake and Clearwater cohorts. Observations on tagged cohorts from the Clearwater River tend to favor the photoperiod hypothesis. Any support for the flow hypothesis is highly speculative.

1991. Tagged cohorts were released from the Snake (n = 28) and Clearwater (n = 29) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.86	r = -0.77
Clearwater	r = -0.80	r = -0.90

Inverse correlations between migration time and flow, and migration time and photoperiod are highly significant (Prob. <0.001) for both release sites. Both flow and photoperiod increase synchronously over periods of observation. Conclusions concerning relative importance of flow and photoperiod as variables controlling migration time would be highly speculative base on 1991 datasets.

1990. Tagged cohorts were released from the Snake (n = 31) and Clearwater (n = 35) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.77	r = -0.58
Clearwater	r = -0.32	r = -0.86

The inverse correlation between migration time and flow was weakly significant (Prob. ~0.050) for Clearwater River cohorts but highly significant (Prob. < 0.001) for Snake River cohorts. The inverse correlation between migration time and photoperiod was highly significant (Prob. <0.001) for cohorts from both release sites. Observations on tagged cohorts from the Clearwater River tend to favor the photoperiod hypothesis. Support for the flow hypothesis would be highly speculative.

1989. Tagged cohorts were released from the Snake (n = 45) and Clearwater (n = 20) river traps. The linear correlation coefficients are:

Release Site	Flow Hypothesis	Photoperiod Hypothesis
Snake	r = -0.79	r = -0.85
Clearwater	r = +0.30	r = -0.88

The inverse correlation between migration time and flow was not significant (the r-value was actually positive) for Clearwater cohorts but highly significant (Prob. <0.001) for Snake River cohorts. The inverse correlation between migration time and photoperiod was highly significant (Prob. <0.001) for cohorts from both release sites. Observations on tagged cohorts from the Clearwater River favor the photoperiod hypothesis. Support for the flow hypothesis would be highly speculative.

1988 and 1987. Tagged cohorts were released only from the Snake (n = 23 and n = 24) river trap. The linear correlation coefficients associating migration time and flow were r = -0.89 (1988) and r = -0.94 (1987). The liner correlation coefficients associating migration time with photoperiod were r = -0.92 (1988) and r = -0.95 (1987). Both flow and photoperiod increased synchronously in both years. Conclusions concerning relative importance of flow and photoperiod as variables controlling migration time would be highly speculative based on 1988 and 1987 datasets.

Summary. Associations between migration time and photoperiod were significant (Prob. <0.010) for all nineteen datasets. Should these results be interpreted as favoring the photoperiod hypothesis, it must be emphasized that they are insufficient without supporting information to establish a cause and effect relationship between migration time and photoperiod.

The association between migration time and flow was significant (Prob. <0.010) in sixteen of the nineteen datasets. These results raise the possibility that flow may be of less importance than photoperiod as an environmental variable affecting migration time and migration.

The coefficient of determination (r^2) provides additional insight into the relative importance of photoperiod and flow as variables influencing migration. The r^2 value represents the proportion of the total variation in migration time that is explained by the linear regression curve fitted to flow or photoperiod for each of the nineteen datasets. The r^2 values corresponding to migration time vs. flow and migration time vs. photoperiod are listed in Table 1.

Values of r^2 tend to be higher for migration time vs. photoperiod (pooled $r^2 = 0.70$) than for migration time vs. flow (pooled $r^2 = 0.52$). This result implies that, on average, the regression model accounts for 70 percent of total variation in migration time vs. photoperiod, but only 52 percent of total variation in migration time vs. flow.

In conclusion, photoperiod provides a better basis to predict migration time (migration speed) of hatchery chinook salmon in the Snake basin than flow. Further, migration speed can be predicted by flow only if collinearity exists between flow and time.

Table 1. Values of r^2 (coefficient of determination) for migration time vs. flow and migration time vs. photoperiod for tagged juvenile chinook salmon released into the Snake, Clearwater, and Salmon Rivers.

Year	Migration Time vs. Flow			Migration Time vs. Photoperiod		
	Snake	Clearwater	Salmon	Snake	Clearwater	Salmon
1987	0.88			0.91		
1988	0.79			0.85		
1989	0.62	0.09		0.72	0.77	
1990	0.60	0.10		0.33	0.74	
1991	0.73	0.64		0.60	0.80	
1992	0.58	0.28		0.79	0.78	
1993	0.46	0.40	0.64	0.53	0.82	0.87
1994	0.54	0.10	0.36	0.50	0.38	0.52
1995	0.63	0.65	0.82	0.79	0.78	0.88
	Mean r^2 (Pooled Data) = 0.52			Mean r^2 (Pooled Data) = 0.70		

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Attachment 3
Effects of Flow Augmentation on Snake River Fall Chinook

J.J. Anderson, R.A. Hinrichsen and C. Van Holmes
March 15, 2000

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1. Introduction

Snake River summer flow augmentation has been used in recent years in an attempt to improve the survival of fall chinook from the Snake River basin.[1] A number of studies have been conducted to evaluate and improve the effectiveness of flow augmentation. Studies on the spawning, rearing and migratory requirements of fall chinook salmon were conducted in the Columbia River basin in the early 1990s (Rondorf and Miller, 1993; Rondorf and Miller 1994; Rondorf and Tiffan, 1994). Studies in 1994 and 1995 (Connor et al. 1996 and 1997) characterized the early life history of Snake River fall chinook and their survival to Lower Granite Dam. Using data from 1991-1995, Giorgi and Schlecte (1997) assessed the volume and shape of flow augmentation delivered in the Snake River basin and attempted to evaluate the consequences of the augmentation on ESA-listed salmon stocks in the drainage using the CRiSP 1.5 smolt passage model (Anderson et al. 1996). In 1999, the PATH (Plan for Analyzing and Testing Hypotheses) analysis group developed spawner recruit data for Snake River fall chinook and addressed issues on the impacts of fish transportation and dam removal on fall chinook (Peters, Marmorek and Parnell eds. 1999). In a four-year study (1995-1998), environmental variables were correlated with fall chinook survival in the Snake and Clearwater Rivers (Williams and Bjornn 1997; Williams and Bjornn 1998; Muir et al. 1999). Finally, in a September 1999 draft White Paper, NMFS reviewed recent data analysis on the effects of flow management in the Columbia River and salmon travel time and survival (NMFS 1999). NMFS concluded: "Direct evidence for a survival benefit to fall chinook from flow management is strongly supported by research results" and "thus, with the existing project configuration and outmigration timing, additional flow augmentation to benefit Snake River fall chinook salmon would likely increase survival."

The objective of this report is to review the existing data with thorough statistical and ecological analysis to quantitatively assess the impacts of flow and flow augmentation and to identify the possible mechanisms by which flow acts on fall chinook survival.

Whereas the NMFS draft White Paper focused on demonstrating correlations between survival and environmental variables, our approach is to address mechanisms as well as correlations. In this manner, we provide a more ecologically-based assessment of the impacts of flow and flow augmentation on fish survival.

In the September 1999 draft White Paper on flow and survival, NMFS justifies flow augmentation for Snake River fall chinook based on four main points:

- In the reaches above dams (life stage 1), travel time is not related to flow but NMFS believes smolts may stop or slow migration as flow decreases and water temperature increases.
- In the reaches above dams (life stage 1), a flow-survival relationship exists within the migration season, and correlations of flow with water clarity and temperature require managers to consider both quality and quantity when managing flows to benefit fall chinook.
- In the hydrosystem (life stage 2), no direct flow survival benefits are detected.
- However, NMFS believes that good flow (spill conditions) since the 1995 BiOP may provide survival benefits downstream as smolts migrate through the estuary and into the near ocean (life stage 3).

However, the recent studies have emphasized that impacts of flow are uncertain because other environmental variables also change at the same time as flow and may affect fish survival. Furthermore, although the studies to date have focused on the correlation between natural seasonal variations in water properties and fish survival, our emphasis is on addressing the impacts of flow augmentation that occurs in addition to the seasonal variations of flow.

2. Approach and Objective

Our objective is to address the impacts of flow augmentation on the outmigration of fall chinook from the Snake River system through ocean entry. We begin by considering

[1]Fall chinook are also known as ocean-type chinook or sub-yearling migrants.

the general life history of these fish. Snake River fall chinook spawn in the Snake River below Hells Canyon Dam. The eggs hatch in early spring. The juveniles rear in the Snake River above Lower Granite Dam in the spring and the smolts slowly migrate out of the Snake River, passing Lower Granite Dam in the summer. The smolt rate of migration increases as they move downstream, beginning at 2 to 5 km per day above Lower Granite Dam and increasing up to 30 km per day as they pass McNary Dam. Smolts reach the estuary in late summer, enter the ocean, and migrate north. The adults spend several years in the ocean where they are caught in fisheries as far north as Alaska. On the return, fall chinook are caught primarily in British Columbia, Oregon, and Washington coastal fisheries, and in the Columbia River. The adults enter the Columbia River in the late summer and pass Lower Granite Dam in September and October.

Our approach is to assess, in a statistical and ecologically mechanistic framework, how flow augmentation affects survival of fall chinook smolts from the beginning of the migration in the Snake and Clearwater Rivers (Figure 1, path 1) through hydrosystem passage (Figure 1, path 2) and into the estuary and ocean (Figure 1, path 3). We consider four sources of data: 1) PIT tag studies, which cover fish survival from the rearing habitat to Lower Granite Dam (Figure 1, path 1) and through the hydrosystem (Figure 1, path 2); 2) spawner-recruit data, which expresses the survival of fish from spawning in the tributaries through freshwater outmigration through the estuary to ocean residence and adult migration back to the spawning grounds (Figure 1, path 4); 3) water quality and flow data from the Snake and Columbia River system; 4) passage timing information of wild fall chinook at Lower Granite Dam.

We first review the studies relating seasonal changes in flow to fish travel time and survival and expand on the analysis conducted by NMFS in their Flow Survival Draft White Paper (NMFS 1999). In the draft White Paper, NMFS concluded that the environmental variables and survival were confounded making it difficult to resolve the impact of flow on fish with its approach. We apply additional statistical methods to clarify the collinearity of the data and show that it is unlikely that flow is the driving factor in the seasonal survival pattern. We next explore the impacts of flow augmentation on environmental variables and fish survival. Taking a mechanistic approach, we find that the seasonal relationships cannot be extrapolated to infer the impacts of flow augmentation on fish. We apply the CRiSP smolt passage model to quantify the likely impacts of Snake and Clearwater augmentation on smolt survival to Lower Granite and Bonneville Dams and find that flow augmentation from Brownlee Reservoir has no discernible effect on survival, but there is a survival benefit from Dworshak Reservoir flow augmentation. Finally, we consider the impacts of flow from a fish life cycle perspective. We find that flow has an insignificant effect on spawner to recruit survival for fish in both the Columbia and Snake River basins. In conclusion, we reconcile the strong seasonal flow/survival relationship discussed by NMFS with the nonexistent year-to-year flow survival relationship and the ineffectiveness of flow augmentation from the Snake River.

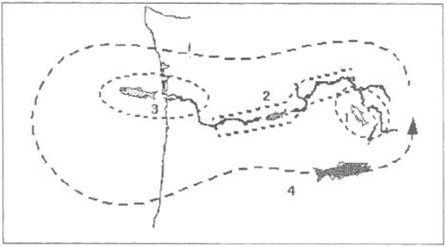

Figure 1. Life cycle stages for which survival data are available.

3. The 1995-1998 Survival Studies

The assessment of the impacts of flow on freshwater juvenile chinook survival are based on the 1995-1998 PIT-tag studies of fish released above Lower Granite Dam. Information on the studies is published in annual reports for 1995 (Williams et al. 1997), for 1996 (Williams et al. 1998), for 1997 (Muir et al. 1999), and for 1998 (Muir in press).

In these studies, PIT-tagged cohorts of fall chinook from Lyons Ferry Hatchery were released at Pittsburg Landing, which is near the upstream end of the fall chinook habitat in the Snake River, at Billy Creek in the Snake River just upstream of the Snake/Clearwater River confluence, and at Big Canyon Creek in the Clearwater River watershed (Figure 2). The fish were detected at Lower Granite Dam. Sixty-two groups of hatchery fish were released over the four years. The reports show fall chinook survival and travel time correlations to indices of flow, temperature, and water clarity.[2] The indices were defined as average values of the environmental variables between the release date and the passage of 5% of the group at Lower Granite Dam. These indices were selected to characterize the conditions experienced by most of the fish after release and before initiation of migration. The general belief is that the fish move quickly to the head of Lower Granite pool where they rear until they reach a size sufficient to begin the downstream migration. The indices based on 5% arrival are intended to characterize the time the fish are in their rearing habitat. The NMFS studies also determined the downstream survival and travel time to Lower Monumental Dam.

The analysis in the reports found that, within a season, fall chinook survival between release location and Lower Granite dam was correlated with flow, temperature and water clarity, but that travel time was not correlated with survival. As the season progresses, flow decreases, while temperature and water clarity increase. The reports also noted that survival decreases markedly with groups released later in the migration season and that the environmental variables (flow, temperature and water clarity) were all significantly correlated with each other, and exhibited seasonal trends. Between Lower Granite Dam and Lower Monumental Dam, survival was not correlated with environmental variables (Muir et al. 1999).

Muir et al. (1999) suggested that river flow, water temperature, and water clarity might affect survival estimates in a number of ways. Hypothesized causes for lower survival of fish migrating later in the season may include disorientation of migrants under lower

[2]Water clarity is the inverse of turbidity that was used in the NMFS reports. Later in this paper, where NMFS data is used in regression analysis, its use of the term "turbidity" or "TURB" has been maintained, but the variable is actually water clarity.

flows, increased risk of predation and disease in the warmer waters, and increased water clarity later in the season, which makes the smolts more visible to predators.

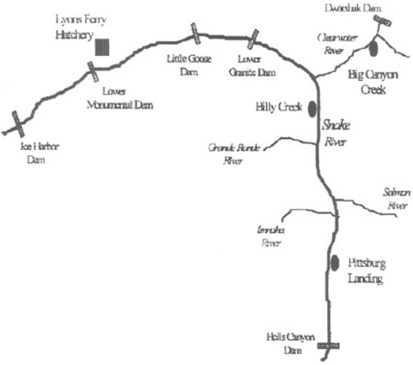

Figure 2. Study area showing location of Lyons Ferry Hatchery and the Pittsburg Landing, Billy Creek, and Big Canyon Creek release sites for the fall chinook survival studies (from Muir et al. 1999).

3.1 Seasonal cycles: flow, water temperature, clarity, survival, and travel time

Between the spring fry emergence and their arrival at Lower Granite Dam in the summer, the chinook are exposed to rapidly changing environmental conditions. During this time, the flows first increase due to the spring freshet and then decrease as the summer progresses. Water clarity follows the flow changes, decreasing as flow increases and then increasing over the summer as flow decreases. Temperature continually increases from winter through summer. Typical examples of the seasonal pattern of flow and temperature are illustrated in Figure 3. As described in a number of studies, all of these processes are related and are coupled to seasonal weather patterns (Rondorf and Miller 1993; Muir et al. 1999).

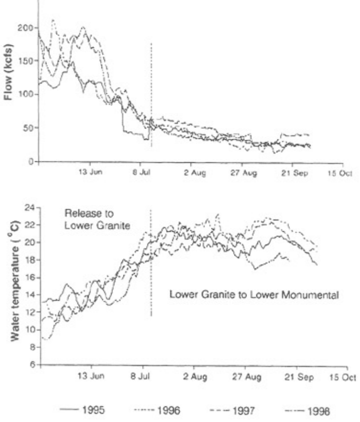

Figure 3. Seasonal patterns of temperature and flow at Lower Granite Dam.

The survival of subyearling fall chinook also exhibits a seasonal pattern. In the PIT tag studies, the fish released earlier in the season had the highest survival, while the fish released latest in the season had the lowest survival. This is evident in regressions of survival vs. release (Rls) day for each year (Table 1). The relationships are linear and the slope and intercept are very similar between years giving a good correlation when the data are combined into a single regression (Figure 4). The outlier was 1995, which was the first year of the study with a limited range of release dates. Fish at Pittsburg Landing and Billy Creek were released over a 9-day period in 1995 while in the other years the release dates extended over a month.

Table 1. Regressions of survival vs. release day (Rls), Survival = a + b * Rls.

	1995	1996	1997	1998	Total
Intercept (a)	1.8	3.29	2.74	2.37	2.69
Slope (b)	-0.0078	-0.0170	-0.0137	-0.0116	-0.0134
r-squared	0.93	0.92	0.81	0.73	0.79

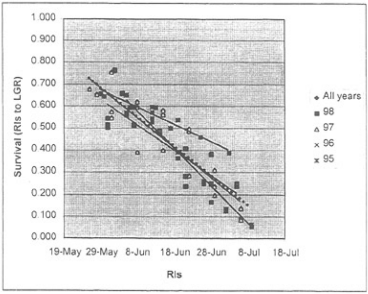

Figure 4. Survival from release to Lower Granite Dam exhibits a linear relationship with release day (Rls). Regression lines depict relationship in each year.

Release day of the fish varied from late May through early July. Over this period of time flow, temperature and water clarity increased in linear fashion (Table 2). The salient point is that survival and all of the environmental variables were strongly correlated with release day.

Table 2. Regressions of environmental variables against smolt release day.

	1995	1996	1997	1998	Total
	Flow = a + b * Rls				
Intercept (a)	345	451	690	287	473
Slope (b)	-1.57	-2.16	-3.38	-1.20	-2.24
r-squared	0.97	0.93	0.96	0.98	0.62
	Temperature = a + b * Rls				
Intercept (a)	-8.93	-8.97	-9.05	-7.11	-6.81
Slope (b)	0.159	0.151	0.151	0.148	0.142
r-squared	0.95	0.93	0.98	0.94	0.82
	Clarity = a + b * Rls				
Intercept (a)	-5.2	-11.6	-7.8	-1.8	-6.0
Slope (b)	0.054	0.087	0.058	0.029	0.053
r-squared	0.97	0.96	0.86	0.95	0.45

The strong linearity of survival and environmental variables with release date insures a strong linearity of each of the environmental variables with survival. As discussed below in the multiple regression analysis, the correlation between these variables does not imply that the survival can be attributed simply to changes in flow or any other single variable. The relationships between the environmental variables and survival are not as strong as the relationship between survival and release day. (The relationships with release day exhibit r-squares greater than or equal to the relationships with environmental variables, see Tables 1 and 3). The seasonal relationship between survival and the environmental variables was different for each year, shifting both the slope and the intercept (Figures 5, 6, 7). In contrast, the relationship between release date and survival was remarkably consistent from year-to-year (Figure 4).

Table 3. Regressions of survival against environmental variables.

	1995	1996	1997	1998	Total
	Survival = a + b * Flow				
Intercept (a)	0.15	-0.20	-0.03	-0.39	0.08
Slope (b)	0.0047	0.0071	0.0038	0.0095	0.0037
r-squared	0.86	0.81	0.74	0.71	0.48
	Survival = a + b * Temperature				
Intercept (a)	1.34	2.25	1.84	1.76	1.72
Slope (b)	-0.045	-0.110	-0.087	-0.752	-0.076
r-squared	0.84	0.92	0.74	0.72	0.61
	Survival = a + b * Water Clarity				
Intercept (a)	1.06	1.00	0.87	1.56	0.762
Slope (b)	-0.137	-0.18	-0.21	-0.37	-0.11
r-squared	0.86	0.90	0.79	0.65	0.35

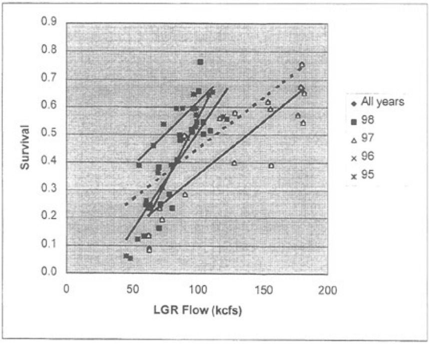

Figure 5. Relationship of survival to Lower Granite Dam and flow. Dashed line is the average regression over all years.

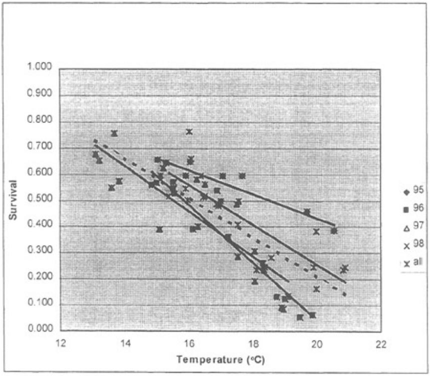

Figure 6. Survival vs. temperature for release to Lower Granite Dam. Dashed line is the average regression for all years.

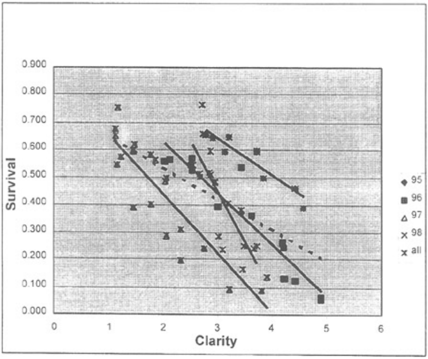

Figure 7. Survival vs. clarity for release to Lower Granite Dam. Dashed line is the average regression for all years.

These regressions suggest that there is no straightforward association between seasonal change in survival and any single environmental variable. Specifically, linear correlations of survival with seasonal flow cannot be directly extrapolated to impacts of flow augmentation on survival. The impacts of seasonally averaged flow are addressed in Section 3.2. The interactions of survival over season with a multiple regression technique are explored in Section 4 where a formal analysis is applied to determine which variables are most statistically significant in explaining survival. However, the statistical evaluation does not consider the mechanisms through which environmental variables act on smolt survival. The mechanistic or ecological processes are considered further in Section 7.

3.2. Hydrosystem survival and environmental factors

The fall chinook release studies from 1995, 1996 and 1997 indicate that survival between Lower Granite Dam and Lower Monumental Dam had no consistent year-to-year relationship with environmental conditions (Muir et al. 1999).

3.3 Migration and environmental factors

In this section, we consider how flow and temperature are related to fish migration properties including the rate of fish migration, travel time from release to Lower Granite Dam and arrival date at Lower Granite Dam. Studies by Connor, Berge and Miller (1993, 1994) considered the rate of migration between release of tagged cohorts and their arrival at Lower Granite Dam. Using a multiple linear regression, they suggested that flow was a dominant factor in determining the migration rate of juvenile fall chinook. However, the PIT-tag studies in 1995-1998 did not support a well-defined relationship between migration rate or travel time and environmental variables. The lack of a relationship is illustrated in Figure 8 and Table 4, which shows the travel time vs. flow for the 1995-1998 studies. The relationship is poor within a year, and the slope and intercept of the flow travel time relationship is highly variable between years. Only in the high flow year of 1997 was there a suggestion that increased flow decreased smolt travel time. In other years, flow exhibits little correlation with travel time; from this we conclude that flow is not related to the travel time of the smolts to Lower Granite Dam. The regressions in Tables 9a and 9b also illustrate that travel time is not correlated with temperature or water clarity.

Table 4. Regressions of travel time vs. flow. Travel time = a + b * Flow.

	1995	**1996**	**1997**	**1998**	**Total**
Intercept (a)	67	48	56	37	55
Slope (b)	-0.116	0.010	-0.136	0.009	-0.118
r-squared	0.25	0.004	0.59	0.003	0.21

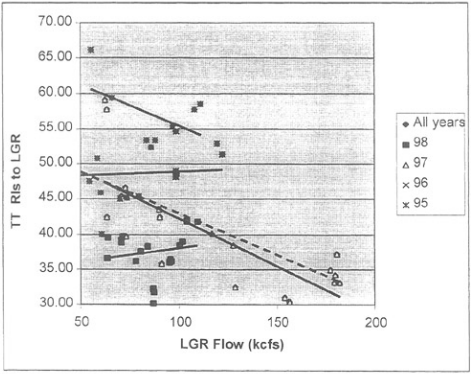

Figure 8. Regressions of flow to travel time of smolts to Lower Granite Dam for each year and for all years (dashed line).

A second measure of smolt migration is the arrival time at Lower Granite Dam. This is a different measure from travel time or migration rate because it involves the date of release in addition to the rate of migration. The arrival time of wild fall chinook smolts to Lower Granite Dam is related to temperature (Peters et al. 1999), the belief being that fish do not begin active migration until they have reached a certain size and they reach the size faster at higher temperatures. Zabel (1999) determined that the arrival time at Lower Granite Dam is linearly related to mean temperature in the first 180 days of the year. The choice of dates over which temperature was averaged was not sensitive to characterizing the temperature- arrival time relationship (Figure 9).

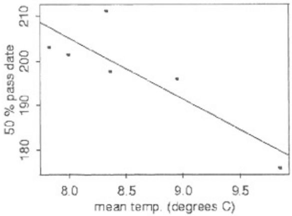

Figure 9. Median passage day of year vs. mean temperature for the years 1992-1997 (from Zabel 1999).

To identify if flow relates to fall chinook arrival timing at Lower Granite Dam, the arrival distribution of Snake River fall chinook was regressed against the average flow in June and July at Lower Granite Dam. Arrival distributions of wild fall chinook were obtained from the Columbia Basin Research — In Season Forecasts webpage at www.cbr.washington.edu/crisprt/index.html. This was supplemented with information from Townsend, Skalski and Yasuda (1996). Flows were obtained from DART www.cbr.washington.edu/dart. The data are given in Table 5 and a regression of arrival date against average flow is shown in Figure 10. The r-squared value is 0.01 and the slope of flow to arrival date is essentially flat. Thus, the results are not sensitive to the selection of dates over which the average flow is defined. This analysis indicates that there is no relationship between average seasonal flow and arrival date.

Table 5. Wild Subyearling Chinook -- Snake River outmigration timing characteristics and flows (kcfs) at Lower Granite Dam.

	----------- Passage Dates ----------					LGR flow
Year	**5%**	**10%**	**50%**	**90%**	**95%**	
1985			07/04			49
1986			06/29			71
1991			07/17			55
1992			06/24			27
1993	06/26	07/01	07/27	09/02	10/25	76
1994	06/23	06/30	07/17	09/03	11/01	39
1995	06/20	06/22	07/23	09/18	10/26	88
1996	06/01	06/06	07/12	08/21	10/31	98
1997	06/09	06/13	07/07	08/14	10/13	118
1998	06/09	06/21	07/09	08/10	10/19	92
1999	06/08	06/11	06/29	08/20	10/16	98

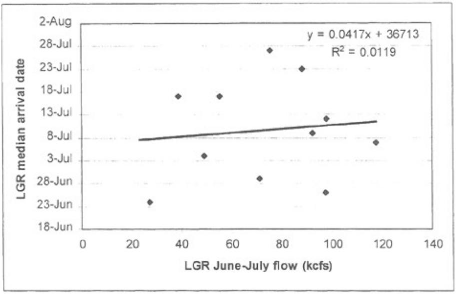

Figure 10. Relationship between Lower Granite Dam June-July average flow and wild fall chinook Lower Granite Dam arrival date.

3.4 Yearly averaged flow survival relationship

Although seasonal variations in survival are evident, a strong seasonal survival relationship with environmental variables does not imply that year-to-year differences in total flow over the outmigration equate to strong year-to-year differences in the survival of the outmigrating population. To explore this, we characterize the yearly average flow survival of juvenile fall chinook in two ways. First, a simple unweighted average of survivals and flows for each year in the 1995-1998 studies was calculated. Second, the individual releases in each year were weighted by the fraction of the total fall chinook outmigration passing Lower Granite Dam at the same time as the average arrival time for each release group. With the available data, we can only define a yearly flow survival relationship based on four data points (Table 6). In particular, in the high flow year 1997, the average survival was no greater than the average survival from the normal flow years of 1995, 1996 and 1998 (Figure 11). This result stands in contrast to the NMFS draft White Paper claim that flow augmentation benefits fish even at high flows: NMFS states, "Benefits of additional flow continue at flows well above those recently observed during a wetter than average hydrologic condition which included the use of stored water to augment flows (NMFS 1999)." The yearly flow survival relationship is not only statistically insignificant, the data indicates that the effect is minuscule. Using the regression in Table 6, a 10 kcfs increase to an 80 kcfs flow would increase survival to Lower Granite Dam from 50% to 50.4%. Our analysis also indicates that yearly average temperature and water clarity exhibits no relationship with yearly average fall chinook survival.

Table 6. Flow survival regression S = a + b * Flow for seasonal data average by unweighted and weighted by smolt passage index. $\Delta S = (S_{80}-S_{70})/S_{80}$ is a relative increase in survival with a 10 kcfs increase in flow where S_{80} and S_{70} are survivals at 80 and 70 kcfs Lower Granite Dam flows.

Type	a	b	R^2	ΔS
Unweighted	0.39	0.0006	0.014	0.013
Weighted	0.45	0.005	0.048	0.010

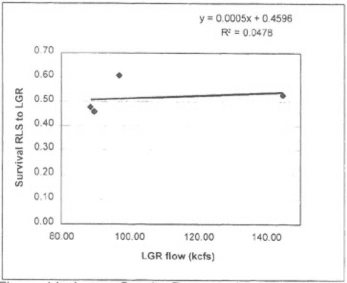

Figure 11. Lower Granite Dam yearly average flow against survival. 1997 flow is at145 kcfs.

3.5 Conclusions from the fall chinook survival studies

Smolt survival to Lower Granite Dam, water temperature, water clarity, and flow exhibit statistically significant linear correlations with smolt release date. Statistically significant correlations between survival and the environmental variables were also found but those relationships were not as significant as the correlation between survival and release date.

Smolt survival and travel time from Lower Granite Dam to Lower Monumental Dam exhibited no consistent year-to-year relationship with flow or other environmental parameters.

Arrival timing of smolts at Lower Granite Dam was related to temperature. Arrival timing had no relationship with flow.

While flow and survival to Lower Granite Dam were related within the year, no relationship exists between years for average flow and survival.

4. Multiple Regressions with PIT-tag Data

4.1 Separating environmental effects

Statistically determining how passage survival relates to environmental variables is essentially impossible because the environmental variables (migration timing, temperature, water clarity, flow, and smolt travel time) are highly correlated with one another. The usual method of determining the statistical effect of each of the environmental variables is to place them in a linear regression as predictor variables (predictors), using survival as the response variable. In the best case, the predictors will not be related to one another, so that each supplies a statistically unique contribution to the regression; this yields useful information about the statistical effect of each predictor on survival. Frequently, however, when analyzing environmental data, the predictors are related in such a way that multiple linear regression results are nonsensical. This is the curse of *collinearity* that often plagues nonexperimental data analysis (Belsley 1991). Collinearity occurs because, *statistically*, the set of predictors contains redundant information. As a result, the model is unable to separate out the unique contribution of each predictor to changes in survival. In other words, the effects are confounded. In a laboratory setting, investigators solve the problem of confounded variables by manipulating the different predictors; usually by varying one predictor while holding the others constant. However, with respect to Snake River flows, it is not feasible to manipulate the temperature, flow, or water clarity regimes in such a way that they are unrelated over time. Flow naturally decreases through the summer coincident with increasing temperatures and increasing water clarity. These natural relationships are difficult (perhaps impossible) to substantially alter by manipulation of the hydrosystem.

4.2 Collinearity

Can collinearity really be detected in multiple regressions of passage survival against the predictors migration timing, temperature, water clarity, flow, and smolt travel time? Absolutely. The telltale signs of collinearity are: high standard errors of the regression coefficients (poor precision) and nonsensical or overly sensitive parameter estimates. To illustrate this, consider the regression of passage survival against flow:

$$\text{survival}_i = B0_{year} + B1_{year} * \text{Flow}_i + \varepsilon_i$$

where $B0_{year}$ and $B1_{year}$ are year-specific regression coefficients, allowing a different intercept and slope for each individual year (1995-1998), and ε_i is a normal error term to account for the unexplained variations in survival and the real errors in measurements of survival and flow. In Table 7, a single regression, the estimates of the slopes of the flow-survival relationship are precise (much smaller than the estimated effect of flow on survival) and the slope for each year is statistically significant at the 0.05 level (denoted by *). However, when temperature is added to the regression, the flow coefficients become nonsignificant and their standard errors are large (Table 8). This classic case of collinearity occurs because flow and temperature are highly correlated in each year of study (Tables 9a and 9b). The *least* correspondence between flow and temperature is seen in 1996 when the correlation is r = -0.965, close to the perfect (negative) correspondence (r = -1). In each year of study, decreases in flow over the season coincide with increases in temperature. (This does not mean that increasing flow through augmentation, however, will decrease temperature. The effects of augmentation on temperature are discussed below.) Tables 9a and 9b demonstrate that, due to the high correspondence between all of the predictors, collinearity will be a problem regardless of what subset of predictors is chosen. The effects of how migration timing, temperature, water clarity, flow, and smolt travel time relate to survival are impossible to ascertain through multiple regressions. In particular, multiple linear regressions cannot be used to infer the impacts of flow over the migration season.

Table 7. Regressions of passage survival against predictor variables. * indicates significance at the α = 0.05 level.

Flow (S =Year + Year×Flow + epsilon)

Parameter	Value	Std. Error	t value	
YEAR95	0.15	0.158	0.93	
YEAR96	-0.20	0.081	-2.47	*
YEAR97	-0.03	0.058	-0.48	
YEAR98	-0.39	0.132	-2.93	*
YEAR95Flow	0.00	0.002	2.69	*
YEAR96Flow	0.01	0.001	7.15	*
YEAR97Flow	0.00	0.000	8.44	*
YEAR98Flow	0.01	0.001	6.31	*

Temperature (S = Year + Year×Temp + epsilon)

	Value	Std. Error	t value	
YEAR95	1.34	0.273	4.90	*
YEAR96	2.25	0.232	9.69	*
YEAR97	1.85	0.156	11.81	*
YEAR98	1.76	0.195	9.02	*
YEAR95Temp	-0.05	0.016	-2.85	*
YEAR96Temp	-0.11	0.013	-8.20	*
YEAR97Temp	-0.09	0.010	-9.10	*
YEAR98Temp	-0.08	0.011	-6.82	*

Table 7 continued on next page

Turbidity (S = Year + Year×Turb + epsilon)

	Value	Std. Error	t value	
YEAR95	1.06	0.175	6.04	*
YEAR96	1.01	0.085	11.87	*
YEAR97	0.87	0.051	17.16	*
YEAR98	1.56	0.175	8.90	*
YEAR95Turb	-0.14	0.048	-2.86	*
YEAR96Turb	-0.19	0.024	-8.01	*
YEAR97Turb	-0.22	0.023	-9.27	*
YEAR98Turb	-0.37	0.057	-6.46	*

Travel time (S = Year + Year×TT + epsilon)

	Value	Std. Error	t value	
YEAR95	1.26	0.749	1.68	
YEAR96	0.84	0.490	1.72	
YEAR97	1.20	0.179	6.68	*
YEAR98	0.53	0.426	1.24	
YEAR95TT	-0.01	0.013	-0.93	
YEAR96TT	-0.01	0.010	-1.00	
YEAR97TT	-0.02	0.004	-4.35	*
YEAR98TT	0.00	0.011	-0.22	

Release Day (S = Year + Year×Rls + epsilon)

	Value	Std. Error	t value	
YEAR95	1.84	0.390	4.71	*
YEAR96	3.29	0.329	10.02	*
YEAR97	2.74	0.224	12.24	*
YEAR98	2.37	0.258	9.19	*

Table 8. Regressions of passage survival against two predictor variables. * indicates significance at the $\alpha = 0.05$ level.

Flow and Temperature (S =Year + Year×Flow + Year×Temp + epsilon)

Parameter	Value	Std. Error	t value	
YEAR95	-0.4582	3.632	-0.13	
YEAR96	3.1624	1.167	2.71	*
YEAR97	1.0539	1.566	0.67	
YEAR98	0.8888	1.373	0.65	
YEAR95Flow	0.0071	0.014	0.50	
YEAR96Flow	-0.0029	0.004	-0.80	
YEAR97Flow	0.0016	0.003	0.51	
YEAR98Flow	0.0039	0.006	0.64	
YEAR95Temp	0.0231	0.139	0.17	
YEAR96Temp	-0.1504	0.052	-2.89	*
YEAR97Temp	-0.0501	0.072	-0.69	
YEAR98Temp	-0.0450	0.048	-0.93	

Flow and Turbidity (S =Year + Year×Flow + Year×Turb + epsilon)

Parameter	Value	Std. Error	t value	
YEAR95	0.4886	1.868	0.26	
YEAR96	1.8588	0.736	2.53	*
YEAR97	0.5286	0.199	2.65	*
YEAR98	-0.4991	1.064	-0.47	
YEAR95Flow	0.0030	0.010	0.31	
YEAR96Flow	-0.0052	0.004	-1.16	
YEAR97Flow	0.0016	0.001	1.75	
YEAR98Flow	0.0100	0.005	1.96	*
YEAR95Turb	-0.0519	0.283	-0.18	
YEAR96Turb	-0.3171	0.113	-2.81	*
YEAR97Turb	-0.1404	0.048	-2.90	*
YEAR98Turb	0.0221	0.207	0.11	

Table 8 continued on next page

Table 8 (continued)

Flow and Travel Time (S =Year + Year×Flow + Year×TT + epsilon)

Parameter	Value	Std. Error	t value	
YEAR95	0.3233	0.577	0.56	
YEAR96	0.4046	0.273	1.48	
YEAR97	0.3272	0.220	1.49	
YEAR98	-0.0500	0.248	-0.20	
YEAR95Flow	0.0044	0.002	2.30	*
YEAR96Flow	0.0072	0.001	7.71	*
YEAR97Flow	0.0030	0.001	4.41	*
YEAR98Flow	0.0098	0.001	6.86	*
YEAR95TT	-0.0026	0.008	-0.32	
YEAR96TT	-0.0127	0.005	-2.30	*
YEAR97TT	-0.0064	0.004	-1.67	
YEAR98TT	-0.0099	0.006	-1.57	

Flow and Rls (S =Year + Year×Flow + Year×Rls + epsilon)

Parameter	Value	Std. Error	t value	
YEAR95	3.5582	3.439	1.03	
YEAR96	4.4928	1.462	3.07	*
YEAR97	4.9981	1.561	3.20	*
YEAR98	3.7902	3.033	1.25	
YEAR95Flow	-0.0050	0.010	-0.50	
YEAR96Flow	-0.0027	0.003	-0.84	
YEAR97Flow	-0.0033	0.002	-1.46	
YEAR98Flow	-0.0049	0.011	-0.47	
YEAR95Rls	-0.0156	0.016	-0.99	
YEAR96Rls	-0.0227	0.007	-3.21	*
YEAR97Rls	-0.0248	0.008	-3.22	*
YEAR98Rls	-0.0175	0.013	-1.38	

Table 9a. Correlations between predictors.

1995

	S	TT	Rls	Flow	Temp	Turb
S	1.000	-0.556	-0.963	0.929	-0.916	-0.926
TT	-0.556	1.000	0.480	-0.503	0.559	0.408
Rls	-0.963	0.480	1.000	-0.988	0.972	0.987
Flow	0.929	-0.503	-0.988	1.000	-0.993	-0.987
Temp	-0.916	0.559	0.972	-0.993	1.000	0.976
Turb	-0.926	0.408	0.987	-0.987	0.976	1.000

1996

	S	TT	Rls	Flow	Temp	Turb
S	1.000	-0.219	-0.961	0.901	-0.960	-0.947
TT	-0.219	1.000	0.170	0.061	0.114	0.060
Rls	-0.961	0.170	1.000	-0.963	0.981	0.980
Flow	0.901	0.061	-0.963	1.000	-0.965	-0.980
Temp	-0.960	0.114	0.981	-0.965	1.000	0.995
Turb	-0.947	0.060	0.980	-0.980	0.995	1.000

1997

	S	TT	Rls	Flow	Temp	Turb
S	1.000	-0.767	-0.898	0.862	-0.863	-0.888
TT	-0.767	1.000	0.791	-0.771	0.755	0.825
Rls	-0.898	0.791	1.000	-0.985	0.991	0.928
Flow	0.862	-0.771	-0.985	1.000	-0.991	-0.887
Temp	-0.863	0.755	0.991	-0.991	1.000	0.898
Turb	-0.888	0.825	0.928	-0.887	0.898	1.000

1998

	S	TT	Rls	Flow	Temp	Turb
S	1.000	-0.050	-0.855	0.842	-0.847	-0.809
TT	-0.050	1.000	-0.123	0.172	0.040	-0.034
Rls	-0.855	-0.123	1.000	-0.993	0.971	0.977
Flow	0.842	0.172	-0.993	1.000	-0.972	-0.964
Temp	-0.847	0.040	0.971	-0.972	1.000	0.971
Turb	-0.809	-0.034	0.977	-0.964	0.971	1.000

Table 9b. R-squared of correlation between predictors.

1995

	S	TT	Rls	Flow	Temp	Turb
S	1.000	0.309	0.927	0.863	0.839	0.857
TT	0.309	1.000	0.231	0.253	0.313	0.166
Rls	0.927	0.231	1.000	0.977	0.946	0.975
Flow	0.863	0.253	0.977	1.000	0.986	0.973
Temp	0.839	0.313	0.946	0.986	1.000	0.953
Turb	0.857	0.166	0.975	0.973	0.953	1.000

1996

	S	TT	Rls	Flow	Temp	Turb
S	1.000	0.048	0.923	0.812	0.922	0.896
TT	0.048	1.000	0.029	0.004	0.013	0.004
Rls	0.923	0.029	1.000	0.927	0.962	0.960
Flow	0.812	0.004	0.927	1.000	0.930	0.960
Temp	0.922	0.013	0.962	0.930	1.000	0.991
Turb	0.896	0.004	0.960	0.960	0.991	1.000

1997

	S	TT	Rls	Flow	Temp	Turb
S	1.000	0.588	0.806	0.743	0.745	0.788
TT	0.588	1.000	0.626	0.595	0.570	0.681
Rls	0.806	0.626	1.000	0.970	0.983	0.862
Flow	0.743	0.595	0.970	1.000	0.982	0.787
Temp	0.745	0.570	0.983	0.982	1.000	0.806
Turb	0.788	0.681	0.862	0.787	0.806	1.000

1998

	S	TT	Rls	Flow	Temp	Turb
S	1.000	0.003	0.732	0.710	0.717	0.654
TT	0.003	1.000	0.015	0.030	0.002	0.001
Rls	0.732	0.015	1.000	0.985	0.942	0.954
Flow	0.710	0.030	0.985	1.000	0.945	0.929
Temp	0.717	0.002	0.942	0.945	1.000	0.943
Turb	0.654	0.001	0.954	0.929	0.943	1.000

4.3 Model selection

Despite the difficulties of collinearity in the multiple regression analysis, we can determine what single predictor or group of predictors provides the best fit to the passage survival data. We examined models defined by all possible combinations of five predictor variables: single predictors (5 models), two predictors (10 models), three predictors (10 models), four predictors (5 models), all five predictors (1 model) and no predictors (1 model), for a total of 32 different models. For fit criteria, we used the standard AIC and BIC goodness-of-fit criteria which weigh the better fit provided by an additional predictor variable against a penalty for its inclusion. The AIC and BIC scores provide measures for selecting a "best" model; that is, a model that best explains the variance in survival (a good fit with the response variable), without over-parameterizing (Akaike 1973, Schwarz 1978).

Mathematically, these criteria are described by

$$AIC = -2 * \log(\text{Likelihood}) + 2 * p$$

$$BIC = -2 * \log(\text{Likelihood}) + \log(n) * p$$

where Likelihood is the likelihood function (evaluated at the maximum likelihood estimates), n is the number of observations, and p is the number of parameters. For both of these criteria, lower numbers imply better fit. The BIC penalizes the addition of parameters more heavily than the AIC criteria, as evidenced by the BIC's penalty term $\log(n) * p$ which is larger than the AIC's penalty term of $2 * p$ when $n>8$.

Based on the AIC criteria, the best of the 32 models examined contains migration timing, as quantified by day of release (Rls), and water temperature (Temp). No other predictor variables, including flow, were needed to explain the survival (Table 10a). This model however, shows minuscule improvement in AIC over the model that contains migration timing (Rls) alone. The best model in terms of BIC contains only migration timing (Rls) (Table 10b). The parameter estimates and r^2 values for these two models are contained in Tables 11a and 11b. The model that contains both migration timing and temperature (the best based on AIC) is plagued by collinearity because these predictors are highly correlated (r>0.97 for each year, Table 9). For this model, therefore, the estimated effects of temperature (Temp) and migration timing (RIs) are generally imprecise and at times nonsensical (Table 11). Most of the slope coefficients are not significant. For this reason, on a statistical basis, the regression model that contains migration timing alone (the one selected by the BIC) is preferable because it has a good fit to the data (the best based on BIC), its parameters are estimated with high precision, and the parameter estimates are all statistically significant.

Notice that migration timing (RIs), temperature (Temp), and turbidity (Turb = water clarity) are each superior to flow (Flow) as predictor variables. Only travel time (TT) is a worse predictor than flow. Based on these results, flow would not be selected as a predictor in the multiple regressions because using migration timing alone, or a combination of migration timing and temperature, provides a superior fit to the survival data.

Table 10a. Models ordered by AIC, with larger negative AIC indicating better fit.

Covariates Included	n	p	ss	aic	bic	r^2	Rank
Temp+Rls	62	12	0.29	-132.8	-107.3	0.98	1
Rls	62	8	0.33	-132.6	-115.6	0.98	2
Temp+Turb+Rls	62	16	0.26	-130.5	-96.5	0.98	3
Turb+Rls	62	12	0.30	-129.8	-104.3	0.98	4
TT+Rls	62	12	0.31	-128.7	-103.2	0.98	5
Flow+Rls	62	12	0.31	-128.6	-103.1	0.98	6
Temp+TT+Rls	62	16	0.27	-128.5	-94.4	0.98	7
Turb+TT+Rls	62	16	0.27	-128.1	-94.0	0.98	8
Flow+Temp+Rls	62	16	0.27	-128.1	-94.0	0.98	9
Temp+Turb+TT+Rls	62	17	0.27	-126.5	-90.3	0.98	10
Flow+Turb+Rls	62	16	0.28	-125.9	-91.8	0.98	11
Flow+Temp+Turb+Rls	62	17	0.28	-125.0	-88.9	0.98	12
Flow+TT+Rls	62	16	0.29	-124.3	-90.3	0.98	13
Temp+Turb	62	12	0.33	-124.1	-98.6	0.98	14
Flow+Turb+TT+Rls	62	17	0.29	-123.1	-87.0	0.98	15
Flow+Temp+TT+Rls	62	17	0.29	-122.5	-86.3	0.98	16
Flow+Temp+Turb+TT+Rls	62	21	0.26	-122.2	-77.5	0.98	17
Flow+Turb	62	12	0.34	-122.1	-96.6	0.98	18
Temp	62	8	0.39	-121.7	-104.7	0.97	19
Flow+Turb+TT	62	16	0.31	-120.9	-86.9	0.98	20
Turb	62	8	0.40	-120.6	-103.5	0.97	21
Flow+Temp+Turb+TT	62	17	0.31	-119.2	-83.0	0.98	22
Temp+TT	62	12	0.36	-118.9	-93.4	0.97	23
Flow+Temp+Turb	62	16	0.32	-118.0	-84.0	0.98	24
Temp+Turb+TT	62	16	0.32	-117.9	-83.9	0.98	25
Flow+TT	62	12	0.38	-116.6	-91.1	0.97	26
Turb+TT	62	12	0.38	-116.2	-90.6	0.97	27
Flow+Temp+TT	62	16	0.33	-116.0	-81.9	0.98	28
Flow+Temp	62	12	0.38	-115.6	-90.1	0.97	29
Flow	62	8	0.46	-112.6	-95.6	0.97	30
TT	62	8	1.36	-44.8	-27.8	0.90	31
Year Effect Only	62	4	1.89	-32.6	-24.0	0.86	32

Table 10b. Models ordered by BIC, with larger negative BIC indicating better fit.

Covariates Included	n	p	ss	aic	bic	r^2	Rank
Rls	62	8	0.33	-132.6	-115.6	0.98	1
Temp+Rls	62	12	0.29	-132.8	-107.3	0.98	2
Temp	62	8	0.39	-121.7	-104.7	0.97	3
Turb+Rls	62	12	0.30	-129.8	-104.3	0.98	4
Turb	62	8	0.40	-120.6	-103.5	0.97	5
TT+Rls	62	12	0.31	-128.7	-103.2	0.98	6
Flow+Rls	62	12	0.31	-128.6	-103.1	0.98	7
Temp+Turb	62	12	0.33	-124.1	-98.6	0.98	8
Flow+Turb	62	12	0.34	-122.1	-96.6	0.98	9
Temp+Turb+Rls	62	16	0.26	-130.5	-96.5	0.98	10
Flow	62	8	0.46	-112.6	-95.6	0.97	11
Temp+TT+Rls	62	16	0.27	-128.5	-94.4	0.98	12
Turb+TT+Rls	62	16	0.27	-128.1	-94.0	0.98	13
Flow+Temp+Rls	62	16	0.27	-128.1	-94.0	0.98	14
Temp+TT	62	12	0.36	-118.9	-93.4	0.97	15
Flow+Turb+Rls	62	16	0.28	-125.9	-91.8	0.98	16
Flow+TT	62	12	0.38	-116.6	-91.1	0.97	17
Turb+TT	62	12	0.38	-116.2	-90.6	0.97	18
Temp+Turb+TT+Rls	62	17	0.27	-126.5	-90.3	0.98	19
Flow+TT+Rls	62	16	0.29	-124.3	-90.3	0.98	20
Flow+Temp	62	12	0.38	-115.6	-90.1	0.97	21
Flow+Temp+Turb+Rls	62	17	0.28	-125.0	-88.9	0.98	22
Flow+Turb+TT+Rls	62	17	0.29	-123.1	-87.0	0.98	23
Flow+Turb+TT	62	16	0.31	-120.9	-86.9	0.98	24
Flow+Temp+TT+Rls	62	17	0.29	-122.5	-86.3	0.98	25
Flow+Temp+Turb	62	16	0.32	-118.0	-84.0	0.98	26
Temp+Turb+TT	62	16	0.32	-117.9	-83.9	0.98	27
Flow+Temp+Turb+TT	62	17	0.31	-119.2	-83.0	0.98	28
Flow+Temp+TT	62	16	0.33	-116.0	-81.9	0.98	29
Flow+Temp+Turb+TT+Rls	62	21	0.26	-122.2	-77.5	0.98	30
TT	62	8	1.36	-44.8	-27.8	0.90	31
Year Effect Only	62	4	1.89	-32.6	-24.0	0.86	32

Table 11a. Survival dependent on migration timing only.

Parameter	Value	Std. Error	t value	
YEAR95	1.839	0.390	4.71	*
YEAR96	3.293	0.329	10.02	*
YEAR97	2.737	0.224	12.24	*
YEAR98	2.373	0.258	9.19	*
YEAR95Rls	-0.008	0.002	-3.27	*
YEAR96Rls	-0.017	0.002	-8.96	*
YEAR97Rls	-0.014	0.001	-10.33	*
YEAR98Rls	-0.012	0.002	-7.53	*

R^2=0.976

* *Indicates significance at the 0.05 level*

Table 11b. Survival model including Rls and temperature.

Parameter	Value	Std. Error	t value	
YEAR95	2.002	0.660	3.03	*
YEAR96	2.817	0.638	4.41	*
YEAR97	4.161	0.625	6.66	*
YEAR98	2.193	0.384	5.72	*
YEAR95Rls	-0.011	0.010	-1.08	
YEAR96Rls	-0.009	0.009	-0.94	
YEAR97Rls	-0.037	0.010	-3.80	*
YEAR98Rls	-0.008	0.006	-1.26	
YEAR95Temp	0.018	0.060	0.30	
YEAR96Temp	-0.053	0.062	-0.86	
YEAR97Temp	0.157	0.065	2.43	*
YEAR98Temp	-0.025	0.041	-0.62	

R^2=0.979

* *Indicates significance at the 0.05 level*

4.4 Conclusions of multiple regression analysis

1) Due to high correlations between variables, it is impossible to statistically separate the effects of migration timing, temperature, water clarity, flow, and travel time on passage survival using the fall chinook PIT-tag survival data (1995-1998). Thus, the actual effect of flow on survival cannot be estimated reliably.

2) The models providing the best fit to the survival data are (1) the model containing migration timing alone and (2) the model containing migration timing and temperature. However, model (2) is plagued by collinearity and the estimated effects of migration timing and temperature are imprecisely estimated. As predictors of survival, migration timing, temperature, and water clarity are superior to flow. This conclusion is based on examining 32 possible models, defined by all possible combinations of the predictor variables.

3) The multiple regression analysis indicates that statistical correlations of survival with seasonal flow are insufficient to infer the impacts of flow on survival. Furthermore, inferences on the impacts of flow *augmentation* on survival are even more problematic. Therefore, to evaluate the impacts of flow augmentation we must take a mechanistic approach that includes the ecological principles on how flow augmentation may affect smolt survival.

5. Effects of Flow Augmentation

To evaluate the impacts of flow augmentation, we need to consider the nature of the source of the flow and its impacts on environmental parameters. It is not enough to infer that seasonal relationships between flow and survival, with or without collinearity, can be simply extrapolated to the effects of flow augmentation. The impact of flow augmentation on river conditions depends on the source of the augmentation and the time of the year. The Snake River system has two augmentation sources, Dworshak Reservoir on the Clearwater River and Brownlee Reservoir Dam on the Snake River. Giorgi et al. (1997) evaluated the impacts of augmentation in the period 1991 through

1995 and concluded that augmentation for fall chinook occurred in July and August from both Dworshak and Hells Canyon. Seasonal water released from the storage reservoirs in the Snake basin increased from 1.35 million-acre-feet (maf) in 1992 to a high of 2.65 maf in 1994. In the Upper Snake River, the 427 kaf target for augmentation was satisfied in all years if augmentation in September is included.

To disentangle the relationship between flow augmentation and fall chinook survival, we need to consider the direct and indirect impacts of seasonal and augmented flows on chinook survival (Figure 12). In particular, we need to consider the impacts of augmentation on the juvenile fall chinook prior to their arrival at Lower Granite Dam. Survival of smolts in the reaches above Lower Granite Dam primarily depends on the amount of predation by smallmouth bass, walleye and northern pikeminnows (Zimmerman 1999). This predator-prey interaction depends on the travel time (TT) of the smolts out of the habitat, the predator reaction distance (RD), which is the distance at which a predator can see and attack a smolt, and the metabolism of the predator (M). In turn, the travel time may depend on the water velocity and the behavior of the fish to the velocity, which changes as fish grow (G). Reaction distance depends on visibility as characterized by water clarity, and the frequency of predation attacks depends on the predator metabolism, which increases with water temperature. The only direct effect of seasonal and augmentation flows is through water velocity, which may affect smolt travel time. The effects of seasonal and augmented flows on water temperature and visibility may indirectly affect smolt survival. Each of the direct and indirect effects of seasonal and augmented flows must be considered. It is not sufficient to simply infer the effects of seasonal flow from correlations while ignoring the ecological mechanisms.

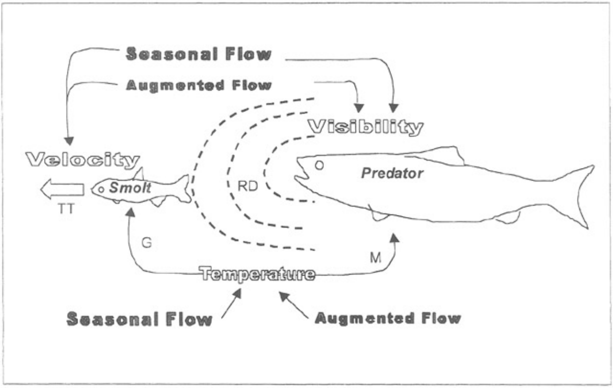

Figure 12. Conceptual diagram illustrating direct and indirect effects of seasonal and augmentation flows on smolt survival.

Figure 12 also characterizes the movement and survival of smolts through the hydrosystem including specific mortality effects of the dams. For subyearling migration in the summer, the main impact of the dams is direct mortality in dam passage. Since total dissolved gas levels are low in the summer, the effects of gas supersaturation from planned or forced spill do not need to be considered.

5.1 Flow augmentation and temperature

A number of studies have demonstrated that augmentation from Hells Canyon does not have an appreciable effect on downstream temperatures, while augmentation from Dworshak does (Bennett, Karr and Madsen 1994; Giorgi et al.,1997; Connor, Garcia, Burge and Taylor 1993;Connor, Bjornn, Burge, Garcia and Rondorf. 1997). To evaluate the impacts on temperature from augmentation, Giorgi et al. (1997) correlated temperature data with augmentation flows at Anatone gage on the Snake River, 76 km downstream of Hells Canyon Dam, at Peck gage 23 km downstream of the Dworshak Dam, and at the Lower Granite Dam. Temperatures during a base line period between 1981-1990 were compared to the temperatures during the augmentation period 1991-1995. The impacts of augmentation on temperature were determined by comparing the difference in the baseline and augmentation temperatures to the augmentation flows. Two regression approaches demonstrated that Dworshak Reservoir augmentation affected temperatures, while the Hells Canyon augmentation had little or no effect on temperature in the Snake River.

This difference in the effect of augmentation in the Clearwater and Snake systems reflects the difference in the storage water temperatures relative to the unregulated stream temperatures. Flow in the Snake River comes from Brownlee Reservoir through the Hells Canyon complex, which represents about 50 to 70% of the water flowing through the lower Snake River above the confluence of the Clearwater (Connor et al. 1993). The remaining contributions come from the Salmon, the Imnaha and the Grande Ronde Rivers. The temperatures of these rivers are similar to each other and the mainstem; thus, flow augmentation from Hells Canyon affects flow but not temperature. The temperature in Hells Canyon is influenced by the air temperature 14 to 30 days prior to flow release from the reservoirs (Connor et al. 1993). In contrast, augmentation from Dworshak Reservoir is with reservoir water that is about 10°C, while the other branches of the Clearwater are on the order of 5 to 10° C warmer. Therefore, augmentation from Dworshak Reservoir has an impact on the Clearwater at the confluence of the Snake and Clearwater Rivers and is evident down to Lower Granite Dam. The characteristic summer temperature distribution in the Snake River system above Lower Granite Dam is illustrated in Figure 13.

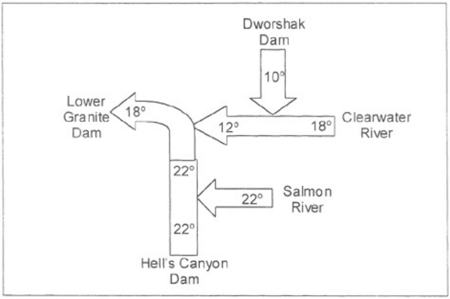

Figure 13. Summer temperatures of normal flows of the Snake River system.

5.2 Flow augmentation and water clarity

The impact of flow augmentation on water visibility has not been evaluated but the mechanisms again depend on the water clarity of the storage reservoirs relative to the clarity of the unregulated streams. Water transparency, or clarity, is measured by the Secchi depth. (Note this measure has been misnamed in the NMFS reports as Turbidity, which moves inversely to water clarity, so that turbidity is higher when water clarity is lower.) A regression of the Secchi depth against seasonal flow has a linear relationship, with visibility decreasing as flow increases. Secchi depth is related to the predator-prey reaction distance. The larger the Secchi reading, the further away the predator can detect a smolt. The Secchi depth and the predator-prey reaction distance both decrease as the concentration of suspended material in the water increases. In turn, the suspended material depends on water velocity and flow, giving a mechanistic basis for the observed seasonal relationship between clarity and flow. The effect of Hells Canyon flow augmentation on water clarity depends on the difference in the clarity of the storage reservoir augmentation flow relative to the clarity of the unregulated stream flows, including the Imnaha, Salmon and Grande Ronde Rivers. If the clarity of water from the storage reservoirs is greater than unregulated streams, because suspended material has settled in the reservoirs, then the augmentation would be expected to increase water clarity, which could increase the rate of predation on smolt.

5.3 Flow augmentation and water velocity

Flow augmentation has been typically applied in the spring and summer to address migration of the yearling and the subyearling chinook. In the 1991-1995 period, spring augmentation increased velocities through Lower Granite Pool an average of 3 to 13% (Giorgi et al. 1997). During the summer, augmentation from Dworshak and Brownlee combined contributed between 5 and 38% of the velocity at Lower Granite Dam. Of this total, the Brownlee can contribute only about one quarter of the flow.

5.4 Flow augmentation and fish travel time

The direct impact of flow on fish survival could be through its impact on travel time of fish from release to Lower Granite Dam. In turn, the seasonal relationship between flow and travel time could be representative of the impacts of flow augmentation. However, flow has no discernable impact on fish travel time (Figure 8). Therefore, flow augmentation would have no impact on fish travel time.

5.5 Conclusions on the effects of flow augmentation

Flow augmentation may affect smolt survival directly through the change in water velocity and indirectly through the changes in temperature and water clarity.

Upper Snake River flow augmentation does not appreciably affect water temperature through the Hells Canyon reach or in Lower Granite Pool. Augmentation from Dworshak lowers the temperature in Lower Granite Pool.

The impact of flow augmentation on water clarity has not been resolved. However, augmentation could increase water clarity, which would increase smolt predation.

Flow augmentation has no discernable impact on fish travel time to Lower Granite Dam or through the hydrosystem.

6. Model Analysis of Flow Augmentation

To further explore the complex effects of flow augmentation in the presence of seasonally changing flows and temperatures we have used the CRiSP smolt passage model. This model simulates the daily movement and survival of fish through the Columbia River system and is based on ecological relationships describing smolt migration and survival. The model describes survival in terms of temperature and travel time of smolt and can characterize the direct and indirect effects of flow on survival. The calibrated model can be used to simulate the individual impact of flow augmentation from the Hells Canyon (Brownlee) and Dworshak storage reservoirs.

6.1 CRiSP description

CRiSP follows the mortality dynamics illustrated in Figure 12, where the activity of predators depends on temperature while the exposure of smolts to predators depends on the smolt travel time (Anderson et al. 1996; Anderson et al. 2000). The model characterizes flow temperature relationships in terms of releases from storage reservoirs and unregulated streams as is illustrated in Figure 13. Flow acts directly on fish travel time using the migration model developed by Zabel and Anderson (1997) and Zabel et al. (1998). Flow acts indirectly on fish via the relationship of flow and temperature from storage reservoirs and the unregulated streams. The model does not consider water clarity. For fall chinook the equation describing smolt survival, S, takes the form

$$S = \exp(\, g(\text{Temp}) * TT(\text{flow, release date})\,)$$

where g is a function of the daily temperature (Temp), TT is fish travel time and is a function of daily flow and the release date of the fish. Note also that temperature is related to flow and day of year.

Travel time between release and arrival at Lower Granite Dam in CRiSP was calibrated with the fall chinook PIT-tag studies discussed in Section (3). For survival of fall chinook through the hydrosystem, CRiSP was calibrated as part of the PATH analysis (Peters, Marmorek and Parnell eds. 1999). In the calibration (Anderson et al. 2000), a nonlinear calibration technique is used in an iterative fashion; first calibrating travel time using flow and smolt date of release and an approximate survival rate. Next, the survival is calibrated using calibrated travel time parameters and temperature. In the second round, the calibrated survival is used in place of the approximated survival and travel time is recalibrated. This in turn is used to recalibrate survival. The calibration between travel time and survival is repeated until the results converge. This iterative process is required because the arrival time distribution of smolts at Lower Granite Dam can be skewed by the mortality rate and the mortality rate, in turn, depends on travel time.

Since the CRiSP model was calibrated with the same data used in the multiple correlation analysis of Section 4, it suffers from problems of collinearity among environmental variables. The model equations explicitly make temperature a primary factor affecting survival and make flow a secondary factor, similar to that found with the multiple linear regression analysis. The CRiSP model provides information about fall chinook and flow augmentation that cannot be obtained from the multiple linear regressions. First, the basic equation above is a better representation of the underlying ecological processes than the multiple linear descriptions of survival against environmental variables. Second, because CRiSP represents the river geometry and the daily variations of flow and temperature, it can be used to evaluate the individual contributions of flow augmentation from the Dworshak and Hells Canyon (Brownlee) storage reservoirs as the hydrosystem operations change.

6.2 Flow augmentation estimates

To explore the impacts of flow augmentation from each storage reservoir and the combination of reservoirs, a matrix of impacts was evaluated in which augmentation was removed, doubled or left unchanged for each reservoir (Table 12). For each scenario, the CRiSP model was run under the calibration conditions for 1995 through 1998 using the actual release locations and dates of the PIT-tag fish discussed in Section 3. In each run, survival for each PIT tag release was determined to Lower Granite Dam and from Lower Granite Dam to Bonneville Dam. In addition, the average Lower Granite Dam flow and temperature during the migration were simulated in each augmentation scenario.

Table 12. Flow augmentation scenarios run with CRiSP. 1 = existing flow augmentation, 0 = no flow augmentation, 2 = doubling flow augmentation.

Scenario	1	2	3	4	5	6	7
Brownlee	1	0	0	0	1	2	2
Dworshak	1	0	1	2	0	0	2

The scenarios with existing flow augmentations used the observed daily flows and temperatures from the Dworshak and Hells Canyon (Brownlee) Reservoirs. To represent zero augmentation from the Dworshak Reservoir, flows during the fall outmigration were removed (Compare Figure 14 with Dworshak flow augmentation to Figure 15, which is Dworshak flow without augmentation). For the doubling scenarios, the observed Dworshak flows were increased by a factor of two. For Hells Canyon (Brownlee) augmentation scenarios, the estimated augmentation obtained from the Idaho Department of Water Resources, were subtracted from observed Hells Canyon Dam flows to represent the no flow augmentation scenarios and the estimated augmentations were added to the observed dam flows to represent the flow doubling scenarios. Note that the zero and double augmentation scenarios are not necessarily hydraulically possible. They were used in this analysis to explore the sensitivity of fish survival to the individual flow augmentation scenarios. The total yearly estimated flow augmentation volumes provided by the Idaho Department of Water Resources are given in Table 13.

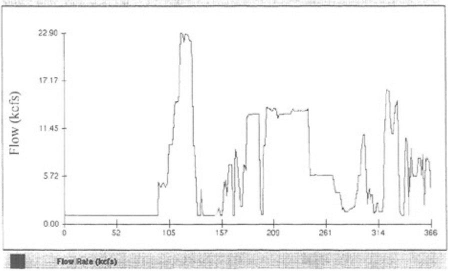

Figure 14. 1995 Dworshak flow vs. day of year with augmentation.

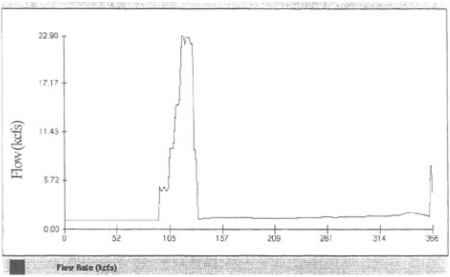

Figure 15. 1995 Dworshak flow vs. day of year without augmentation.

Table 13. Yearly flow augmentation estimate (maf). Data source: Idaho Department of Water Resources.

Reservoir	1995	1996	1997	1998
Hells Canyon (Brownlee)	0.52	0.68	0.65	0.77
Dworshak	1.40	1.87	1.64	1.25

6.3 Augmentation effects on survival and environmental variables

To explore the individual contribution of augmentation from each reservoir, the percent change in survival to Lower Granite and Bonneville Dams was defined relative to the base conditions with the actual flows in the years 1995-1998. The relative measure of survival change is defined

$$\Delta S = 100 * (S_1 - S_i)/S_1$$

where S_1 is survival from release to arrival at a dam from a particular release site under existing conditions (Scenario 1), and S_i is survival with an addition or deletion of flow augmentation from a particular reservoir or combinations of reservoirs (Scenario I).

The relative effects of augmentation on survival to Lower Granite and Bonneville Dams are given in Tables 14 and 15 for flow augmentation scenarios 1-7. Relative survival, ΔS, and absolute survival, S, are given for each release site averaged over the four years. A comparison of Scenario 1 to 3 in Table 14 illustrates that removing augmentation from Hells Canyon (Brownlee) increases survival. This is because the Brownlee augmentation increases water temperature, which is a major factor in determining survival in the CRiSP model.

Table 15a shows the models predictions of average changes in flow and temperature at Lower Granite Dam over the fall chinook migration season with the seven flow augmentation scenarios. Table 15b shows the difference in flow, temperature and maf for each Scenario relative to the base condition, Scenario 1. Removing the Hells Canyon (Brownlee) augmentation decreases the flow by about 5 kcfs and lowers the temperature about 0.1 °C.

Table 14. Relative change in average Snake River fall chinook survival to Lower Granite and Bonneville Dams, ΔS (%), and average in-river survival, S (%), under different flow augmentation scenarios. Averages are over years 1995-1998.

Scenario	1	2	3	4	5	6	7
Aug. Brownlee	1	0	0	0	1	2	2
Aug. Dworshak	1	0	1	2	0	0	2
Fall Chinook Survival Rls thru LGR Dam							
Average Survival	38	33	39	52	33	33	46
ΔS	0	-11	3	37	-13	-12	22
Survival from LGR thru Bon Dam							
Average Survival	38	35	37	39	35	36	39
ΔS	0	-8	-4	1	-8	-6	2
Survival from Rls thru Bon Dam							
Average Survival	14	12	14	20	12	12	18
ΔS	0	-19	-1	38	-20	-17	24

Table 15a. Scenario average flows (kcfs) and temperatures (centigrade) plus flow augmentation (maf) between day 160 and 220. Results for Lower Granite Dam over years 1995-1998 and 1998 at Bonneville Dam.

Scenario			1995 LGR			1996 LGR			1997 LGR			1998 LGR			1998 BON		
#	BRN	DWK	flow	temp	maf	flow	temp	maf	flow	temp	maf	flow	temp	maf	flow	temp	maf
1	1	1	67.9	18.2	1.3	84.4	17.1	1.1	97.7	17.5	1.9	73.8	18.9	1.6	225.4	20.6	19.6
2	0	0	57.0	18.8	0.0	74.8	17.3	0.0	82.0	18.3	0.0	60.3	19.3	0.0	212.0	20.5	18.0
3	0	1	65.2	18.0	1.0	83.8	17.1	1.1	95.3	17.3	1.6	69.3	18.7	1.1	221.0	20.5	19.1
4	0	2	73.8	17.0	2.0	86.9	15.9	1.4	104.5	16.5	2.7	78.6	17.2	2.2	230.3	20.0	20.2
5	1	0	59.8	18.9	0.3	78.7	17.4	0.5	84.4	18.4	0.3	64.7	19.5	0.5	216.4	20.6	18.5
6	2	0	62.5	18.9	0.6	82.6	17.5	0.9	86.8	18.5	0.6	69.2	19.6	1.1	220.8	20.7	19.1
7	2	2	79.2	17.4	2.6	94.6	16.4	2.4	109.3	16.8	3.2	87.5	17.9	3.2	239.2	20.2	21.2

Table 15b. Difference between Scenarios 2-7 and Scenario 1 for average flows (kcfs), temperatures (centigrade), and flow augmentation (maf) between day 160 and 220. Predictions for Lower Granite Dam for years 1995-1998 and 1998 at Bonneville Dam.

	1995 LGR			1996 LGR			1997 LGR			1998 LGR			1998 BON		
#	flow	temp	maf	flow	temp	maf	flow	temp	maf	flow	temp	maf	flow	temp	maf
2 - 1	-10.9	0.6	-1.3	-9.6	0.1	-1.1	-15.7	0.9	-1.9	-13.5	0.4	-1.6	-13.5	0.0	-1.6
3 - 1	-2.7	-0.2	-0.3	-0.7	0.0	-0.1	-2.4	-0.2	-0.3	-4.4	-0.2	-0.5	-4.4	-0.1	-0.5
4 - 1	5.8	-1.2	0.7	2.4	-1.2	0.3	6.9	-1.0	0.8	4.9	-1.6	0.6	4.9	-0.5	0.6
5 - 1	-8.2	0.7	-1.0	-5.8	0.3	-0.7	-13.3	1.0	-1.6	-9.1	0.6	-1.1	-9.1	0.1	-1.1
6 - 1	-5.5	0.7	-0.6	-1.9	0.4	-0.2	-10.9	1.0	-1.3	-4.6	0.7	-0.5	-4.6	0.2	-0.5
7 - 1	11.2	-0.8	1.3	10.2	-0.7	1.2	11.7	-0.7	1.4	13.7	-1.0	1.6	13.7	-0.3	1.6

6.4 Conclusions on passage model analysis

The CRiSP passage model simulates smolt survival in terms of travel time, which is flow related, and temperature, which is related to the flows of the unregulated streams and the flows from the storage reservoirs. The model can evaluate the individual impacts of augmentation from Dworshak and Brownlee storage reservoirs.

The model was used to determine the survival impacts of Scenarios that removed or doubled flow augmentation from Hells Canyon (Brownlee) and Dworshak individually and together. Survival was simulated from the Snake River fall chinook habitat to Lower Granite and Bonneville Dams. The model predicts that removing Hells Canyon (Brownlee) flow augmentation decreases flow, decreases water temperature and increases fish survival.

7. Analysis of Fall Chinook Spawner-Recruit (SR) Data

To consider the effects of flow on the returns of progeny adults, we use the conceptual spawner recruit model illustrated in Figure 16. Mature adults return in the autumn to lay their eggs. The eggs hatch and fry emerge in the spring. In the summer, the young fish move down river and enter the estuary and ocean in the late summer. The adults spend several years in the ocean and then return to the Snake River to spawn. Seasonal flows may affect the eggs and juveniles prior to their migration, and juveniles during their migration to the sea. The information on Snake River spawners and recruits (adult progeny) is on a (brood) yearly basis, so that there is only one pair of spawner and recruit numbers for each brood year. Thus, analysis of SR data reflects between-year variation in survival, not within-year variation. To compare the effects of flows on SR relationships the flows must be seasonally averaged.

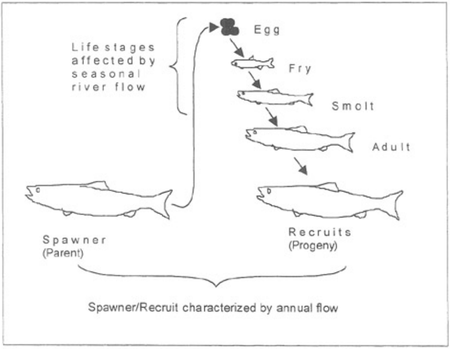

Figure 16. Life cycle framework with early life stage related to seasonal flows and spawner-recruit relationships related to annual flows.

The relationship between spawners and recruits is revealed by plotting the total recruits produced by each spawning cohort (Figure 17). Because the freshwater habitat is limited, the rate of mortality increases with increasing population size. This "density dependent" mortality makes the relationship between the number of spawners and the number of recruits domed shaped. At equilibrium, the number of recruits exactly replaces the spawning population, S^*. Below S^* there is a surplus recruit production, and above S^* the recruit production is not sufficient to replace the spawners. In our analysis we apply the classical Ricker spawner recruit equation to characterize these life cycle relationships. The equation can be expressed

$$R = S \exp(a - b S)$$

where R is the number of recruits returning to the river from the spawning population of size S, a is the average productivity rate over the years of data, and b is the density dependent factor expressing the decrease in stock productivity as the carrying capacity of the habitat S* is approached.

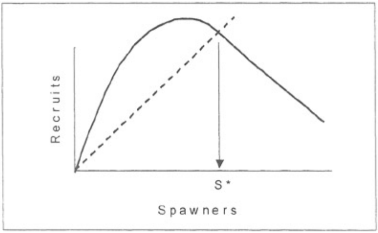

Figure 17. Ricker spawner recruit relationship showing equilibrium point S*.

7.1 Approach

In this analysis, we examine whether there is a statistically significant relationship between flow and life-cycle survival for three different Columbia River fall chinook stocks, the Hells Canyon stocks in the Snake River, the Hanford Reach stocks in the mid-Columbia, and Deschutes River stock in the Lower Columbia. The approach is to determine whether there is a significant effect of flow that can be detected in the spawner recruit (SR) data that extends back to the 1960s (for the Snake and Hanford stocks) and to Brood Year (BY) 1977 for the Deschutes stock. There are many assumptions behind the SR data used for this analysis (Peters et al. 1999), but these data remain the best available indicator of life-cycle survival over a long time record.

The index populations used for this report are the Snake River Bright, the Hanford Reach Upriver Bright, and the Deschutes River Upriver Bright. The characteristics of these populations are listed in Table 16. For each of these populations, spawners (S) and recruits (R) are estimated for each year. The spawners represent the total adults (age 3-6) that spawn, including both natural and hatchery origin fish, and are indexed by the year of spawning. The recruits represent the progeny of a spawner group and are indexed by the year the group spawns. For BY1991, for example, the recruits represent the number of offspring produced by the adults that spawned in year 1991. The recruits (offspring) are counted as adults returning to the mouth of the Columbia, adjusted to represent offspring that would have returned to the Columbia's mouth had harvest not occurred. This allows an estimate of the year-to-year fluctuations in recruitment not due to harvest, but perhaps due to environmental influences. Because these data are derived from many expansions and assumptions (Peters et al. 1999), it is best to view them as representing an index of spawners and recruits, with the understanding that they probably contain large, unknown, measurement errors and biases. Table 17 contains the SR data for the three index stocks.

Daily average flow records were available at Bonneville Dam and Ice Harbor Dam for the entire record of SR data. To characterize the relationship of flow and survival, two places and periods were used for estimating average flow: 1) average Bonneville Dam flows between July 15 and September 15 were used to characterize the flows that affect survival while smolts passed through the estuary; 2) average Ice Harbor flows in June and July were used to characterize the flows that affect survival prior to arrival in the hydrosystem.

Since the flows are correlated between Bonneville and Lower Granite Dams, characterizing the flow survival using the flow from either region should be similar. However, since the Lower Columbia flows are two to three times larger than the Snake River flows, the inferred effects of augmentation using the Lower Granite Dam flows would be two to three times larger than using the Bonneville Dam flows. Thus, establishing a correlation between flow and spawner recruit data does not tell us where the effect occurs. If it occurs in the estuary, then using the Lower Granite flows for the correlation could overestimate the impact of flow augmentation by two to three times. Our approach is to correlate SR based survival to flows when the fish are in the tributaries (June-July) and when they are in the estuary (July 15 to September 15). The flows are indexed by brood year, so that the average daily flow during June-July 1991, for example, is indexed by BY1990. The BY1990 flow thus represents the flow experienced by the progeny of spawners in 1990 during their out migration in 1991. Table 18 contains the daily average flow data used in the analysis.

Table 16. Wild fall chinook index populations in Columbia and Snake River basins.

Stock	Years of S-R Data	# Dams Passed	Distance From Ocean (km)
Snake River above Lower Granite	1964-1991	8	720
Columbia River at Hanford Reach	1964-1991	4	79
Deschutes River	1977-1991	2	167

Table 17. Fall chinook spawner-recruit data. D = Deschutes, H = Hanford Reach, S = Snake River.

Brood Year	Stock	S	R	Stock	S	R	Stock	S	R
1964				H	22703	100043	S	7648	35240
1965				H	26668	239681	S	6339	62471
1966				H	29724	193231	S	8623	34329
1967				H	24638	307471	S	10414	71436
1968				H	24035	263670	S	17556	48681
1969				H	28937	286328	S	4649	35129
1970				H	20511	590130	S	4353	43363
1971				H	26393	471622	S	4091	22699
1972				H	19327	361190	S	1371	17390
1973				H	36343	398212	S	2194	15716
1974				H	28940	333580	S	668	12910
1975				H	34628	268136	S	1387	10619
1976				H	39987	108581	S	691	7019
1977	D	6414	17641	H	40745	107827	S	1011	9259
1978	D	4099	16172	H	21644	56563	S	841	4946
1979	D	3728	15831	H	24840	164027	S	802	11657
1980	D	2788	15490	H	21224	304686	S	515	7817
1981	D	4704	17145	H	14213	265436	S	878	4746
1982	D	5176	15725	H	22598	458905	S	1209	7500
1983	D	4160	16090	H	37038	647038	S	842	8723
1984	D	2690	56348	H	48149	956878	S	552	9721
1985	D	6333	11974	H	71732	274308	S	885	4821
1986	D	6045	11576	H	100626	239529	S	1067	4971

Table 17 continued on next page

1987	D	6278	4125	H	105347	101086	S	462	2171
1988	D	7903	8804	H	96329	96391	S	495	3748
1989	D	3927	10043	H	72022	151284	S	418	2031
1990	D	2320	14416	H	47856	131271	S	63	975
1991	D	3684	5765	H	37580	38067	S	509	717

Table 18. Average daily flows (kcfs).

Actual Year	Brood Year	Bonneville Flow (July15-Sept15)	Ice Harbor (June July)
1965	1964	182	102
1966	1965	158	41
1967	1966	173	93
1968	1967	162	63
1969	1968	134	59
1970	1969	129	98
1971	1970	169	118
1972	1971	192	105
1973	1972	121	37
1974	1973	182	136
1975	1974	142	115
1976	1975	225	83
1977	1976	100	28
1978	1977	149	79
1979	1978	114	50
1980	1979	125	75
1981	1980	164	77
1982	1981	176	116
1983	1982	173	96
1984	1983	147	126
1985	1984	100	49
1986	1985	134	71
1987	1986	108	23
1988	1987	107	33
1989	1988	99	50
1990	1989	130	50
1991	1990	150	55
1992	1991	113	27

7.2 Correlation analysis

For each of these stocks, we fit Ricker-type models to the SR data (Ricker 1975). For the correlation analysis, we fit Ricker models of the form:

$$\log(R_i/S_i) = a - bS_i + \varepsilon_i$$

for each of the three index stocks. The resulting series of residuals, ε_i, then contains the deviations of the actual log(R/S) from that estimated by the line a - bS_i. During years of higher-than-predicted log(R/S), the corresponding residual is positive; during years of lower-than-predicted log(R/S), it is negative. Thus, the time series of residuals represents a trace of how life-cycle survival, measured by log(R/S), has changed over time. This series can then be matched against the flow time series in an attempt to detect a relationship between flow and life-cycle survival (Figure 16). A correlation table quickly reveals little correspondence between flow and life-cycle survival for any of the three index stocks. We examined the correlation over two periods: 1) BY1964-1991 and, 2) BY1977-1991 and for two flow averages: 1) June and July for Ice Harbor flow to represent the possible of effects of tributary flows on survival in the western reaches of the Lower Snake River basin and, 2) July 15 to September 15 for Bonneville Dam flows to represent the possible effects of flows in the estuary on life cycle survival. We included the BY1977-1991 correlations because one could argue that only after the Snake dams were in place did a relationship form between flow and survival. The low correlations, however, do not support a flow-survival relationship (Table 19 and Figure 18).

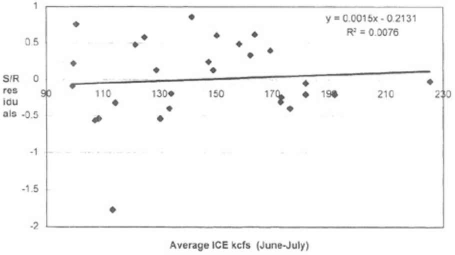

Figure 18. SR/ Residuals against average Ice Harbor Dam flows in June-and July.

Table 19. Correlations of brood year to flows.

Correlations (BY1964-1991)	Snake Residuals	Hanford Residuals	Bon Flow (Jul15-Sep15)	Ice Harbor (June July)
Snake Residuals	1.00			
Hanford Residuals	0.44	1.00		
Bon Flow(Jul15-Sep15)	0.09	0.22	1.00	
Ice Harbor (June-July)	0.23	0.38	0.68	1.00

Correlations (BY1977-1991)	Snake Residuals	Hanford Residuals	Deschutes Residuals	Bon Flow (Jul15-Sep15)	Ice Harbor (June-July)
Snake Residuals	1.00				
Hanford Residuals	0.47	1.00			
Deschutes Residuals	0.64	0.54	1.00		
Bon Flow(Jul15-Sep15)	0.21	0.19	0.09	1.00	
Ice Harbor (June-July)	0.37	0.39	0.34	0.78	1.00

7.3 Regression analysis

We also fit Ricker models of the form

$$\log(R_i/S_i) = a - b\ S_i + c\ Flow_i + \varepsilon_i$$

where the flow during migration enters directly into the Ricker equation. The goal is to formally test whether there is a correspondence between log(R/S) and migration flow (Flow) by fitting the model using least squares, then testing whether the estimate of the regression coefficient for migration flow, c, is significant. None of the regressions, for any of the stocks, or any of the periods (BY1964-1991 and BY1977-1991), indicated a significant ($\alpha = 0.05$) relationship between flow and log(R/S) (Tables 20 and 21). In other words, it is impossible to detect statistically an effect of flow on life-cycle survival. Each of the regressions did, however, indicate a slightly positive relationship, although not statistically significant relationship.

The possible benefits to life-cycle survival predicted by these estimates, however, are small. For the Snake River fall chinook, an increase in flow of 1 maf for 60 days, results in an estimated relative increase in life-cycle survival of 3.2% (based on BY1964-1991 regression) or 9.3% (based on the BY1977-1991 regression) (Tables 22 and 23). That is, if 1% of the smolts return as adults (SAR = 1%) then with a 1 maf augmentation from the Snake River basin the SAR becomes 1.03 to 1.09%. Therefore, not only are these effects not statistically significant, they are not biologically significant.

Table 20. Regression of log(R/S) against flow and S using July 15 to September 15 flows at Bonneville Dam.

Snake fall chinook (BY1964-1991)

Variable	coefficient	Value	Std. Error	t value	
(Intercept)	A	1.9180882	0.50137809	3.83	*
SPAWNERS	B	-5.554E-05	2.7877E-05	-1.99	
FLOW	c	0.0015612	0.00346965	0.45	
r^2=0.137					

Hanford fall chinook (BY1964-1991)

		Value	Std. Error	t value	
(Intercept)	a	1.8271988	9.15E-01	2.00	
SPAWNERS	b	-2.315E-05	6.48E-06	-3.57	*
FLOW	c	0.0066258	5.13E-03	1.29	
r^2=0.508					

Deschutes fall chinook (BY1977-1991)

		Value	Std. Error	t value	
(Intercept)	a	2.5415769	1.02669269	2.48	*
SPAWNERS	b	-0.0003643	9.7553E-05	-3.73	*
FLOW	c	0.0020087	0.00609241	0.33	
r^2=0.562					

Snake fall chinook (BY1977-1991)

		Value	Std. Error	t value
(Intercept)	a	1.4323303	0.9603595	1.49
SPAWNERS	b	-0.0004671	0.00062039	-0.75
FLOW	c	0.0065357	0.00721824	0.91
r^2=0.084				

Hanford fall chinook (BY1977-1991)

		Value	Std. Error	t value
(Intercept)	a	0.3169835	1.94E+00	0.16
SPAWNERS	b	-1.611E-05	9.92E-06	-1.62
FLOW	c	0.0149292	1.18E-02	1.26
r^2=0.487				

* indicates a significant parameter estimate

Table 21. Regression of log(R/S) data against S and Ice Harbor Dam flow June and July.

Snake fall chinook (BY1964-1991)

	Value	Std. Error	t value
(Intercept)	1.868856	0.263755	7.085585
SPAWNERS	-5.5E-05	2.66E-05	-2.083796
FLOW	0.00375	0.003233	1.159974

R^2=0.174

Snake fall chinook (BY1977-1991)

	Value	Std. Error	t value
(Intercept)	1.80039	0.473824	3.799702
SPAWNERS	-0.00075	0.000599	-1.246733
FLOW	0.010698	0.005966	1.793193

r^2=0.228

Note Ice Harbor Dam flow is significant at the 0.10 level but not the 0.05 level.

Table 22. Estimated survival change with augmentation based on Bonneville flow (August 15 to September 15).

MAF	KCFS	% Change In Survival
Hanford (BY1964-1991)		
-1.5	-12.45	-1.92
-1	-8.3	-1.29
-0.5	-4.15	-0.65
0	0	0.00
0.5	4.15	0.65
1	8.3	1.30
1.5	12.45	1.96
Hanford (BY1964-1991)		
-1.5	-12.45	-7.92
-1	-8.3	-5.35
-0.5	-4.15	-2.71
0	0	0.00
0.5	4.15	2.79
1	8.3	5.65
1.5	12.45	8.60

Table 22 continued on next page

Deschutes (BY1977-1991)		
-1.5	-12.45	-2.47
-1	-8.3	-1.65
-0.5	-4.15	-0.83
0	0	0.00
0.5	4.15	0.84
1	8.3	1.68
1.5	12.45	2.53
Snake (BY1977-1991)		
-1.5	-12.45	-7.81
-1	-8.3	-5.28
-0.5	-4.15	-2.68
0	0	0.00
0.5	4.15	2.75
1	8.3	5.57
1.5	12.45	8.48

Hanford (BY1977-1991)		
-1.5	-12.45	-16.96
-1	-8.3	-11.65
-0.5	-4.15	-6.01
0	0	0.00
0.5	4.15	6.39
1	8.3	13.19
1.5	12.45	20.43

Table 23. Estimated survival change for Snake River augmentations in June and July.

Snake Fall Chinook (BY1964-1991)

MAF	KCFS	% Change in Survival
-1.5	-12.45	-4.56
-1	-8.3	-3.06
-0.5	-4.15	-1.54
0	0	0.00
0.5	4.15	1.57
1	8.3	3.16
1.5	12.45	4.78

Snake Fall Chinook (BY1977-1991)

MAF	KCFS	% Change in Survival
-1.5	-12.45	-12.47
-1	-8.3	-8.50
-0.5	-4.15	-4.34
0	0	0.00
0.5	4.15	4.54
1	8.3	9.29
1.5	12.45	14.25

7.4 Conclusions of the SR analysis

There was no statistically discernable relationship (using $\alpha = 0.05$) between recruits per spawner (a measure of life-cycle survival) and flow during juvenile out migration for any of the three fall chinook index stocks studied.

The estimates of the effect of flow on life-cycle survival indicated only a 5 to 14% increase in survival for an increase in flow of 1.5 maf over 60 days. Thus, if SAR is 1%, the flow increase results in a SAR of 1.05 to 1.14%.

The models estimated a small change in survival for a decrease in flow of 1.5 maf over 60 days (survival decrease of 5 to 12%).

8. Discussion and Conclusion

In the NMFS draft White Paper on the effects of flow management on salmonid travel time and survival, NMFS concludes that direct evidence for a survival benefit to fall chinook from flow management is strongly supported by research results (NMFS 1999). Our evaluation of the data and mechanisms relating flow to fall chinook survival do not support the draft White Paper conclusion. We evaluated fall chinook survival, spawner recruit data, and environmental variable data from the NMFS and PATH studies. Our findings are in agreement with the basic elements of the NMFS and PATH analyses. However, when we consider in detail the difference between seasonal flow variation and flow augmentation, we conclude there is no evidence that Snake River flow augmentation has any measurable or ecologically significant impact on Snake River fall chinook.

We evaluated NMFS data and found a significant relationship between survival to Lower Granite Dam and the environmental variables. Using linear regression and multiple linear regression methods, as well as standard goodness-of-fit criteria, we found that the best predictors of seasonal changes in survival were release day and temperature, while flow was the poorest predictor of survival. We also evaluated the environmental factors that affect the arrival date of wild fall chinook to Lower Granite

Dam and found that while fish arrived earlier in the season if the temperature was warmer, flow was not a predictor of arrival time to the dam.

Although temperature plays a large role in fish behavior, temperature cannot be separated from the other environmental variables statistically. In order to understand the impacts of each variable, we considered the ecological principles affecting fish migration and survival. In terms of predator-prey interactions, flow might have a secondary impact on temperature. However, from reviewing studies on the impacts of flow augmentation on temperature, we found that flow augmentation from Brownlee Reservoir did not significantly affect the downstream temperature in Hells Canyon or in Lower Granite Reservoir. Therefore, the only direct effect of Snake River flow augmentation could be on fish travel time. However, we conclude there are no impacts because flow is unrelated to fall chinook travel time. In fact, there is evidence suggesting that Snake River flow augmentation will increase summer water temperature and water clarity, which would tend to increase the predation rate on smolt.

To quantify the impacts of flow augmentation, we used CRiSP 1.6, the newest version of the smolt passage model, as calibrated for the fall chinook analysis in PATH. This model was determined in PATH to be the best fitting available model for evaluating fall chinook smolt passage. We considered three augmentation regimes, the existing levels of flow augmentation in the years 1995-1998, doubling the augmentation over those years, and removing flow augmentation over those years. Contrary to the conclusions of the NMFS draft White Paper our analysis predicts that flow augmentation from Brownlee Reservoir model is detrimental to fall chinook. The highest Snake River fall chinook survivals were predicted with no Brownlee Reservoir flow augmentation.

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Attachment 4
Life Cycle Survivorship of Snake River Fall (Ocean-Type) Chinook

Executive Summary

Life cycle survival of Snake River ocean-type chinook is partitioned into five intervals:

1. Egg deposition to premigrant juveniles,
2. Juvenile migration,
3. Estuarine/marine occupancy,
4. Adult migration, and
5. Adult maturation.

Median survival from egg deposition to premigrant juvenile is estimated to be $S_1 = 0.115$ based on 35 observations.

Survival during juvenile migration is negatively correlated with distance traveled. Reach survival estimates have been converted to survival per unit distance traveled. The median survival per kilometer traveled, based on 97 PIT-tagged cohorts, was S/km = 0.995.

Highly variable estimates of survival during estuarine/marine occupancy are reported in the literature. The various studies are based on non PIT-tagged cohorts. This report assesses 29 marked cohorts ($S_3 = 0.004$) plus eight large cohorts of about 500,000 coded wire tagged juveniles each ($S_3 = 0.015$). Median survival estimates varied nearly four fold between the two data sets.

Large numbers of adult ocean-type chinook disappear between dams. Factors causing disappearance may result from pre-spawning mortality or from undetected post-spawning mortality in reservoirs. If disappearance is attributed to pre-spawning mortality, survival between entry to the Columbia River and passage at Lower Granite Dam is estimated in this assessment to be approximately

$S_4 = 0.46$ for non-fishing mortality.

If disappearance is attributed to spawning in reservoirs, river passage survival would increase from $S_4 = 0.46$ to $S_4 = 0.72$ for non-fishing mortality. The estimate $S_4 = 0.72$ assumes that mortality associated with dam passage is about the same for ocean-type chinook and summer steelhead which overlap in migration timing but do not overlap in timing of spawning.

Data are sparse on pre-spawning survival. A provisional estimate of $S_5 = 0.950$ is used to calculate estimates of life cycle survival.

Using the most optimistic values for interval estimates of survival, total life cycle survival is estimated to be S = 0.0006. This value of S exceeds bare replacement of ocean-type chinook by 50 percent. However, the use of less optimistic values for interval estimates of survival quickly reduces total survival to bare replacement (S = 0.0004) and below.

Introduction

The present fresh water nursery of Snake River ocean-type chinook encompasses the Snake basin downstream from Hells Canyon Dam. Because high summer water temperatures render the lower Snake River unsuitable for cold-water salmonids, juveniles typically evacuate the river by July (Karr and DeHart 1986: Fish Passage Center 1987; Corps of Engineers 1991). The majority of underyearling fall chinook from all sources pass Bonneville Dam by July (Corps of Engineers 1991; Hawkes et al. 1991). It thus appears that most juvenile ocean-type chinook in the Snake River undertake a directed downstream migration by early summer.

This analysis assesses survivorship of Snake River ocean-type chinook between egg deposition and return of adult progeny to spawning grounds. A stable population of anadromous salmonids will, on average, produce one progeny spawner per parent spawner. An expanding population will produce more than one adult progeny per parent spawner. A declining population will produce fewer than one adult progeny per spawner. Declining populations face a risk of becoming extinct if adult progeny-to-parent spawner ratios remain below unity for extended periods of time.

Survival of a stable population can be calculated from empirical data on ratio of females and their fecundity. This analysis uses data on female ratio and fecundity (Table 1) from Seidel and Bugert (1987). The estimated mean number of eggs per spawner is estimated to be 2,335.

Life cycle survival for bare replacement of Snake River ocean-type chinook is estimated from the reciprocal of 2,335 eggs per spawner or

$$S = (1)\,(2{,}335)^{-1} = 0.0004.$$

The reciprocal of eggs per spawner is a useful benchmark for assessing trends in survival of a population.

Table 1. Eggs per spawner for adult Snake River ocean-type Chinook, 1977 through 1987. Data are from Seidel and Bugert (1987).

Year of Adult Return	Average Fecundity	Female Ratio	Eggs per Spawner
1977	4,533	0.61	2,765
1978	3,936	0.51	2,007
1979	4,526	0.62	2,806
1980	4,302	0.74	3,183
1981	4,339	0.60	2,603
1982	4,282	0.24	1,028
1983	4,271	0.42	1,794
1984	4,191	0.68	2,850
1985	4,622	0.64	2,958
1986	4,386	0.32	1,404
1987	3,874	0.59	2,286
Mean			2,335

Apportionment of Survival

Life cycle survival (S) of Snake River ocean-type chinook is partitioned into the following intervals for this analysis:

- S_1 -- Interval from egg deposition to premigrant juveniles.
- S_2 -- Interval of juvenile migration from fresh water to the estuary.
- S_3 -- Interval in marine waters (estuary plus ocean).
- S_4 -- Interval of adult migration in the Columbia River basin.
- S_5 -- Interval of adult maturation in proximity of spawning grounds.

The operative relationship for life cycle survival is:

$$S = (S_{i=1})\,(S_{i=2})\,(S_{i=3}) \ldots (S_{i=k}).$$

Interval from Egg Deposition to Premigrant Juveniles (S_1)

Three references are cited here (Table 2) to assess survival between egg deposition and initiation of juvenile emigration from fresh water.

The median estimate is

$$S_1 = 0.115.$$

Table 2. Median survival (S_1) from egg deposition to initiation of juvenile emigration of ocean-type chinook from Columbia basin rivers.

Reference	Number of Observations	Median Survival
Mullan (1990)	9	0.085
Norman (1992)	9	0.097
Fisher (1993)	17	0.141
Total	35	
Estimated Median Survival		0.115

Interval of Juvenile Migration from Fresh Water to the Estuary (S_2).

Data from 97 PIT-tagged cohorts of ocean-type juvenile chinook from the Snake River are used here to assess S_2. The field observational data were obtained in 1995 and 1996.

The 1995 studies are reported by Smith et al. (1997) and Connor et al. (1997). The 1996 studies are reported by Connor et al. (1998) and Muir et al. (1998). Studies were also conducted in 1997 (Muir et al. 1999), but results had not been evaluated and integrated into this analysis.

Results of the 1996 and 1997 studies show a highly significant inverse linear correlation between survival of PIT-tagged cohorts and distance traveled by juvenile migrants, i.e.,

$$r\ (95\ df) = -0.57\ (Prob < 0.001).$$

Prior to wide-spread use of PIT tags to estimate reach survival, numerous cohorts of ocean-type juvenile chinook had been marked by other methods including branding, fin removal, and wire tags. Reach survival of 72 cohorts of marked fish has been summarized by Dawley et al. 1980, Dawley et al. 1986, and Norman 1992. These estimates of reach survival also show a significant inverse relationship between survival and distance traveled, i.e.,

$$r\ (70\ df) = -0.56\ (Prob < 0.001).$$

The correlation coefficients for PIT-tagged and non PIT-tagged cohorts are nearly the same.

Variable reach distances complicate comparisons of survival between and among marked cohorts. This is because cohorts migrating long distances experience lower survival, on average, than cohorts migrating short distances. This problem can be partially addressed by converting reach survival into survival per unit distance traveled. The relationship is:

$$S_2 = (S/km)^n.$$

This equation states that reach survival (S_2) is equal to the n^{th} power of S/km. The method can be explained by a hypothetical example. Assume S/km = 0.997 and n = 100 km. $S_2 = (0.997)^{100} = 0.740$. This means that for each 100 marked juveniles released at the upper boundary of a 100 km reach, 74 will survive to pass the lower boundary.

In practice, a value of S_2 is obtained from field observational data and a value of S/km is obtained by rearranging the equation:

$$S/km = (S_2)^{1/n}.$$

This states that S/km is equal to the n^{th} root of S_2. Since S_2 is the parameter that is commonly estimated in the field, S/km is calculated from measurement of the length of the reach and calculation of the n^{th} root of S_2. The hypothetical example yielded a value $S_2 = 0.740$. The 100^{th} root of $S_2 = 0.740$ is S/km = 0.997, which is the value of S/km assumed in the example.

Values for S/km have been calculated for each of the 97 PIT-tagged cohorts of ocean-type juvenile chinook. The median value for the 97 cohorts is S/km = 0.995. Based on the value of S/km, schedules for estimating survival between entry to the estuary (Bonneville Dam) and various upstream release locations can be constructed. A schedule based on approximately 100 km increments in lengths of reaches beginning at Bonneville and extending upstream to various locations is given in Table 3.

Estimates of survival of PIT-tagged cohorts (Table 3) suggest large differences in survival of cohorts originating from upstream and downstream locations.

Table 3. Reach survival (S_2) schedule for PIT-tagged cohorts of ocean-type juvenile Chinook salmon beginning at Bonneville Dam and extending upstream in increments of approximately 100 km. Survival per km is estimated to be S/km = 0.995.

Reach Extending from Bonneville Dam Upstream to:	Length of Reach	Reach Survival
Deschutes R.	100 km	0.610
The Dalles Reservoir	200 km	0.370
Ice Harbor Dam	300 km	0.220
Little Goose Dam	400 km	0.130
Lower Granite Reservoir	500 km	0.080
Imnaha R.	600 km	0.050
Hells Canyon Dam	700 km	0.030

Interval in Marine Waters (S_3)

For the third life cycle interval, juvenile ocean-type chinook migrate through the Columbia River estuary and at sea. Median survival of 29 marked (non PIT-tagged) cohorts of hatchery juveniles is estimated to be

$$S_3 = 0.004.$$

The 29 survival estimates based on marked cohorts are reported by Harmon et al. (1996), Matthews et al. (1992), Mundy et al. (1994), and Park (1993).

A separate study by Wahle and Vreeland (1978) reports on survival of marked (coded wire tag) ocean-type chinook juveniles released from two lower Columbia River hatcheries (Spring Creek and Kalama Falls) over four years (1962 through 1965). Approximately four million marked juveniles were released (about 500,000 per hatchery per year). Median survival was observed to be

$$S_3 = 0.015.$$

This survival estimate is nearly four times higher than that obtained from the 29 marked cohorts yielding a median value of $S_3 = 0.004$.

Interval of Adult Migration (S_4)

Counts of adult ocean-type chinook passing Lower Granite Dam are used by fishery agencies to index spawner escapement. The disappearance of adult anadromous fish between Ice Harbor and Lower Granite dams is approximately 57 percent for ocean-type chinook and 15 percent for summer steelhead (see McNeil 1993). The unanswered question is whether disappearance of ocean-type chinook is due largely to pre-spawning mortality or to spawning in reservoirs? Life history differences between migrating adult ocean-type chinook and summer steelhead support a hypothesis that chinook spawn in reservoirs as well as in free flowing reaches of the Snake River.

Most ocean-type adult chinook migrate to Snake basin spawning grounds in September and October. The majority of adult summer steelhead also migrate in the September/October interval. Ocean-type chinook spawn in autumn. Summer steelhead overwinter in Snake basin streams and spawn the following spring. Thus, ocean-type chinook are mature and summer steelhead are immature when they pass mainstem dams.

Both species are exposed to similar environmental variables (flow, temperature, etc.) in the September/October interval. However, the nutritional condition of the two is quite different due to differences in maturity. Chinook are mature and spawn soon after entry to the Snake River. Steelhead, on the other hand, are immature when they enter the Snake River, and they migrate far beyond the lower Snake River to reach spawning grounds in headwater tributaries.

Total mortality of adult ocean-type chinook during river migration can be partitioned into natural and fishing mortality. The seven-year period of 1991 through 1997 is characterized by relatively low riverine harvest rates (see Oregon Department of Fish and Wildlife, Table 44, 1998) on Snake basin ocean-type chinook. The median estimate is 17 percent mortality from harvest (83 percent survival). During the same period (1991 through 1997), median survival from Columbia River entry to passage of Lower Granite Dam (mortality from fishing combined with other causes) is estimated from ODFW data to be

$$S_4 = 0.38$$

This estimate implies that non-fishing survival is only 46 percent.

If spawning occurs in reservoirs, survival from non-fishing mortality would be higher than 46 percent. Should adult ocean-type chinook experience survival rates similar to summer steelhead, survival from non-fishing mortality could be as high as 72 percent and

$$S_4 = (0.83)\,(0.72) = 0.60.$$

Interval of Adult Maturation in Proximity of Spawning Ground (S_5).

Survival from final maturation prior to spawning describes the last life cycle state assessed in this analysis. Data for estimating S_5 are sparse. A report by Blankenship and Mendel (1997) suggests a pre-spawning survival of 0.95 should be a minimum rate for ocean-type chinook spawning above Lower Granite Dam. This value of

$$S_5 = 0.950$$

will be used in calculations of life cycle survival estimates below.

Life Cycle Survival Estimates

The most optimistic (highest) values for interval estimates of survival developed in this assessment yield

$$S = (S_1)\,(S_2)\,(S_3)\,(S_4)\,(S_5) = 0.0006, \text{ where}$$

S_1	0.115 (spawning to juvenile migrant)
S_2	0.610 (juvenile migrant)
S_3	0.015 (marine waters)
S_4	0.600 (adult migrant)
S_5	0.950 (pre-spawning)

Under the above scenario, total survival (S = 0.0006) exceeds survival for bare replacement (S = 0.0004 based on female ratio and fecundity) by 50 percent. The population produces 1.5 adult progeny returning to spawn per parent spawner.

Survival estimates for each of the life cycle intervals are assumed to be independent of one another. A major uncertainty is the possible dependence of S_2 on migration distance. The above scenario, for example, uses a value $S_2 = 0.610$, which assumes a short migration reach of 100 km. Increasing the migration distance from 100 to 200 km above Bonneville Dam reduces $S_2 = 0.610$ to $S_2 = 0.370$. Total survival where the other four survival values remain unchanged is reduced to

$$S = (0.115)\,(0.370)\,(0.015)\,(0.600)\,(0.950) = 0.0004.$$

Under this scenario, total survival is sufficient only for bare replacement of the population, i.e., one progeny adult spawner per parent spawner.

As migration distances above Bonneville Dam exceed 200 km, this model predicts that the ratio of progeny adult spawners to parent spawners will trend downward from unity.

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