Response to the ISAB Review of Flow Augmentation: Update and Clarification Feb 10, 2003

By James Anderson
Columbia Basin Research
February 25 2003.

Introduction

I am responding to your request for comments on the ISAB review of flow augmentation update and clarification. I was asked by the ISAB to provide information to them on my research. I provided four reports:

1. The Flow Survival Relationship and Flow Augmentation Policy in the Columbia River Basin
2. Supplement to The Flow Survival Relationship and Flow Augmentation Policy in the Columbia River Basin
3. A collision theory based predator-prey model and application to juvenile salmonids in the Snake River Basin
4. An analysis of smolt survival with implications to flow management

These analyses are germane to the three questions the Council put forward to the ISAB on flow augmentation and smolt survival. In particular, documents 3 and 4 are relevant to the questions and the ISAB analysis. None of this work was noted by the ISAB.

My reply to the ISAB review is based on my work. I first present a brief overview of how I am evaluating the flow survival issues. Second, I consider the ISAB's responses to the Council questions in light of my analysis. My conclusions on the impacts of flow and survival and my responses to the Councils differ significantly from the ISAB's. I have intended my response to be respectful but candid with the belief that this is the best way to assist the Council in its difficult task.

The XT model

My analysis on the impacts of flow on smolt survival begins with a new theory I call the XT model because it describes survival in terms of both migration distance, X, and migration time T. The XT model represents a new approach to understanding smolt survival and predator prey interactions in general. It synthesizes in a single framework the CRiSP, SIMPAS, and the ISAB's new fluctuating flow theories. Furthermore, the model provides an ecologically-based foundation that includes the effects of temperature and turbidity on smolt survival.

The number of salmon that predators eat depends largely upon three things: 1) the frequency of encounters with predators as the smolts swim downstream (primarily a function of distance traveled), 2) whether the predators can see them (primarily a function

of the turbidity of the water), and 3) how hungry the predators are (metabolism, largely a function of temperature).

The frequency of encounters depends on the balance of the smolts' directed downstream migration and their random movements relative to the predators. In this approach, the importance of smolt travel time depends on the fish behaviors. If smolts move directly down river in a steady flow and the predators sit-and-wait for the smolts to pass, then the smolts pass a gauntlet of predators and their survival is independent of the amount of time it takes to migrate, only the number of predators they encounter, which depends on migration distance. If smolts exhibit random movements in addition to their directed movements, then multiple encounters between predators and the smolts may occur, especially if the predators also move about searching for smolts. In this case migration time as well as distance traveled determine the amount of mortality. The balance of migration time and distance in determining smolt survival is characterized by a single variable, the random encounter velocity between predators and prey. This in turn can be estimated from survival, travel time, and travel distance.

Turbidity plays a role since the predators must see the smolts in order to capture them. The significance of visibility is characterized by a shape parameter, which can be estimated from survival and turbidity. Furthermore, the shape parameter is determined by the relationship between visibility and the reaction field of a predator and can be estimated independently from individual predator prey studies and ecological theory.

Temperature in the model affects the hunger of predators and is characterized by a factor that can be estimated from temperature and survival data and independently by the response of predators to temperature.

Thus, the XT model relates smolt survival to their travel time, their travel distance, water temperature and water turbidity. Put into a regression form, the values of the regression coefficients describe the contribution of each factor to smolt mortality.

My co-author and I are submitting a paper describing the basic XT model to the American Naturalists.

I applied the model to several thousand days of survival studies over the Snake and Columbia Rivers for spring, summer and fall chinook, and steelhead. This work was submitted to the NRC panel studying the impacts of flow on smolt survival in a study requested by the State of Washington. This document will be submitted to a journal soon. Enclosed is a draft manuscript. However, like the ISAB's hypothesis, mine is a work in progress.

The Council's Questions

Council Question 1. *What is the evidence and to what extent will flow augmentation from storage reservoirs result in the same environmental attributes as higher flow under*

natural conditions? In other words, how sound is the scientific approach of research that looks at correlations of fish movement and survival in relation to natural variations of environmental conditions such as flow, temperature, and turbidity, and then extrapolates to infer that man-made additions of flow will result in the same environmental attributes? Are there studies that more directly measure the effects of flow augmentation? If so what are the results of those studies?

ISAB Answer to Question 1:

The ISAB was unable to answer the question of whether the flow increments produced by flow augmentation will or will not induce conditions that enhance smolt survival. The ISAB could not answer this question because they viewed flow as the only variable affecting fish survival. The ISAB's approach cannot resolve the flow survival issue. Fish survival is not affected by a single variable and linear regressions of survival against a flow as constructed by NMFS and accepted by the ISAB are wholly inadequate to address the problem.

What the XT model reveals:

From my analysis of the data with the XT model, I conclude that temperature, migration distance and the amount of spill are the largest factors determining smolt survival. Smolt travel time is of minor importance. My work indicates that flow, through its effect on smolt travel time, is a minor variable. Furthermore, the effects of flow augmentation on smolt survival depend on the resulting impact of the augmentation on temperature and, secondarily, on turbidity. Therefore, I conclude that man-made additions of flow will not result in the same environmental attributes and effects on smolt survival as natural variations.

My paper "An analysis of smolt survival with implications to flow management" addresses these factors. To illustrate the basis of my conclusion, consider the relationship between flow and survival between Lower Granite and McNary Dam in 2001. In this data, survival continually decreases over the season as the water warms (Figure 1) but the flow follows a different pattern, increasing up to the spring maximum flow and then decreasing into the summer resulting in a > shape (Figure 2). This clearly demonstrates that survival is not monotonically related to flow as has been assumed in other studies. That is, the other studies all assume that survival increases with flow. The data shows survival can increase or decrease with flow. Note also that the figures show both the data (?) and the model (?) predictions of survivals of fish grouped according to their passage date at Lower Granite Dam. The model fits the flow survival and travel time survival relationships (Figure 3) but contains neither fish travel time nor flow. Furthermore, in both examples, the data and modeled relationships are highly nonlinear; that is survival both increases and decreases with travel time and flow. These facts alone should cast doubt on any analysis based exclusively on flow, whether flow is expressed as an average index as was done by NMFS, in terms of water particle travel time as was done by the Fish Passage Center, or in terms of fluctuating flows as was done by the ISAB.

What the XT analysis says about flow augmentation.

The effect of flow augmentation should be viewed in terms of its impacts on temperature, turbidity, and fish velocity. Thus, addressing how flow affects fish requires first addressing how flow affects temperature, turbidity, and velocity, and second, addressing how these variables affect smolt survival.

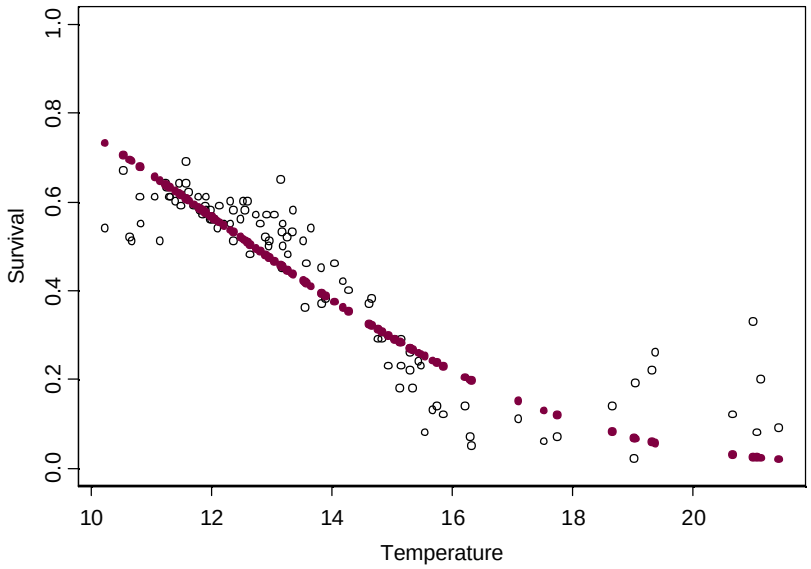

Figure 1. Modeled and observed chinook survival vs. temperature (^{o}C) for migration between LGR and MCN in 2001. Survival estimated with PIT tags designated (?); survival estimated with the X-model designated (?).

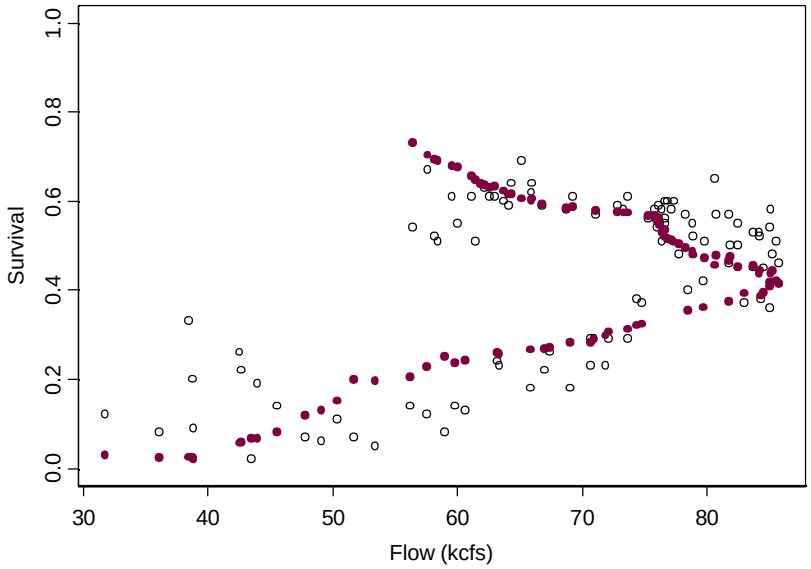

Figure 2. Modeled and observed chinook survival vs. flow for migration between LGR and MCN in 2001. Survival estimated with PIT tags designated (?); survival estimated with the X-model designated (?).

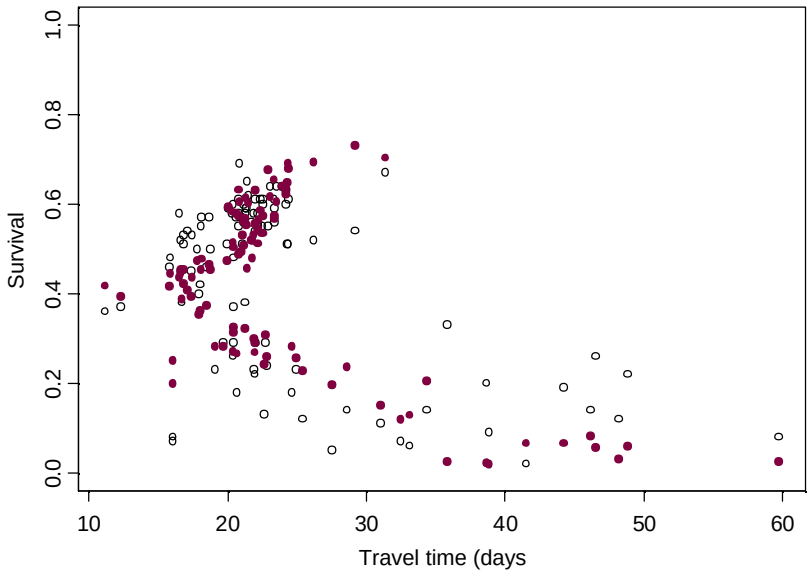

Figure 3. Modeled and observed chinook survival vs. travel time for migration between LGR and MCN in 2001. Survival estimated with PIT tags designated (?); survival estimated with the X-model designated (?).

Council Question 2. *To what extent will incremental flow augmentation within a year have 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?*

> *A. Relevant to the draft mainstem amendments, to what extent will changes in reservoir release strategies that could result in decreases in spring and summer flows of approximately 10% or less have a statistically significant effect on juvenile salmon and steelhead survival?*
>
> *B. A linked question is what scientific evidence exists that decreased travel time as a result of flow augmentation will result in increased juvenile survival*?

<u>ISAB Answer to Question 2:</u>
The ISAB concluded that incremental flow augmentation is not likely to have dramatic beneficial effects on in-river smolt survival. They also conclude that effects of flow augmentation on survival in the ocean and estuary is unknown.

<u>My response:</u>
In my analysis, I determined that both the year-to-year survival patterns and the within year survival patterns could be explained principally by temperature only. From this explanation, I conclude that we need to consider the impact of flow augmentation on river and ocean temperatures relative to the impacts of year-to-year variations in climate on river and ocean temperatures in order to address the Council's question. Flow augmentation from Dworshak, which is colder than the water body it enters, will improve survival slightly but flow augmentation from the Hells Canyon complex, which is warmer than the Snake River (Anderson 2001) will decrease survival. However, the

amount of temperature change in both cases is small and I expect that it will have unmeasurable impacts on fish survival through the river. However, this analysis has not been done. Furthermore, since the flow augmentation is small compared to the total river flow into the estuary and ocean, the impact of flow augmentation is insignificant irrespective of the basis of any relationship between flow and survival one assumes (Anderson, Hinrichsen and Van Holmes 2000).

ISAB Answer to Question 2A:

The ISAB believes a 10% decrease in augmentation would not affect survival for flows above 100 kcfs but could have an impact below that level. They based their conclusion on a breakpoint in the flow survival plot presented by NMFS on December 11, 2002 (Figure 4).

My response:

By plotting essentially the same data, grouped daily instead of weekly as was done by NMFS, I obtained a similar pattern (Figure 5). The ISAB interpreted the NMFS plot as evidence that survival decreases as a result of the lower flow below a flow of 100 kcfs. Note that the pattern was entirely generated by the low flow and survival in 2001. If the relationship were driven by flow then the ISAB's conclusion of a benefit of flow augmentation below 100 kcfs is reasonable. However, if the survival decline was not a result of flow but of another variable that exhibits a seasonal pattern with flow then we may not expect the same benefit of flow augmentation that is exhibited in the seasonal pattern. In fact, this is what I have found.

My analysis included water temperature, turbidity and fish travel time, which is linearly correlated with flow and therefore is a surrogate for flow for spring chinook. Using these variables in the XT model the regression determining the significance of each variable revealed that temperature was the only factor needed to fit the survival pattern within years and between years. Figure 1 illustrates the temperature survival pattern for 2001 and Figure 6 illustrates the pattern over the years 1995 through 2002. The patterns were the same across all years. However, even though the XT model contains only temperature it actually fits the flow vs. survival data better than the NMFS flow vs. survival curve. Compare the fits of the 2001 data with the NMFS flow line (Figure 4) and the temperature based prediction of flow vs. survival from the XT model (Figure 5). The NMFS prediction pass through the main scatter of points but for 2001, which is within the oval in Figure 4, the flow line is unable to track the > shaped pattern. In contrast, the XT temperature-based model fits both the general pattern and the within-season 2001 pattern.

Clearly, if temperature, not flow, is the operative variable, then the effect of flow augmentation depends on the temperature of the augmentation water compared to the temperature of the water body. Augmentation from Dworshak, which is cooler than the Snake River, would have a small benefit on survival while augmentation from Hells Canyon, which is warmer than the Snake River, would decrease survival.

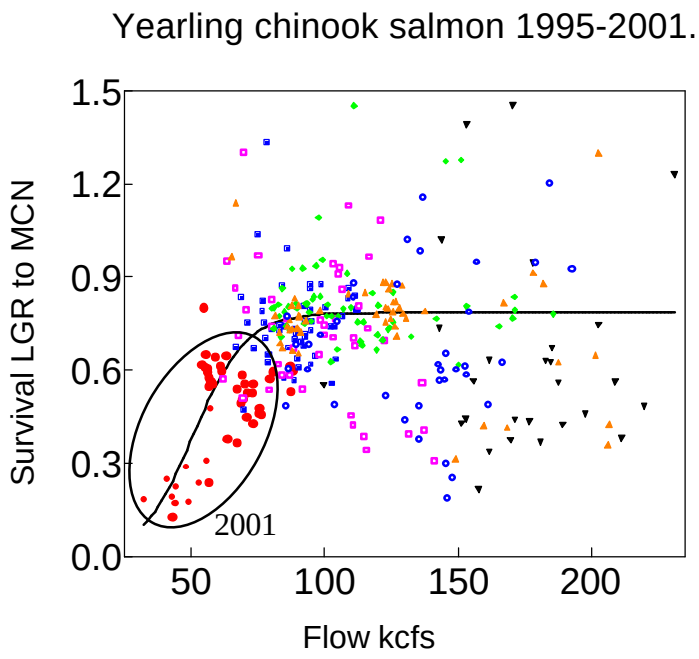

Figure 4. Relationship of flow and survival between LGR and MCN dams presented by NMFS December 11, 2002. The oval depicts the data from 2001.

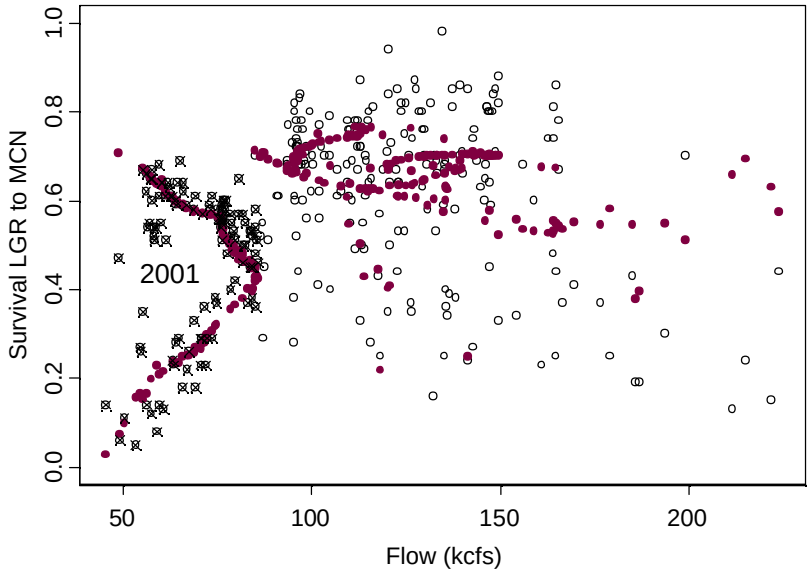

Figure 5. Modeled and observed chinook survival vs. flow for migration between LGR and MCN in over the years 1995 through 2002. Survival estimated with PIT tags designated (?) survival estimated with the X-model designated (?). The 2001 data is designated by an x in the symbol ? .

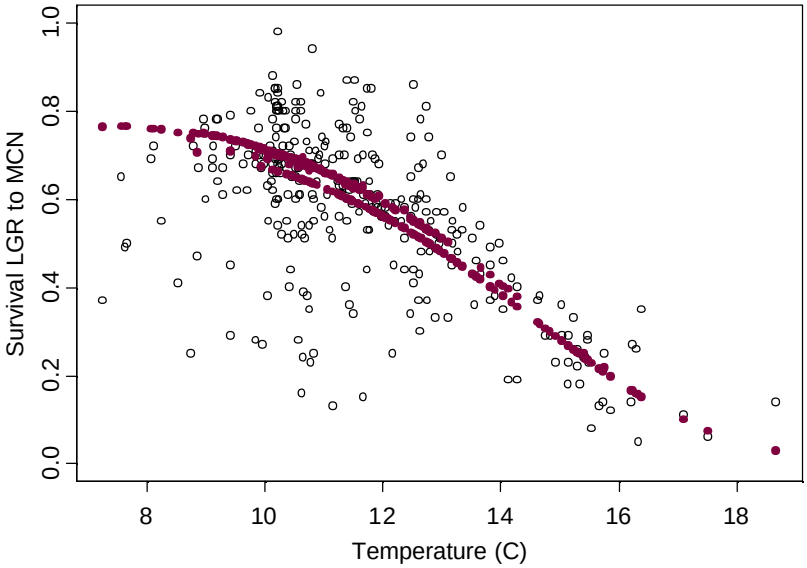

Figure 6. Modeled and observed chinook survival vs. temperature (^{o}C) for migration between LGR and MCN between 1995 and 2002. Survival estimated with PIT tags designated (?); survival estimated with the X-model designated (?).

However, the breakpoint inferred by the ISAB must exist. When the flow goes to zero, the survival must also go to zero, and because flow and survival are unrelated over most of the observed range, we expect some breakpoint. The XT model establishes an ecological foundation for flow survival breakpoints and it is thus possible to estimate the breakpoint when temperatures are essentially uniform from year-to-year over a range of flows. Such conditions exist for migration of Dworshak hatchery fish to Lower Granite Dam. Data collected between a 1990 and 2001 (Figure 7) clearly show that survival is independent of flow over a range 38 to 133 kcfs. Fitting the XT data to this model indicates that the flow survival break point is on the order of 25 kcfs and is very sharp. Here again, the model and data both agree that flow is not a factor in determining smolt survival.

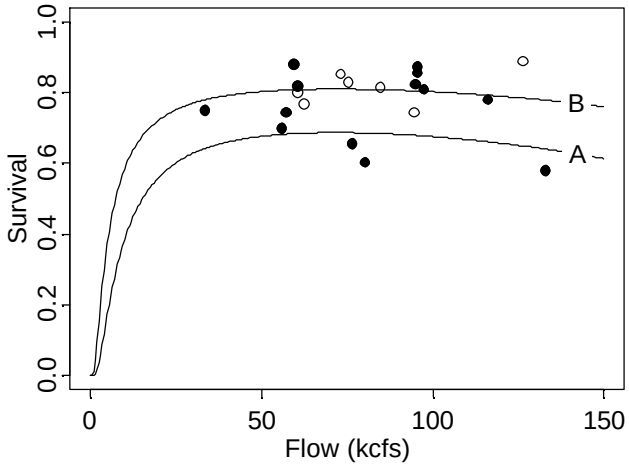

Figure 7. Relationship of flow to smolt survival from Dworshak Hatchery to Lower Granite Dam. Curve A uses travel distance X = 116 km and curve B uses X = 64 km. Open points are survivals for release dates greater than Julian Day 100. Solid points are survivals for release dates Julian Day 100 or less.

My analysis supports the ISAB statement that a 10% decrease in spring and summer flows will not have a deleterious effect on reach survival. In fact, my analysis allows a stronger statement. Because my analysis indicates temperature, not flow, controls survival over observed ranges of flow and the breakpoint is the below 33 kcfs a flow augmentation reduction should not impact reach survival unless it also impacts river temperature. In this case, the reduction could increase or decrease survival very slightly depending on the temperature differential of the river water and the augmentation water. However, I do not see changes in flow augmentation consigning "salmon to death by a thousand cuts" as suggested by the ISAB.

ISAB Answer to Question 2B:

The ISAB believes that the more time fish spend in a reach, the higher their mortality. They further believe that a more critical question involves the instantaneous mortality, which is the percent mortality per day. From their note on the mathematics of reach survival and flow, they conclude that the mortality rate may increase as a result of low flow or other factors such as temperature and turbidity.

My response:

Although I applaud the ISAB in considering the problem beyond simply regressions of flow against survival I suggest their analysis is insufficient. The manuscript "A prey survival model based on path length theory with application to juvenile salmonids in the Snake River Basin" presents a rigorous mathematical foundation for studying reach survival.

In contrast to the ISAB, I conclude from my work that the amount of time it takes smolts to migrate through the river does not have a significant impact on their survival through the river. The only clear exception I have found so far is for the survival of Snake River fall chinook to Lower Granite Dam. For these fish, survival depends on the velocity, travel time, water temperature, and turbidity. For the other stocks investigated to data, including spring chinook migrating through the hydrosystem, survival depends on distance traveled, which characterizes the number of predators encountered, temperature that affects the predator activity, and spill that affects the survival in dam passage.

Both NMFS and the ISAB have expressed concern for the effect of fish arrival time on their survival in the estuary. Whether or not this is a problem, it can be summarily disregarded in the context of flow augmentation. Simply stated, flow augmentation changes the water velocity too little to affect fish arrival time to the estuary. Analysis with the CRiSP model indicates flow augmentation can only change arrival time by a few hours over a migration of several weeks. Furthermore, the impacts of the flow

augmentation on the estuary and freshwater plume dynamics can similarly be discounted because flow augmentation alters the total flow very little.

Council Question 3. *Are the statistical methods used in recent flow-survival analyses rigorous and technically sound? Did the analyses properly incorporate and treat 2001 low-water-year data?*

ISAB Answer to Question 3:
The ISAB considered the statistical methods sound but questioned whether they were appropriate, citing the Fish Passage Center flow survival review.

My response:
I disagree on the adequacy of the methods used to date. The flow survival analyses conducted by NMFS, FPC and the ISAB are all inadequate. In particular, with minor variations, they all consider only flow: NMFS used a flow index, the Fish Passage Center used water particle travel time, and the ISAB used flow fluctuations. All are incomplete. The NFMS analysis is correlative without causation. The FPC analysis is also correlative, and as my analysis and the ISAB's both noted, the flow survival relationship in the FPC analysis is driven by 2001 data.

Smolt migratory survival depends a number of factors so to try and understanding the impacts of flow on survival by considering only flow is simply wrong. However, the region has focused on flow and the brokenstick flow survival hypothesis for two decades. I applaud the Council for its efforts to review the problem and move forward with new information and ideas. I applaud ISAB for its efforts to think beyond linear regressions and encourage them to become further aware and involved in the work being conducted in the region.

Comments on the ISAB alternative hypothesis explaining data.

In seeking an explanation for the brokenstick in the flow survival pattern, the ISAB hypothesize that the fluctuating flows due to variable dam operations may be responsible. Variations in dam operations create seiches in the reservoirs and alter the forebay hydrodynamics with the effect being most pronounced under low flow conditions. The ISAB hypothesize these changes may disorient fish causing them to wandering through the reservoir. While the ISAB has not quantitatively linked flow variations to fish survival there are several analyses through which this can be done.

The XT model provides one approach. The model partitions smolt velocity into fluctuating and average parts and the relative magnitudes of the two determine the contributions of migration distance and time to smolt survival. Through this model we can, for example, evaluate the importance of seiches in producing a brokenstick flow survival relationship. Taking the elevation data presented by the ISAB the seiche wave velocity is about 30 mph, such that the Lower Monumental Reservoir elevation exhibits an oscillation on the order of an hour. Assuming an average reservoir depth of 100 ft,

and a seiche amplitude of 1 foot the root-mean squared horizontal velocity is u = 4 cm/s. In comparison the average migration velocity of the fish is about U = 23 cm/s. If the seiche is the only contributor to random movement in the smolt migration, then the survival equation would be expressed

$$S = \exp\left(-\frac{t}{d}\sqrt{23^2 + 4^2} \right) \tag{1}$$

where δ is the length scale of the ecological neighborhood in which the predator interacts with the prey. The equation factors in the contribution of the average downstream migration velocity, 23 cm/s, and the seiche induced random velocity 4.36 cm/s. With the seiche, the characteristic velocity is $\sqrt{23^2 + 4.36^2} = 23.41$ cm/s, which increases the rate by 1.7% when the average migration velocity is 23 cm/s. Thus, at typical migration velocities a seiche would have no significant effect of the rate or mortality. However, at some point the average migration velocity becomes sufficiently low such that the seiche does become significant. This is illustrated in the Figure 8 below where the average velocity is in terms of multiples of the seiche velocity, which is normalized to 1. The figure demonstrates the breakpoint in the flow survival curve occurs when the average migration velocity is equal to 1.8 times the random velocity. Thus, the XT model predicts that for a seiche with a 4.3 cm/s rms velocity to produce the flow survival breakpoint the average fish migration velocity is 7 cm/s. If fish velocity decreases linearly with flow and the average flow is 100 kcfs then the flow induced breakpoint is on the order of 30 kfcs. From this cursory example I conclude that a 1 foot seiche is not responsible for the breakpoint in the flow survival plots. More important though, the example illustrates that theory is available to evaluate the ISAB's fluctuating flow hypothesis.

Other work in progress will contribute to evaluating the effects of flow on survival. In particular, Andy Goodwin and John Nestler of the Army Corps have made significant progress is modeling the response of salmon smolts to river flows and the hydraulic conditions at the forebay of dams. The work, which is part of Goodwin Ph.D dissertation from Cornell University, has combined a computational fluid dynamics model with a behavior model to predict the detailed movement of fish in the forebay of Lower Granite Dam. The model was calibrated with detailed movements of radio and hydroacoustic tagged fish. Goodwin reports "I've been able to match the percentages with which juvenile steelhead use each of the passage routes through the dam (+/- 10%), which Gary Johnson said was within the error of the data. I can capture behaviors in the forebay such as shadowing of the BGS, tracing of the trash boom, (more or less) the proper holding & milling locations, and (within an order-of-magnitude) the residence time (A. Goodwin Personal communication)." This work and the XT model are important because they illustrate that other ongoing research is advancing the quantitative approaches hypotheses proposed in the ISAB review.

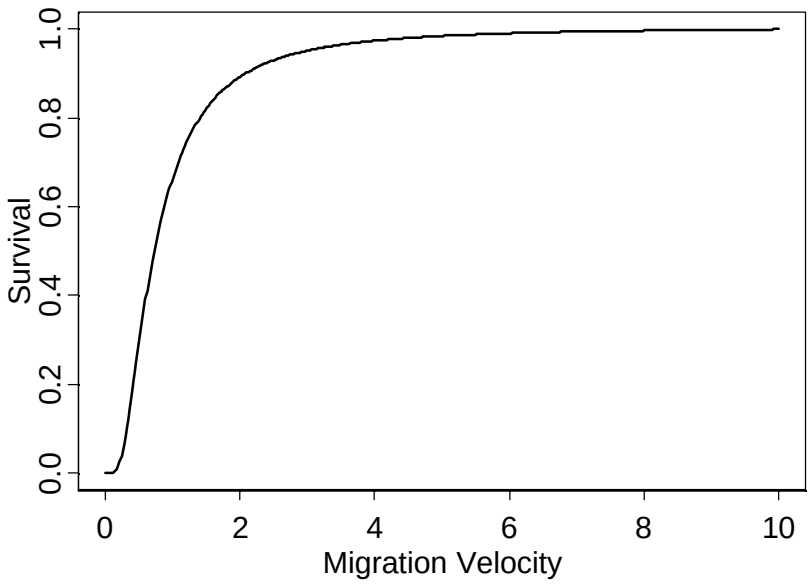

Figure 8. The XT model survival vs. average migration velocity expressed as multiples of the smolts random component of their migration velocity

Summary

NMFS and FPC used linear and multiple-linear regression techniques to analyze factors affecting flow. These approaches have no ecological basis and are incapable of explaining flow breakpoints or the differences in survival patterns within a year and between years. NMFS concluded that within-year patterns are not statistically significant and have generally ignored them. However my analysis clearly shows there are within-year patterns, which must be explained along with the between-year patterns in any coherent robust analysis. The NMFS and FPC analyses are unsatisfactory because they are devoid of ecological foundations. The ISAB moved closer to an ecological basis by approaching the problem with their fluctuating flow hypothesis. However, their work to date is speculative, qualitative, and is not based on solid first principles of ecology. NMFS, FPC, and the ISAB are all too flow centric in their approach. In fact, for over two decades the region has attempted to explain the effects of flow on fish survival without consideration of other environmental factors. This approach has yielded little to an understanding of smolt survival.

Whereas the flow centric models assume flow is the operative variable controlling survival, the XT model, offers an ecologically-based approach to study the effect of environmental properties on smolt survival and allows the data to indicate the significance of each variable. The model addresses the fluctuating flow hypothesis proposed by the ISAB, explains and quantifies flow-induced breakpoints, and fits both the between- and within-year patterns of survival. Additionally, because the model coefficients have ecological meaning, coefficient values derived by fitting survival data can be tested against values determined independently. For example, the model's coefficient predicting how predator activity increases with temperature compares favorably with laboratory estimates of predator feeding activity changes with temperature.

The conclusions that I reach from with the XT model disagree with the findings of the ISAB.

- I find the break in the flow survival curve is not due to flow, but to differences in temperature in 2001 compared to other years.

- My initial analysis indicates that seiches of the intensity identified by the ISAB are not response for the breakpoint at 100 kcfs. I estimate a flow induced flow survival breakpoint would occur at about 25 to 30 kfcs.

- My analysis does not support the ISAB hypothesis that regulating river flows will significantly affect fish survival unless river flow drops below 30 kcfs.

- My analysis does not support the ISAB belief that changes in estuary conditions and smolt arrival time to the estuary resulting from flow augmentation are significant. The contribution of flow augmentation to estuary processes is simply too small to be significant.

- I disagree with the ISAB's statement that the within year survival data does not show a pattern. There are patterns, especially in 2001, and any model used to evaluate the flow augmentation program must be able to explain and fit both the within year and the between year patterns.

I do reach several conclusions that agree with the ISAB's review:

- The prevailing flow-augmentation paradigm is no longer supportable by the data.

- Valid approaches must be based on ecological mechanisms for explaining smolt survival.

- Interpretation of flow requires an understanding of the relation between reach survival, instantaneous mortality, migration speed, and flow. I add to this list the need to understand the contributions of environmental factors including temperature and turbidity. Also, the understanding must have a theoretical basis that is mathematically rigorous and based on first principles of ecology.

Final thoughts

The XT model and resulting analysis are new and important to the understanding the impacts of flow on survival. However, the ISAB's review contains no reference to the work, which admittedly is in progress, but was available to the ISAB. Furthermore, I realize that the work must be completed and reviewed before it factored into the Council's decision. However, even though it is work in progress, it illustrates that the ISAB review was significantly incomplete and conclusions reach by the ISAB may be open to challenge on a solid scientific foundation.