APPENDIX 2

HISTORY OF THE FLOW SURVIVAL RELATIONSHIP AND FLOW AUGMENTATION POLICY IN THE COLUMBIA RIVER BASIN

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Flow augmentation and flow targets have been central programs in Columbia River salmon management for twenty years. Over this time, water requests have increased from 3.75 MAF in 1983 when the Water Budget was established (NPPC 1983), to between 13 and 16 MAF in the 1995 and 2000 NMFS Biological Opinions (NMFS 1995a; NMFS 2000a). Over the same period, the science on the effects of flow augmentation grew from a single graph between smolt survival and Snake River flow, to a body of information involving the entire life cycle of salmon. Whereas the scientific justification of flow augmentation has become more uncertain, the management policy has become more established and simplified. This paper reviews the history of the flow survival research to provide a perspective on the evolution of the flow policy.

Important policy decisions and research that support and challenge a strong flow augmentation hypothesis are illustrated in Table 1. The original flow augmentation, known as the Water Budget, was implemented in 1983 because ten years of survival studies suggested that a strong increase in fish passage survival could be obtained from modest increases in flow through the hydrosystem. This survival relationship was based on the now infamous Sims and Ossiander data (1981), which was a plot of seven years (1973-1979) representing yearly averaged flows at Ice Harbor Dam against the per-project survival of spring chinook and steelhead smolts from the Snake River (Figure 1). The relationship, used in a model, suggested spring chinook survival would increase by 180% with a 47 kcfs increase in flow at Ice harbor Dam (CBFWA 1990).

Table 1. History of Flow-Survival Relationship Key Studies and Program/Plans

Year	Evidence for Flow-Survival Hypothesis and Policy	Evidence Against Flow Survival Hypothesis and Policy
1981	**Sims and Ossiander 1981** (73-79 Spring Chinook Studies)	
1983	**NPPC 1983** Fish & Wildlife Program*	
1990	**CBFWA 1990** Integrated System Plan	
1992	**Petrosky 1992** (Adult Returns Rates Correlated with water Travel Time in Snake River)	**Marsh and Achord 1992** (First PIT-tag Study Shows High Survival with Low Flow)
1993	**Hilborn et al. 1993; Berggren and Filardo 1993** (Fall Chinook Flow-Travel Time Relationship)	
1994	**Cada et al. 1994** (Review from Several Systems Conclude Flow and Other Factors Affect Survival)	**Giorgi et al. 1994** (No Fall Chinook Flow-Travel Time Relationship) **Olsen and Richards 1994** (Ocean Conditions affect West Coast Chinook)
1995	**NMFS 1995** BiOp* (Proposed Flow Targets)	**Williams and Matthews 1995** (1970s, Low survival from Trash at Dams) **Skalski et al. 1996** (Fall Chinook Survival Depends on Comparison Stock)
1997		**Smith et al. 1997a** (1993-1997 Data Shows No Within-Year Flow Survival Relationship for Spring Chinook) **Giorgi et al. 1997; Smith et al. 1997b** (No Within-Year Flow Survival Relationship in Fall Chinook) **Mantua et al. 1997** (Ocean Regime Shifts Alter Salmon Production is an Alternative Reason for Stock Decline)
1998	**Marmorek et al. 1988** (FLUSH Passage Model Predicts Strong Flow Survival Relationship)	**Marmorek et al. 1988** (CRiSP Passage Model Predicts Weak Flow Survival Relationship) **Olsen et al. 1998** (Comprehensive Review of the Flow Program Questioning Policy, Hydrology, Biology, and Economics)
2000	**NMFS 2000a** BiOp* (Continues with Flow Targets and Flow Augmentation Proposed in 1995 BiOP)	**NMFS 2000b** (No Flow Survival Relationship for Snake River Spring Migrants for 1995-1999) **NMFS 2000a** SIMPASS (Smolt Passage Model Survival Depends On Distance not travel time) **Anderson et al. 2000; NMFS 2000b** (Snake River Fall Chinook Survival to LGR Dam Not Related to Travel Time, Survival has Highest Correlation with Release Date and Water Quality Parameters, which covary)
2001		**Muir et al. 2001** (Hatchery Chinook Survival Varied Inversely with Distance to LGR Dam. Hydrosystem Survivals in 1990S Equal Survivals in the1960s and Little Mortality Occurs in Reservoirs) **Williams et al. 2001** (Survival Increases from 1970s to 1990s not Accompanied by Change in Flow) **Anderson and Zabel in review** (Model Shows Smolt Survival Depends on Distance)

*Fish migration and recovery programs.

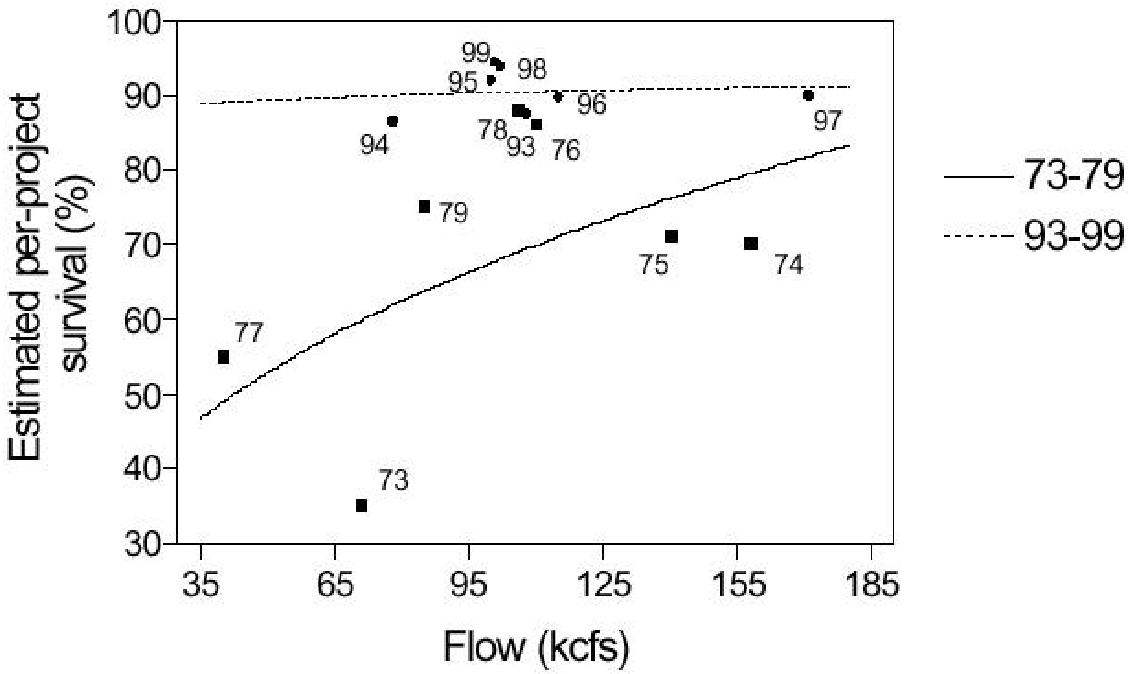

Figure 1. Historical and recent estimates of per-project survival (%) for yearling chinook salmon vs. index of Snake River flow (kcfs). Curves depict fitted nonlinear regression equations describing relationship between flow and survival in the two time-periods. Early period data from Raymond (1979) and Sims and Ossiander (1981). Graph from NMFS (2000b).

In the 1980s, research seemed to support the hypothesis that flow determined smolt survival and suggested a mechanism through smolt travel time. Petrosky (1992) demonstrated the smolt to adult survival (SAR) decreased as Snake River water travel time increased (Figure 2). A paper by Berggren and Filardo (1993) showed flow and smolt travel time were significantly related. Hilborn (1993) compared SARs of spring chinook from the Upper and Lower Columbia, and concluded the SAR difference between the two reaches was greater for years with lower flows. From these studies, the hypothesis emerged that flow affected survival through travel time: higher flows meant shorter travel times, which meant less exposure to predators and therefore higher survival. Cada et al. (1994) reviewed a range of studies and suggested other factors were also of importance, especially temperature. With these reports, NMFS justified flow augmentation primarily thorough the effect of flow on fish travel time (NMFS 1995b). However, the link between travel time and survival was hypothetical: longer exposures to predators were assumed to increase mortality. The hypothesis also involved temperature: fish arriving later at projects with higher temperatures would encounter more active predators and could have lower bypass efficiency causing more fish to pass through turbines. In the 1995 Biological Opinion, NMFS used travel time as one of the main performance measures to establish flow targets (NMFS 1995a).

From these reports and analyses emerged the beliefs that flow and travel time were the major factors affecting smolt to adult survival, and that small increments of flow augmentation within a season would achieve the same effect on survival as the year-to-year variations in flows. However, the Water Budget contained an untested and questionable assumption that incremental flow augmentation within a year has the same effect on survival as the year-to-year changes in flow that are also accompanied by year-to-year changes in climate and ocean conditions.

Fish managers also proposed removing the four lower Snake River dams, which would remove the dam passage mortality as well as improve survival by decreasing water travel time (NMFS 1995a).

During the 1980s, while fishery managers were implementing the Water Budget, the PIT-tag marking system was developed, which allowed scientists to measure smolt survival with greater precision and accuracy within the migration season. With this system, researchers began a decade-long test of the flow survival relationship. The first results were obtained from Little Goose Reservoir in 1992, which was a low flow year similar to 1973. Researchers expected survival to be low, but surprisingly, the PIT-tag measured survival was higher than any survival in the Sims and Ossiander study. It is noteworthy that in the 1995 analysis of flow, NMFS rejected the 1993 and 1994 PIT tag studies, which showed no flow survival relationship (NMFS 1995b). However, after eight years, the conclusion from the PIT-tag studies is unequivocal; flow survival and travel time survival relationships for spring chinook and steelhead migration through the hydrosystem were not found (NMFS 2000b; Muir et al. 2001). The flow survival hypothesis must be rejected. Furthermore, both PIT-tag studies (Muir et al. 2001) and theory (Anderson and Zabel, in review) suggest smolt survival depends primarily on distance traveled and involves smolts migrating past territorial predators, which produces a gauntlet effect.

As a final note, the strong flow survival relationship shown in the Sims and Ossiander data (Figure 1) depended on low survivals in the two drought flow years, 1973 and 1977. It is now believed that in these years, passage conditions at Snake River dams were poor (Williams and Matthews 1995). The present day smolt survival through the eight dams of the current hydrosystem is equal to survival in the 1960s, when the Snake River smolts passed only four dams (Anderson 2000; Williams et al. 2001).

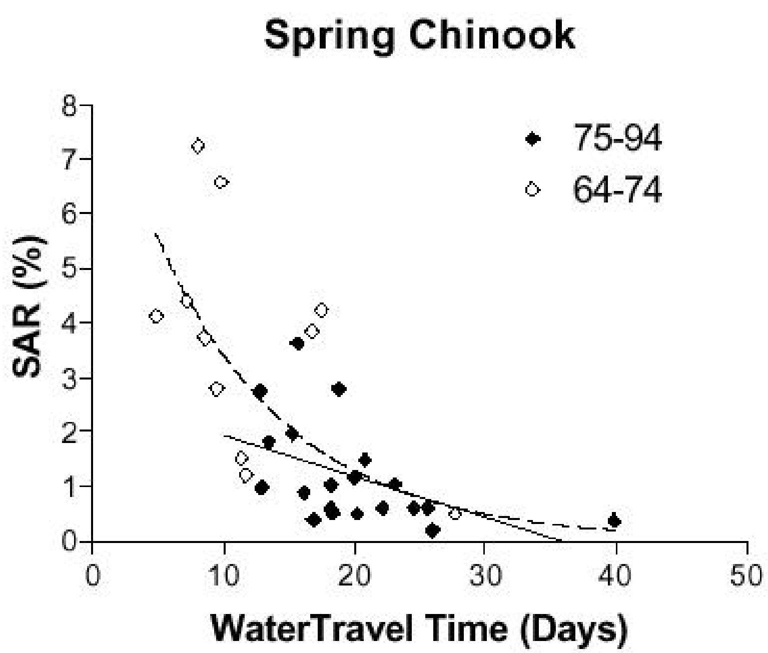

Figure 2. Regressions of smolt-to-adult returns versus water travel time for Snake River spring/summer chinook salmon for the 1964-1994 smolt migration (after Petrosky and Schaller 1998). The dashed line represents the regression line for the entire period; the solid line is for the years 1975-1994. From NMFS(2000b).

Even though the evidence against a flow survival relationship was steadily building, fishery managers up through 1998 supported a strong flow survival relationship (Marmorek et al. 1998a). In particular, the PATH work group, charged with evaluating the impact of dam removal on salmon, favored the FLUSH smolt passage model, which predicted hydrosystem survivals between 5 and 20%. The alternative model, CRiSP predicted survivals between 15 and 50% (CBR 2000). With the overwhelming evidence in 1999, fishery managers abandoned the FLUSH model in favor a simplified passage model, SIMPAS (NMFS 2000c). Both SIMPAS and CRiSP were calibrated with the PIT-tag survival studies and are in basic agreement that hydrosystem survival is high.

Although the strong flow survival relationship has been virtually rejected, the results of PATH, which significantly depend on the FLUSH model, were used in developing the 2000 Biological Opinion (NMFS 2000a).

The second intended benefit of the flow program involves a hypothesized effect on adult returns, as expressed through an SAR water travel time relationship (Petrosky 1992). NMFS, noting problems with the Petrosky study, re-evaluated the relationship using data representative of the current fish passage environment and found a weaker relationship between SAR and water travel time than proposed by Petrosky (Figure 2) (NMFS 2000b). With the hypothesized flow survival relationship disproved for smolts, flow augmentation now depends on a possible relationship with SAR. This support is equivocal though: the NFMS flow survival white paper states “Correlation does not necessarily imply causation (Sokal and Rohlf 1981), and higher SARs associated with higher flows does not necessarily indicate the SARs can be increased by adding more flow to the river” (p 53 NMFSb). However, with this caution expressed, NMFS continued to call for flow targets: “These results support management actions to provide flows of at least 85 kcfs in the Snake River and 135 kcfs in the upper (mid-) Columbia River during spring and 200 kcfs in the lower Columbia River during the summer” (page 57 NMFS 2000b). Finally, in support of the targets, NMFS concluded that although a direct flow survival relationship cannot be established by data, it does not preclude benefits of flow augmentation because increased flows may improve survival outside the hydrosystem as a result of earlier arrival to the estuary, improved estuary conditions and reduced delayed mortality (page 58, NMFS 2000b).

The debate of flow augmentation on Snake River fall chinook has a more recent history. Studies demonstrate Snake River fall chinook survival to Lower Granite dam is correlated with release date, temperature, flows and turbidity (Anderson et al. 2000; Dreher et al. 2000; NMFS 2000b). The analyses conclude that with the existing data, flow cannot be the identified as the operative variable affecting survival. The studies also demonstrate that the effects of these variables on survival are more pronounced through the river passage corridor above Lower Granite Dam than through the Lower Snake River.

A review by the ISAB, however, observed that the data also are inadequate to deny beneficial effects of flow augmentation (ISAB 2001). The ISAB report goes further to express a prevalent belief about flow. While no direct benefits have been observed, it is assumed that if flow positively correlates with variables that actually do affect survival, then flow augmentation may be valuable as long as the result is higher survival. While it is difficult to envision how small flow augmentations may be detrimental, the data does suggest a plausible scenario. Since fall chinook travel time is unrelated to flow or survival, flow does not affect exposure time to predators and its impacts must work indirectly through correlations with temperature and turbidity. For the seasonal pattern, high flow correlates with low temperature and so flow should correlate with survival, as the seasonal data indicate. However, flow augmentation from the Hells Canyon Reservoir complex is warmer than the Snake River and its tributaries, so flow produced through reservoir releases can be detrimental to smolt survival (Anderson 2001).

With science now showing that flow does not affect smolt survival in the hydrosystem, the flow survival hypothesis has been reformulated as a qualitative statement that flow may affect survival in the estuary and the Columbia River plume. The NMFS flow white paper hypothesizes that deceased spring flows reduce the extent of the plume and the turbidity load, thus reducing the ability of the smolts to hide from predators (page 54, NMFS 2000b). Studies conducted in the plume since 1998 show that predator numbers around the plume are important. In 1998, the plume was of a normal size, but the ocean environment was warm and contained tremendous numbers of predators. Initial studies for 2001 revealed a significantly smaller plume in a cooler ocean virtually absent of predators (E. Casillas, personal communication). It is too early to conclude the impacts of river flow and ocean conditions on smolt survival in the plume, but the data clearly indicate that plume survival cannot be simply attributable to a single factor, be it flow, ocean temperature, or predator abundance. Statements about the impacts of flow on estuary and plume conditions are speculations that do not constitute a justification for flow augmentation, but they do point to needed areas of research.

This does not mean that evaluation of the flow augmentation must wait for another decade of research. Analyses to evaluate flow augmentation can be performed with the available information. Specifically, a sensitivity analysis can be developed to ascribe a range of expected survivals for different levels of flow augmentation. However, an analysis must have an ecologically realistic foundation. Otherwise spurious regressions of flow against survival, such as was done with the Sims and Ossiander data, will continue to misrepresent the science.

The history of the flow survival research and policy contains many details but the essential elements are this: In the 1980s, limited data suggested that flow had a strong effect on fish survival. Using this information and the intuitive belief that flow is good for fish, fishery managers embarked on a water budget program with the hope that fish survival would dramatically increase. However, fish stocks declined and fishery managers incrementally increased augmentation to its current level, which is five times the initial level in the 1980s (Olsen et al. 1998). Today, with two decades of research, the flow survival hypothesis envisioned in 1980 can be rejected. Furthermore, the hypothesis relating flow augmentation to SARs through mechanisms that occur outside the hydrosystem are likely untestable with the current technology. However, using the available data and ecologically-based models it should be possible to characterize the upper and lower benefits of flow augmentation on salmon.

It is essential that the limits of flow augmentation be characterized quantitatively, especially when the cumulative impacts are considered. While an incremental increase or decrease in augmentation may have a small biological effect, it does not follow that the cumulative effect is significant. For example, daily fluctuations in project flows alone may significantly overshadow any future impacts caused by either seasonal water withdrawals or flow augmentation attempts. Not quantifying what is meant by "cumulative impact" can inadvertently imply that without flow augmentation, or with new water withdrawals, the river would "go dry."

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