# State, Federal, and Tribal Anadromous Fish Managers Comments on the Northwest Power Planning Council Draft Mainstem Amendments as they Relate to Flow/Survival Relationships for Salmon and Steelhead

## FINAL DOCUMENT

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# *Executive Summary*
## *of the State, Federal, and Tribal Anadromous Fish Managers Comments on the Northwest Power Planning Council Draft Mainstem Amendments as they Relate to Flow/Survival Relationships for Salmon and Steelhead*

1. The state, federal, and tribal anadromous fish managers reviewed the NPPC's draft Mainstem Amendments to the Columbia River Basin Fish and Wildlife Program, which are contained in Council Document 2002-16. This review focused on the scientific information, as anticipated in section 839(h)(B) of the Northwest Power Act, regarding the effect of flow on salmon and steelhead survival.

2. The Council draft mainstem amendment document relies heavily on a conclusion from Giorgi et al. (2002) questioning the scientific basis of a flow survival relationship. There was little reliance by the Council on recommendations or comments of the fish and wildlife management agencies, scientific support for flow-survival relationships previously summarized in NMFS (2000) white papers, or recently peer-reviewed articles on chinook summer migrants.

3. The Council did not seem to heed the caution from the ISRP review that the Giorgi et al. (2002) report concerning a flow survival relationship was "…very conservative in drawing statistical conclusions. From a purely statistical standpoint, tests that fail to show statistical significance in data can be definitive in stating *no effect was found*, yet these tests do not definitively prove the absence of an effect."

4. The assessment and conclusions of the state, tribal and federal anadromous fish managers regarding the mechanisms by which flow and water velocity may affect juvenile survival in freshwater and from migrating smolt to adult return have been summarized in this paper. This includes a summary on juvenile migratory characteristics related to flow and spill that also provide evidence of flow-survival relationships, and the supporting empirical evidence from patterns of smolt-to-adult return rates (SARs) and life cycle survival analyses (ratio of recruits to the spawning grounds vs. spawners the previous generation; S/S).

5. The conclusion of the state, tribal and federal salmon managers, based on review of the scientific information regarding the effect of flow on salmon and steelhead are:
    a. **Juvenile steelhead and chinook spring migrants**
        i. A water travel time/ survival relationship exists for spring migrating chinook and steelhead of Snake River and Mid-Columbia River origin.
        ii. A water travel time and fish travel time relationship exists for spring migrating chinook and steelhead.
        iii. Within the management range of the Biological Opinion and the flow spill risk analysis dissolved gas levels of 125% there is minimal risk of reducing survival by increasing spill.
        iv. It is difficult to define a flow survival relationship because survival is the combined result of many interacting variables and the methodology for

estimating survival does not lend itself to identifying each individual environmental or biotic variable individually.

b. **Juvenile fall chinook migrants**
    i. Wild subyearling fall chinook salmon spend from 20 to 42 days in Lower Granite Reservoir primarily during the months of July and August.
    ii. Meeting summer flow targets decreases the time young fall chinook salmon spend in Lower Granite Reservoir by 1 to 5 days.
    iii. Survival of wild subyearling Snake River fall chinook is influenced simultaneously by flow and temperature.
    iv. Meeting summer flow targets increases flow and decreases temperature
    v. Meeting summer flow targets in July and August increases survival of wild subyearling fall chinook migrants.
    vi. Shifting flow augmentation from July and early August to later times in the year would decrease survival of the largest portion of the wild subyearling fall chinook salmon run.

c. **Adult return analysis**
    i. Numerous mechanisms exist by which flow and water velocity may affect survival from migrating smolt to adult return.
    ii. Juvenile migration conditions and ocean climate conditions were both influential in explaining patterns of adult recruitment of Snake River spring and summer chinook (spawner to spawner ratio).
    iii. The BIOP flow targets appear to represent a minimum needed to maintain the Snake River spring summer chinook populations for average to good ocean conditions and provide inadequate protection for poor ocean conditions.
    iv. The Councils proposed relaxation of spring flow targets would increase water travel time and reduce protection against population declines and the likelihood of rebuilding spring and summer chinook stocks.
    v. Juvenile migration conditions and ocean climate conditions were both influential in explaining patterns of SARs in Snake River spring and summer chinook and steelhead.
    vi. Relaxation of Spring flow objectives would likely decrease the SARs of wild Snake River spring and summer chinook and steelhead.

# State, Federal, and Tribal Anadromous Fish Managers Comments on the Northwest Power Planning Council Draft Mainstem Amendments as they Relate to Flow/Survival Relationships for Salmon and Steelhead.

## Introduction

The initial recommendations for the Northwest Power Planning Council Fish and Wildlife Program were submitted to the Northwest Power Planning Council under the auspices of Section 4(h) of the Northwest Power Act by the state, federal and tribal salmon managers in November of 1981. Flow and spill for the juvenile out migration of salmon and steelhead were critical facets of those recommendations. The joint recommendations of the salmon management entities were based upon passage and migration data and analysis collected to the date of the initial Fish and Wildlife Program. Over the past decades significant additional study and analysis has taken place.

The Council draft mainstem amendment document relies heavily on a conclusion from Giorgi et al. (2002) questioning the scientific basis of a flow survival relationship. There was little reliance by the Council on recommendations or comments of the fish and wildlife management agencies, scientific support for flow-survival relationships previously summarized in NMFS (2000) white papers, or recently peer-reviewed articles on chinook summer migrants. The Council did not seem to heed the caution from the ISRP review that the Giorgi et al. (2002) report was "…very conservative in drawing statistical conclusions. This fact needs to be understood for proper interpretation of the report. From a purely statistical standpoint, tests that fail to show statistical significance in data can be definitive in stating *no effect was found*, yet these tests do not definitively prove the absence of an effect." See Peterman (1990) for a review of this problem in fisheries research and management.

This paper briefly summarizes the assessment and conclusions of the state, tribal and federal anadromous fish managers regarding the mechanisms by which flow and water velocity may affect juvenile survival in freshwater and from migrating smolt to adult return. This includes a summary on juvenile migratory characteristics related to flow and spill that also provide evidence of flow-survival relationships, and the supporting empirical evidence from patterns of smolt-to-adult return rates (SARs) and life cycle survival analyses (ratio of recruits to the spawning grounds vs. spawners the previous generation; S/S). The document is organized in terms of juvenile migration characteristics and adult analysis. The conclusion of the state, tribal and federal salmon managers, based on review of the scientific information as anticipated in section 839(h)(B) of the Northwest Power Act, regarding the affect of flow on salmon and steelhead are:

### Juvenile steelhead and chinook spring migrants

- A water travel time/ survival relationship exists for spring migrating chinook and steelhead of Snake River and Mid-Columbia River origin.
- A water travel time and fish travel time relationship exists for spring migrating chinook and steelhead.

- Within the management range of the Biological Opinion and the flow spill risk analysis, there is minimal risk of reducing survival by increasing spill up to dissolved gas levels of 125%.
- It is difficult to define a flow survival relationship because survival is the combined result of many interacting variables and the methodology for estimating survival does not lend itself to identifying each individual environmental or biotic variable individually.

**Juvenile fall chinook migrants**

- Wild subyearling fall chinook salmon spend from 20 to 42 days in Lower Granite Reservoir primarily during the months of July and August
- Summer flow augmentation decreases the time young fall chinook salmon spend in Lower Granite Reservoir by 1 to 5 days
- Survival of wild subyearling Snake River fall chinook is influenced simultaneously by flow and temperature
- Summer flow augmentation increases flow and decreases temperature
- Summer flow augmentation in July and August increases survival of wild subyearling fall chinook migrants
- Shifting flow augmentation from July and early August to later times in the year would decrease survival of the largest portion of the wild subyearling fall chinook salmon run

**Adult return analysis**

- Numerous mechanisms exist by which flow and water velocity may affect survival from migrating smolt to adult return.
- Juvenile migration conditions and ocean climate conditions were both influential in explaining patterns of adult recruitment of Snake River spring and summer chinook (spawner to spawner ratio)
- The BIOP flow targets appear to represent a minimum needed to maintain the Snake River spring summer chinook populations for average to good ocean conditions and provide inadequate protection for poor ocean conditions
- The Councils proposed relaxation of spring flow targets would increase water travel time and reduce protection against population declines and the likelihood of rebuilding spring and summer chinook stocks.
- Juvenile migration conditions and ocean climate conditions were both influential in explaining patterns of SARs in Snake River spring and summer chinook and steelhead.
- Relaxation of Spring flow objectives would likely decrease the SARs of wild Snake River spring and summer chinook and steelhead

## Background of Flow Related Effects on Salmonid Smolt Travel Time, Rate of Seaward Movement, and Survival and Adult Returns

The analyses are approached in three components, the Snake River from Lower Granite to McNary Dam, Mid-Columbia from Rock Island to McNary and Lower Columbia River reaches from McNary to Bonneville tailrace. The following assessment focuses on the migration characteristics of juvenile salmonids including; travel time (migration speed), rate of seaward movement, survival and migration timing, addressing these migration characteristics and the suite of biotic and abiotic factors that affect them.

Increases in flow in the hydrosystem are thought to be beneficial to migrating young salmonids for several reasons. These species evolved in systems without dams and were dependent on the river current to aid in their migration to the ocean. The migration of spring/summer and fall chinook and steelhead was timed with periods of high spring runoff. During a free-flowing condition Snake River yearling chinook and steelhead migrated to the ocean in about $^1/_3$ to ½ the time that is now observed with the dams in place. Dam construction changed juvenile fall chinook salmon life history in the Snake River basin by shifting production to areas with relatively cool water temperatures and comparatively lower growth opportunity. Consequently, young fall chinook salmon do not attain migratory status until late spring and the majority of the wild fish are present in lower Snake and Columbia River reservoirs in July and August after spring runoff is complete (Connor et al. 2002). Increases in the time spent in the reservoirs increases the exposure time to higher temperature and predators, now more abundant in the reservoir system than in pre-dam riverine conditions. (Poe et al 1991, Poe et al 1994) In addition to the direct effects of increases in flow on downstream passage of smolts, there are several other flow related mechanisms that manifest in life history constraints hence smolt survival. Increases in flow are associated with decreases in temperature and increases in turbidity. When flow falls to low levels, the accompanying increases in temperature increase the energetic demands for migrating smolts, increase their susceptibility to disease, disrupt smoltification, and increase the energy demands of predators hence predation on smolts. Low turbidity increase the susceptibility of smolts to visual predators such as fish and birds. Studies also suggest that the extended time smolts spend in freshwater affect marine survival by depleting energy reserves before the smolts arrive at the ocean. This phenomenon is especially prevalent under low flow conditions (Congelton, ACOE Delayed Mortality Workshop). A delay in seawater entry might also disrupt physiological changes necessary for adapting to saltwater. Decreased flows may also form greater physical barriers with the freshwater/saltwater interface (Schreck and Stahl 1998).

Travel time is one of the key migrational characteristics reflecting the dynamics of the migration of juvenile salmonids. The physiological condition of smolts changes over time and arrival at the estuary during the “biological window” determines the success of the smolts transition to seawater. Studies conducted since 1998 (Congleton et al., 2000, 2001 and 2002) have observed the rate of energy use and the blood chemistry changes that occur in fish as they migrate from hatcheries above Lower Granite Dam to Bonneville Dam In general, the juvenile chinook salmon studied were in negative energy balance throughout the downstream migration. The low flows in 2001 caused fish to undergo a migration that was significantly longer and the low flows and extended travel times resulted in the exhaustion of lipid reserves at points further upstream and greater use of protein reserves than in earlier years. The use of protein reserves means that muscle mass is metabolized and the activities of critical rate-limiting enzymes involved in metabolism, saltwater adaptation, and other vital functions may be reduced (Congleton, 2002).

Giorgi et al. (2002) points to these life-history constraints as rationale for flow augmentation. They provided information supporting increased migration rates with increases in flow for yearling chinook and steelhead (Sims and Ossiander 1981, Berggren and Filardo 1993). Most of these analyses demonstrate increasing migration speeds by increasing flows provides the greatest benefits at lower flows. Regardless of flow level, several studies have produced equivocal results with respect to the relation between flow and seaward movement of summer migrating subyearling chinook salmon. Berggren and Filardo (1993), Giorgi et al. (1997), and Tiffan et al. (2000) studied ocean-type chinook salmon passing downstream in Columbia River reservoirs. Berggren and Filardo (1993) concluded that seaward movement of summer migrants increased as flow increased, thus flow augmentation helps to mitigate dam-caused passage delays. Tiffan et al. (2000) concluded that flow was weakly related to seaward movement. Giorgi et al. (1997) concluded that there is no evidence for a relation between downstream migration rate and flow. A recent study, however, showed that wild subyearling fall chinook salmon progress through a series of complicated migrational behaviors during which their response to changes in flow varies (Connor et al. In press a). Subyearling fall chinook salmon respond to increases in flow as they pass downstream from the free-flowing Snake River to Lower Granite Dam. The Connor et al. analysis, however, failed to find evidence for a flow-migration rate relation as fish passed downstream between Lower Granite and Little Goose dams probably because of limitations on their study. This does not suggest a downstream relationship does not exist, rather that different degrees of smoltification will result in different rates of migration and therefore, complicate such relationships.

Giorgi et al. (2002) reiterate a concern by several researchers that many environmental variables may be responsible for patterns of survival through the hydrosystem. Flow and spill are unlikely the only variables affecting survival; however, many of the variables of concern are a result of changes in flow. Turbidity and temperature, for example, have been suggested to be driving survival patterns, but these are often dependent on flow, flow is not dependent on turbidity and temperature. These factors may make flow/survival patterns more difficult to observe but they should not be used as evidence that flow is not an important driver to relationships that we do observe.

A large proportion of Snake River spring/summer chinook and steelhead have been removed from the river for transportation since Snake River dam construction, yet their subsequent survival may also be influenced by the environmental conditions (flow and spill in particular) experienced prior to collection and transportation (Budy et al. 2002; Mundy et al. 1994). Examples of mechanisms by which flow or water travel time may influence post-transport survival of smolts include effects of delayed migration on energetic condition (reduced lipids), exacerbated by stress at the collection projects, holding facilities and in transportation.

As with transportation and spill, considerations to the impacts of flow outside the hydrosystem, including delayed mortality to both transported fish and those that migrated in-river (Budy et al. 2002), must be taken into consideration. Flow may be important below Bonneville where fish and avian predators are most abundant and survival is not currently estimated as fish and avian predators are most abundant in this area. As stated above, smolts undergo dramatic physiological changes to cope with entry into the estuary and saltwater. Changes in flow can greatly affect the physiological timing of this transition. For example, Schreck and Stahl (1998) have documented that smolts that are stressed (from barging or migrating in-river) avoid entry into saltwater by remaining on the floating freshwater lens at the saltwater-freshwater interface. This forces smolts to the surface where they are susceptible to avian predation. Increased flows out of the Columbia enhance mixing of freshwater and saltwater and aid migrating salmon into the transition to saltwater decreasing this delayed hydrosystem mortality. Through these mechanisms both transported and in-river fish can be greatly affected by the flow regime. How this and other factors in the hydrosystem affect survival back to adults is of prime importance. Giorgi et al. (2002) does not evaluate the impacts of flow on these other life stages but evidence can be found for this in NMFS white papers, and in previous fish and wildlife agency comments to the Council.

## Methods of Travel time and Survival Data Analysis for Juvenile Steelhead and Chinook Springs Migrants

### Travel time and survival

The juvenile migrants considered for these analyses represent groups for which travel time and survival was estimated for the entire Snake River (Lower Granite Dam to McNary Dam) reach using PIT tag technology. The first year that PIT tag data was available for survival estimation in the entire Lower Granite to McNary reach was 1995, however, not until 1998 when installation of full bypass PIT tag detection at John Day Dam was completed did we begin to obtain reliable estimation of survival to McNary Dam. Although survival studies using PIT tags were initiated as soon as the PIT tag detection units were installed at the projects, the reaches covered were limited in the early years. In 1993 survival studies could only be conducted between Lower Granite and Little Goose dams. This was expanded in 1994 to the Lower Granite to Lower Monumental river reach when PIT tag detectors were installed at additional projects. In 1995 to 1997, direct estimates of survival in the Lower Granite to McNary Dam reach were possible; however, due to limited detection capability at John Day Dam (detection of sampled fish from one gatewell slot out of 48) and moderate detection capability at Bonneville Dam due to operational spill levels at that facility, the resulting reach survival estimates had low precision. The detection limitations of the early years necessitated the extrapolation of the shorter river reach survival estimates to the longer reach (Lower Granite to McNary). It is now known that these earlier estimates using extrapolation resulted in a miss-representation of survival when applied to the longer reach. Consequently, we have chosen not to include these estimates in our analysis. Reliable estimation of survival to McNary Dam was not possible until installation of bypass detectors at John Day in 1998. For these reasons we have chosen to use survival estimate from 1998 to 2002 in creating the bivariate and multiple regression models. The above detection limitations below McNary Dam do not impact the quality of the travel time data from Lower Granite Dam to McNary Dam and therefore, travel time analyses use data from 1995 to 2002 for yearling chinook and 1996 to 2002 for steelhead. All juvenile yearling chinook and steelhead marked using PIT tags at hatcheries and fish traps above Lower Granite Dam and subsequently recaptured at the initial site, as well as those fish marked and released at Lower Granite Dam, were used in our analysis.

For the analyses pertaining to the Mid Columbia River, travel time and survival was estimated from Rock Island to McNary dams for releases of yearling chinook and steelhead marked and released at Rock Island Dam from 1998 to 2002. The Mid-Columbia fish used in our analysis were marked at Rock Island as part of the Fish Passage Center's Smolt Monitoring Program.

For the Snake River this study used all juvenile yearling chinook and steelhead marked using PIT tags at hatcheries and fish traps above Lower Granite Dam and subsequently recaptured at the initial site, as well as those fish marked and released at Lower Granite Dam. In the Mid Columbia the fish used were marked at Rock Island Dam as part of the Fish Passage Center's Smolt Monitoring Program. The accuracy and precision associated with any estimate of survival or travel time will be dependent on the number of fish in a release group (N) and the number of fish subsequently recaptured. The intent of the analysis was to relate the dependent variables (travel time and survival) to a series of independent environmental variables. As fish migrate through the hydrosystem the initial release group disperses over time making the description of an average environmental condition difficult. The best chance of describing the environmental variable for each group was to limit the time frame over which the variable was estimated before groups became too dispersed and to reduce the overlap among groups. Consequently, when grouping daily releases of PIT tagged groups together over longer periods of time to provide the most accurate and precise estimate, it is important to not group too large a time period to mask the effect of environmental variables. For smolts originating in the Snake River basin, travel time and survival estimates were developed for each weekly release block in the available years of data. Each year was divided into eight weekly periods for wild and hatchery yearling chinook and into six weekly periods for steelhead. For the Mid Columbia migrants, the season was divided into three two-week blocks for each year.

Smolt travel time is amount of time needed for juvenile migrants to transit the river system between any two points. For each temporal block, an estimate of median travel time was calculated from the smolts transiting the entire reach of interest.

Survival is estimated using the Cormack-Jolly-Seber (CJS) tag-recapture methodology. This method estimates survival components between each dam within the index reach having PIT tag detection equipment such as Little Goose, Lower Monumental, and McNary dams (additional detections at John Day and Bonneville dams downstream of McNary Dam also contribute to process of estimating survival in the upstream reaches. In the case of the Snake River reach, the survival estimate is the product of survival from Lower Granite Dam tailrace to Little Goose Dam tailrace, Little Goose Dam tailrace to Lower Monumental Dam tailrace, and Lower Monumental Dam tailrace to McNary Dam tailrace. In the case of the Mid-Columbia River reach, the survival estimate is the single estimate from Rock Island Dam tailrace to McNary Dam tailrace. The Snake River reach includes four reservoirs and dams and the Mid-Columbia River reach includes three reservoirs and dams.

Because the recovery of the PIT tags is dependent on being observed in a bypass system at downstream hydroprojects, the river and project operations exert considerable influence on the ability to obtain sufficient tag recoveries to obtain a valid estimate. Several criteria were employed to distinguish among the resulting estimates to assure their validity. Any temporal blocks which contained less than 300 smolts in the release group provided too few recoveries to make valid estimates of survival. Consequently, no estimates of survival and travel time were made when less than 300 smolts were available. In addition, another criterion was applied to the estimates of survival. When the coefficient of variation (standard error divided by estimate) of any component survival estimate exceeded 0.25, the full reach survival estimate was excluded from the analysis. This check was made prior to multiplying the several component survival estimates to create a full reach survival estimate, as was the case in the Snake River basin. Whenever a component survival estimate was greater than 1, then the standard error divided by 1 was used as the threshold criteria. In the years 1998 to 2002, only one wild chinook, two hatchery chinook, and one steelhead temporal block needed to be excluded due to the minimum coefficient of variation criterion. In the Snake River reach, the final survival data set contained 66 estimates of survival for yearling chinook (hatchery and wild combined) and 26 estimates for steelhead. In the Mid Columbia, the final survival data set contained 13 estimates for yearling chinook and 15 estimates for steelhead. All survival estimates were accompanied with associated environmental variables.

## Environmental Variables: Water transit time, spill proportion, and water temperature

Predictor variables of in-river survival were considered that are related to how flow or velocity may affect the survival of smolts migrating in-river through the hydro system in specific reaches of the Snake and Columbia rivers. The final set of predictor variables included a water velocity related variable, a spill related variable, and river temperature.

### *Water Transit Time*

Previous analyses suggested that changes in flow produced changes in water velocity, which determined how quickly smolts migrated through the hydrosystem. The actual flow regime experienced by a group of migrating juvenile fish is difficult to quantify. Past analyses have used an index of flow through a specific reach for a period of time around the median passage dates of the migration or an average flow over the entire passage period. Because of the discrete relation between flow and water transit time (WTT) (also known as water particle travel time) and the implication of velocity as the important determining factor, the flow variable was quantified as the summation of water transit times for each reservoir incorporated in a reach (Figures 1 and 2 showing relation between WTT and average flow in the Snake River and McNary Dam reservoir).

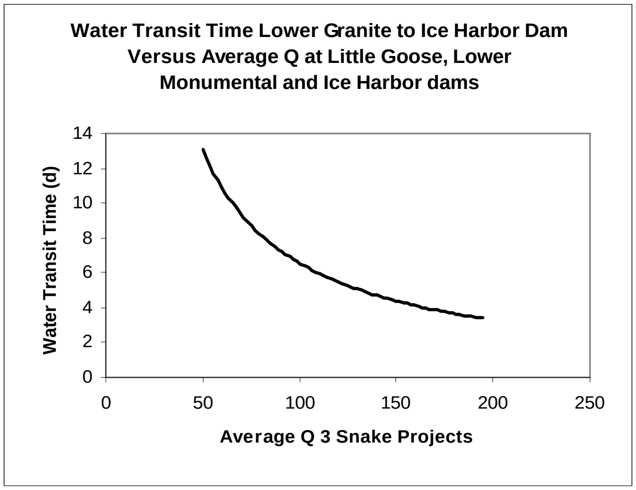


**Figure 1. Relation between water transit time flow in Lower Snake River.**

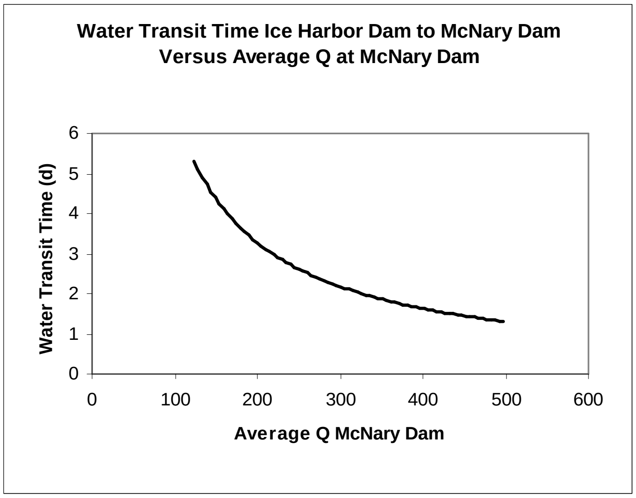


**Figure 2. Relation between water transit and average time and average flow in McNary Pool.**

The water transit time is the estimated amount of time required for a water particle to travel the fixed distance from the start of the reach to the end of the reach (WTT = distance / average water velocity). This fixed distance was 140 miles for the Snake River reach from Lower Granite Dam tailrace to McNary Dam tailrace and 161 miles for the Mid-Columbia River reach from Rock Island Dam tailrace to McNary Dam tailrace. The median travel time was estimated to each down stream project for each weekly block. The mid-date of release from LGR was used and to it was added median travel time for the release group to the downstream project. For each day, WTT is computed by dividing each reservoir volume by its corresponding daily average flow to determine the water particle transit time for that day. Reservoir volumes are obtained using COE tables and current reservoir elevations. For each reservoir, an average WTT is computed over a 7-day window of WTT's around the date of median passage of the fish of interest at the reservoir's downstream dam. These average WTT are then summed over the number of reservoirs in the reach of interest. The dates of median fish passage at each dam are obtained from PIT tagged smolts released from or passing during weekly blocks of time at Lower Granite Dam. This process is repeated for each weekly release group of PIT tagged smolts at Lower Granite Dam. Each weekly (7-day) release, starting April 1 for yearling chinook and April 17 for steelhead, was numbered sequentially from first through last week for each year to create a variable for week of entry into the reach.

### *Spill Proportion*

For each reservoir and dam segment of the reach, survival may be viewed as the product of two components, a reservoir survival component and a dam passage component. In the dam passage component, survival may be viewed as the weighted average survival across each passage route, such as spillway route, turbine route, and bypass channel route (if present), where the weight is equal to the population of smolts using each route. Because the spill passage route has been shown to be the safest route of passage (except during periods of excessively high flows when gas may be a problem), increases in the amount of spill and numbers of fish passing through that route will have a direct effect on the reach survival estimate. Therefore, it is essential to include a spill related variable in all multiple regression models, otherwise the effect of spill will be confounded within the parameter estimates of the other variables in the model (*i.e*., a case of model misspecification). The variable representing spill at Little Goose, Lower Monumental, Ice Harbor, and McNary between April and June of 1998 and 2002 was the percentage of daily spill to total discharge. It was calculated using daily average spill and daily average total discharge at each project. Each daily percent Spill/Total Discharge was averaged over a seven-day passage window (centered around the median passage date) for each species and project. The average spill proportion is denoted as SPILLPROP in the subsequent text and tables.

### ***Water Temperature***

The dates of median fish passage at each dam are obtained from PIT tagged smolts released from or passing during weekly blocks of time at Lower Granite Dam. From these same 7-day windows around the dates of median smolt passage at each dam of interest, averages of river temperature are generated. Initially, a variable for the week of entry into the reach was considered, however, it was felt that the river temperature variable would already include the effect of this temporal variable in two ways. First, the general timing of the smolts at Lower Granite Dam is highly influence by river temperature. In years of warmer winters and earlier warming of the river, the smolts begin their migration earlier, whereas in years of cooler winter and later snowmelt, the smolts begin their migration later. Second, river temperature increase over time during the migration period, and so any effects of week of entry into the reach is already confounded within the river temperature variable. Therefore, week of entry into the reach was not used in the multiple regression analyses. The water temperature variable is denoted simply as TEMP in the subsequent text and tables.

## Results of Travel Time Analysis

### Snake River Reach: Lower Granite Dam to McNary Dam

Bivariate relations between smolt travel time and WTT were modeled using linear regression (Table 1). Relations for smolts originating above Lower Granite Dam and migrating between the tailrace of Lower Granite Dam and McNary Dam are shown for wild yearling chinook in Figure 3, hatchery yearling chinook in Figure 4, and steelhead (wild and hatchery) in Figure 5.

**Table 1. Summary of linear regressions of median travel time versus water transit time for wild and hatchery yearling chinook and steelhead.**

| Group | Regression Equation | $R^2$ |
|---|---|---|
| Wild Chinook | $y = 1.245x + 0.8745$ | 0.51 |
| Hatchery Chinook | $y = 1.107x + 2.3327$ | 0.58 |
| Steelhead | $y = 1.250x - 1.2075$ | 0.87 |

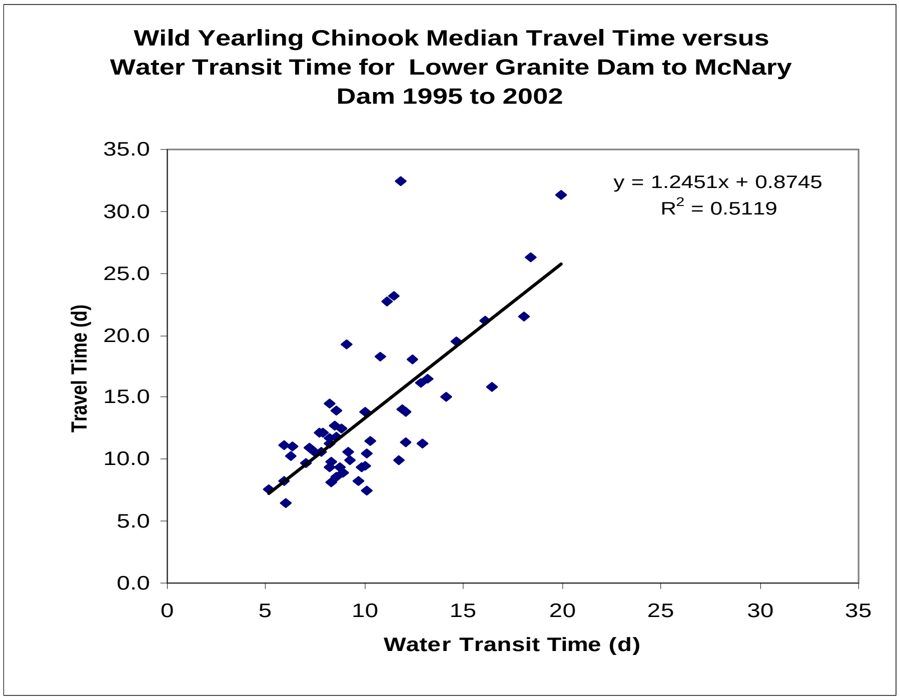


**Figure 3. Wild yearling chinook travel time versus water transit time.**

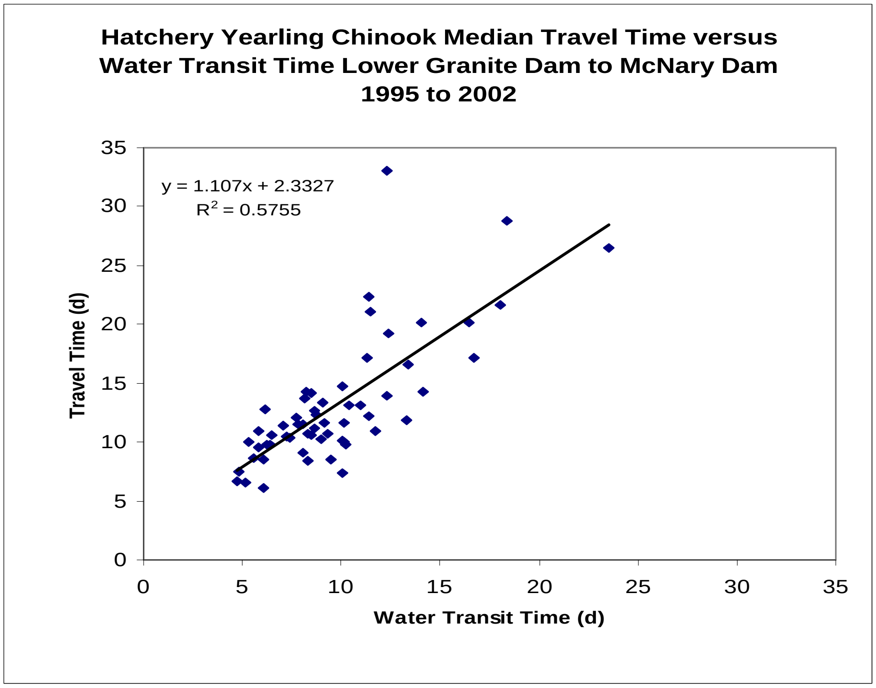


**Figure 4. Hatchery yearling chinook travel time versus water transit time.**

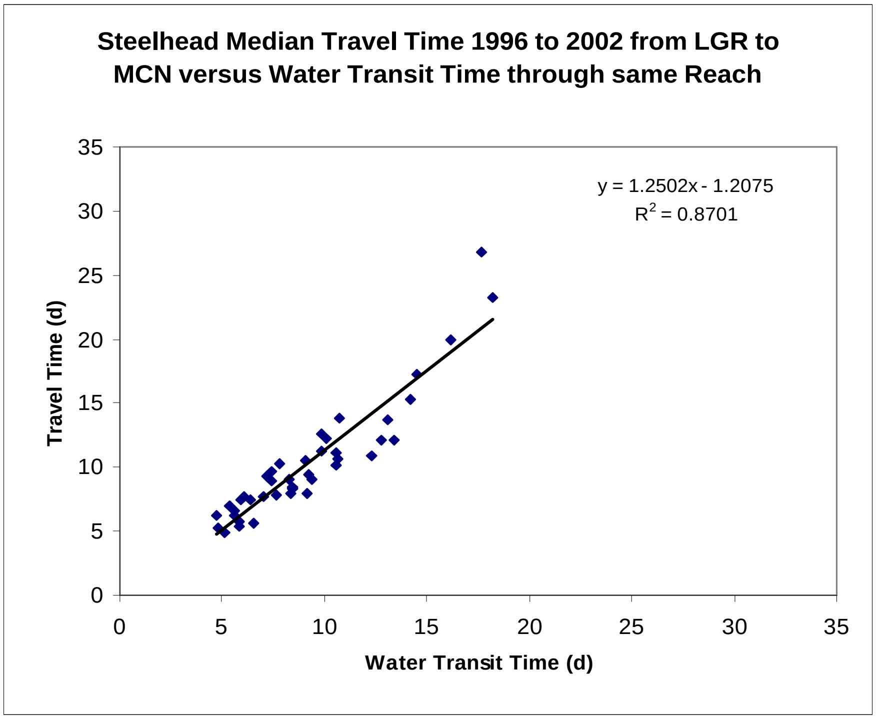


**Figure 5. Steelhead travel time versus water transit time.**

## Mid-Columbia River Reach: Rock Island Dam to McNary Dam

Bivariate relations between smolt travel time and WTT were modeled using linear regression (Table 2). Relations for smolts originating above Rock Island Dam and migrating between the tailrace of Rock Island Dam and McNary Dam are shown for yearling chinook in Figure 6 and steelhead in Figure 7. For each species, the data is a mixture of wild and hatchery smolts.

**Table 2. Summary of linear regressions of median travel time versus water transit time for wild and hatchery chinook and steelhead.**

| Group | Regression Equation | $R^2$ |
|---|---|---|
| Yearling Chinook | y = 2.0797x - 1.8816 | 0.55 |
| Steelhead | y = 1.8899x - 3.5432 | 0.93 |

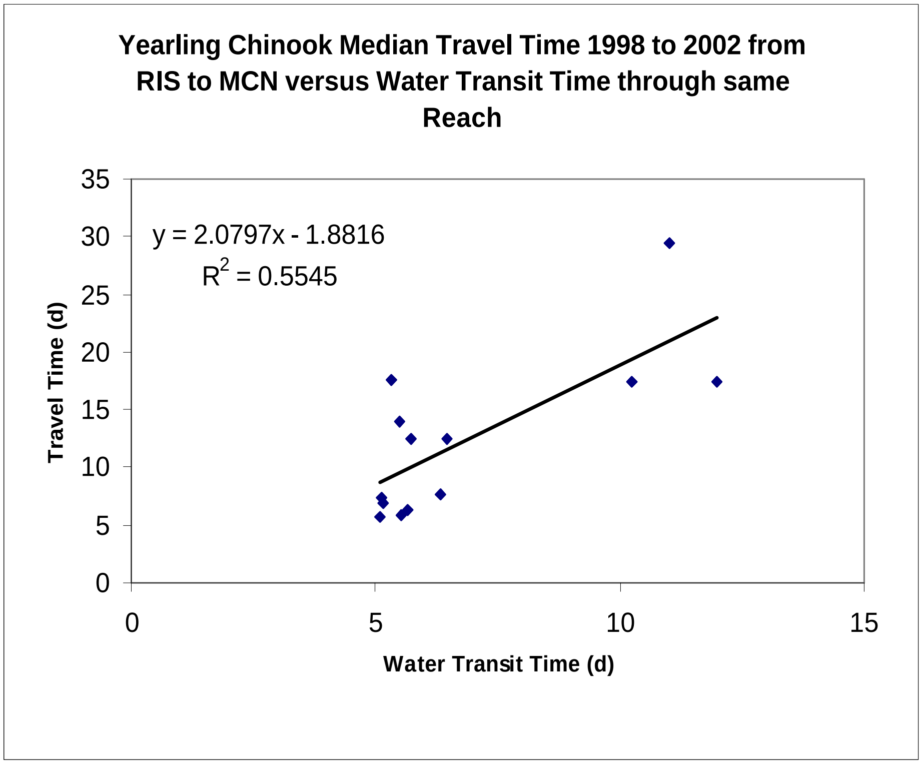


Figure 6. Yearling chinook travel time versus water transit time.

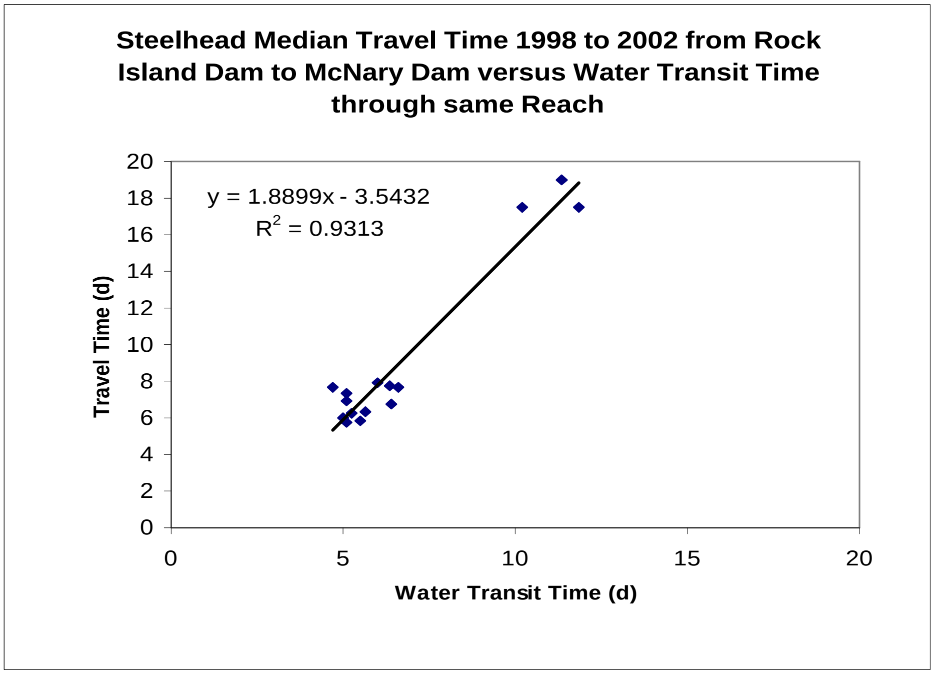


Figure 7. Steelhead travel time versus water transit time.

## Results of Survival Analysis

Snake River Reach: Lower Granite Dam to McNary Dam

### *Survival Analysis for steelhead*

The water transit time (WTT) and spill proportion (SPILLPROP) variables both had high correlation with the dependent variable survival (Table 3). Correlation between WTT and SPILLPROP was r = -0.81, a level low enough so that multicollinearity is not a problem. The square root of the variance-inflation factor, sqrt[1/(1-$R^2$)] provides a measure of the extent to which the standard error of the regression coefficients will be inflated due to high correlation between the predictor variables in a model. In the case of our model with WTT and SPILLPROP, the regression coefficient standard error will be inflated by a factor of approximately 1.7. Myers (1990) and Fox (1991) show that multicollinearity doesn't become a problem until the variance-inflation factor exceeds 10, which triples the standard error of the regression parameters. A plot of estimated survival of steelhead from the tailrace of Lower Granite Dam to the tailrace of McNary Dam relative to WTT shows a linear relation in Figure 8.

**Table 3. Correlation matrix for variables related to steelhead.**

| | SURVIVAL | WTT | SPILLPROP |
|---|---|---|---|
| WTT | -0.914 | | |
| SPILLPROP | 0.869 | -0.809 | |
| TEMP | -0.430 | 0.300 | -0.464 |

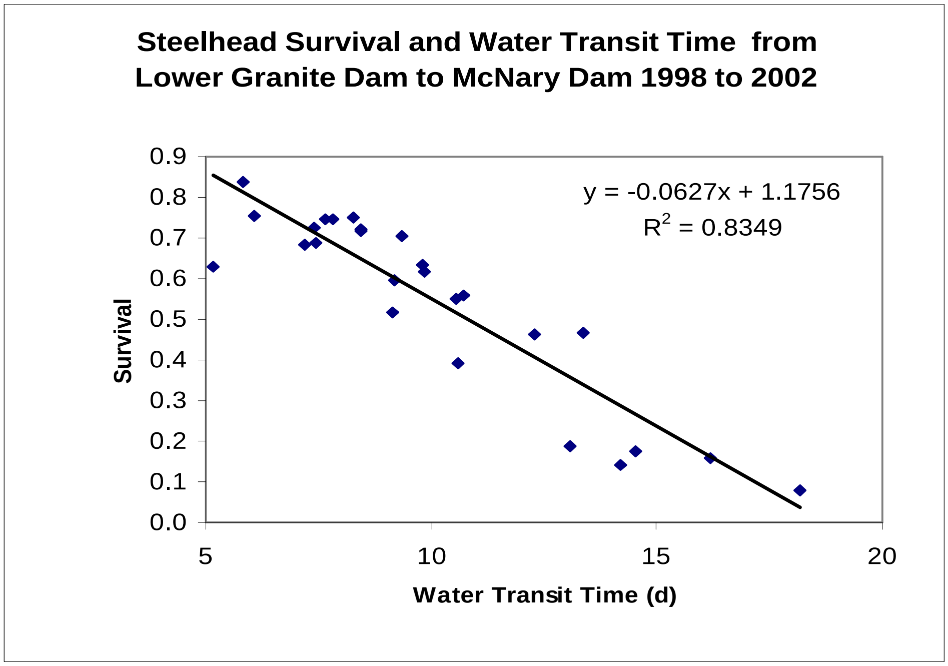


**Figure 8. Steelhead survival versus water transit time**

In the multiple regression analysis for steelhead, WTT and SPILLPROP were both significant variables in explaining variation in the dependent variable survival (Table 4). In the presence of these two variables, water temperature (TEMP) did not significantly explain any variation in survival. Since the various routes of passage, each with differential rates survival for passing fish, at a particular dam is an integral component of any reach "true" survival rate, it is encouraging to see a spill-related variable remain in the model. Any mechanistic model should always include the influence of spill, and it does so in the steelhead regression model. The joint model of WTT and SPILLPROP provides the best model for predicting steelhead survival in the Snake River reach.

**Table 4. Multiple regression models for predicting survival of steelhead salmon in the Snake River from the tailrace of Lower Granite Dam to the tailrace of McNary Dam.**

| | Variable | Coefficient | SE | P | MSE | $R^2$ |
|---|---|---|---|---|---|---|
| N = 26 | Constant | 0.79901 | 0.13203 | 0.00000 | 0.00639 | 0.87 |
| | WTT | -0.04184 | 0.00831 | 0.00004 | | |
| | SPILLPROP | 0.00527 | 0.00117 | 0.00508 | | |

### *Survival for Yearling Chinook*

Analysis of covariance was used to determine whether hatchery and wild chinook differed in survival response as a function of the predictor variables. Wild and hatchery chinook did not significantly differ with any of the predictor variables (Table 5). Plots of estimated survival of yearling chinook from the tailrace of Lower Granite Dam to the tailrace of McNary Dam relative to WTT shows similar linear relations for hatchery and wild fish (Figures 9a and 9b, respectively). All further analyses were conducted on the combined set of wild and hatchery chinook data.

**Table 5. Analysis of Covariance comparison of hatchery and wild yearling chinook survival when all covariates are accounted for in the model.**

| | Variable | SS | df | MSE | F-ratio | P |
|---|---|---|---|---|---|---|
| N = 66 | RearType | 0.00191 | 1 | 0.00191 | 0.32314 | 0.57182 |
| H = 32 | WTT | 0.05225 | 1 | 0.05225 | 8.81804 | 0.00426 |
| W= 34 | SPILLPROP | 0.04096 | 1 | 0.04096 | 6.91232 | 0.01082 |
| | TEMP | 0.06892 | 1 | 0.06892 | 11.63241 | 0.00115 |
| | Error | | 61 | 0.00593 | | |

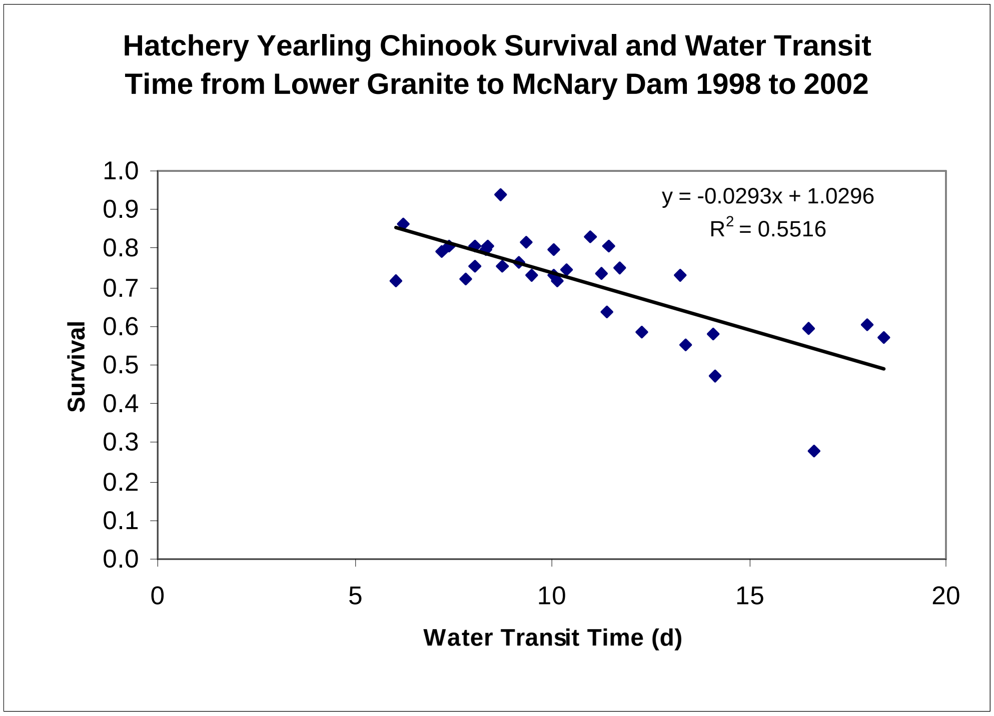


**Figure 9a. Hatchery yearling chinook survival versus water transit time.**

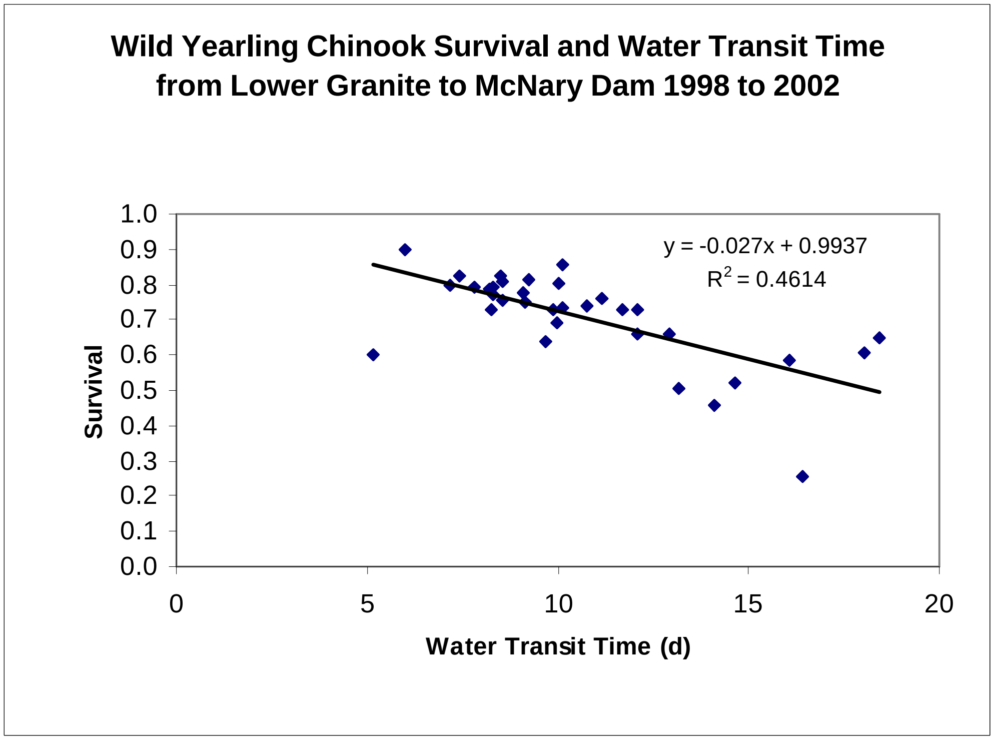


**Figure 9b. Wild yearling chinook survival versus water transit time.**

For the combined wild and hatchery yearling chinook, the WTT and SPILLPROP variables both had high correlation with the dependent variable survival (Table 6). As was observed with steelhead, the correlation between WTT and SPILLPROP for yearling chinook was r = -0.81, a level low enough so that multicollinearity is not a problem

**Table 6. Correlation matrix for variables related to wild and hatchery yearling chinook salmon.**

| | SURVIVAL | WTT | SPILLPROP |
|---|---|---|---|
| WTT | -0.70898 | | |
| SPILLPROP | 0.75498 | -0.80546 | |
| TEMP | -0.46136 | 0.16461 | -0.34821 |

In the multiple regression analysis for yearling chinook, WTT and SPILLPROP were both significant variables in explaining variation in the dependent variable survival (Table 7). In the presence of these two variables, TEMP also was significant in explaining variation in survival. The joint model of WTT, SPILLPROP, and TEMP provides the best model for predicting yearling chinook survival in the Snake River reach.

**Table 7. Multiple regression models for predicting survival of combined hatchery and wild yearling chinook salmon in the Snake River from the tailrace of Lower Granite Dam to the tailrace of McNary Dam.**

| | **Variable** | **Coefficient** | **SE** | **P** | **MSE** | **$R^2$** |
|---|---|---|---|---|---|---|
| N = 66 | Constant | 1.09264 | 0.13901 | 0.00000 | 0.0586 | 0.65 |
| | WTT | -0.01497 | 0.00504 | 0.0042 | | |
| | SPILLPROP | 0.00281 | 0.00106 | 0.01027 | | |
| | TEMP | -0.02624 | 0.00765 | 0.00109 | | |

## Mid-Columbia River Reach Rock Island Dam to McNary Dam

### *Survival Analysis for steelhead*

For steelhead in the Mid-Columbia River reach, WTT had the highest correlation with the dependent variable survival, while both SPILLPROP and TEMP had similar moderate levels of correlation with survival (Table 8). The correlation between WTT and SPILLPROP for steelhead was r = -0.87, a level still low enough so that multicollinearity is not a problem. A plot of estimated survival of steelhead from the tailrace of Rock Island Dam to the tailrace of McNary Dam relative to WTT shows a linear relation in Figure 10.

**Table 8. Correlation matrix for variables related to steelhead salmon.**

| | SURVIVAL | WTT | AVGSPILLPROP |
|---|---|---|---|
| WTT | -0.808 | | |
| AVGSPILLPROP | 0.647 | -0.870 | |
| AVTEMP | -0.587 | 0.312 | -0.193 |

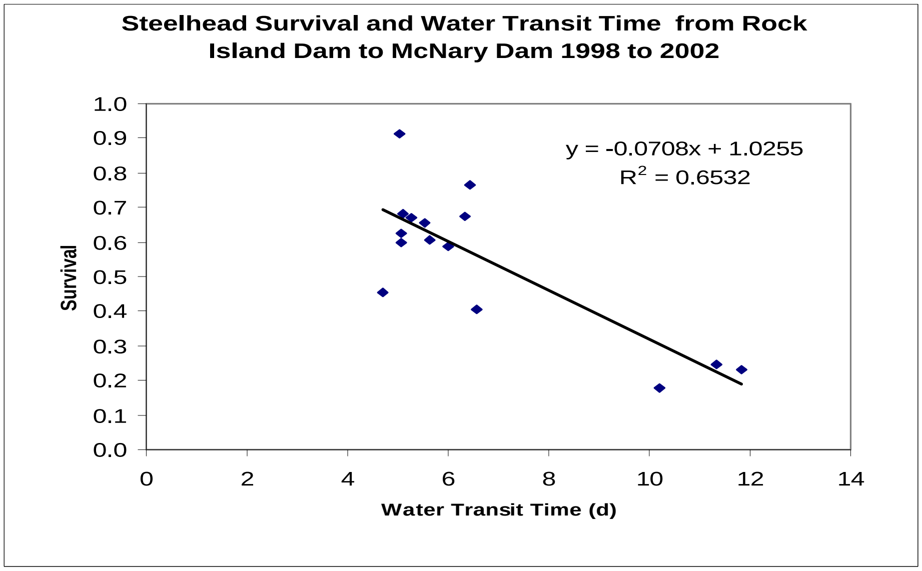


**Figure 10. Steelhead survival versus water transit time.**

In the multiple regression analysis for steelhead, WTT and TEMP were both significant variables in explaining variation in the dependent variable survival (Table 9). In the presence of these two variables, SPILLPROP did not significantly explain any variation in survival. Since the level of spill at Wanapam and Priest Rapids dams remained fairly constant over the years covered in the analysis, it is not surprising that SPILLPROP did not explain additional variation in survival. However, this finding does not reduce the intrinsic benefits of spill. Any mechanistic model should always include the influence of spill, and when it doesn't, the effect of spill becomes confounded within the coefficients of the other parameters in the model. For survival prediction purposes, the joint model of WTT and TEMP provides the best model for predicting steelhead survival from the tailrace of Rock Island Dam to the tailrace of McNary Dam.

**Table 9. Multiple regression models for predicting survival of steelhead salmon in the Mid-Columbia River from the tailrace of Rock Island Dam to the tailrace of McNary Dam.**

| | Variable | Coefficient | SE | P | MSE | $R^2$ |
|---|---|---|---|---|---|---|
| N = 15 | Constant | 1.6135 | 0.2425 | 0.00002 | 0.01136 | 0.74 |
| | WTT | -0.06065 | 0.01256 | 0.00041 | | |
| | TEMP | -0.0553 | 0.02138 | 0.02383 | | |

### *Survival for Yearling Chinook*

For yearling chinook in the Mid-Columbia River reach, WTT and SPILLPROP had similar moderate correlation with the dependent variable survival (Table 10). The correlation between WTT and SPILLPROP for steelhead was r = -0.83, a level low enough so that multicollinearity is not a problem, but higher than observed for yearling chinook in the Snake River reach. A plot of estimated survival of yearling chinook from the tailrace of Rock Island Dam to the tailrace of McNary Dam relative to WTT shows a linear relation in Figure 11.

**Table 10. Correlation matrix for variables related to yearling chinook salmon.**

| | SURVIVAL | WTT | AVGSPILLPROP |
|---|---|---|---|
| WTT | -0.543 | | |
| AVGSPILLPROP | 0.461 | -0.828 | |
| AVTEMP | -0.230 | 0.421 | -0.211 |

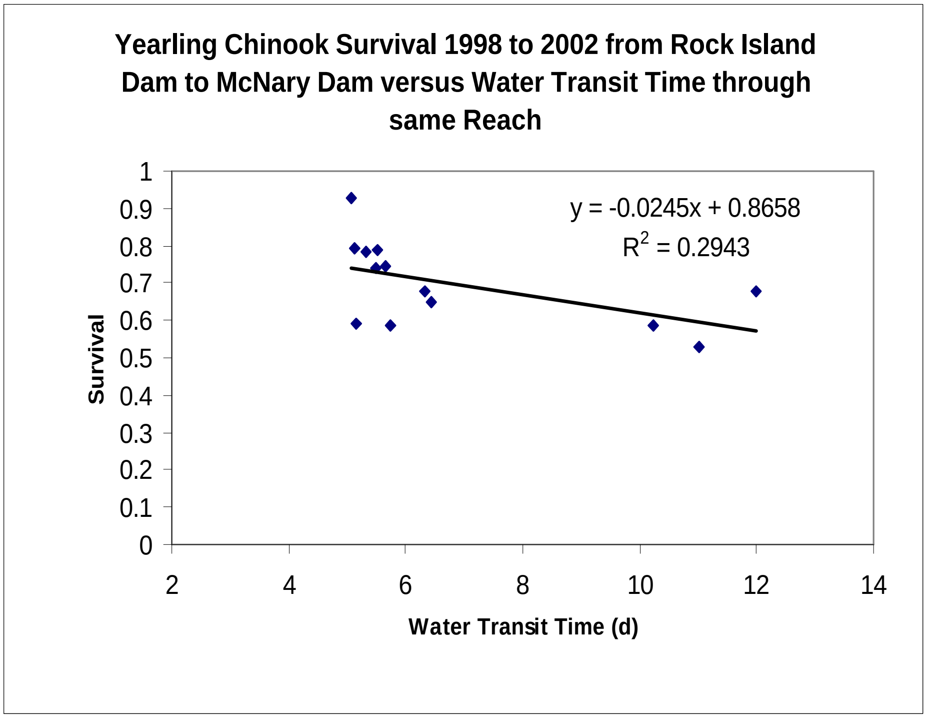


**Figure 11. Yearling chinook survival versus water transit time.**

In the multiple regression analysis for yearling chinook, only WTT was moderately significant in explaining variation in the dependent variable survival (Table 11). In the presence WTT, SPILLPROP did not significantly explain any variation in survival. Since the level of spill at Wanapam and Priest Rapids dams remained fairly constant over the years covered in the analysis, it is not surprising that SPILLPROP did not explain additional variation in survival. For survival prediction purposes, the simple bivariate model of WTT provides the best model for predicting yearling chinook survival from the tailrace of Rock Island Dam to the tailrace of McNary Dam.

**Table 11. Multiple regression model for predicting survival of yearling chinook salmon in the Mid-Columbia River from the tailrace of Rock Island Dam to the tailrace of McNary Dam.**

| | **Variable** | **Coefficient** | **SE** | **P** | **MSE** | **$R^2$** |
|---|---|---|---|---|---|---|
| N = 13 | Constant | 0.86052 | 0.08282 | 0.00000 | 0.00956 | 0.23 |
| | WTT | -0.02446 | 0.54250 | 0.05543 | | |

## Lower Columbia River Reach: McNary Dam to Bonneville Dam

### *Survival Analysis for steelhead*

For combined hatchery and wild steelhead, the water transit time (WTT), spill proportion (SPILLPROP), and water temperature (TEMP) variables each had high correlation with the dependent variable survival (Table 12). Correlation between each pair of predictor variables was also very high, which lead to problems of multicollinearity when trying to include more than one predictor variable in the model. Thus, a model with only one predictor variable was obtained. Since WTT had the highest correlation with steelhead smolt survival, it entered into the bivariate model that explained the most variation in the dependent variable survival (Table 13). A plot of estimated survival of steelhead from the tailrace of Lower Granite Dam to the tailrace of McNary Dam relative to WTT shows a linear relation in Figure 12. Although a multiple regression model was not attainable, one must keep in mind that SPILLPROP still has a direct influence on the resulting magnitude of the survival estimate. This is because, as stated earlier, the survival of smolts that pass through the spill route is typically higher than any other passage route at a dam.

**Table 12. Correlation matrix for variables related to steelhead.**

| | SURVIVAL | WTT | SPILLPROP |
|---|---|---|---|
| WTT | -0.959 | | |
| SPILLPROP | 0.871 | -0.969 | |
| TEMP | -0.948 | 0.985 | -0.930 |

**Table 13. Bivariate regression model for predicting survival of steelhead salmon in the lower Columbia River from the tailrace of McNary Dam to the tailrace of Bonneville Dam.**

| | **Variable** | **Coefficient** | **SE** | **P** | **MSE** | **$R^2$** |
|---|---|---|---|---|---|---|
| N = 4 | Constant | 0.97747 | 0.10775 | 0.0119 | 0.00518 | 0.92 |
| | WTT | -0.06481 | 0.01358 | 0.0412 | | |

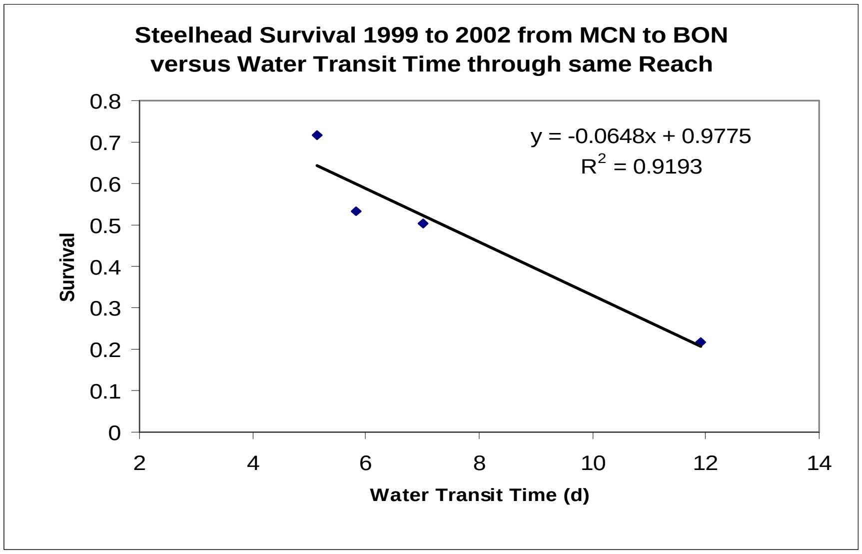


**Figure 12. Steelhead survival versus water transit time**

### *Survival for Yearling Chinook*

For combined hatchery and wild yearling chinook, both WTT and SPILLPROP variables had high correlation with the dependent variable survival (Table 14), whereas AVTEMP had only a moderate correlation. Correlation between WTT and SPILLPROP was not high enough to create multicollinearity problems, but it was high enough to both variables from remaining together in a multiple regression model.

**Table 14. Correlation matrix for variables related to yearling chinook salmon.**

| | SURVIVAL | WTT | SPILLPROP |
|---|---|---|---|
| WTT | -0.771 | | |
| SPILLPROP | 0.870 | -0.882 | |
| TEMP | -0.433 | 0.431 | -0.341 |

Since SPILLPROP had the highest correlation with yearling chinook smolt survival, it entered into the bivariate model that explained the most variation in the dependent variable survival (Table15). This is not to say that WTT is less important than SPILLPROP with regards to yearling chinook survival though. But it does show a major weakness in using regression techniques to pick the most important "causative" factors from the set of factors being considered in the modeling exercise. Although SPILLPROP has a direct influence on the resulting magnitude of the survival estimate, it level in the hydro system operation does not occur independent of the prevailing flows. Thus flows have a direct influence on WTT and so both variables must be considered as key elements affecting the inriver survival of smolts thorough the hydro system. A bivariate plot of estimated survival of yearling chinook from the tailrace of McNary Dam to the tailrace of Bonneville Dam is shown in Figure 13 relative to WTT and in Figure 14 relative to SPILLPROP.

**Table 15. Bivariate regression models for predicting survival of yearling chinook salmon in the lower Columbia River from the tailrace of McNary Dam to the tailrace of Bonneville Dam.**

| | Variable | Coefficient | SE | P | MSE | $R^2$ |
|---|---|---|---|---|---|---|
| N = 11 | Constant | 0.37096 | 0.05513 | 0.00009 | 0.00272 | 0.76 |
| | SPILLPROP | 0.87267 | 0.16458 | 0.00049 | | |

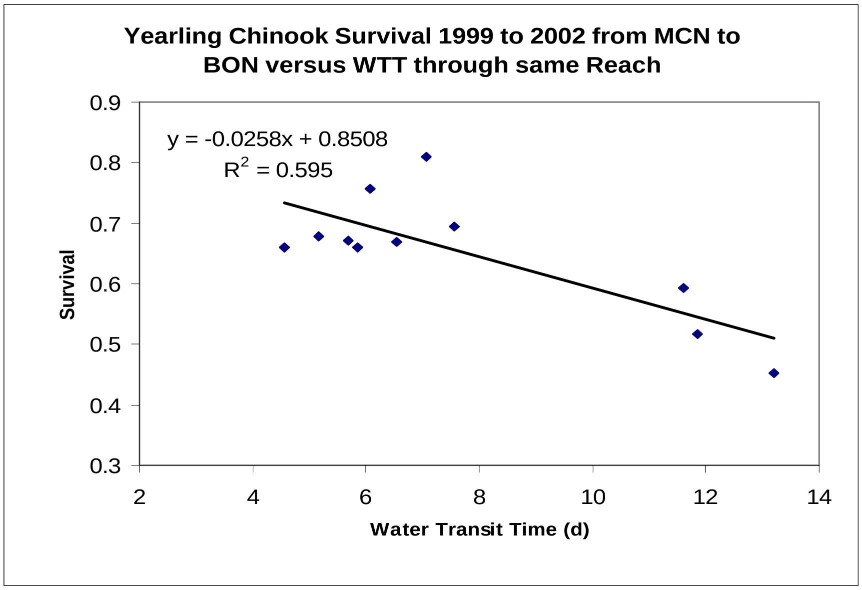


Figure 13. Yearling chinook survival versus water transit time.

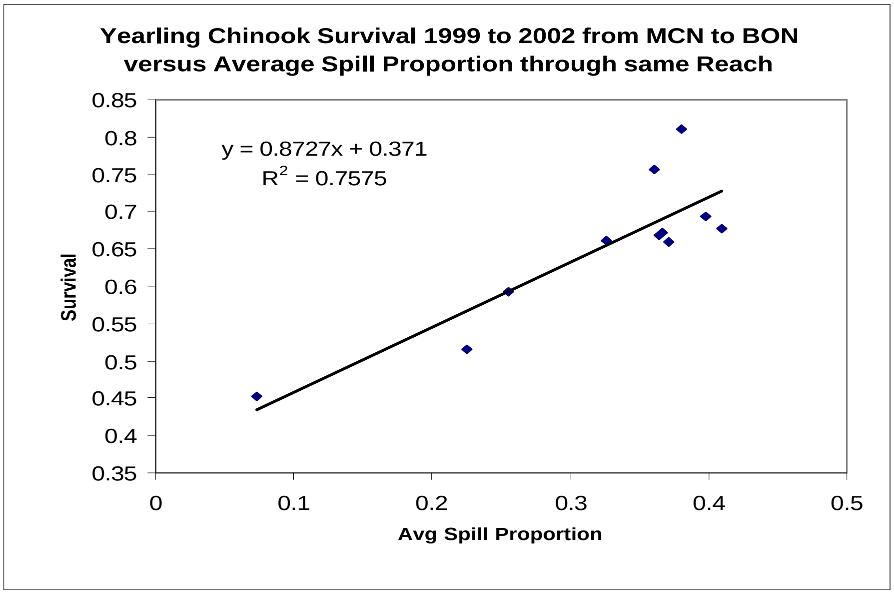


Figure 14. Yearling chinook survival versus average spill proportion.

## Migration Timing in the Lower Columbia River as measured at John Day Dam

The population of juvenile salmon is not homogeneous throughout the entire migration season. Consequently, the concept of migration timing is extremely important in fish management. Some fish migrate in discrete time periods that may be significantly different from the timing displayed by the migration as a whole. We observed PIT tagged yearling chinook and steelhead at John Day Dam in 2001 and quantified their timing in the Lower Columbia River. Yearling chinook and steelhead stocks that originated in the Walla Walla, Umatilla and John Day rivers are the earliest stocks to pass John Day Dam in 2001. In 2001, the percent of PIT tagged yearling chinook from the John Day and Umatilla rivers detected at John Day Dam in April was approximately 53% and 13%, respectively (Table 16), whereas virtually no PIT tagged yearling chinook from the Snake and Mid-Columbia River basins were detected until May. The percent of PIT tagged steelhead from the John Day and Umatilla rivers detected at John Day Dam in April was approximately 31% and 11%, respectively (Table 17), and again virtually no PIT tagged steelhead from the Snake and Mid-Columbia River basins were detected until May.

**Table 16. Proportion of PIT tagged yearling chinook detected at John Day Dam over specific periods of the 2001 migration season.**

| Dates of PIT tag detections at John Day Dam | Snake R basin | Mid-Columbia R basin at/above Rock Island Dam[1] | Yakima R basin | Umatilla R basin | John Day R basin |
|---|---|---|---|---|---|
| Total detections | 14,086 | 2,091 | 4,041 | 1,291 | 1,743 |
| 3/30 – 4/30 | 0.0002 | 0.0000 | 0.0084 | 0.1332 | 0.5295 |
| 5/1 – 5/24 | 0.3369 | 0.1836 | 0.3606 | 0.7854 | 0.4509 |
| 5/25 – 6/15 | 0.5422 | 0.6738 | 0.5048 | 0.0736 | 0.0132 |
| 6/16 – 9/15 | 0.1207 | 0.1425 | 0.1262 | 0.0077 | 0.0063 |

[1] PIT tagged hatchery chinook released on alternating days at Rock Island & Rocky Reach dams in large numbers for specific studies were omitted because they do not represent the timing of the run-of-the-river fish.

**Table 17. Proportion of PIT tagged steelhead detected at John Day Dam over specific periods of the 2001 migration season.**

| Dates of PIT tag detections at John Day Dam | Snake R basin | Mid-Columbia R basin at/above Rock Island Dam | Walla Walla R basin | Umatilla R basin | John Day R basin |
|---|---|---|---|---|---|
| Total detections | 440 | 59 | 23 | 1,005 | 97 |
| 3/30 – 4/30 | 0.0045 | 0.0000 | 0.0000 | 0.1124 | 0.3093 |
| 5/1 – 5/24 | 0.4841 | 0.1525 | 0.8696 | 0.7532 | 0.6082 |
| 5/25 – 6/15 | 0.3886 | 0.5254 | 0.0870 | 0.1085 | 0.0825 |
| 6/16 – 9/15 | 0.1227 | 0.3220 | 0.0435 | 0.0259 | 0.0000 |

## Rate of Seaward Movement of Subyearling Fall Chinook Summer Migrants Measured from Release in the Free-flowing Snake River to Passage Lower Granite Dam

### Fall Chinook Rate of Seaward Movement Methods

From 1992 to 2001, U.S. Fish and Wildlife Service personnel used a beach seine to capture juvenile fall chinook salmon in the free-flowing Snake River (Connor et al. In press a). Sampling typically started in April soon after fry began emerging from the gravel. Sampling was conducted at permanent stations 1 d/week in the upper reach of the Snake River, and 2 d/week in the lower reach. Supplemental sampling was conducted 1 or 2 d/week for three consecutive weeks at additional stations within each reach once the majority of fish were at least 60-mm fork length. Sampling was discontinued in June or July when the majority of fish had moved into Lower Granite Reservoir. Passive integrated transponder tags were inserted into fall chinook salmon 60-mm fork length and longer. Data were pooled the data across reaches and years (1992-2001) to increase the range of the predictor variables (Berggren and Filardo 1993; Giorgi et al. 1997).

Tagged fish were released at the collection site after a 15-min recovery period. Some of the PIT-tagged fish were detected after they passed into the fish bypass systems of Lower Granite Dam. Rate of seaward movement for PIT-tagged fall chinook passing downstream from initial tagging sites to Lower Granite Dam was calculated as the distance traveled to Lower Granite Dam (located 173 km from the Snake River mouth) divided by travel time to Lower Granite Dam.

The predictor variables analyzed included: flow, the mean stream discharge ($m^3/s$) measured by U. S. Army Corps of Engineers personnel at Lower Granite Dam between initial tagging of a PIT-tagged fall chinook salmon and its detection at Lower Granite Dam; temperature, the mean temperature (°C) measured by U. S. Army Corps of Engineers personnel in the forebay of Lower Granite Dam between initial tagging and detection at Lower Granite Dam; tagging date, day of year a fish was initially tagged; fork length, fork length (mm) measured on at initial tagging; and, riverine distance, the distance (km) traveled in the free-flowing Snake River before entering Lower Granite Reservoir.

Rate of seaward movement was natural-log-transformed to improve linearity and remedy heteroscedasticity of residuals, and bivariate and multiple regression models were fit from every possible combination of predictor variables. The slope coefficients of each predictor variable in every model were examined for sign change, and for inflated standard errors (hence, failure to reject $H_o$: $B = 0$). Sign changes and large standard errors are indications of problematic multicollinearity (Dielman 1996). A Pearson correlation matrix was calculated to examine the level of collinearity between each factor. Models with problematic multicollinearity, or that included factors with non-significant ($P > 0.05$) slope coefficients, were removed from further analysis. Fit was compared among the remaining regression models based on the coefficient of determination ($R^2$). The three regression models that had the highest $R^2$ values were reported.

Residual plots were made for flow and temperature as described for flow in the following example. Natural-log-transformed rate of seaward movement was regressed against fork length and riverine distance. The residuals from this regression were then plotted against flow. A line was then fit to the residuals by regressing them against flow. The resulting residual plots provided a better graphical representation of the relation between flow and rate of seaward movement because the variability in downstream migration rate attributable to fork length and riverine distance had been removed.

## Fall Chinook Rate of Seaward Movement Results

A total of 2,808 observations were available (years 1992-2001) to describe the factors affecting rate of seaward movement of PIT-tagged fall chinook salmon from initial tagging to detection at Lower Granite Dam. After pooling the data across reaches and running every possible regression model, the slope coefficient for flow changed from being positive to negative when flow and temperature were entered into the same regression models. The correlation coefficient for the relation between flow and temperature was $r = -0.77$ ($P < 0.0001$). The slope coefficient for tagging date changed from being negative to positive when tagging date and temperature were entered in the same regression models. The correlation coefficient for the relation between tagging date and temperature was $r = 0.60$ ($P < 0.0001$). All models containing both flow and temperature, and tagging date and temperature, were removed from the analysis because of problematic multicollinearity.

The regression model with the best fit included the predictor variables temperature, fork length and riverine distance (Table 18). The slope coefficients for each of the three factors differed significantly from zero, and together the three factors explained 73% of the variability observed in natural-log-transformed rate of seaward movement (Table 18). Natural-log-transformed rate of seaward movement generally decreased as temperature increased, and increased as fork length and riverine distance increased, as shown by the sign and *P* values of the slope coefficients (Table 18). The slope in the residual plot indicates that rate of seaward movement decreased as temperature increased throughout the range of 9 to 21$^{o}$C (Figure 15).

The regression model that had the second-best fit included the factors flow, fork length, and riverine distance (Table 18). Flow, fork length, and riverine distance explained 66% of the variability observed in natural-log-transformed rate of seaward movement. Natural-log-transformed rate of seaward movement generally increased with increases in each of the three factors based on the slope coefficients, all of which differed significantly from zero (Table 18). The slope in the residual plot shows that rate of seaward movement increased as flow increased over the entire range of observed flows (Figure 15).

The regression model that had the third-best fit included the factors tagging date, fork length, and riverine distance (Table 18). Natural-log-transformed rate of seaward movement generally decreased with increases in tagging date, and increased as fork length and riverine distance increased, as shown by the signs and *P* values of the slope coefficients (Table 18). Together, these three factors explained 58% of the variability observed in natural-log-transformed rate of seaward movement (Table 18).

**Table 18. Results from multiple regression models fit to describe rate of seaward movement of PIT-tagged wild subyearling fall chinook salmon from initial tagging in the Snake River and detection at Lower Granite Dam, 1992 to 2001.**

| Variable | coefficient | SE | t value | Probability | $R^2$ | *P* |
|---|---|---|---|---|---|---|
| Constant | 0.81598 | 0.07490 | 10.89 | ≤ 0.0001 | 0.726 | ≤ 0.0001 |
| Temperature | - 0.15190 | 0.00382 | - 39.73 | ≤ 0.0001 | | |
| Fl | 0.02773 | 0.00060 | 46.16 | ≤ 0.0001 | | |
| Km | 0.00798 | 0.00018 | 44.42 | ≤ 0.0001 | | |
| | | | | | | |
| Constant | - 2.07197 | 0.05627 | - 36.82 | ≤ 0.0001 | 0.659 | ≤ 0.0001 |
| Flow | 0.00024 | 0.00001 | 26.73 | ≤ 0.0001 | | |
| Fl | 0.02498 | 0.00066 | 37.66 | ≤ 0.0001 | | |
| Km | 0.00876 | 0.00020 | 43.88 | ≤ 0.0001 | | |
| | | | | | | |
| Constant | -1.17620 | 0.10755 | -10.94 | ≤ 0.0001 | 0.575 | ≤ 0.0001 |
| Date | -0.00304 | 0.00083 | -3.68 | 0.0002 | | |
| Fl | 0.02568 | 0.00090 | 28.64 | ≤ 0.0001 | | |
| Km | 0.01061 | 0.00022 | 49.56 | ≤ 0.0001 | | |

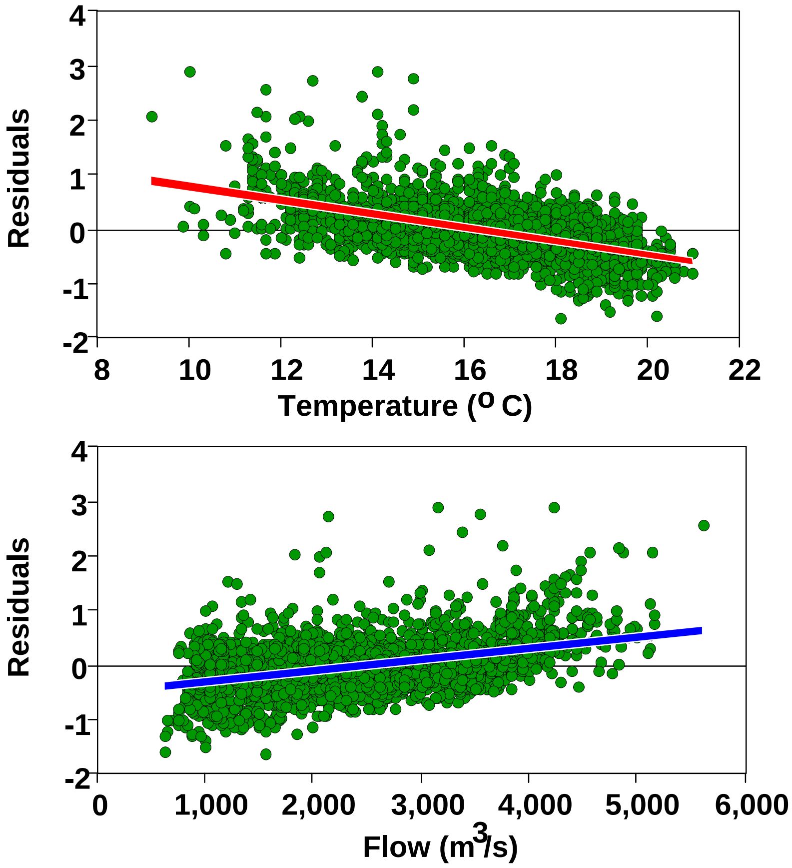


**Figure 15. Wild subyearling chinook rate of seaward movement versus temperature and flow.**

## Fall Chinook Rate of Seaward Movement Discussion and Conclusions

Though the regression model that predicted natural-log-transformed rate of seaward movement from the predictor variables temperature, fork length, and riverine distance had the best fit of all models tested, Connor et al. (In press a) concluded that it is unrealistic to expect an inverse relation between temperature and rate of seaward movement over the entire range of temperatures studied (9 to 21$^{o}$C). Fall chinook salmon that are exposed to mean temperatures of 20$^{o}$C and above before they become smolts would be expected to move seaward at slower rates than those that experience cooler temperatures because of a reduced likelihood of successful smoltification (e.g., Marine 1997). However, rate of seaward movement should have increased as temperature increased up to at least 17$^{o}$C as a result of increased growth and normal patterns of smolt development (Banks et al. 1971; Boeuf 1993; Marine et al. 1997; Connor and Burge in press). Connor et al. (In press a) concluded that the decrease in rate of seaward movement as temperature increased to 17$^{o}$C was most likely caused by the accompanying decreases in flow.

The regression model with the second-best fit included the predictor variables flow, fork length, and riverine distance. This regression model showed that the relation between rate of seaward movement and flow was positive consistent with the results of other studies (Berggren and Filardo 1993; Tiffan et al. 2000). Higher rates of seaward movement at higher flows (or vice versa) can be explained by the relation between discharge and water velocity. Water velocity in reservoirs is proportional to the ratio of discharge to channel volume. Since the length of Lower Granite Reservoir presumably changes little over time, the change in volume can be described by changes in pool elevation. Lower Granite Reservoir was held at minimum operating pool elevations ranging from approximately 223 to 224 m above mean sea level during the summer (U. S. Army Corps of Engineers, unpublished data). Therefore, the flow values Connor et al. (In press a) used in their regression modeling were proportional to velocities in Lower Granite Reservoir upstream of Lower Granite Dam forebay suggesting that rate of seaward movement increased as velocity increased. These results support a flow-migration rate relation.

Rate of seaward movement from release in the Snake River to passage at Lower Granite Dam decreased as tagging date increased according to the results of the regression model with the third-best fit. Tagging date (a.k.a., release date) is used as a surrogate for time-based physiological, behavioral, and environmental processes when describing seaward movement of juvenile anadromous salmonids (e.g., Berggren and Filardo 1993; Giorgi et al. 1997; Connor et al. 2000). There was no significant tagging date effect when flow and tagging date were entered into the same regression model. Problems with multicollinearity were encountered when tagging date and temperature were entered into the same regression model. In the Connor et al. In press a) analyses, tagging date apparently functioned as a surrogate for flow and temperature. To a lesser extent, increases in date also reflected the decreased potential for successful smoltification of fish initially tagged late in the seining season.

Connor et al. (In press a) concluded that the increases in flow and decreases in temperature resulting from summer flow augmentation increases the rate of seaward movement of fall chinook salmon in Lower Granite Reservoir (where fish spend prolonged periods of time) provided that augmentation occurs when the fish have moved offshore in the free-flowing river and are behaviorally disposed to being displaced downstream. The regression model that included flow predicts an increase in rate of seaward movement of approximately 0.1 km/d with each increase of 100 $m^3/s$ in flow when fork length and riverine distance are held at 74 mm and 40 km (the overall 1992-2001 medians). At temperatures above 17°C, the regression model that included temperature predicts an increase in rate of seaward movement of approximately 0.2 km/d with each decrease of 1°C when fork length and riverine distance are held at 74 mm and 40 km. Increasing the rate of seaward movement by 0.1 to 0.2 km reduces travel time to Lower Granite Dam by 1 to 5 d (Connor 2001).

## Survival of Wild Subyearling Fall Chinook Summer Migrants Measured from Release in the Free-flowing Snake River to Passage at Lower Granite Dam and Passage Timing at the Dam

### Fall Chinook Survival Methods

Data collected on fall chinook salmon from 1998 to 2000 were analyzed. Data for these years were selected because sample sizes of tagged fall chinook salmon were large, and tagged fish were not handled as they passed Lower Granite Dam. Field personnel captured and PIT tagged fall chinook salmon by using a beach seine as described for analyses on rate of seaward movement . After detection at Lower Granite Dam, the PIT-tagged smolts were routed through flumes back to the river. Smolts then had to pass seven more dams to reach the Pacific Ocean. Little Goose, Lower Monumental, McNary, John Day, and Bonneville dams were also equipped with monitoring systems that recorded the passage of PIT-tagged smolts that used the bypass systems, and then routed the bypassed fish back to the river.

The first step in the analysis was to divide the annual samples of PIT-tagged fall chinook salmon into four sequential within-year release groups referred to as cohorts. The annual samples into cohorts based on estimated fry emergence dates. Fry emergence date was estimated for each fish in two steps. First, the number of days since each PIT-tagged fish emerged from the gravel was calculated by subtracting 36 mm from its fork length measured at initial capture, and then dividing by the daily growth rate observed for recaptured PIT-tagged fish (range 0.9 to 1.3 mm/d; Connor and Burge in press). The 36-mm fork length for newly emergent fry was the mean of the observed minimum fork lengths. Second, emergence date was estimated for each fish by subtracting the estimated number of days since emergence from its date of initial capture, tagging, and release. The data in ascending order by estimated fry emergence date, and then divided it into four cohorts of approximately equal numbers of fish. The single release-recapture model (Cormack 1964; Skalski et al. 1998) was used to estimate survival probability to the tailrace of Lower Granite Dam for each cohort. Three assumption tests described by Burnham et al. (1987) and Skalski et al. (1998) were applied to insure that the single release-recapture model fit the data.

Cohort survival was the dependent variable for the analysis. The predictor variables were: tagging date, median day of year fish from each cohort were captured, tagged, and released; fork length, mean fork length (mm) at capture, tagging, and release for the fish of each cohort; flow, a flow ($m^3/s$) exposure index calculated as the mean flow measured at Lower Granite Dam by U.S. Army Corps of Engineers personnel during the period when the majority of smolts from each cohort passed the dam; and temperature, a water temperature ($^{o}$C) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam by U.S. Army Corps of Engineers personnel during the period when the majority of smolts from each cohort passed the dam.

To determine when the majority of smolts passed Lower Granite Dam, the PIT-tag detection data were used to calculate a passage date distribution for each cohort including the 25th percentile, median, 75th percentile, range of non-outliers, and mild outliers. The date cutoffs for mild outliers were calculated as the 25th percentile minus the inter-quartile range multiplied by 1.5 (i.e., the lower fence; Ott 1993), and the 75th percentile plus the inter-quartile range multiplied by 1.5 (i.e., the upper fence; Ott 1993). All but the mild outliers were considered to be in the majority. See Connor et al . In press b for more details on calculating flow and temperature exposure indices.

A Pearson correlation coefficient (*r*) was calculated to test for collinearity among the predictor variables. Predictor variables that were correlated ($r \geq 0.6$; $P \leq 0.05$) were not entered into the same model. Multiple regression models were fit from every combination of non-collinear predictor variables. Fit was compared among models based on Mallow's Cp scores (Dielman 1996), Akaike's information criteria (AIC; Akaike 1973), and the coefficient of determination ($R^2$). The final (i.e., best) regression model had a Mallow's Cp score similar to the number of parameters, the lowest AIC value, the highest $R^2$ value, and predictor variables with slope coefficients that differed significantly ($t \geq 2.0$; $P \leq 0.05$) from zero. Only the top three models are reported.

We made residual plots for each predictor variable in the final regression model as described for flow in the following example. Estimated survival was regressed against temperature. The residuals from this regression were then plotted against flow. A line was then fit to the residuals by regressing them against flow. The resulting residual plots provided a better graphical representation of the relation between survival and flow because the variability in survival attributable to temperature had been removed.

We assessed the effect of summer flow augmentation on cohort survival to the tailrace of Lower Granite Dam by comparing two predictions. First, we predicted cohort survival to the tailrace of Lower Granite Dam by entering the observed mean flow and water temperature exposure indices for each cohort into the final regression model. Cohort survival was then predicted a second time by entering mean flow and water temperature exposure indices into the final regression model that were recalculated to remove effects of summer flow augmentation.

The flow exposure index was recalculated after subtracting the daily volume of water released for summer flow augmentation. The water temperature exposure index was recalculated using temperatures that were simulated for the tailrace of Lower Granite Dam under the flow conditions had the summer flow augmentation not been implemented. Water temperatures were simulated using a one-dimensional heat budget model developed for the Snake River by the U.S. Environmental Protection Agency (Yearsley et al. 2001). Past model validation showed that daily mean water temperatures simulated for July and August were within an average of 1.1$^{o}$C of those observed (Yearsley et al. 2001).

## Fall Chinook Survival and Passage Results

During the 3 years, 5,030 fall chinook salmon were captured, PIT tagged, and released along the free-flowing Snake River. Annual sample sizes of PIT-tagged fall chinook salmon were 2,060 in 1998, 1,761 in 1999, and 1,209 in 2000. The number of fall chinook salmon in the resulting 12 cohorts ranged from 302 to 515 (Table 19). Emergence dates, tagging dates, fork lengths, and water temperature exposure indices generally increased from cohort 1 to 4 (Table 19). Flow exposure indices and survival estimates decreased from cohort 1 to 4 (Table 19).

Tagging date and fork length were negatively correlated ($N = 12$; $r = -0.76$; $P = 0.004$). Therefore, tagging date and fork length were not entered into the same multiple regression model. Fork length and flow ($N = 12$; $r = 0.47$; $P = 0.12$), fork length and temperature ($N = 12$; $r = -0.54$; $P = 0.07$), and flow and temperature ($N = 12$; $r = -0.45$; $P = 0.15$) were non-collinear.

The model that predicted cohort survival from flow and temperature had a Mallow's Cp score one less than the number of parameters, the lowest AIC value, and an $R^2$ of 0.92 (Table 20). The models that included fork length or tagging date had Mallow's Cp scores that equaled the number of parameters, relatively low AIC values, and $R^2$ values of 0.92 (Table 20), but the slope coefficient for fork length ($t = 0.05$; $P = 0.96$) and tagging date ($t = 0.07$; $P = 0.94$) did not significantly differ from zero.

**Table 19. Emergence dates, predictor variables, and estimates of survival probability (%±SE) to the tailrace of Lower Granite Dam for each cohort of wild subyearling fall chinook salmon, 1998 to 2000. Predictor variables: Tagging date, median day of year of tagging; Fl, mean fork length (mm) at tagging; Flow, a flow ($m^3/s$) exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam; and Temperature, a water temperature ($^oC$) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam.**

| Cohort | *N* | Emergence date | Tagging date | Fl | Flow | Temperature | Survival |
|---|---|---|---|---|---|---|---|
| | | | | **1998** | | | |
| 1 | 515 | 7 April | 140 | 80 | 2,344 | 17.6 | 70.8±2.9 |
| 2 | 515 | 15 April | 141 | 75 | 2,021 | 18.7 | 66.1±3.3 |
| 3 | 515 | 23 April | 153 | 73 | 1,898 | 19.0 | 52.8±3.1 |
| 4 | 515 | 7 May | 167 | 70 | 1,299 | 19.8 | 35.6±2.9 |
| | | | | **1999** | | | |
| 1 | 441 | 20 April | 147 | 80 | 2,378 | 16.3 | 87.7±4.6 |
| 2 | 440 | 30 April | 153[A] | 77 | 1,963 | 17.1 | 77.0±3.8 |
| 3 | 440 | 5 May | 152[A] | 70 | 2,116 | 16.7 | 81.2±5.8 |
| 4 | 440 | 13 May | 167 | 68 | 1,353 | 18.3 | 36.4±3.5 |
| | | | | **2000** | | | |
| 1 | 303 | 6 April | 130 | 77 | 1,510 | 16.7 | 57.1±4.1 |
| 2 | 302 | 15 April | 144 | 77 | 1,296 | 17.6 | 53.4±4.2 |
| 3 | 302 | 22 April | 146 | 77 | 1,274 | 17.8 | 44.4±3.6 |
| 4 | 302 | 29 April | 158 | 71 | 859 | 18.5 | 35.7±4.3 |

[A] Fish from cohort 2 emerged earlier than fish of cohort 3, but they were initially captured, tagged, and released later than fish of cohort 3.

**Table 20. Mallow's Cp scores, Akaikes information criteria (AIC), and coefficients of determination ($R^2$) used to compare the fit of multiple regression models describing the survival of cohorts of wild subyearling fall chinook salmon from tagging in the Snake River to the tailrace of Lower Granite Dam, 1998 to 2000. Predictor variables: Tagging date, median day of year of tagging; Fl, mean fork length (mm) at tagging; Flow, a flow ($m^3/s$) exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam; and Temperature = a water temperature ($^oC$) exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam.**

| C(p) | AIC | $R^2$ | Variables in model |
|---|---|---|---|
| 2 | 44 | 0.92 | Flow, Temperature |
| 4 | 46 | 0.92 | Fl, Flow, Temperature |
| 4 | 46 | 0.92 | Tagging date, Flow, Temperature |

The final multiple regression model was: Cohort survival = 140.82753 + 0.02648 Flow -7.14437 Temperature. The final model was significant ($N = 12$; $P \leq 0.0001$) as were the coefficients for flow ($t = 6.81$; $P \leq 0.0001$) and temperature ($t = -3.96$; $P = 0.003$). Flow and temperature explained 92% of the observed variability in cohort survival to the tailrace of Lower Granite Dam. Cohort survival generally increased as flow increased, and decreased as temperature increased (Figure 16).

The majority of fall chinook salmon passage occurs in July and August (Figures 17-19). Water releases for summer flow augmentation in 1998, 1999, and 2000 were generally timed to coincide with the passage of smolts from mid-July through August at Lower Granite Dam (Figures 17-19). Therefore, these later migrants were usually predicted to accrue greater survival benefits than the earlier migrants cohorts (Table 21). For all cohorts, estimated survival to the tailrace of Lower Granite Dam was predicted to be higher when summer flow augmentation was implemented than when it was not implemented (Table 21; Figure 20). Notably, eliminating flow augmentation in early July and August would likely decrease survival of a large portion of the smolts.

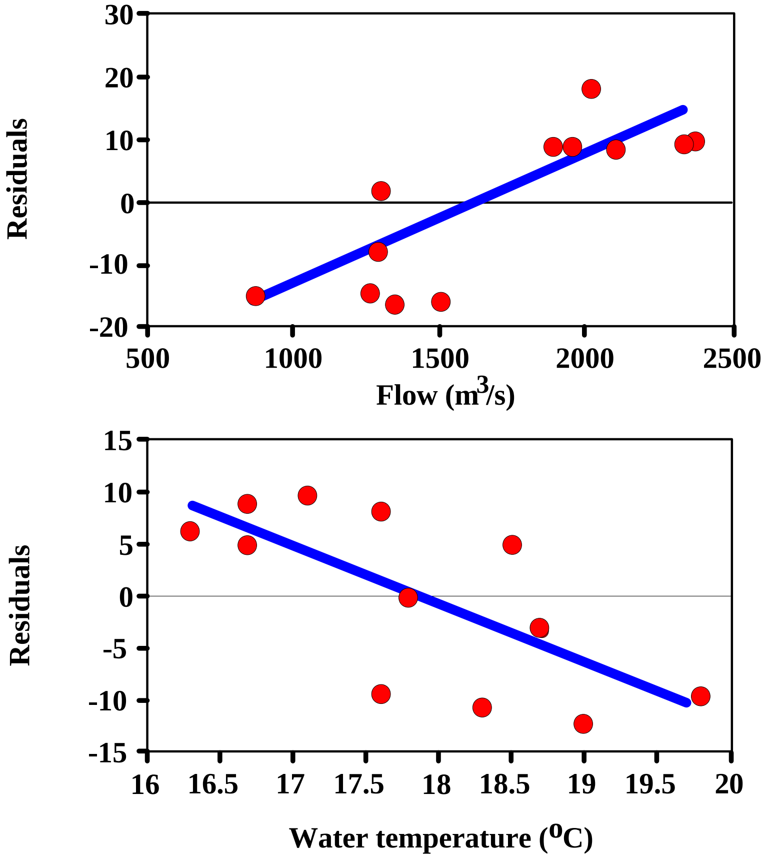


**Figure 16. Residuals plots for flow and temperature. Residuals are from ordinary least-squares multiple regression models fit to predict cohort survival from the predictor variables that is not on the X-axis. The line in each plot was predicted by regressing the residuals against the predictor variable on the X-axis.**

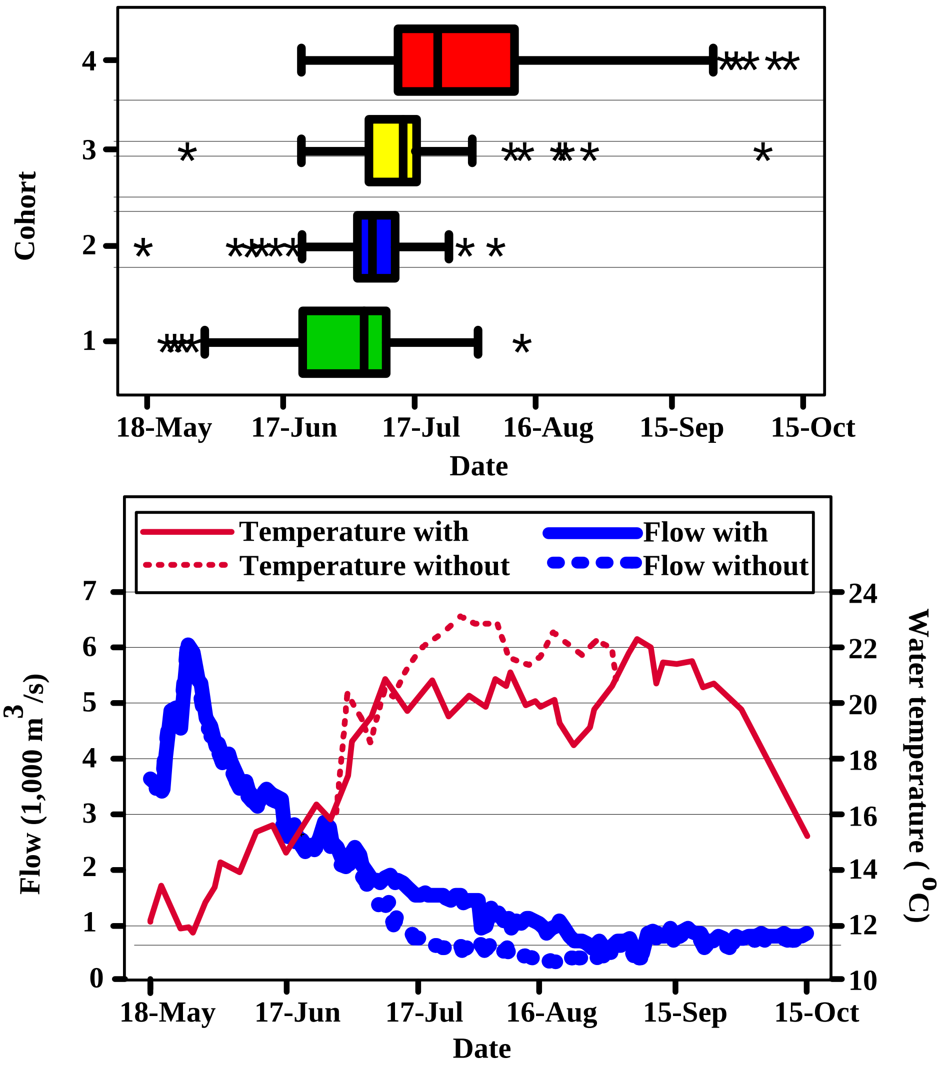
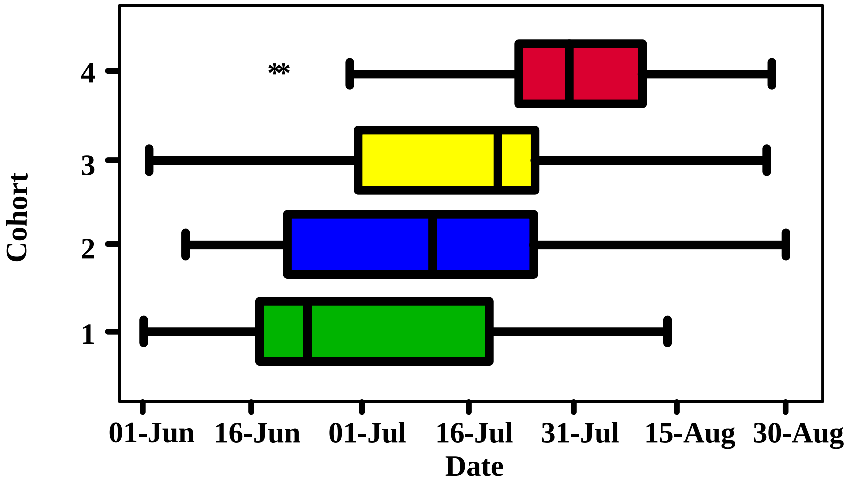


**Figure 17. Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 1998 (top), and the mean daily flows and water temperatures observed in Lower Granite Reservoir when flow was augmented (with) compared to those that may have occurred if flows had not been augmented (without; bottom).**



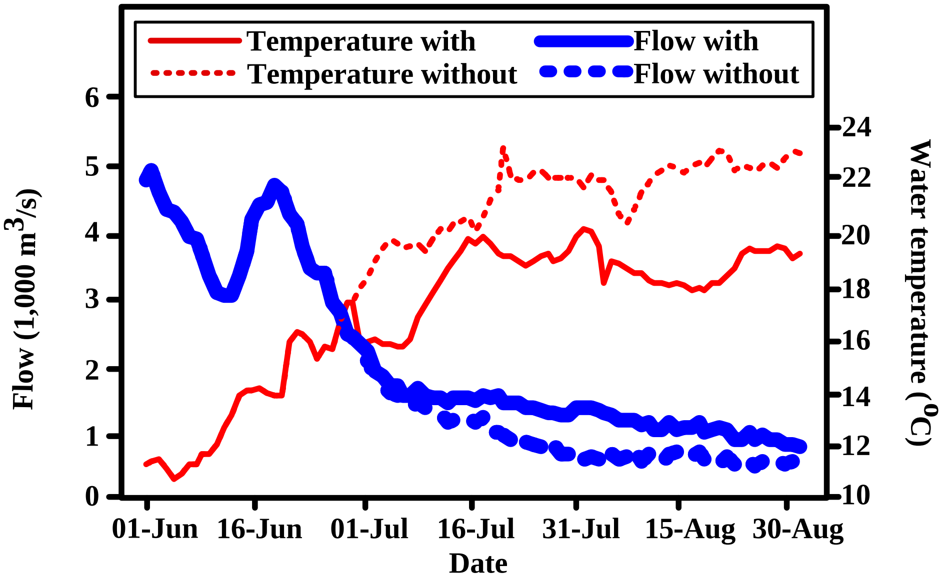


**Figure 18. Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 1999 (top), and the mean daily flows and water temperatures observed in Lower Granite Reservoir when flow was augmented (with) compared to those that may have occurred if flows had not been augmented (without; bottom).**

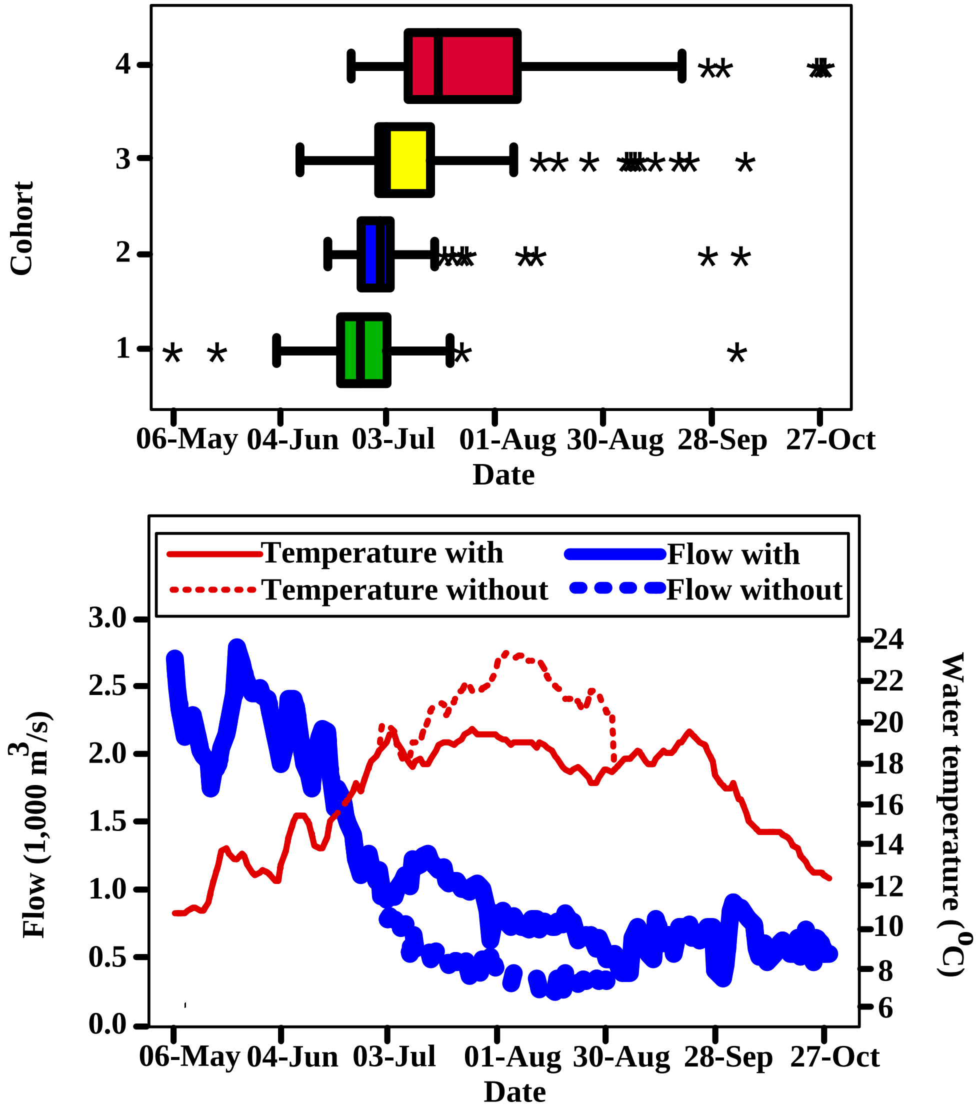


**Figure 19. Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 2000 (top), and the mean daily flows and water temperatures observed in Lower Granite Reservoir when flow was augmented (with) compared to those that may have occurred if flows had not been augmented (without; bottom).**

**Table 21. Predicted survival (%±95% C.I.) to the tailrace of Lower Granite Dam for cohorts of wild subyearling fall chinook salmon tagged in the Snake River from 1995 to 1998. Predictions were made using the observed flow and water temperature indices in Table 1 (Survival with), and by using flow (m$^3$/s) and water temperature ($^o$C) exposure indices recalculated to approximate conditions that would have occurred if flow had not been augmented (Survival without).**

| Cohort | Survival with | Recalculated | | Survival without | Difference in survival |
|---|---|---|---|---|---|
| | | Flow | Temperature | | |
| | | | **1998** | | |
| 1 | 77.2±6.5 | 2,066 | 18.3 | 64.8±5.8 | 12.4 |
| 2 | 60.7±6.6 | 1,689 | 19.3 | 47.7±7.0 | 13.0 |
| 3 | 55.3±6.8 | 1,468 | 20.1 | 36.1±9.3 | 19.2 |
| 4 | 33.8±8.0 | 988 | 21.3 | 14.8±13.1 | 19.0 |
| | | | **1999** | | |
| 1 | 87.3±7.5 | 2,128 | 17.1 | 75.0±5.2 | 12.3 |
| 2 | 70.6±4.7 | 1,667 | 18.4 | 53.5±4.3 | 17.1 |
| 3 | 77.5±5.8 | 1,837 | 18.0 | 60.9±4.0 | 16.6 |
| 4 | 45.9±4.6 | 943 | 20.1 | 22.2±9.4 | 23.7 |
| | | | **2000** | | |
| 1 | 61.5±6.7 | 1,314 | 17.0 | 54.2±6.8 | 7.3 |
| 2 | 49.4±5.5 | 1,078 | 17.9 | 41.5±6.5 | 7.9 |
| 3 | 47.4±5.3 | 978 | 18.6 | 33.8±6.7 | 13.6 |
| 4 | 31.4±7.5 | 587 | 20.1 | 12.8±10.6 | 18.6 |

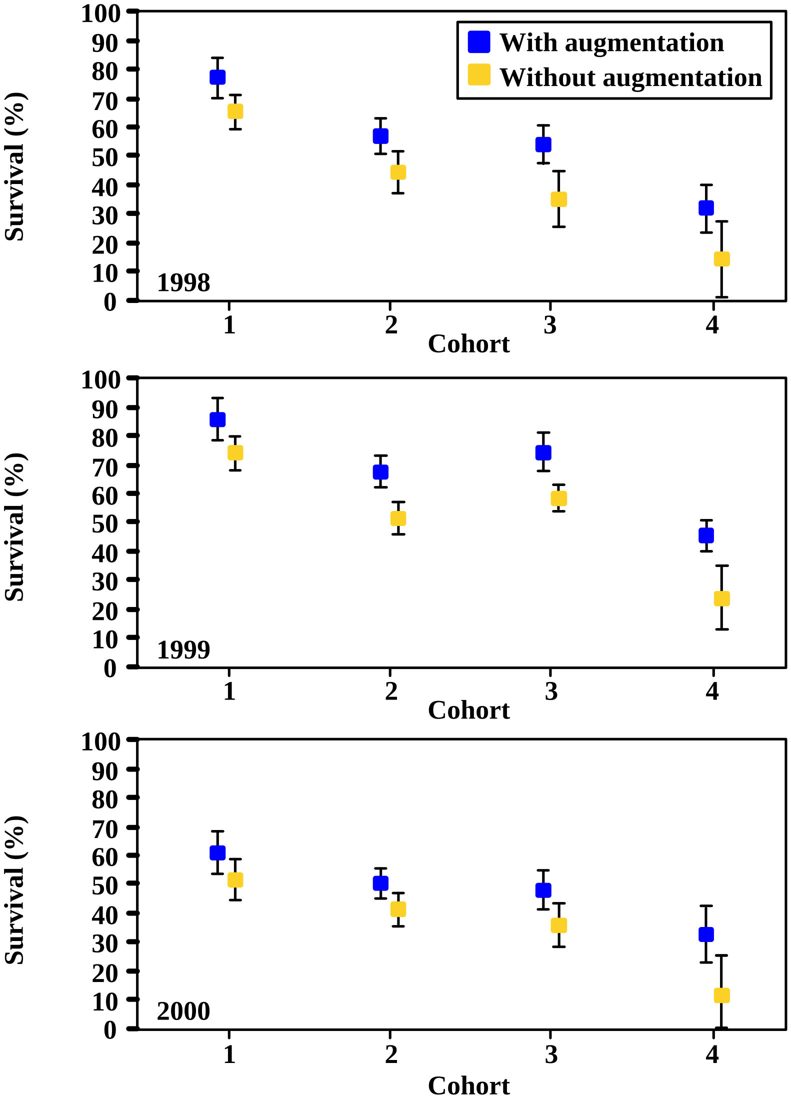


**Figure 20. Survival (±95% C.I.) to the tailrace of Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon (1998 top; 1999 middle; 2000 bottom) predicted from observed mean flow and water temperatures (from Table 1), and from mean flows and water temperatures recalculated to represent those that would have occurred if flow were not augmented (from Table 3). The equation Cohort survival = 140.82753 + 0.02648 Flow -7.14437 Temperature was used to make both sets of predictions.**

Fall Chinook Survival and Passage Discussion and Conclusions

Survival of wild subyearling fall chinook salmon from release in the Snake River to the tailrace of Lower Granite Dam generally increased as flow increased and decreased as temperature increased. Based on the regression model developed by Connor et al. (In press b) and reported herein, survival is predicted to change by approximately 3% with each change of 100 $m^3/s$ in flow when temperature is held constant. The change in survival is approximately 7% for each $1^oC$ increase or decrease in temperature when flow is held constant. Kjelson et al. (1982), Kjelson and Brandes (1989), and Connor et al. (1998) also reported that survival of subyearling chinook salmon during seaward migration is directly proportional to flow and inversely proportional to temperature.

Flow and temperature were closely correlated in the above three studies (e.g., $r = -0.999$; Connor et al. 1998), thus the researchers could not determine if the high correlation between survival and one variable was caused by the other variable. Flows and temperatures were atypically uncorrelated ($r = -0.45$) fin the 1998-2000 Connor et al. (In press b) study, therefore the researchers were able to enter both of these predictor variables in the same multiple regression equation without detectably biasing the regression coefficients. Both regression coefficients differed significantly from zero (flow $P \leq 0.0001$; temperature $P = 0.003$). Connor et al. (In press b) conclude that flow and temperature act together to influence fall chinook salmon survival.

After a candid discussion on the shortcomings of their study, Connor et al. (In press b) concluded that summer flow augmentation increased the survival of young fall chinook salmon passing downstream in Lower Granite Reservoir especially when flow releases were timed to the passage of smolts in July and August.

## Spill

Employing the use of spill for juvenile migrants has long been used as an effective management tool for improving passage survival of migrating juvenile salmon at mainstem hydroelectric projects. Routing smolts through spillways at hydroelectric projects in the Columbia and Snake rivers is generally considered to be the safest passage strategy, when compared to the passage survival through bypass systems and turbine routes. Recently, analyses conducted by Muir et al. (2001) reconfirmed the findings of numerous earlier studies by demonstrating that spillway survival of smolts exceeds that incurred through both turbines and collector/bypass systems at dams on the Snake River.

Spill is also an effective tool in decreasing the amount of delay experienced by fish in forebays and tailraces of dams where predator populations and predation rates are highest. Spill can greatly reduce delay of smolts as demonstrated at the forebay of The Dalles Dam by Snelling and Schreck (1994). Spill establishes a large flow net with increased velocity that disperses predators from the forebay and tailrace areas thus reducing the potential for predator/prey interactions (Faler et al., 1988).

Spilling water can cause high dissolved gas to concentrate by entrainment of air in the form of bubbles as it passes over the spillway and plunges to the tailrace. The air is forced into solution, causing the water to become "supersaturated" at ambient atmospheric pressure with respect to dissolved gas. Water that is supersaturated with respect to dissolved gases may cause gas bubbles to form in the bodies of fish and other aquatic animals under certain conditions that impair their ability to function, or in extreme situations may lead to death. Consequently, spill management must recognize the tradeoff between survival benefits and the detrimental effects of high total dissolved gas levels.

The "Spill and 1995 Risk Management" report was developed by the region's fishery agencies and tribes document and provided part of the biological justification for the implementation of the 1995 Biological Opinion spill program. The document reviewed all available studies and quantified the trade-off between the increase in salmon survival associated with an increase in spill passage, against the potential fish mortality that might be incurred from increased levels of total dissolved gas (TDG). The assessment concluded that the benefits of spill passage outweighed the risk up to TDG levels between 120 to 125%. The annual voluntary spill program has been implemented within these constraints since that time.

In 2000 the NMFS included Appendix E in their Biological Opinion. This appendix was meant to serve as the justification and risk assessment for the spill program included in the 2000 Biological Opinion. The appendix addresses the 120% dissolved gas ceiling and builds on the findings of the 1995 document with information collected subsequently. The NMFS also uses the SIMPAS model as a means of quantifying an amount of system survival attributable to the 120% TDG spill program. The NMFS concludes, "the risk associated with a managed spill program to the 120% total dissolved gas (TDG) level is warranted by the projected 4% to 6% increase in system survival of juvenile salmonids. Recent research and biological monitoring results support the findings of the 1995 report, which predicted that the TDG in the 120% to 125% range, coupled with vertical distribution fish passage information indicating that most fish migrate at depths providing some gas compensation, would not cause juvenile or adult salmon mortalities exceeding the expected benefits of spillway passage. NMFS finds little evidence that this expected survival improvement would be reduced by the mortality related to gas bubble trauma (GBT). NMFS also concludes that physical and biological monitoring of GBT signs can continue to be used to indicate dissolved gas exposure in adult and juvenile salmon migrants."

## Evidence for Spill Survival Benefits

The multiple regression analyses conducted for survival of steelhead and chinook from Lower Granite Dam to McNary Dam all include a spill related variable in the models. This suggests the importance of spill in the determination of juvenile survival.

An analysis of smolt survival in the lower Columbia River index reach was possible based on the implementation of a limited spill program during the drought year, 2001. The McNary Dam passage distribution of PIT tagged yearling chinook was split into nine multi-day blocks with at least 10,000 PIT tagged smolts per block. The plot (Figure 21) of the estimated survival from McNary Dam tailrace to Bonneville Dam tailrace shows evidence of shifts in estimated survival for yearling chinook smolts passing McNary Dam in the May 1-10, May 11-21, and May 22 to

June 9 periods. Spill at The Dalles and Bonneville dams only began on May 16 and at John Day Dam on May 25. It is likely that the survival data is grouped due to the impacts of spill, with higher survivals estimated during periods of higher spill. Further evidence implicating spill as a causal factor in increasing survival is based on the significant change in collection efficiency at John Day Dam, dropping nearly 45% for yearling chinook post initiation of spill, suggesting a far greater proportion of fish passing over the spillway at John Day Dam.

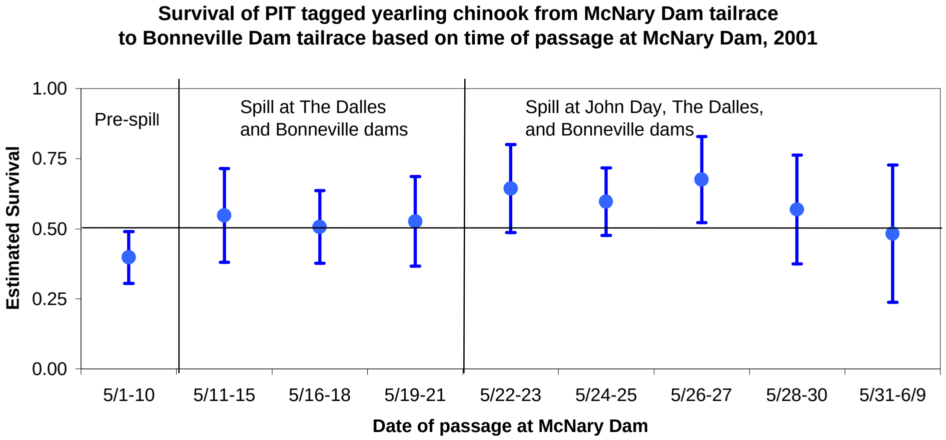


**Figure 21. Survival of PIT tagged yearling chinook from McNary Dam tailrace to Bonneville Dam tailrace based on time of passage at McNary Dam, 2001.**

## Evidence for the Appropriateness of the Current Total Dissolved Gas Standards

The effects of elevated dissolved gas on migrating juvenile and adult salmon due to voluntary spill have been monitored each year of spill program implementation. Based on seven years of data from the biological monitoring program, the average incidence of gas bubble disease signs has been low, although the state-allowed maximum TDG due to spill was 120 percent in the tailrace and 115 percent in forebays during periods of voluntary spill. A high percentage of the spill that did occur in some years was involuntary, and often resulted in dissolved has levels above the 120% waiver. The following graphs (Figures 22 and 23) depict the incidence and severity of signs of GBT in fish collected for observation over the seven years, grouped in 5 percent TDG levels. Increases in the incidence of signs were observed with increases in the levels of TDG. The severity of signs also increased, but not until dissolved gas levels were above the 120 to 125% level.

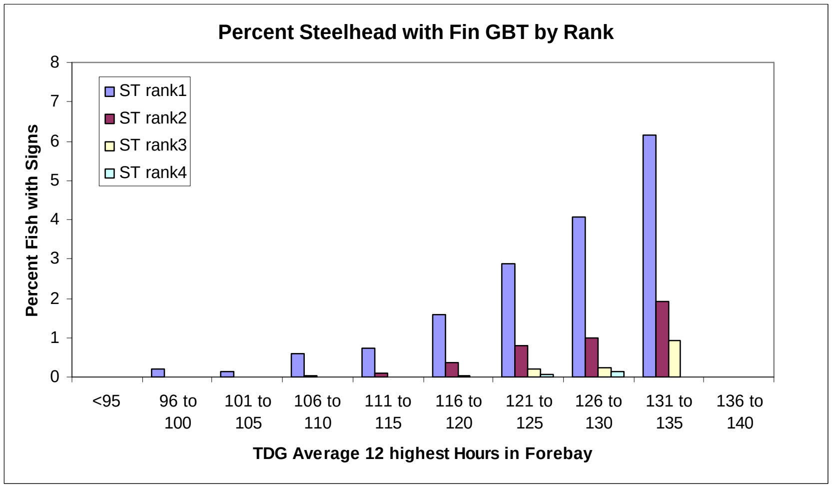


**Figure 22. Percent Steelhead with Fin GBT by Rank.**

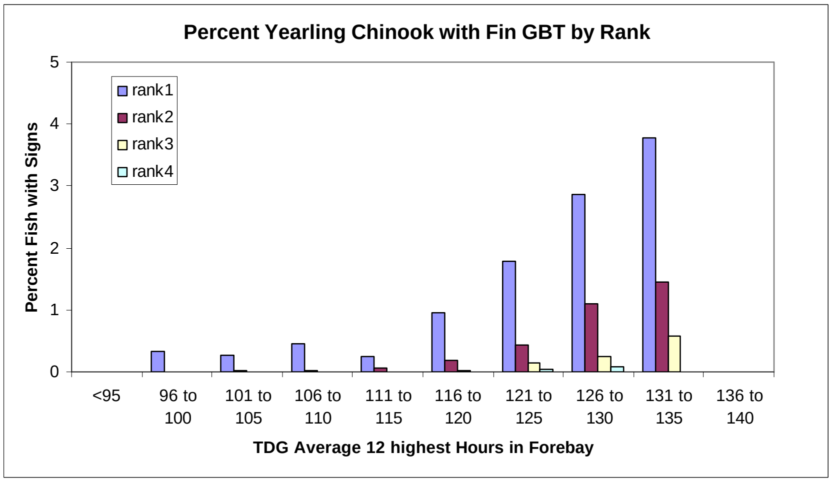


**Figure 23. Percent Yearling Chinook with Fin GBT by Rank.**

Additional information regarding the effects of total dissolved gas on the survival of juvenile salmonids can be ascertained from the relation between juvenile survival and total dissolved gas concentrations. The following graphs (Figures 24 and 25) depict the relation between smolt survival between the tailrace of Lower Granite to the tailrace of McNary Dam plotted as a function of the average total dissolved gas concentration at Ice Harbor indexed as described in the multiple regression analyses performed previously in this document.

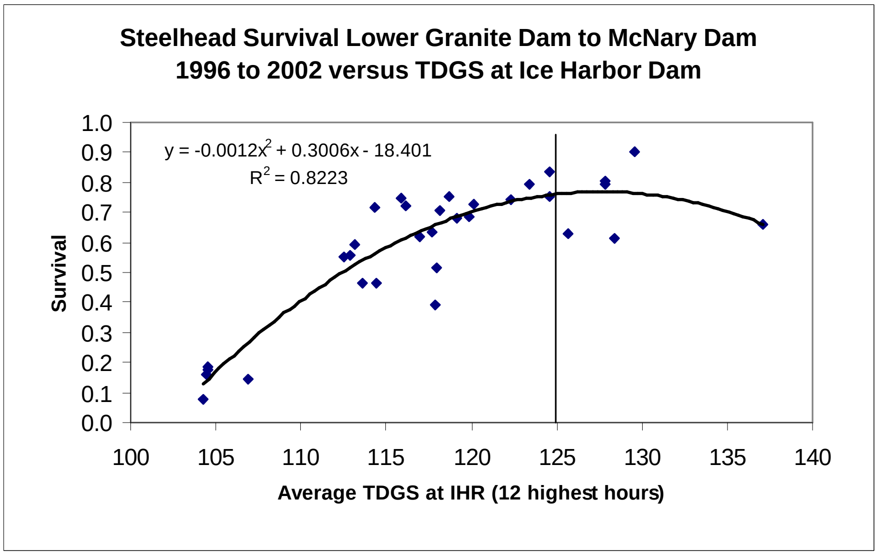


**Figure 24. Steelhead Survival Lower Granite Dam to McNary Dam 1996 to 2002 versus TDGS at Ice Harbor Dam.**

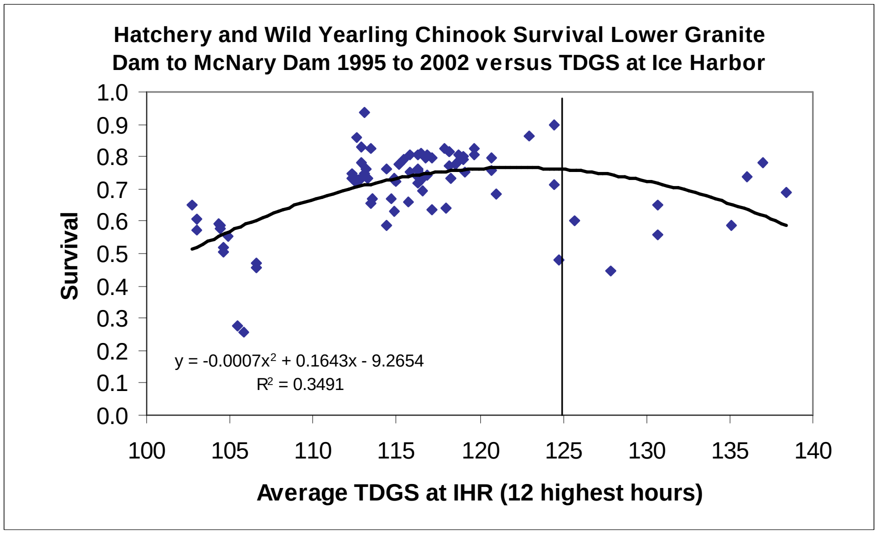


**Figure 25. Hatchery and Wild Yearling Chinook Survival Lower Granite Dam to McNary Dam 1995 to 2002 versus TDGS at Ice Harbor.**

These data suggest that total dissolved gas concentrations above 125% may have had a negative impact on survival. These high total dissolved gas measurements are a function of uncontrolled spill that occurred in the hydrosystem because of flow in excess of the hydraulic capacity of the project, or due to spill in excess of generation needs. They are not caused by the implementation of the Biological Opinion Spill Program.

All of the information collected to-date of survival and the benefits associated with spill indicate that spill provides a significant benefit to juvenile survival at levels up to 125% in the tailrace of the dam. The data suggest that the spill program has a built-in margin of error for total dissolved gas. This allows the implementation of the Biological Opinion Spill Program with little or no impact due to small excursions from the 115% forebay and 120% tailrace total dissolved gas criteria.

## Adult Return Analysis

We evaluated the impacts of flow and spill on the survival of smolts-to-adults and spawner-to-spawner to investigate the total impact of these factors on overall survival. The data set used in the adult analyses is presented in Table 1 (Appendix A). Because the ocean has a very large influence on these survival rates we included a measure of climate and ocean conditions in this analyses. We used the parameter delta derived in the Plan for Analyzing and Testing Hypotheses (PATH), which is a measure of climate/ocean mortality influences that are common to both spring/summer chinook stocks originating lower in the Columbia (e.g. John Day River) and in the Snake River (Deriso et al. 2001). Because these stocks are genetically very similar, have similar migration, ocean entry and adult return timing, we expect both to respond to ocean changes in a similar manner (Schaller et al. 1999, 2000). This is evidenced by the large returns occurring for all stocks during recent good ocean conditions (see Figure 26). The Yakima SARs averaged (geometric mean) nearly 4 times higher than Snake River SARs, but were similar in pattern over time to the Snake River SARs (Figure 1; Joint Technical Memorandum to NWPPC, March 19, 2002).

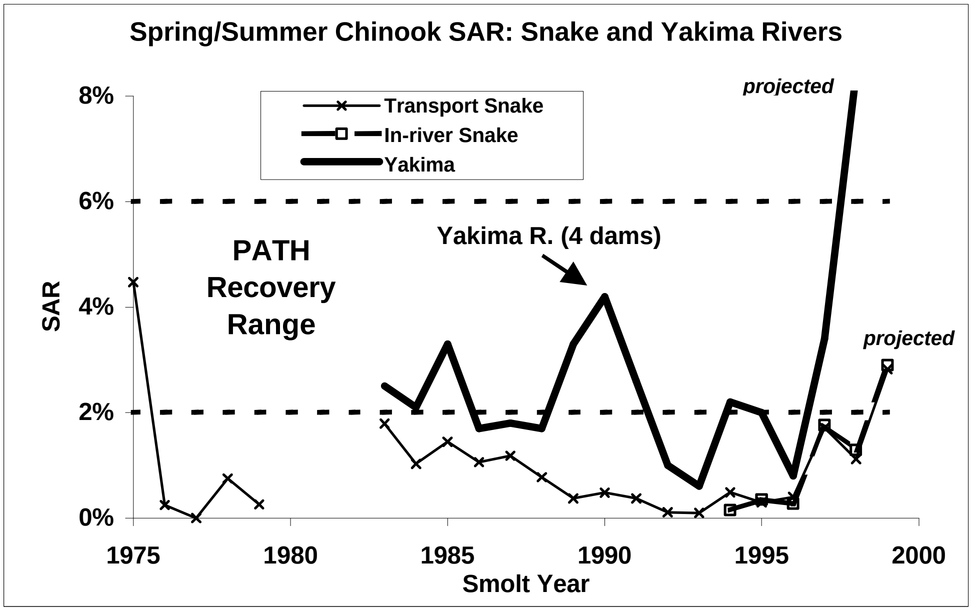


**Figure 26. Smolt to adult return rates (SAR) Snake River spring/summer chinook, (transported 1975-1999; inriver migrants 1994-1999), and Yakima spring chinook, 1983-1998.**

Dependent variables were wild Snake River chinook and steelhead SARs; spawner to spawner ratios from index stocks of Snake River spring/summer chinook used in PATH and NMFS Biological Opinion; and the direct and delayed hydrosystem survival of Snake River spring/summer chinook relative to downriver spring/summer chinook, estimated in PATH by the parameter mu (Deriso et al. 2001). Snake River wild chinook SARs for 1975-1994 were from

PATH and reported in NMFS (2000) white papers; SARs for 1995-1999 from the CSS annual report (Bouwes et al. 2002). Snake River steelhead SARs for 1975-1994 were from PATH and reported in NMFS (2000) white papers. The chinook spawner to spawner ratios (S:S) used in the analysis were from updated run reconstructions, as of March 2002. The S:S ratio used in this analysis was the median of the seven index stocks. Independent variables included water travel time, two measures of spill , updated estimates of climate effects (delta), and the proportion of smolts that were transported in barges and trucks. Annual water travel times (WTT) were the average times for water to move through the hydrosystem, LGR reservoir to BON dam, between April 16-May 31 and estimated as function of reservoir volume and flow. The proportion of water spilled each migration year (PropSpill) was represented as the daily spill/flow averaged over the migration season and across the 8 projects. Average volume spilled was calculated as daily spill averaged over the migration season and across all projects. The transport proportion was calculated as the number of smolts arriving at LGR dam divided by the number of smolts transported at LGR, LGS, and LMN over the whole season. The number of smolts arriving at LGR dam was estimated by methods described in Petrosky et al. (2001). The data source for the number of smolts transported came from Park (1985) for migration years 1975-1980, FTOT reports for migration years 1981-1984 and from the Fish Passage Center database from 1985-1996. Calvin Peters (ESSA Technologies, personal communication, March 2002) provided updated estimates of the climate effect (delta) and relative hydrosystem survival of Snake River versus downriver stocks (mu) (Deriso et al. 2001), through the 1995 migration year.

We transformed the dependent (SAR and S:S) variables by natural logarithms. We regressed Snake River spring/summer chinook ln(SARs) between 1975 (the year the last dam went in on the Snake River) and 1996 (SARs were not available between migration years 1985-1991) to all possible combinations of the above water travel time ,spill, climate, and transportation proportion variables. In addition, we conducted a stepwise regression between these response and explanatory variables to avoid using explanatory variables that were highly correlated with each other.

Both BIC scores and the stepwise regression suggested that the most parsimonious model (the model with the fewest number of explanatory variables explaining the greatest amount of variability in survival) that best explained spring/summer chinook SARs was the transportation proportion (Appendix A, Tables 2 and 3). We found a moderate to strong relationship between chinook SARs and transportation proportion ($r^2$=0.64, $p<0.001$); however this relationship was negative suggesting years in which the proportion transported increased the SARs decreased (Figure 27).

After demonstrating the large negative influence of transportation proportion on spring/summer chinook SARs (the best 10 models all included this variable), we evaluated the influence of other variables on survival of transported and non-transported fish over these life-stages by removing this variable from the model. BIC scores and the stepwise regression suggested that spring/summer chinook SARs were best explained by WTT and climate effects (Appendix A, Tables 4 and 5). A moderate relationship was observed between SARs explained by WTT and climate effects ($r^2$=0.48, $p<0.03$).

We also did a similar regression analyses for spring/summer chinook spawner-to-spawner ratios ln(S:S) because we had a more complete time series and data were collected in a similar fashion over the time series. The spawner/spawner ratio for chinook was best explained by WTT and climate effects ($r^2$=0.63, p<0.001; Appendix A, Tables 6 and 7).
Regression analyses were also performed on the relative hydrosystem mortality (mu) using the explanatory variables. The best model explaining relative hydrosystem mortality was WTT ($r^2$=0.42, p<0.002, Appendix A Tables 8 and 9). As WTT increased the relative hydrosystem mortality also increased (Figure28).

Finally, using the same regression analyses we evaluated the variables that influenced steelhead SARs. The best model selected suggested a moderate relationship between steelhead SARs and water travel time, the interaction between spill and water travel time, and climate ($r^2$=0.52, p<0.007).

Although these relationships are not driven by water travel time in itself, given the numerous environmental factors that influence survival of salmonids over this large portion of their life cycle as well as the large variability in the data, this factor remained as an important contributor to salmon survival.

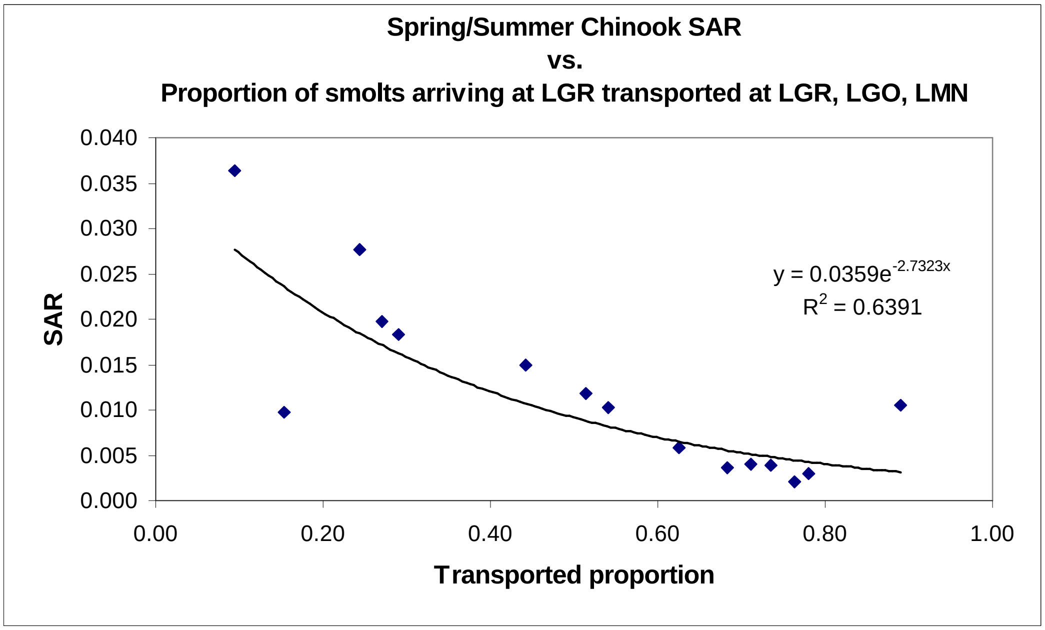


**Figure 27. Relationship between Snake River spring/summer chinook smolt-to-adult survival (SAR) and the proportion of smolts arriving LGR that were transported at LGR, LGO, LMN.**

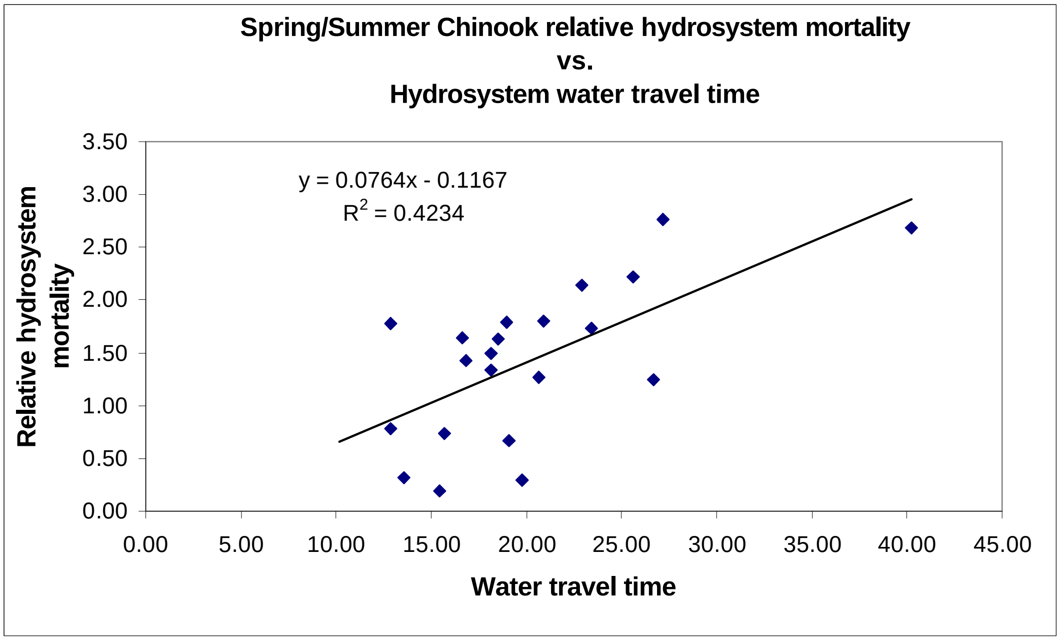


**Figure 28. The relationship between water travel time through the hydrosystem and the hydrosystem mortality for Snake River spring/summer chinook relative to Lower-Columbia River spring/summer chinook (mu). Relationships of Spawner:Spawner Ratios to Water Travel Time and Climate/Ocean Conditions.**

Juvenile migration conditions and climate/ocean conditions were both influential in explaining patterns of adult recruitment of wild Snake River spring/summer chinook. The relationship of predicted spawner-to-spawner ratios to water travel time and the climate/ocean influence (delta) is shown in Table 22 and Figure 29. The water travel times from Biological Opinion spring flow targets range from approximately 16.5 to 20 days, and are shaded in Table 22 and Figure 29. Observed water travel times ranged from 14 to 46 days in the fitted data (11 days was observed in 1997); and delta ranged from –1.9 (poor ocean) to 1.0 (favorable ocean). Salmon managers have no control of climatic/ocean conditions, thus we focus this discussion on predicted life-cycle survival (S:S ratio) at different water travel times, for average (delta = 0), good (delta = 1.0) and poor (delta = -1.0) climate/ocean conditions. A delta value of 1.0 indicates climate/ocean influence resulted in nearly a three-fold higher than average survival (exp(1.0)); a delta value of –1.0 indicates ocean survival was only about 1/3 as high as average. The time frame in designating “average”, “poor” or “good” climate/ocean conditions was 1959-1995 smolt migration years (Deriso et al. 2001).

**Table 22. Predicted spawner:spawner ratios from observed ln(S:S), water travel time (WTT) and climate/ocean influence (delta), Snake River spring/summer chinook, smolt migration years 1975-1995. Combinations of WTT and delta that predict population declines (S:S < 1.0) are in red, those that predict population increases (S:S > 1.0) are bolded. BiOp flow targets produce WTT in the range of 16.5 to 20 days (shaded cells). Good, average, and poor climate/ocean conditions are represented by delta = 1.0, 0, and –1.0 respectively.**

| | **DELTA** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **WTT** | **-1** | **-0.75** | **-0.5** | **-0.25** | **0** | **0.25** | **0.5** | **0.75** | **1** |
| **10** | 0.57 | 0.73 | 0.93 | **1.18** | **1.50** | **1.90** | **2.42** | **3.07** | **3.90** |
| **15** | 0.40 | 0.51 | 0.65 | 0.82 | **1.05** | **1.33** | **1.69** | **2.15** | **2.73** |
| **20** | 0.28 | 0.36 | 0.45 | 0.58 | 0.73 | 0.93 | **1.18** | **1.50** | **1.91** |
| **25** | 0.20 | 0.25 | 0.32 | 0.40 | 0.51 | 0.65 | 0.83 | **1.05** | **1.34** |
| **30** | 0.14 | 0.17 | 0.22 | 0.28 | 0.36 | 0.46 | 0.58 | 0.74 | 0.93 |
| **35** | 0.10 | 0.12 | 0.16 | 0.20 | 0.25 | 0.32 | 0.40 | 0.51 | 0.65 |
| **40** | 0.07 | 0.09 | 0.11 | 0.14 | 0.18 | 0.22 | 0.28 | 0.36 | 0.46 |
| **45** | 0.05 | 0.06 | 0.08 | 0.10 | 0.12 | 0.16 | 0.20 | 0.25 | 0.32 |

Under average climatic/ocean conditions (delta = 0), the predicted spawner-to-spawner ratio exceeded 1.0 (indicating population growth) only when water travel times were faster than 16 days (Table 22; Fig. 29). Predicted spawner to spawner ratios for water travel times associated with the Biological Opinion flow targets would approach or meet replacement of the populations for average climatic/ocean conditions. At 30 days WTT, the predicted recruits to the spawning ground were only 36% of the parent generation. At 20 days WTT, 73% of the parent generation was predicted to return to the spawning grounds, over a doubling of life cycle survival for a 10 day reduction in WTT, but insufficient for the population to increase.

Under good climatic/ocean conditions (delta = 1.0), the predicted spawner-to-spawner ratio exceeded 1.0 (indicating population growth) when water travel times were faster than 29 days (Table 22; Fig. 29). Predicted spawner to spawner ratios for water travel times associated with the Biological Opinion flow targets would exceed replacement of the populations for good climatic/ocean conditions. At 30 days WTT, the predicted recruits to the spawning ground were 93% of the parent generation. At 20 days WTT, 191% of the parent generation was predicted, again over a doubling of life cycle survival for a 10-day reduction in WTT.

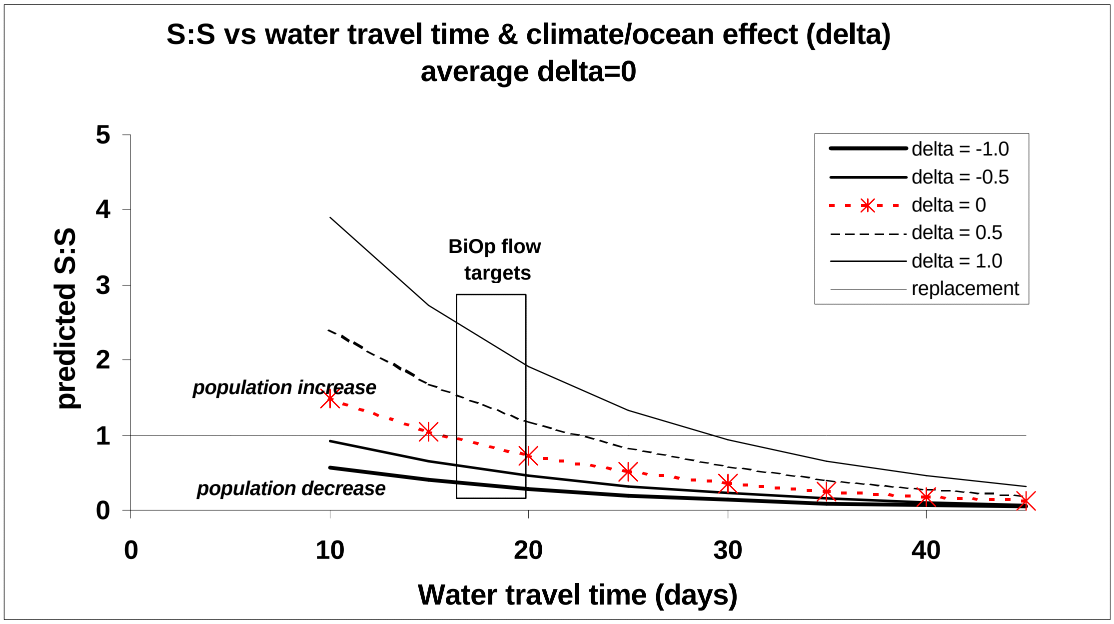


**Figure 29. Predicted spawner:spawner ratios from observed ln(S:S), water travel time (WTT) and climate/ocean influence (delta), Snake River spring/summer chinook, smolt migration years 1975-1995. Population increases when S:S exceeds 1.0; and decreases when S:S < 1.0. BiOp flow targets produce WTT in the range of 16.5 to 20 days.**

Under poor climatic/ocean conditions (delta = -1.0), the predicted spawner-to-spawner ratio was always less than 1.0 (indicating population decline) at all water travel times (Table 22; Fig. 29). Predicted spawner-to-spawner ratios for water travel times associated with the Biological Opinion flow targets would provide protection for the populations for poor climatic/ocean conditions, but be insufficient to prevent declines. At 30 days WTT, the predicted recruits to the spawning ground were only 14% of the parent generation. At 20 days WTT, 28% of the parent generation was predicted to return to the spawning grounds.

It is important to recognize that the relationships described above are inherently optimistic because we fit a density independent model. In reality, as the population increased toward carrying capacity, egg-to-smolt survival would decrease, and higher SARs would be needed for population growth to occur. For a given ocean condition, faster water travel times would be needed to maintain or rebuild the populations at higher spawner levels, particularly if regional harvest goals were to be achieved.

The Biological Opinion flow targets appear to represent a minimum needed to maintain the Snake River spring/summer chinook populations for average to good ocean conditions, and provide inadequate protection for poor ocean conditions. The Council's proposed relaxation of spring flow targets would increase water travel times and reduce protection against population declines and the likelihood of rebuilding Snake River spring/summer chinook.

## Relationships of Chinook and Steelhead SARs to Water Travel Time and Climate/Ocean Conditions

Juvenile migration conditions and climate/ocean condition were both influential in explaining patterns of smolt-to-adult survival rates (SARs) of wild Snake River spring/summer chinook and steelhead. The relationships of predicted chinook and steelhead SARs to water travel time and the climate/ocean influence (delta) are shown in Figures 30 and 31. The water travel times from Biological Opinion spring flow targets range from 16.5 to 20 days, and are shaded in the figures. Observed water travel times ranged from 14 to 46 days in the fitted data; and delta ranged from –1.9 (poor ocean) to 1.0 (favorable ocean). We again focus this discussion on predicted smolt-to-adult survival at different water travel times, for average (delta = 0), good (delta = 1.0) and poor (delta = -1.0) climate/ocean conditions.

PATH estimated a median 4% SAR was needed for spring/summer chinook recovery, and 2% SAR to meet survival criteria. PATH did not establish a steelhead SAR range associated with survival and recovery criteria.

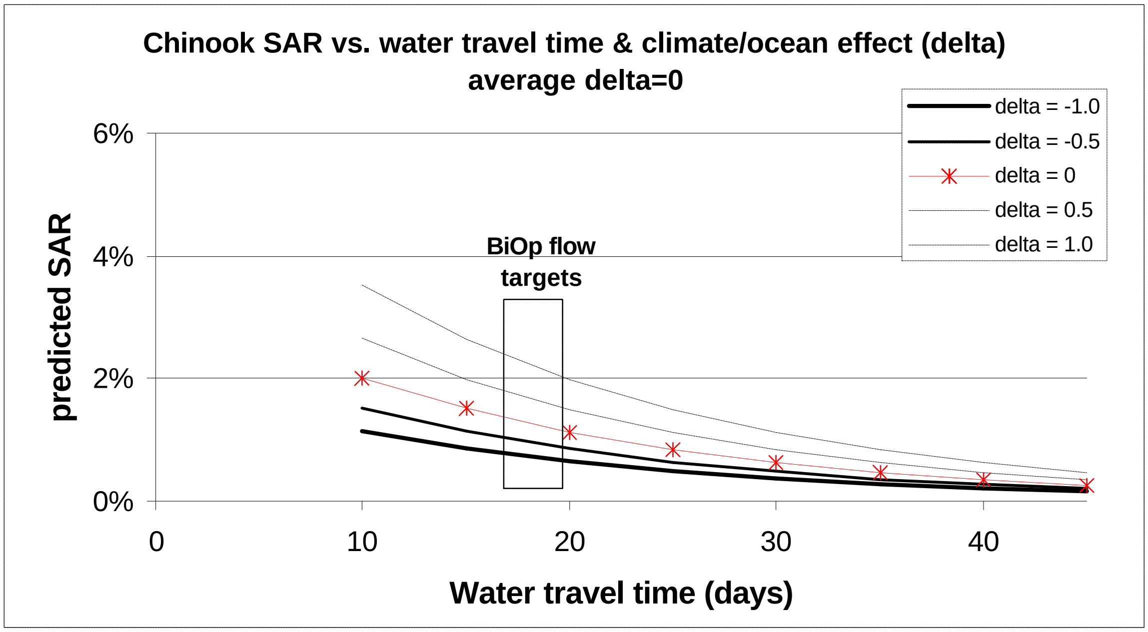


**Figure 30. Predicted SAR from observed ln(SAR), water travel time (WTT) and climate/ocean influence (delta), Snake River wild spring/summer chinook, smolt migration years 1975-1995. Estimated SAR range needed for recovery is 2%-6%. BiOp flow targets produce WTT in the range of 16.5 to 20days.**

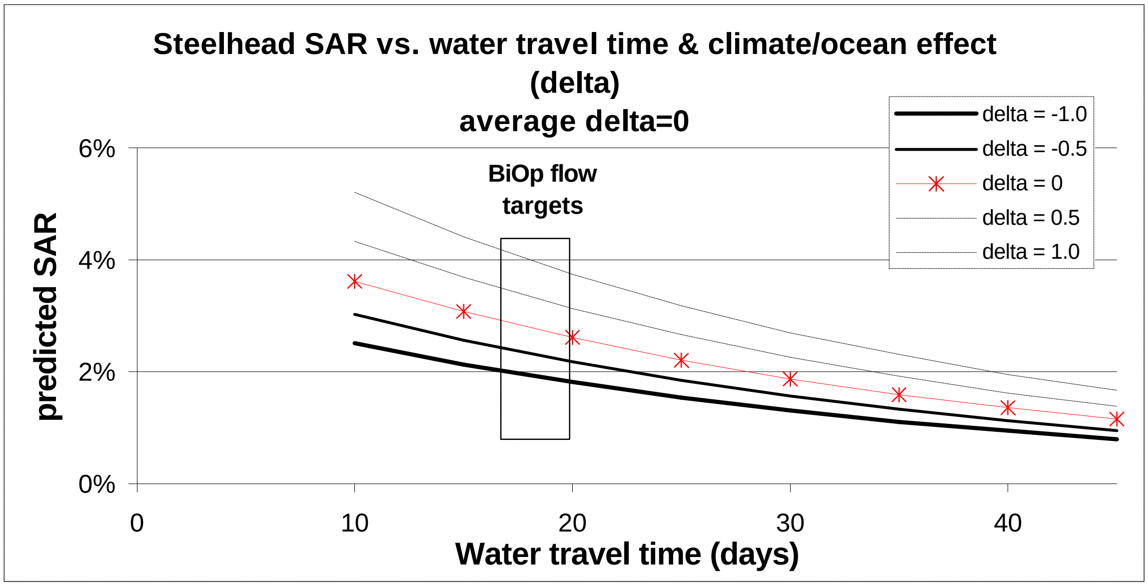


**Figure 31. Predicted SAR from observed ln(SAR), water travel time (WTT) and climate/ocean influence (delta), Snake River wild steelhead, smolt migration years 1975-1995. SAR range needed for recovery has not been established. BiOp flow targets produce WTT in the range of 16.5 to 20days.**

Under average climate/ocean conditions (delta = 0), the predicted SARs for spring/summer chinook exceeded 2% only at the high flows and water velocities (WTT = 10 days; Fig. 30). Predicted SARs for water travel times associated with the Biological Opinion flow targets ranged from 1.1% to 1.4% for average climatic/ocean conditions. At 30 days WTT, the predicted SARs were only 0.6%. At 20 days WTT, predicted SARs were 1.1%, a 78% improvement in life stage survival for a 10-day reduction in WTT, but less than the SAR range identified in PATH as needed for survival and recovery.

Under average climate/ocean conditions, the predicted steelhead SARs for water travel times associated with the Biological Opinion flow targets ranged from 2.6% to 2.9% (Fig. 31). At 30 days WTT, the predicted SARs were 1.9%. At 20 days WTT, predicted SARs were 2.6%, a 39% improvement in life stage survival for a 10-day reduction in WTT.

Under favorable climate/ocean conditions (delta = 1.0), the predicted SARs for spring/summer chinook exceeded 2% at average and above flows and faster water velocities (WTT = 20 days; Fig. 30). Predicted SARs for water travel times associated with the Biological Opinion flow targets ranged from 2.0% to 2.4% for good climatic/ocean conditions. At 30 days WTT, the predicted SARs were only 1.1%. At 20 days WTT, predicted SARs were 2.0%, a 78% improvement in life stage survival for a 10-day reduction in WTT, and within the SAR range identified by PATH as needed for survival and recovery.

Under good climate/ocean conditions, the predicted steelhead SARs for water travel times associated with the Biological Opinion flow targets ranged from 3.75% to 4.2% (Fig. 31). At 30 days WTT, the predicted SARs were 2.7%. At 20 days WTT, predicted SARs were 3.75%, a 39% improvement in life stage survival for a 10-day reduction in WTT.

Under poor climate/ocean conditions (delta = -1.0), the predicted SARs for spring/summer chinook never approached 2% at any flows and water velocities (Fig. 30). Predicted SARs for water travel times associated with the Biological Opinion flow targets ranged from 0.65% to 0.8% for poor climatic/ocean conditions. At 30 days WTT, the predicted SARs were only 0.36%. At 20 days WTT, predicted SARs were 0.65%, a 78% improvement in life stage survival for a 10 day reduction in WTT, but much lower than the SAR range identified by PATH as needed for survival and recovery.

Under poor climate/ocean conditions, the predicted steelhead SARs for water travel times associated with the Biological Opinion flow targets ranged from 1.8% to 2.0% (Fig. 31). At 30 days WTT, the predicted SARs were 1.3%. At 20 days WTT, predicted SARs were 1.8%, a 39% improvement in life stage survival for a 10-day reduction in WTT.

Results from this study suggest that relaxation of spring flow objectives from those specified in the Biological Opinion would likely decrease the SARs of wild Snake River spring/summer chinook and steelhead.

## TRANSPORTATION

Several studies summarized in Giorgi et al. (2002) provide mechanisms and empirical information that suggests that increasing flow decreases the amount of time a smolt spends in the hydrosystem and subsequently mortality. Giorgi et al. (2002) also summarizes results reported by NMFS, which have not been able to reject hypotheses that increases in flows have no benefit to salmon survival. Based on this study, the Council has suggested relying mainly on transportation as mitigation for the impacts of the hydropower system rather than meeting flow targets. However, the benefits to transportation also remain equivocal. The Giorgi et al. (2002) report reviewed Bouwes et al. (2001) and Sandford and Smith (2002) as recent studies evaluating the benefit of transportation relative to migrating through the hydrosystem. Giorgi et al. (2002) concluded that transported fish generally exhibited higher SARs than fish that migrate in-river. Giorgi et al. (2002) failed to emphasize the important conclusions to these studies relevant to actual hydrosystem operations. Emphasis should have been placed on the comparison between wild smolts transported at all sites to the control, wild smolts that experienced a migration through the hydrosystem as if the transportation/collection system were not in place. Bouwes et al. (2001) found in 4 out of the 6 years analyzed, transported wild fish actually exhibited slightly lower SARs (point estimates) than wild fish that migrated through the hydrosystem undetected. Sandford and Smith (2002) also demonstrated equivocal differences between transported (they did not evaluated total transport SAR from all projects) and control in-river migrants as only 4 out 20 data sets demonstrated significant benefits to an optimistic representation of transportation. See Joint Technical Memorandum to NWPPC, March 19, 2002.

Our analysis also does not support the hypothesis that transportation provides a benefit to the overall survival of wild spring/summer chinook and steelhead. The spring/summer chinook S:S and steelhead SARs were not significantly influenced by the transportation proportion, and the spring/summer chinook SARs actually decreased as the proportion of smolts transported increased.  Because transportation has failed to demonstrate statistically significant increases over fish that migrate in-river, by applying similar logic used to reject flow target as a management tool, we would expect the Council to adopt a management action that ceased transportation as well.  The Council's draft mainstem amendments to the Fish and Wildlife program appear to apply a double standard to what are acceptable and unacceptable management strategies.

Because the benefits of flow and transportation are not clear the region has adopted a spread the risk approach whereby both flow augmentation and transportation strategies be used as partial mitigation to the hydrosystem.  The Council has proposed a spread the risk approach only for transportation, however; based on our results removing flow targets will increase the risk to populations evaluated in this analysis.

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# APPENDIX A

**Table 1: Information used in analysis. See text for details on data compilation of SARch (Snake River spring/summer chinook smolt-to-adult survival), lnSSch (Snake River spring/summer chinook ln Spawner to Spawner), mu (direct and delayed hydrosystem survival of Snake River spring/summer chinook relative to Mid-Columbia spring/summer chinook survival), SARst (Snake River steelhead smolt-to-adult survival), wtt (water particle travel time through Lower Granite Reservoir to Bonneville Dam), spill (average proportion of the flow spilled over dams), avgspill (average volume-kcfs-spilled over dams), climate (climate affect), ptranss (proportion of Snake River spring/summer chinook smolts arriving at LGR, LGO, LMN that were transported in barges and trucks), ptranst(proportion of Snake River steelhead smolts arriving at LGR, LGO, LMN that were transported in barges and trucks)**

| Obs | year | SARch | lnSSch | mu | SARst | wtt | spill | avgspill | climate | ptranss | ptranst |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1975 | 0.036 | -0.347 | 0.74 | 0.021 | 15.71 | 0.406 | 69.74 | 0.22 | 0.09 | 0.17 |
| 2 | 1976 | 0.010 | -0.905 | 1.78 | 0.020 | 12.89 | 0.481 | 112.36 | -0.18 | 0.15 | 0.14 |
| 3 | 1977 | 0.004 | -2.031 | 2.68 | 0.010 | 40.23 | 0.004 | 0.82 | -0.41 | 0.68 | 0.64 |
| 4 | 1978 | 0.010 | -0.641 | 1.33 | 0.033 | 18.16 | 0.145 | 29.28 | -0.50 | 0.54 | 0.65 |
| 5 | 1979 | 0.012 | -0.410 | 0.29 | 0.034 | 19.75 | 0.073 | 16.46 | -1.26 | 0.51 | 0.66 |
| 6 | 1980 | 0.006 | -1.405 | 1.49 | 0.027 | 18.11 | 0.081 | 19.34 | -0.45 | 0.63 | 0.79 |
| 7 | 1981 | 0.015 | -0.153 | 1.27 | 0.012 | 20.65 | 0.089 | 20.72 | -0.33 | 0.44 | 0.74 |
| 8 | 1982 | 0.018 | 1.281 | 0.32 | 0.040 | 13.55 | 0.355 | 85.41 | 0.15 | 0.29 | 0.53 |
| 9 | 1983 | 0.020 | 0.504 | 0.19 | 0.034 | 15.45 | 0.326 | 74.31 | -0.33 | 0.27 | 0.67 |
| 10 | 1984 | 0.028 | 0.489 | 0.78 | 0.046 | 12.84 | 0.300 | 74.92 | 0.22 | 0.24 | 0.65 |
| 11 | 1985 | . | 1.556 | 0.67 | 0.040 | 19.06 | 0.109 | 22.36 | 0.87 | 0.69 | 1.00 |
| 12 | 1986 | . | -0.240 | 1.64 | 0.041 | 16.64 | 0.210 | 48.27 | 0.33 | 0.64 | 0.92 |
| 13 | 1987 | . | -0.786 | 2.22 | 0.052 | 25.58 | 0.053 | 11.73 | 0.42 | 0.64 | 0.96 |
| 14 | 1988 | . | -0.425 | 1.25 | 0.027 | 26.67 | 0.031 | 5.17 | -0.03 | 0.58 | 0.87 |
| 15 | 1989 | . | -1.116 | 1.79 | 0.012 | 18.93 | 0.117 | 22.71 | -0.49 | 0.60 | 0.80 |
| 16 | 1990 | . | -0.444 | 2.14 | 0.030 | 22.92 | 0.108 | 19.45 | 0.58 | 0.64 | 0.85 |
| 17 | 1991 | . | -0.570 | 1.81 | 0.019 | 20.91 | 0.161 | 38.75 | -0.35 | 0.81 | 0.93 |
| 18 | 1992 | 0.002 | -2.318 | 2.77 | 0.013 | 27.18 | 0.150 | 22.28 | -1.09 | 0.76 | 0.93 |
| 19 | 1993 | 0.004 | -2.199 | 1.43 | 0.013 | 16.80 | 0.231 | 56.65 | -1.94 | 0.74 | 0.85 |
| 20 | 1994 | 0.010 | -0.269 | 1.73 | 0.015 | 23.40 | 0.199 | 28.98 | 0.34 | 0.89 | 0.92 |
| 21 | 1995 | 0.003 | -0.379 | 1.63 | . | 18.49 | 0.258 | 51.96 | 0.07 | 0.78 | 0.86 |
| 22 | 1996 | 0.004 | -0.608 | . | . | 13.38 | 0.395 | 107.41 | . | 0.71 | 0.82 |

**Table 2: Model comparisons with parameter estimates for ln (spring/summer chinook SARs) as function of wtt, spill, inter (interaction of wtt and spill estimated as wtt*spill), climate, and ptranss (see definitions to variables in Table 1). Shaded row is the best-fit model based on BIC score (lower scores are better fit models). Only the best 10 models with 3 or less explanatory variables are displayed.**

| Adjusted $r^2$ | $r^2$ | AIC | BIC | Parameter Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | wtt | spill | inter | climate | ptranss |
| 0.6363 | 0.6923 | -15.7283 | -12.7173 | -3.36120 | . | . | . | 0.33405 | -2.36221 |
| 0.6262 | 0.7124 | -14.6778 | -10.7195 | -2.89070 | . | -1.18510 | . | 0.38215 | -2.74048 |
| 0.6210 | 0.7085 | -14.4861 | -10.6477 | -3.14694 | -0.01862 | . | . | 0.34198 | -2.05827 |
| 0.6126 | 0.7020 | -14.1795 | -10.5319 | -3.09728 | . | . | -0.05143 | 0.37047 | -2.48514 |
| 0.6064 | 0.6367 | -15.4047 | -13.4093 | -3.34185 | . | . | . | . | -2.66249 |
| 0.5868 | 0.6504 | -13.9412 | -11.7168 | -3.14497 | -0.01707 | . | . | . | -2.39034 |
| 0.5842 | 0.6802 | -13.1887 | -10.1480 | -2.29878 | -0.03303 | -1.65791 | . | . | -2.72556 |
| 0.5789 | 0.6437 | -13.6753 | -11.5658 | -3.07160 | . | -0.67668 | . | . | -2.90316 |
| 0.5722 | 0.6380 | -13.4555 | -11.4406 | -3.24728 | . | . | -0.01828 | . | -2.71782 |
| 0.5643 | 0.6649 | -12.5347 | -9.8858 | -2.83270 | . | -4.47013 | 0.24669 | . | -3.50571 |

## Table 3: Relationship between SAR and WTT, PropSpill, and ptrans stepwise regression for sp/su chinook SARs

**Dependent Variable: lnSARch**

**Stepwise Selection: Step 1**

**Variable ptranss Entered: R-Square = 0.6367 and C(p) = 4.0159**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 1 | 6.13535 | 6.13535 | 21.03 | 0.0006 |
| Error | 12 | 3.50086 | 0.29174 | | |
| Corrected Total | 13 | 9.63620 | | | |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| Intercept | -3.34185 | 0.32457 | 30.92697 | 106.01 | <.0001 |
| ptranss | -2.66249 | 0.58058 | 6.13535 | 21.03 | 0.0006 |

**Bounds on condition number: 1, 1**

**All variables left in the model are significant at the 0.1500 level.**

**No other variable met the 0.1500 significance level for entry into the model.**

| Summary of Stepwise Selection | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Step | Variable Entered | Variable Removed | Number Vars In | Partial R-Square | Model R-Square | C(p) | F Value | Pr > F |
| 1 | ptranss | | 1 | 0.6367 | 0.6367 | 4.0159 | 21.03 | 0.0006 |

**Table 4: Model comparisons with parameter estimates for ln (spring/summer chinook SARs) as function of wtt, spill, inter (interaction of wtt and spill estimated as wtt*spill), climate (see definitions to variables in Table 1). Ptrans was not included in this analysis. Shaded row is the best-fit model based on BIC score (lower scores are better fit models). Only the best 10 models with 3 or less explanatory variables are displayed.**

| Adjusted $r^2$ | $r^2$ | AIC | BIC | Parameter Estimates | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | wtt | spill | inter | climate |
| 0.3842 | 0.4789 | -8.3548 | -4.5910 | -3.33244 | -0.05754 | . | . | 0.55993 |
| 0.3710 | 0.5161 | -7.3927 | -2.3054 | -2.53110 | -0.07474 | . | -0.11762 | 0.65058 |
| 0.3298 | 0.4844 | -6.5046 | -1.9849 | -2.98382 | -0.06657 | -0.70309 | . | 0.60322 |
| 0.2816 | 0.4474 | -5.5327 | -1.6264 | -4.52431 | . | 7.07556 | -0.41603 | 0.49688 |
| 0.2474 | 0.3053 | -6.3283 | -4.3370 | -3.38346 | -0.06618 | . | . | . |
| 0.2160 | 0.3969 | -4.3100 | -1.1582 | -3.73312 | -0.04500 | 5.68111 | -0.36117 | . |
| 0.2130 | 0.3340 | -4.9207 | -2.6783 | -4.89273 | . | 1.88233 | . | 0.50695 |
| 0.2068 | 0.3288 | -4.8120 | -2.6167 | -4.91379 | . | 8.10073 | -0.42484 | . |
| 0.1927 | 0.2548 | -5.3475 | -3.6359 | -4.41290 | . | . | . | 0.66837 |
| 0.1901 | 0.3147 | -4.5199 | -2.4507 | -3.79631 | -0.05458 | 0.84218 | . | . |

### Table 5: Stepwise regression for sp/su chinook SARs w/o ptrans

**Dependent Variable: lnSARch**

**Stepwise Selection: Step 2**

**Variable climate Entered: R-Square = 0.4789 and C(p) = 2.5236**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 2 | 4.61479 | 2.30740 | 5.05 | 0.0277 |
| Error | 11 | 5.02141 | 0.45649 | | |
| Corrected Total | 13 | 9.63620 | | | |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| Intercept | -3.33244 | 0.54054 | 17.34979 | 38.01 | <.0001 |
| wtt | -0.05754 | 0.02646 | 2.15917 | 4.73 | 0.0523 |
| climate | 0.55993 | 0.29245 | 1.67332 | 3.67 | 0.0819 |

**Bounds on condition number: 1.0299, 4.1198**

**All variables left in the model are significant at the 0.1500 level.**

**No other variable met the 0.1500 significance level for entry into the model.**

| Summary of Stepwise Selection | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Step | Variable Entered | Variable Removed | Number Vars In | Partial R-Square | Model R-Square | C(p) | F Value | Pr > F |
| 1 | wtt | | 1 | 0.3053 | 0.3053 | 4.0304 | 5.27 | 0.0405 |
| 2 | climate | | 2 | 0.1736 | 0.4789 | 2.5236 | 3.67 | 0.0819 |

**Table 6: Model comparisons with parameter estimates for ln (spring/summer chinook spawner:spawner survival) as function of wtt, spill, inter (interaction of wtt and spill estimated as wtt*spill), climate, and ptranss (see definitions to variables in Table 1). Shaded row is the best-fit model based on BIC score (lower scores are better fit models). Only the best 10 models with 3 or less explanatory variables are displayed.**

| Adjusted $r^2$ | $r^2$ | AIC | BIC | Parameter Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | wtt | spill | inter | climate | ptranss |
| 0.6026 | 0.6622 | -16.1548 | -11.5179 | 1.95728 | -0.09331 | . | -0.12420 | 0.96941 | . |
| 0.5928 | 0.6335 | -16.4417 | -13.0381 | 1.11800 | -0.07148 | . | . | 0.95809 | . |
| 0.5926 | 0.6537 | -15.6327 | -11.2172 | 1.87762 | -0.09459 | -1.56578 | . | 0.97455 | . |
| 0.5725 | 0.6366 | -14.6194 | -10.6302 | 1.16529 | -0.06596 | . | . | 0.94862 | -0.29051 |
| 0.4598 | 0.5139 | -10.5078 | -8.8338 | 0.36724 | . | . | . | 0.94382 | -1.25700 |
| 0.4309 | 0.5163 | -8.6127 | -7.0065 | 0.17478 | . | 0.49460 | . | 0.94239 | -1.07498 |
| 0.4292 | 0.5148 | -8.5496 | -6.9668 | 0.26871 | . | . | 0.01959 | 0.94290 | -1.19218 |
| 0.4249 | 0.5111 | -8.3906 | -6.8666 | -0.39686 | . | 5.40226 | -0.29117 | 0.95190 | . |
| 0.4241 | 0.4817 | -9.1622 | -7.8601 | -0.63634 | . | 1.69162 | . | 0.96638 | . |
| 0.4039 | 0.4337 | -9.3035 | -8.1231 | -0.31694 | . | . | . | 0.99816 | . |

### Table 7: Stepwise regression for ln(spawner/spawner) sp/su chinook

**Dependent Variable: lnSSch**

**Stepwise Selection: Step 2**

**Variable wtt Entered: R-Square = 0.6335 and C(p) = 1.7233**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 2 | 12.46888 | 6.23444 | 15.56 | 0.0001 |
| Error | 18 | 7.21289 | 0.40072 | | |
| Corrected Total | 20 | 19.68177 | | | |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| Intercept | 1.11800 | 0.48035 | 2.17074 | 5.42 | 0.0318 |
| wtt | -0.07148 | 0.02282 | 3.93244 | 9.81 | 0.0058 |
| climate | 0.95809 | 0.21664 | 7.83736 | 19.56 | 0.0003 |

**Bounds on condition number: 1.0035, 4.014**

**All variables left in the model are significant at the 0.1500 level.**

**No other variable met the 0.1500 significance level for entry into the model.**

| Summary of Stepwise Selection | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Step | Variable Entered | Variable Removed | Number Vars In | Partial R-Square | Model R-Square | C(p) | F Value | Pr > F |
| 1 | climate | | 1 | 0.4337 | 0.4337 | 8.8409 | 14.55 | 0.0012 |
| 2 | wtt | | 2 | 0.1998 | 0.6335 | 1.7233 | 9.81 | 0.0058 |

**Table 8: Model comparisons with parameter estimates for mu (relative hydrosystem mortality of spring/summer chinook) as function of wtt, spill, inter (interaction of wtt and spill estimated as wtt*spill), climate, and ptranss (see definitions to variables in Table 1). Shaded row is the best-fit model based on BIC score (lower scores are better fit models). Only the best 10 models with 3 or less explanatory variables are displayed.**

| Adjusted $r^2$ | $r^2$ | AIC | BIC | Parameter Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | wtt | spill | inter | climate | ptranss |
| 0.4828 | 0.5604 | -23.4717 | -18.6082 | -1.55562 | 0.08454 | 2.46368 | . | . | 1.48165 |
| 0.4690 | 0.5487 | -22.9186 | -18.2906 | -1.21933 | 0.07934 | . | 0.13625 | . | 1.10161 |
| 0.4291 | 0.4862 | -22.1964 | -19.0993 | -0.27614 | 0.05803 | . | . | . | 0.96012 |
| 0.4084 | 0.4675 | -21.4466 | -18.5718 | -0.88393 | 0.09649 | . | 0.11352 | . | . |
| 0.3965 | 0.4870 | -20.2298 | -16.7277 | -0.67953 | 0.08538 | -2.65864 | 0.27399 | . | . |
| 0.3955 | 0.4862 | -20.1964 | -16.7081 | -0.27613 | 0.05803 | . | . | 0.00074325 | 0.96040 |
| 0.3929 | 0.4232 | -21.7680 | -19.5162 | -0.11758 | 0.07647 | . | . | . | . |
| 0.3783 | 0.4405 | -20.4048 | -17.8369 | -0.63183 | 0.09221 | 1.06168 | . | . | . |
| 0.3751 | 0.4689 | -19.4995 | -16.2959 | -0.89277 | 0.09639 | . | 0.11439 | -0.04097 | . |
| 0.3600 | 0.4240 | -19.7952 | -17.4054 | -0.11979 | 0.07628 | . | . | -0.03055 | . |

## Table 9: Stepwise regression for relative mortality sp/su chinook

**Dependent Variable: mu**

**Stepwise Selection: Step 1**

**Variable wtt Entered: R-Square = 0.4232 and C(p) = 2.7175**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 1 | 4.51739 | 4.51739 | 13.94 | 0.0014 |
| Error | 19 | 6.15630 | 0.32402 | | |
| Corrected Total | 20 | 10.67370 | | | |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| Intercept | -0.11758 | 0.43170 | 0.02403 | 0.07 | 0.7883 |
| wtt | 0.07647 | 0.02048 | 4.51739 | 13.94 | 0.0014 |

**Bounds on condition number: 1, 1**

**All variables left in the model are significant at the 0.1500 level.**

**No other variable met the 0.1500 significance level for entry into the model.**

| Summary of Stepwise Selection | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Step | Variable Entered | Variable Removed | Number Vars In | Partial R-Square | Model R-Square | C(p) | F Value | Pr > F |
| 1 | wtt | | 1 | 0.4232 | 0.4232 | 2.7175 | 13.94 | 0.0014 |

**Table 10: Model comparisons with parameter estimates for ln (steelhead SARs) as function of wtt, spill, inter (interaction of wtt and spill estimated as wtt*spill), climate, and ptranss (see definitions to variables in Table 1). Shaded row is the best-fit model based on BIC score (lower scores are better fit models). Only the best 10 models with 3 or less explanatory variables are displayed.**

| Adjusted $r^2$ | $r^2$ | AIC | BIC | Parameter Estimates | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | wtt | spill | inter | climate | ptranst |
| 0.4323 | 0.5220 | -34.2612 | -29.7278 | -2.12802 | -0.05528 | . | -0.13030 | 0.36968 | . |
| 0.3897 | 0.4861 | -32.8129 | -28.9194 | -2.22112 | -0.05625 | -1.60427 | . | 0.37760 | . |
| 0.3403 | 0.4444 | -31.2554 | -28.0354 | -3.20726 | -0.03910 | . | . | 0.35574 | 0.46735 |
| 0.3346 | 0.4046 | -31.8704 | -29.3959 | -2.99219 | -0.03272 | . | . | 0.36305 | . |
| 0.2101 | 0.2933 | -28.4414 | -26.9918 | -2.19424 | -0.05657 | . | -0.12575 | . | . |
| 0.2049 | 0.3304 | -27.5221 | -25.8331 | -3.50977 | . | 3.53358 | -0.25331 | 0.35650 | . |
| 0.2000 | 0.2421 | -29.0449 | -27.6923 | -3.65203 | . | . | . | 0.37972 | . |
| 0.1750 | 0.3053 | -26.7843 | -25.3817 | -2.29969 | -0.05065 | 1.46060 | -0.21558 | . | . |
| 0.1694 | 0.3006 | -26.6498 | -25.2988 | -2.40124 | -0.05684 | . | -0.10992 | . | 0.22259 |
| 0.1614 | 0.2497 | -27.2451 | -26.1373 | -3.71540 | . | 0.34267 | . | 0.37405 | . |

**Table 11: Stepwise regression for steelhead SARs**

**Dependent Variable: lnSARst**

**Stepwise Selection: Step 3**

**Variable inter Entered: R-Square = 0.5220 and C(p) = 2.8508**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 2.63954 | 0.87985 | 5.82 | 0.0069 |
| Error | 16 | 2.41735 | 0.15108 | | |
| Corrected Total | 19 | 5.05690 | | | |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| Intercept | -2.12802 | 0.52776 | 2.45640 | 16.26 | 0.0010 |
| wtt | -0.05528 | 0.01807 | 1.41428 | 9.36 | 0.0075 |

| Variable | Parameter Estimate | Standard Error | Type II SS | F Value | Pr > F |
|---|---|---|---|---|---|
| inter | -0.13030 | 0.06575 | 0.59347 | 3.93 | 0.0649 |
| climate | 0.36968 | 0.13361 | 1.15656 | 7.66 | 0.0138 |

**Bounds on condition number: 1.6624, 12.985**

**All variables left in the model are significant at the 0.1500 level.**

**No other variable met the 0.1500 significance level for entry into the model.**

Summary of Stepwise Selection

| Step | Variable Entered | Variable Removed | Number Vars In | Partial R-Square | Model R-Square | C(p) | F Value | Pr > F |
|---|---|---|---|---|---|---|---|---|
| 1 | climate |  | 1 | 0.2421 | 0.2421 | 7.5439 | 5.75 | 0.0275 |
| 2 | wtt |  | 2 | 0.1625 | 0.4046 | 4.4967 | 4.64 | 0.0459 |
| 3 | inter |  | 3 | 0.1174 | 0.5220 | 2.8508 | 3.93 | 0.0649 |

# Appendix B
# Survival Estimates for Survival Analysis

### Survival Estimates For Survival Analysis For Reach McNary to Bonneville ST 1999 to 2002; CH1 1999 to 2002

| Species | Migr_yr | Release | Reach | Survival | Species | Migr_yr | Release | Reach | Survival |
|---|---|---|---|---|---|---|---|---|---|
| ST | 1999 | 5/11 to 6/8 | MCN to BON | 0.717 | CH1 | 1999 | 4/25-5/8 | MCN to BON | 0.672 |
| ST | 2000 | 5/11 to 6/8 | MCN to BON | 0.505 | CH1 | 1999 | 5/9-5/22 | MCN to BON | 0.756 |
| ST | 2001 | 5/11 to 6/8 | MCN to BON | 0.217 | CH1 | 1999 | 5/23-6/5 | MCN to BON | 0.660 |
| ST | 2002 | 5/11 to 6/8 | MCN to BON | 0.532 | CH1 | 2000 | 4/25-5/8 | MCN to BON | 0.661 |
| | | | | | CH1 | 2000 | 5/9-5/22 | MCN to BON | 0.669 |
| | | | | | CH1 | 2001 | 4/25-5/8 | MCN to BON | 0.452 |
| | | | | | CH1 | 2001 | 5/9-5/22 | MCN to BON | 0.516 |
| | | | | | CH1 | 2001 | 5/23-6/5 | MCN to BON | 0.593 |
| | | | | | CH1 | 2002 | 4/25-5/8 | MCN to BON | 0.694 |
| | | | | | CH1 | 2002 | 5/9-5/22 | MCN to BON | 0.819 |
| | | | | | CH1 | 2002 | 5/23-6/5 | MCN to BON | 0.671 |

### Survival Estimates For Survival Analysis For Reach Rock Island to McNary ST 1998 to 2002; CH1 1998 to 2002

| Species | Migr Yr | Release | Reach | Survival | Species | Migr Yr | Rel Dates | Reach | Survival |
|---|---|---|---|---|---|---|---|---|---|
| CH1 | 1998 | 4/21-5/4 | RIS to MCN | 0.589 | ST | 1998 | 4/21-5/4 | RIS to MCN | 0.586 |
| CH1 | 1998 | 5/5-5/18 | RIS to MCN | 0.926 | ST | 1998 | 5/5-5/18 | RIS to MCN | 0.600 |
| CH1 | 1999 | 4/21-5/04 | RIS to MCN | 0.741 | ST | 1998 | 5/19-6/1 | RIS to MCN | 0.455 |
| CH1 | 1999 | 5/05-5/18 | RIS to MCN | 0.744 | ST | 1999 | 4/21-5/04 | RIS to MCN | 0.670 |
| CH1 | 1999 | 5/19-6/01 | RIS to MCN | 0.794 | ST | 1999 | 5/05-5/18 | RIS to MCN | 0.607 |
| CH1 | 2000 | 4/21-5/4 | RIS to MCN | 0.783 | ST | 1999 | 5/19-6/01 | RIS to MCN | 0.681 |
| CH1 | 2000 | 5/5-5/18 | RIS to MCN | 0.790 | ST | 2000 | 4/21-5/4 | RIS to MCN | 0.913 |
| CH1 | 2001 | 4/21-5/4 | RIS to MCN | 0.527 | ST | 2000 | 5/5-5/18 | RIS to MCN | 0.657 |
| CH1 | 2001 | 5/5-5/18 | RIS to MCN | 0.677 | ST | 2000 | 5/19-6/01 | RIS to MCN | 0.405 |
| CH1 | 2001 | 5/19-6/01 | RIS to MCN | 0.588 | ST | 2001 | 4/21-5/4 | RIS to MCN | 0.247 |
| CH1 | 2002 | 4/21-5/4 | RIS to MCN | 0.649 | ST | 2001 | 5/5-5/18 | RIS to MCN | 0.230 |

**Survival Estimates For Survival Analysis For Reach Lower Granite to McNary ST 1996 to 2002; CH1H 1995 to 2002; CH1W 1995,1996,1998 to 2002**

| Species | Dates | migr_yr | Reach | Survival | Species | Release | Migr_yr | Reach | Survival | Species | Release | Migr_yr | Reach | Survival |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ST | 4/17-4/23 | 1998 | LGR to MCN | 0.616 | CH1H | 4/1-4/7 | 1998 | LGR to MCN | 0.806 | CH1W | 4/1-4/7 | 1998 | LGR to MCN | 0.760 |
| ST | 4/24-4/30 | 1998 | LGR to MCN | 0.752 | CH1H | 4/8-4/14 | 1998 | LGR to MCN | 0.737 | CH1W | 4/8-4/14 | 1998 | LGR to MCN | 0.741 |
| ST | 5/1-5/7 | 1998 | LGR to MCN | 0.682 | CH1H | 4/15-4/21 | 1998 | LGR to MCN | 0.744 | CH1W | 4/15-4/21 | 1998 | LGR to MCN | 0.804 |
| ST | 5/8-5/14 | 1998 | LGR to MCN | 0.688 | CH1H | 4/22-4/28 | 1998 | LGR to MCN | 0.807 | CH1W | 4/22-4/28 | 1998 | LGR to MCN | 0.786 |
| ST | 5/15-5/21 | 1998 | LGR to MCN | 0.754 | CH1H | 4/29-5/5 | 1998 | LGR to MCN | 0.793 | CH1W | 4/29-5/5 | 1998 | LGR to MCN | 0.799 |
| ST | 5/22-5/28 | 1998 | LGR to MCN | 0.627 | CH1H | 5/6-5/12 | 1998 | LGR to MCN | 0.805 | CH1W | 5/6-5/12 | 1998 | LGR to MCN | 0.823 |
| ST | 4/17-4/23 | 1999 | LGR to MCN | 0.746 | CH1H | 5/13-5/19 | 1998 | LGR to MCN | 0.863 | CH1W | 5/20-5/26 | 1998 | LGR to MCN | 0.600 |
| ST | 4/24-4/30 | 1999 | LGR to MCN | 0.721 | CH1H | 4/1-4/7 | 1999 | LGR to MCN | 0.830 | CH1W | 4/1-4/7 | 1999 | LGR to MCN | 0.776 |
| ST | 5/1-5/7 | 1999 | LGR to MCN | 0.705 | CH1H | 4/8-4/14 | 1999 | LGR to MCN | 0.754 | CH1W | 4/8-4/14 | 1999 | LGR to MCN | 0.808 |
| ST | 5/8-5/14 | 1999 | LGR to MCN | 0.632 | CH1H | 4/15-4/21 | 1999 | LGR to MCN | 0.720 | CH1W | 4/15-4/21 | 1999 | LGR to MCN | 0.795 |
| ST | 5/15-5/21 | 1999 | LGR to MCN | 0.744 | CH1H | 4/22-4/28 | 1999 | LGR to MCN | 0.806 | CH1W | 4/22-4/28 | 1999 | LGR to MCN | 0.790 |
| ST | 5/22-5/28 | 1999 | LGR to MCN | 0.837 | CH1H | 4/29-5/5 | 1999 | LGR to MCN | 0.815 | CH1W | 4/29-5/5 | 1999 | LGR to MCN | 0.814 |
| ST | 4/17-4/23 | 2000 | LGR to MCN | 0.715 | CH1H | 5/6-5/12 | 1999 | LGR to MCN | 0.799 | CH1W | 5/6-5/12 | 1999 | LGR to MCN | 0.694 |
| ST | 4/24-4/30 | 2000 | LGR to MCN | 0.595 | CH1H | 5/13-5/19 | 1999 | LGR to MCN | 0.796 | CH1W | 5/13-5/19 | 1999 | LGR to MCN | 0.756 |
| ST | 5/1-5/7 | 2000 | LGR to MCN | 0.549 | CH1H | 5/20-5/26 | 1999 | LGR to MCN | 0.716 | CH1W | 5/20-5/26 | 1999 | LGR to MCN | 0.900 |
| ST | 5/8-5/14 | 2000 | LGR to MCN | 0.559 | CH1H | 4/15-4/21 | 2000 | LGR to MCN | 0.936 | CH1W | 4/8-4/14 | 2000 | LGR to MCN | 0.727 |
| ST | 4/24-4/30 | 2001 | LGR to MCN | 0.159 | CH1H | 4/22-4/28 | 2000 | LGR to MCN | 0.764 | CH1W | 4/15-4/21 | 2000 | LGR to MCN | 0.825 |
| ST | 5/1-5/7 | 2001 | LGR to MCN | 0.177 | CH1H | 4/29-5/5 | 2000 | LGR to MCN | 0.717 | CH1W | 4/22-4/28 | 2000 | LGR to MCN | 0.748 |
| ST | 5/8-5/14 | 2001 | LGR to MCN | 0.187 | CH1H | 5/6-5/12 | 2000 | LGR to MCN | 0.749 | CH1W | 4/29-5/5 | 2000 | LGR to MCN | 0.727 |
| ST | 5/15-5/21 | 2001 | LGR to MCN | 0.143 | CH1H | 5/20-5/26 | 2000 | LGR to MCN | 0.729 | CH1W | 5/6-5/12 | 2000 | LGR to MCN | 0.731 |
| ST | 5/22-5/28 | 2001 | LGR to MCN | 0.079 | CH1H | 4/8-4/14 | 2001 | LGR to MCN | 0.573 | CH1W | 5/13-5/19 | 2000 | LGR to MCN | 0.732 |
| ST | 4/24-4/30 | 2002 | LGR to MCN | 0.461 | CH1H | 4/15-4/21 | 2001 | LGR to MCN | 0.605 | CH1W | 5/20-5/26 | 2000 | LGR to MCN | 0.858 |
| ST | 5/1-5/7 | 2002 | LGR to MCN | 0.466 | CH1H | 4/22-4/28 | 2001 | LGR to MCN | 0.593 | CH1W | 4/8-4/14 | 2001 | LGR to MCN | 0.649 |
| ST | 5/8-5/14 | 2002 | LGR to MCN | 0.390 | CH1H | 4/29-5/5 | 2001 | LGR to MCN | 0.578 | CH1W | 4/15-4/21 | 2001 | LGR to MCN | 0.605 |
| ST | 5/15-5/21 | 2002 | LGR to MCN | 0.516 | CH1H | 5/6-5/12 | 2001 | LGR to MCN | 0.552 | CH1W | 4/22-4/28 | 2001 | LGR to MCN | 0.588 |
| ST | 5/22-5/28 | 2002 | LGR to MCN | 0.724 | CH1H | 5/13-5/19 | 2001 | LGR to MCN | 0.470 | CH1W | 4/29-5/5 | 2001 | LGR to MCN | 0.521 |
| ST | 4/24-4/30 | 1996 | LGR to MCN | 0.793 | CH1H | 5/20-5/26 | 2001 | LGR to MCN | 0.276 | CH1W | 5/6-5/12 | 2001 | LGR to MCN | 0.507 |
| ST | 5/1-5/7 | 1996 | LGR to MCN | 0.792 | CH1H | 4/22-4/28 | 2002 | LGR to MCN | 0.586 | CH1W | 5/13-5/19 | 2001 | LGR to MCN | 0.458 |
| ST | 5/15-5/21 | 1996 | LGR to MCN | 0.659 | CH1H | 4/29-5/5 | 2002 | LGR to MCN | 0.733 | CH1W | 5/20-5/26 | 2001 | LGR to MCN | 0.258 |
| ST | 4/17-4/23 | 1997 | LGR to MCN | 0.902 | CH1H | 5/6-5/12 | 2002 | LGR to MCN | 0.638 | CH1W | 4/22-4/28 | 2002 | LGR to MCN | 0.730 |
| ST | 4/24-4/30 | 1997 | LGR to MCN | 0.611 | CH1H | 5/13-5/19 | 2002 | LGR to MCN | 0.732 | CH1W | 4/29-5/5 | 2002 | LGR to MCN | 0.657 |
| ST | 5/1-5/7 | 1997 | LGR to MCN | 0.804 | CH1H | 5/20-5/26 | 2002 | LGR to MCN | 0.755 | CH1W | 5/6-5/12 | 2002 | LGR to MCN | 0.660 |
|  |  |  |  |  | CH1H | 4/15-4/21 | 1995 | LGR to MCN | 0.725 | CH1W | 5/13-5/19 | 2002 | LGR to MCN | 0.640 |
|  |  |  |  |  | CH1H | 4/22-4/28 | 1995 | LGR to MCN | 0.668 | CH1W | 5/20-5/26 | 2002 | LGR to MCN | 0.773 |
|  |  |  |  |  | CH1H | 4/29-5/5 | 1995 | LGR to MCN | 0.779 | CH1W | 4/15-4/21 | 1995 | LGR to MCN | 0.825 |
|  |  |  |  |  | CH1H | 4/15-4/21 | 1996 | LGR to MCN | 0.586 | CH1W | 4/22-4/28 | 1995 | LGR to MCN | 0.669 |
|  |  |  |  |  | CH1H | 4/22-4/28 | 1996 | LGR to MCN | 0.683 | CH1W | 4/29-5/5 | 1995 | LGR to MCN | 0.795 |
|  |  |  |  |  | CH1H | 4/29-5/5 | 1996 | LGR to MCN | 0.652 | CH1W | 5/6-5/12 | 1995 | LGR to MCN | 0.759 |
|  |  |  |  |  | CH1H | 5/6-5/12 | 1996 | LGR to MCN | 0.689 | CH1W | 4/15-4/21 | 1996 | LGR to MCN | 0.736 |
|  |  |  |  |  | CH1H | 5/13-5/19 | 1996 | LGR to MCN | 0.779 | CH1W | 4/22-4/28 | 1996 | LGR to MCN | 0.480 |
|  |  |  |  |  | CH1H | 4/29-5/5 | 1997 | LGR to MCN | 0.444 | CH1W | 4/29-5/5 | 1996 | LGR to MCN | 0.556 |