Chapter 6 Appendix 5
Comparison of CRISP and FLUSH Flow:
Travel Time and Flow: Survival Relationships

Paul Wilson
Rich Zabel
Josh Hayes

1.0 Comparison Of CRiSP/FLUSH Water Travel Time, Fish Travel Time, and Fish Speed

We compared water travel time, fish travel time, and fish speed in all reservoirs between the two models for two years: a low flow year (1992) and a high flow year (1982).

Table C6 A5-1: CRiSP and FLUSH water travel times.

Reach	Reach Length (km)		1982 Water TT (days)		1992 Water TT (days)	
	CRiSP	**FLUSH**	**CRiSP**	**FLUSH**	**CRiSP**	**FLUSH**
Lower Granite	49.0	49.0	2.06	1.79	4.35	3.91
Little Goose	59.9	59.9	1.56	2.06	3.33	4.54
Low Mon	46.2	46.2	1.75	1.44	3.56	3.15
Ice Harbor	51.4	51.4	1.81	1.55	3.73	3.39
McNary	67.6	67.6	1.90	1.48	3.05	2.44
John Day	123.0	123.0	3.80	3.43	6.28	6.04
The Dalles	38.8	38.8	1.00	0.51	1.15	0.82
Bonneville	73.1	73.1	1.11	1.16	1.69	1.96
Total	509	509	14.99	13.42	27.13	26.26

Table C6 A5-2: Comparison of CRiSP and FLUSH fish travel times.

	1982 Fish TT (days)		1982 Fish Speed (km/day)		1992 Fish TT (days)		1992 Fish Speed (km/day)	
	CRiSP	**FLUSH**	**CRiSP**	**FLUSH**	**CRiSP**	**FLUSH**	**CRiSP**	**FLUSH**
Lower Granite	6.83	3.81	7.17	12.86	10.4	8.57	4.71	5.72
Little Goose	3.16	2.89	18.96	20.70	3.52	4.27	17.02	14.02
Low Mon	2.27	2.03	20.35	22.80	2.83	2.96	16.33	15.59
Ice Harbor	2.06	2.18	24.95	23.54	2.21	3.19	23.26	16.12
McNary	2.22	2.07	30.45	32.61	2.22	2.30	30.45	29.41
John Day	3.54	3.41	34.75	36.12	3.62	6.37	33.98	19.32
The Dalles	1.13	0.50	34.34	77.41	1.20	0.87	32.33	44.76
Bonneville	1.30	1.15	56.23	63.70	1.49	2.07	49.06	35.35
Total (Avg)	22.51	18.04	22.61	28.2	27.49	30.60	18.52	16.6

Notes: McNary reach includes Snake below Ice Harbor. CRiSP travel times are for a release date of April 20

2.0 Fish Travel Time vs Water Travel Time

In the following graphs of fish travel time vs. water travel time, the FLUSH relationships apply only at normal pool levels. At low fish travel times, the spillway crest and natural river relationships diverge from the normal operating level relationships.

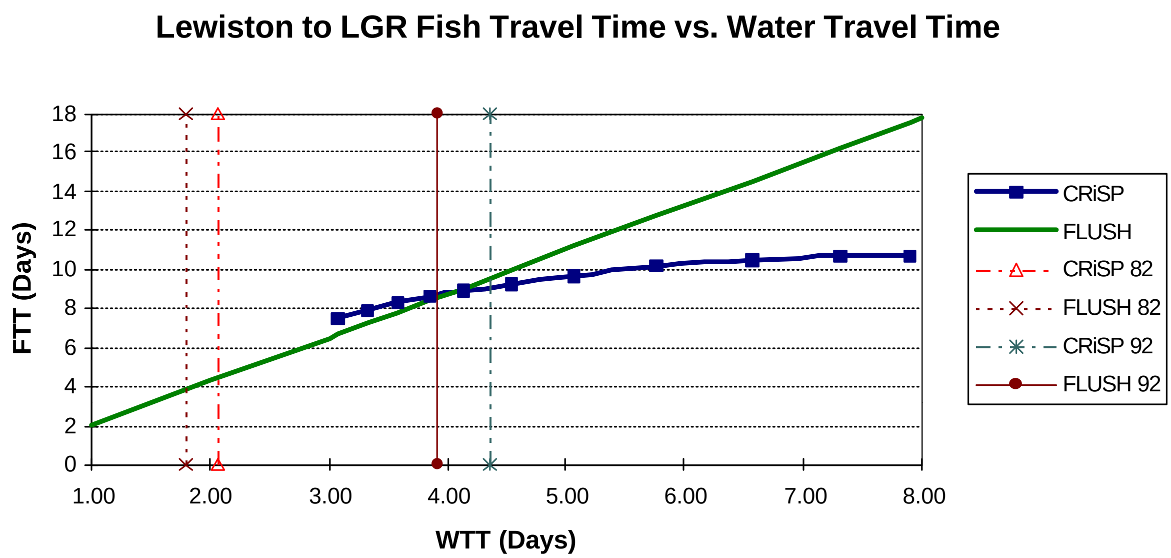

Figure C6 A5-1: Fish travel time vs. water travel time in LGR pool at normal operating levels. Vertical lines represent estimated water travel times for the two models in 1982 and 1992.

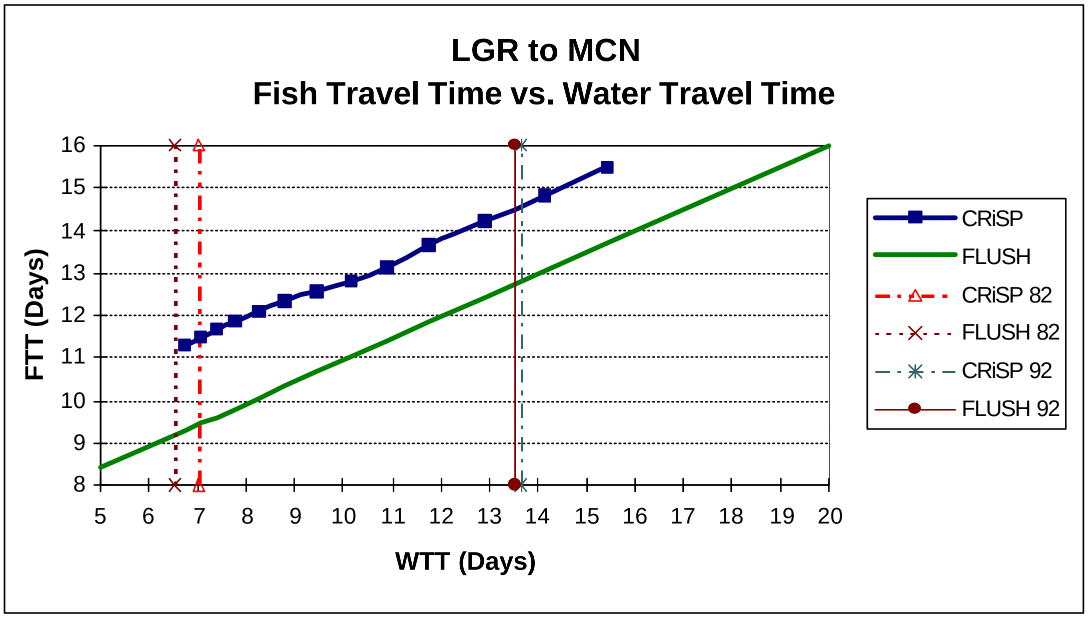

Figure C6 A5-2: Fish travel time vs. water travel time from LGR dam to MCN dam, at normal operating levels. Vertical lines represent estimated water travel times for the two models in 1982 and 1992.

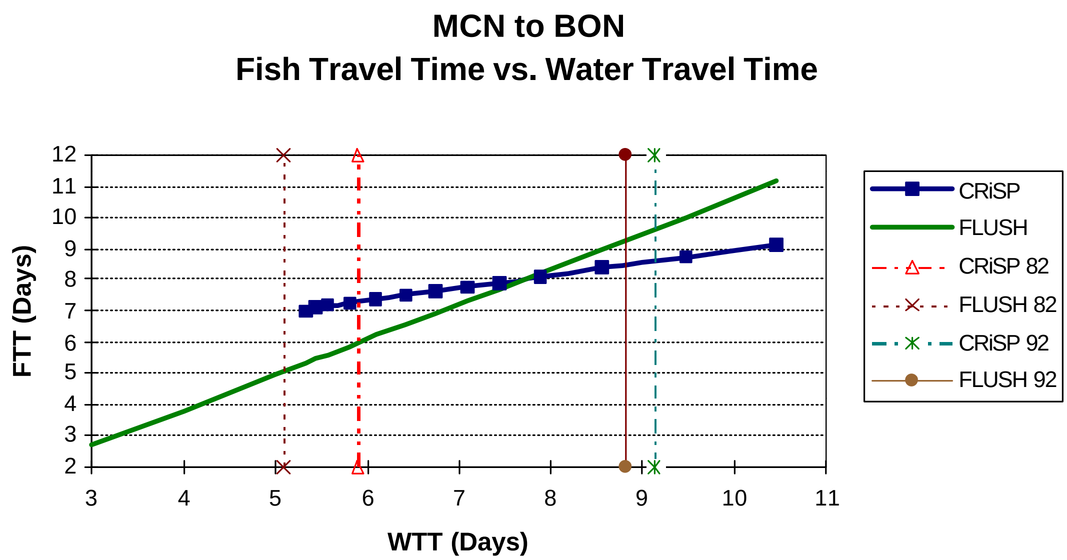

Figure C6 A5-3: Fish travel time vs. water travel time from MCN dam to BON dam at normal operating levels. Vertical lines represent estimated water travel times for the two models in 1982 and 1992.

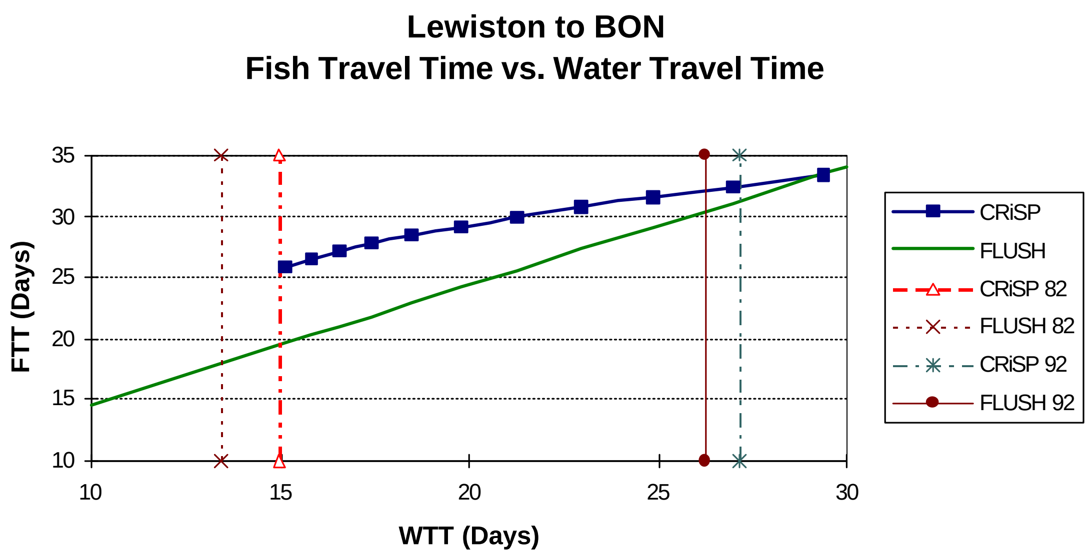

Figure C6 A5-4: Fish travel time vs. water travel time for 8 pool reach at normal operating levels. Vertical lines represent estimated water travel times for the two models in 1982 and 1992.

3.0 Reservoir Survival vs Fish Travel Time

CRiSP Methods (Rich Zabel):

To demonstrate the survival versus fish travel time relationship in CRiSP, the following procedure was used. First, two recent flow years were selected to represent a range in flow conditions: 1992 (low flow) and 1995 (moderate/high flow). A range of fish travel times was created by multiplying model migration rates by a constant term that varied for each model run. The survival and travel times were computed from the head of Lower Granite Reservoir to Bonneville tail race.

The plot (Figure C6 A5-5) shows a linear relationship between survival and fish travel time in CRiSP. The two main sources of reservoir mortality are predation and gas bubble disease. The linear relationship arises because mortality is directly proportionate to the length of time exposed to these two detrimental factors. The 1992 fish experienced a higher predation rate, which is related to temperature, while the 1995 fish were exposed to higher concentrations of nitrogen due to higher spill levels.

FLUSH Methods

Derivation of the FLUSH relationship is described in Section 6.0 of Appendix 5 (Survival-Travel Time Relationship in Spring FLUSH). In the model, assuming no predator control, reservoir survival depends only upon fish travel time: i.e., it varies from year to year only because of variation in fish travel time. The relationship fit to data from the 1970-1980 is shown, as well as an adjusted relationship to bound the expected increase in reservoir survival to due the recently initiated predator control program. Running simulations of future years with the model is usually done with alternate assumptions about the effectiveness of predator control. The adjusted curve shown in Figure C6 A5-5 is arrived at by decreasing daily mortality for each point by 25%. Because CRiSP is fit to survival data from the most recent years, the comparable FLUSH relationship probably lies between the two FLUSH curves.

Discussion

The relationship of reservoir survival to fish travel time in the two models is shown in Figure C6 A5-5. CRiSP shows a relatively shallow relationship, of almost constant slope, so that survival per day appears to change little with time. The FLUSH relationship grows in steepness for the first fifteen days or so, resulting in substantially lower survival than CRiSP after that point.

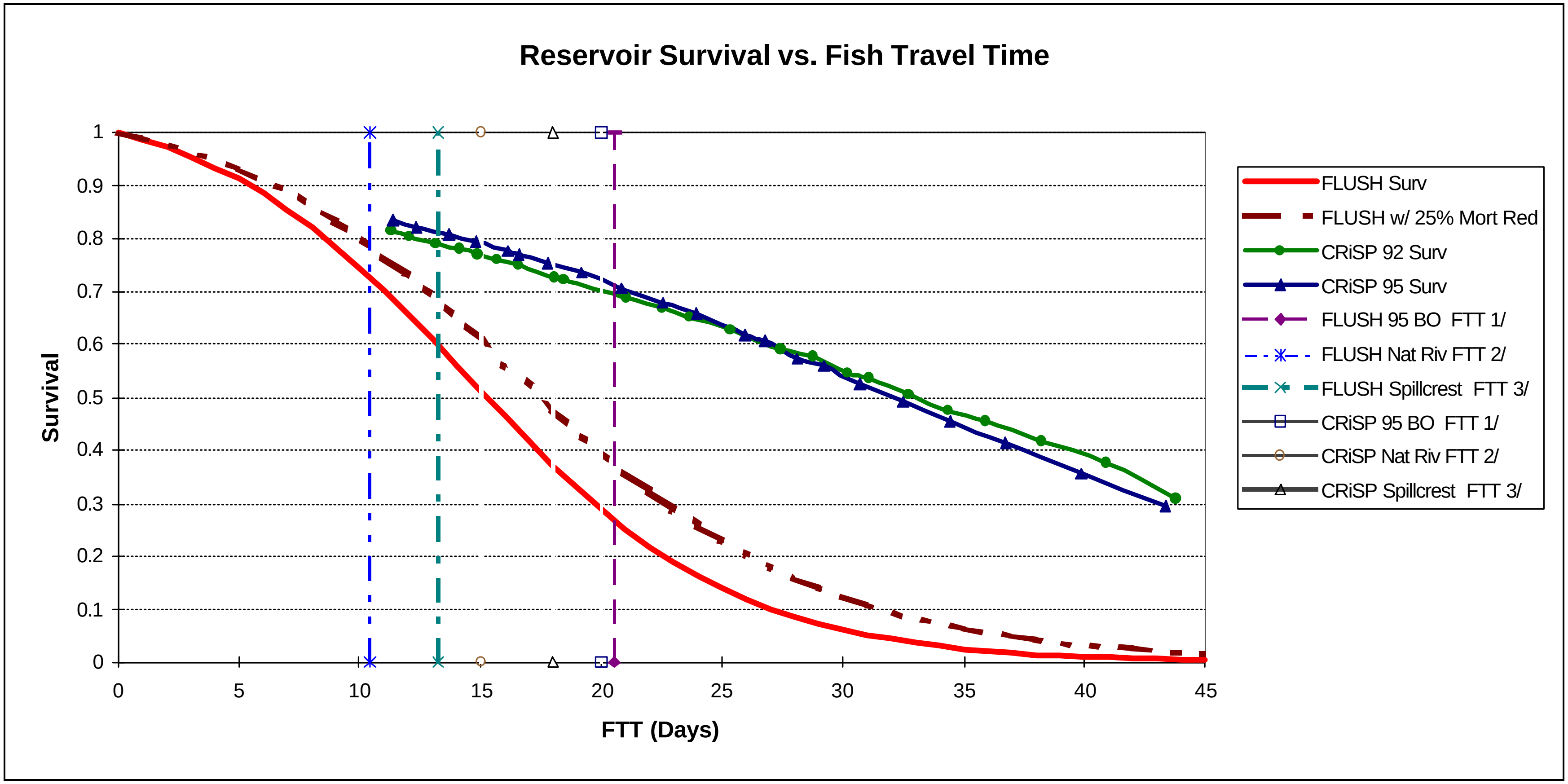

Figure C6 A5-5: Model reservoir survival vs. fish travel time relationships. Vertical lines are average estimated system fish travel times in the models, for three different scenarios.

1/ Snake @ MOP, 50 yr 95 Biop flow avg FTT
2/ Snake @ natural river, JDA @ spillway crest, 50 yr DFOP NR flow avg FTT
3/ Snake @ spillway crest, JDA @ MOP, 50 yr BO SC flow avg FTT

4.0 Biological Rationale for and Derivation of Fish Travel Time Relationships used in Spring FLUSH

P. Wilson - PATH Task 3.1.3

Rationale

Smolt travel time in Spring FLUSH is modeled as a function of water travel time. Water travel time in each reservoir is a function of the volume (or elevation) and the rate of outflow (in kcfs) as measured at the dam at the downstream end of the reservoir. The rationale for using water travel time as a predictor of fish travel time comes from post-lower Snake River dam completion studies of yearling chinook and steelhead migrants in the Snake and lower Columbia Rivers, and from estimates of migration rates and their relationship to water velocity in free-flowing sections of the lower Snake and Columbia rivers, prior to completion of the last dams in both reaches (1975 and 1968, respectively).

Studies on the behavior and physiology of anadromous salmonid smolts provide reason to believe that water velocity is the key determinant of migration rate. CBFWA (1991) cites literature suggesting that passive transport is the most energetically efficient way to move downstream during the hydrological conditions (runoff timing, water velocity) under which the fish evolved. CBFWA (1991) also summarizes the literature regarding a number of physiological changes (e.g., decrease in swimming efficiency and negative rheotaxis) at smoltification that act as mechanisms to facilitate a passive mode of migration, depending mostly on water flow to determine migration speed and direction.

Hydroelectric development has altered the free-flowing Columbia and Snake Rivers, and created a series of reservoirs through which water moves much more slowly. Coincident with this development, the time required for a smolt to travel from its point of origin to entry into salt water ("travel time") has increased (CBFWA 1991). Summarizing data from previous studies (Raymond 1968, 1969; Bentley and Raymond 1976), Raymond (1979) reported that rates of migration for chinook and steelhead were, depending on flow, about one-third to slightly less than one-half as fast in impounded sections compared to free-flowing sections (range of 8 to 24 km/day in impounded, compared to 24 to 54 km/day in free-flowing sections).

In studies conducted during and after the construction of the last dam on the lower Snake-lower Columbia reaches, positive relationships between smolt travel times and water travel times (or a surrogate, namely different flows at similar volumes) have continued to be found. For data from 1973 to 1979 migration studies, Sims and Ossiander (1981) found significant inverse relationships between fish travel time and flows at both Ice Harbor and The Dalles dams, for yearling chinook and steelhead migrating between the uppermost lower Snake River dam and The Dalles Dam. Sims et al. (1982) found that chinook and steelhead smolt travel time and water particle travel time were closely correlated through the lower Snake and Columbia Rivers, based on nine years of data (1973-81). During the very low flow year of 1973, smolts from the Salmon river took 54 days to reach The Dalles Dam (Raymond 1979), and in the record low runoff and flows of 1977, measured travel time for smolts from the Salmon River to The Dalles Dam was 57 days (Sims et al. 1978). This compares to an estimate of 26 days at low flows just after The Dalles Dam was constructed, when McNary was the only dam between the Salmon River and The Dalles (Raymond 1979).

CBFWA (1991) reported that data for 1982-1989 corroborated the earlier findings. It also noted the similarity in general form of the relation between average flow and both water travel time and fish travel time, and suggested that this indicated a causative, rather than simply correlative, relation between flow and travel time of juvenile salmonids. Using bivariate- and multiple-regression models, Berggren and Filardo (1993) found that average river flow made the largest contribution to explaining variation in smolt travel time for yearling chinook and steelhead in the Snake and lower Columbia River. They concluded that increased flows reduce the travel time of chinook in the Snake River and of steelhead in the Snake and middle Columbia River.

Derivation Of Relationships

The relationships used in Spring FLUSH are determined from data from recent studies linking observed fish travel times to estimated average water particle travel times. Separate relationships are used for three different reaches comprising the eight reservoir system. The three relationships come from downstream migration studies conducted by the Smolt Monitoring Program for Lower Granite Pool, the four pools immediately below Lower Granite, and John Day Pool. The studies were done by the Fish Passage Center.

Fish travel time in Lower Granite Pool is derived from PIT tag data on yearling chinook smolts released from the Snake River Trap (Lewiston, ID) and detected at Lower Granite Dam, for migration years 1988-93. Each year groups of tagged fish were released on different days in April and May. For each group, a median travel time was calculated, and indexed to an average flow for the period (T. Berggren, FPC, pers. comm.). Water travel time in days for each index flow is calculated by the U.S. Army Corps of Engineers' storage replacement method [calculate water volume represented by a given flow (kcfs) over an entire day, and divide reservoir volume by this amount]. Data can be found in Fish Passage Center Annual Reports for years 1988-93 (e.g. FPC 1993). A linear model was fit to the data.

Predicted fish travel time in days (FTT) for Lower Granite Pool (pool 1) is given by

$$FTT_1 = -0.2235 + 2.2484 * WTT_1$$

Table C6 A5-3 presents measures of the fit. Figure C6 A5-6 shows the observed data (medians of group travel times), predicted (best fit) relationship, and the lines for the 'fast' and 'slow' 95% confidence intervals on the parameters of the Lower Granite Reservoir relationship.

Table C6 A5-3: Details of fit of regression of Lower Granite Fish travel time data.

Regression Statistics	
Multiple R	0.8328
R Square	0.6936
Adjusted R Square	0.6905
Standard Error	1.4118
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	442.2	442.2	221.9	0.0000
Residual	98	195.3	1.9931		
Total	99	637.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.2235	0.5028	-0.4445	0.6576	-1.2212	0.7742
X Variable 1	2.2484	0.1509	14.8949	0.0000	1.9488	2.5479

For the four pool reach immediately below Lower Granite, Spring FLUSH relates total reach fish travel time to total reach water travel time. This total water travel time is calculated, and from the relation a total fish travel time is obtained. The reach fish travel time is apportioned to each reservoir according to the proportion of total reach water travel time due to that reservoir. Data are from the FPC (T. Berggren, pers. comm.). The smolt travel time data come from both freeze branded and, more recently, PIT tagged fish. A linear model was fit to the data for this reach.

Predicted fish travel time for the lower three Snake River projects and McNary Pool is, for reservoir *i*

$$FTT_i = (5.8588 + 0.5078 * SnakeTrav) * \frac{WTT_i}{SnakeTrav}$$

where *SnakeTrav* is the sum of the WTT_i's from Little Goose through McNary.

Table C6 A5-4 presents details of the fit. Figure C6 A5-7 shows the observed data (medians of group travel times), predicted (best fit) relationship, and the lines for the ‘fast’ and ‘slow’ 95% confidence intervals on the parameters of the Little Goose Reservoir through McNary Reservoir relationship.

Table C6 A5-4: Details of fit of regression of Lower Granite to McNary fish travel time data.

Regression Statistics	
Multiple R	0.5317
R Square	0.2827
Adjusted R Square	0.2571
Standard Error	2.6700
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	78.7	78.7	11.0	0.00250
Residual	28	199.6	7.1		
Total	29	278.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.8588	2.0246	2.8938	0.0073	1.7116	10.006
X Variable 1	0.5078	0.1529	3.3221	0.0025	0.1947	0.8209

The fish travel time / water travel time relationship in John Day pool is derived from eight years of mark-recapture studies on freeze-branded yearling chinook smolts, for fish released below McNary Dam and recaptured at John Day Dam. Each year groups of tagged fish were released on different days in April and May. For each group, a median travel time was calculated, and indexed to an average flow for the period. Water travel time for each index flow is calculated by the storage replacement method. The data are from Fish Passage Center (pers. comm.) and can be found in Fish Passage Center Annual Reports for years 1986-93 (e.g. FPC 1993). A model assuming a linear dependence of fish travel time on water travel time was fit to the data.

Predicted fish travel time in days (FTT) for John Day Reservoir (pool 6) is given by

$$FTT_6 = -0.4978 + 1.1364 * WTT_6$$

Measures of fit of the John Day relationship are shown in Table C6 A5-5. Figure C6 A5-8 shows the observed data (medians of group travel times), predicted (best fit) relationship, and the lines for the ‘fast’ and ‘slow’ 95% confidence interval on the parameters of the John Day Reservoir relationship.

Since no data are available from the Smolt Monitoring Program for the two reservoirs below John Day, the John Day Pool relationship is used to approximate the relationships in these pools. To predict the fish travel time for these reservoirs, the John Day fish travel time is multiplied by the ratio of water travel time in the particular pool (TDA or BON) to the water travel time in John Day. Fish travel time for The Dalles and Bonneville reservoirs (pools 7 and 8) is calculated from the John Day fish travel time (FTT_6) according to:

$$FTT_i = FTT_6 * \frac{WTT_i}{WTT_6}$$

Table C6 A5-5: Details of fit of regression of John Day fish travel time data

Regression Statistics	
Multiple R	0.7884
R Square	0.6216
Adjusted R Square	0.6137
Standard Error	1.0131
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	80.9	80.9	78.8	1.07E-11
Residual	48	49.3	1.0		
Total	49	130.2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.4978	0.6782	-0.7340	0.4665	-1.8613	0.8658
X Variable 1	1.1364	0.1280	8.8793	0.0000	0.8790	1.3937

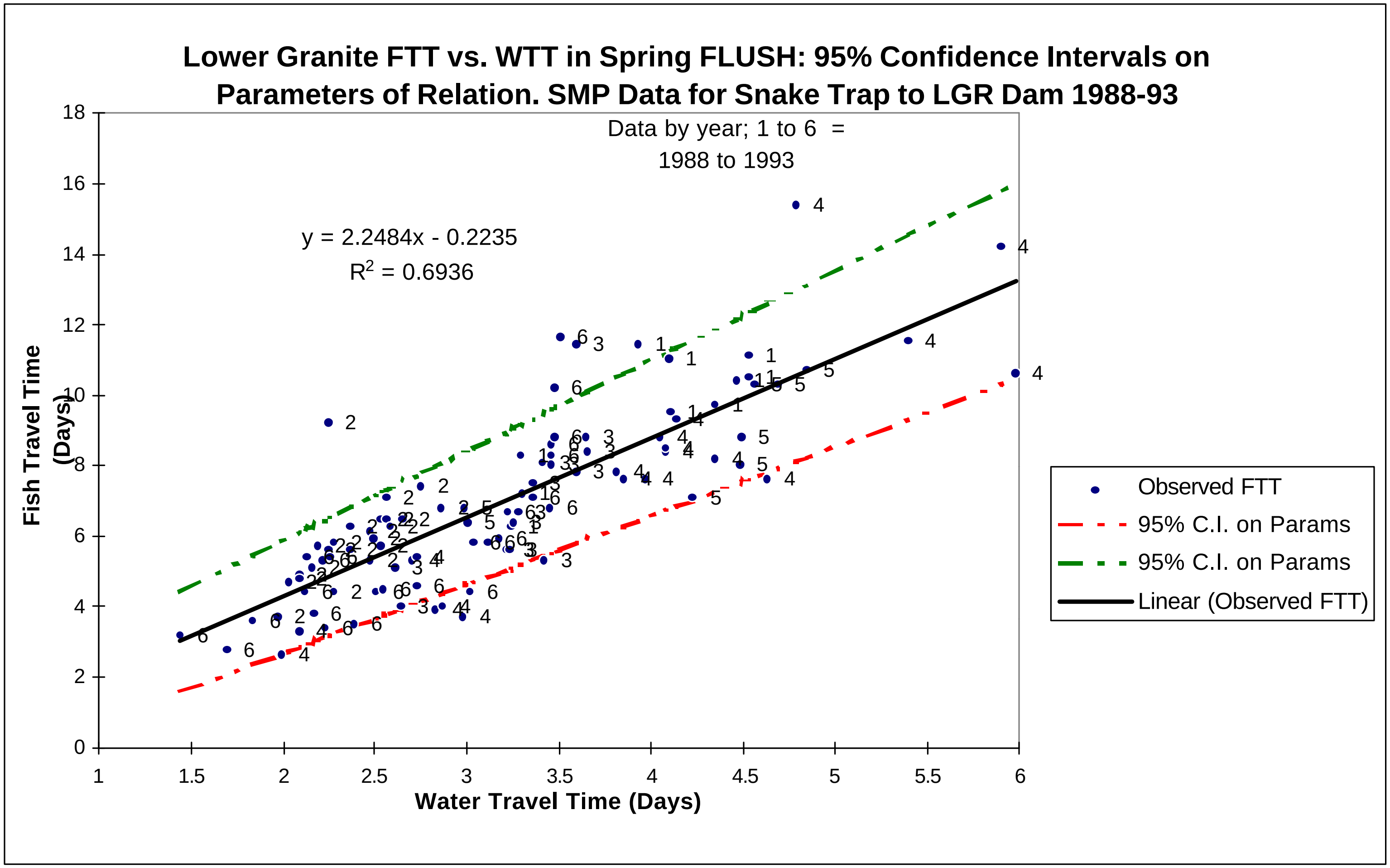

Figure C6 A5-6

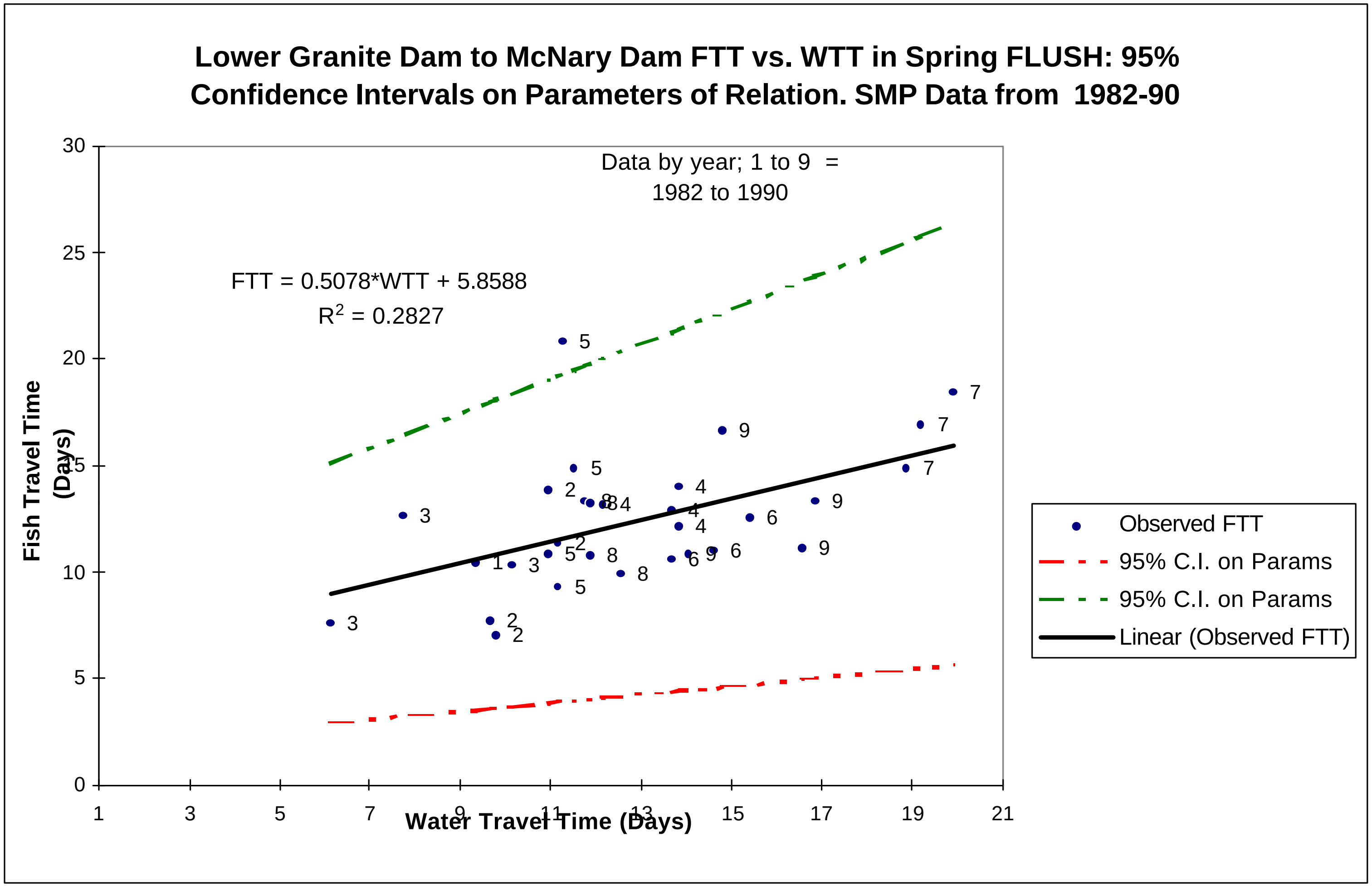

Figure C6 A5-7

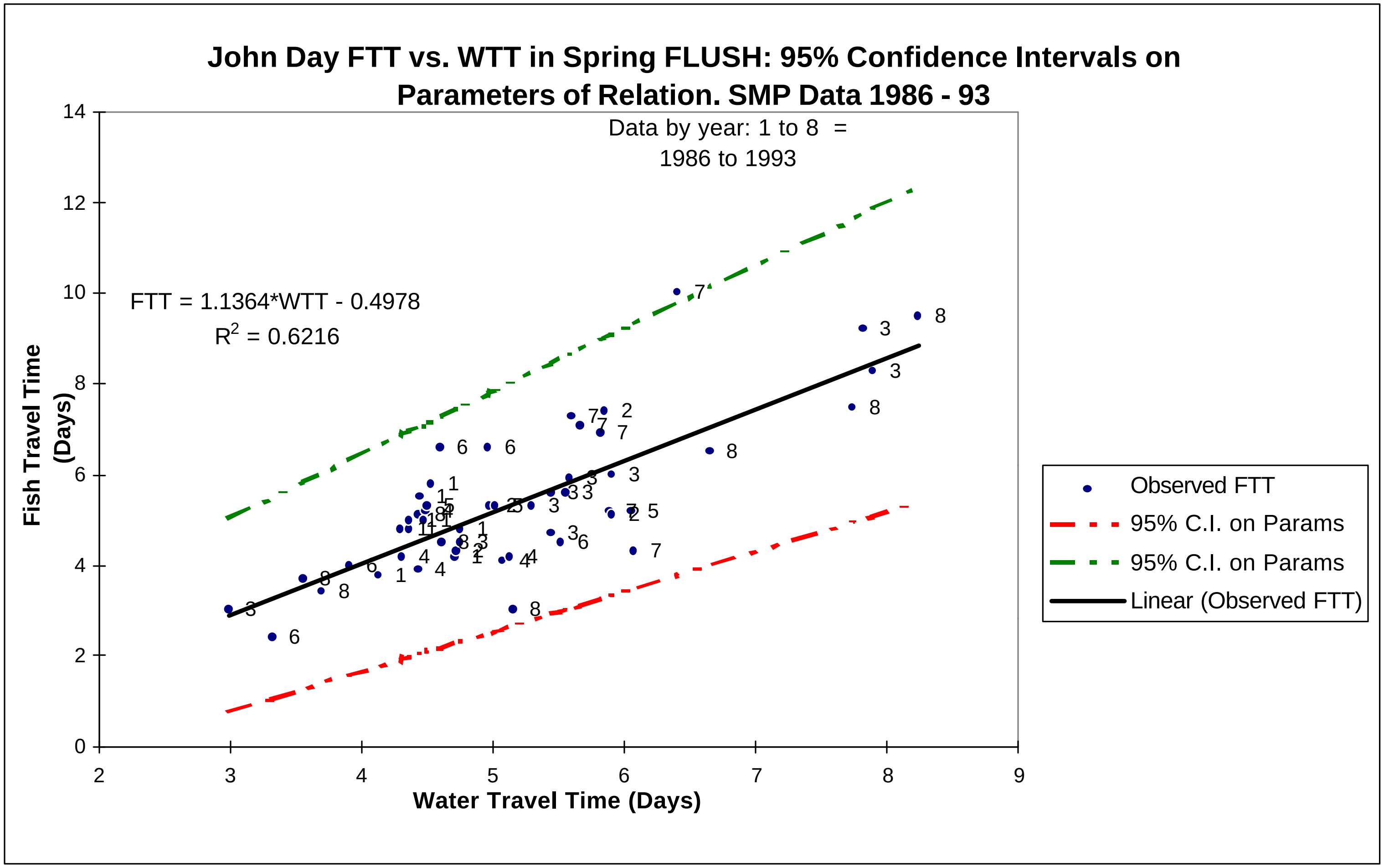

Figure C6 A5-8

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5.0 A Summary of the Flow/Travel Time Relationship in CRiSP

Richard W. Zabel

Overview

A flow/travel time relationship arises in CRiSP based on the particular parameterization of the migration rate equation. Each stock is calibrated separately, and hence a different relationship exists for each stock. In some cases (for example Snake River spring chinook), the migration rate equation is fairly complex with the flow/travel time relationship varying depending on the date in the season and the length of time fish have spent in the river. In other cases (e.g., Mid-Columbia fall chinook) the flow/travel time relationship is a simple linear relationship. The nature of the relationship is determined by the data.

The primary data for travel time calibration is PIT tag data. These data are desirable for several reasons: many stocks are represented, releases have occurred over several years (1989-1995), and during individual years releases may occur over extended periods through the migration season. Brand release data is used as a secondary source of data, particularly in cases where stocks are not represented in the PIT tag database.

Travel time in CRiSP is modeled by two submodels:

reach model

- Moves groups of fish through individual reaches according to specified migration rate and rate of population spreading.

migration rate model

- Determines migration rate as a function of river flow, date in season, and duration of migration time. Migration rate varies on a per reach and per time-step basis.

Migration Rate Equation

The goal of the migration rate equation is to be flexible enough to capture a variety of migratory behaviors without requiring an excessive number of parameters to fit. The equation has a term that relates migration rate to river velocity and a term that is independent of river velocity. Both terms have temporal components, with migration rate increasing with time.
Migration rate is modeled as:

$$r(t) = b_0 + b_1\left[\frac{1}{1+\exp(a_1(t - T_{RLS}))}\right] + b_{FLOW}V_t\left[\frac{1}{1+\exp(a_2(t - T_{SEASN}))}\right] \qquad (1)$$

where $r(t)$ =migration rate (miles/day)
t =Julian date
b's = regression coefficients
V_t = average river velocity during the average migration period
a = slope parameter
T_{SEASN} = seasonal inflection point (in Julian Days)
T_{RLS} = release date (in Julian Days).

Both the flow dependent and flow independent components of equation (1) use the logistic equation (term in brackets). The logistic equation is used instead of a linear equation because upper and lower bounds can be set. This eliminates the problem of unrealistically high or low migration rates that can occur outside observed ranges with linear equations. Also, for suitable parameter values, the logistic equation effectively mimics a linear relationship.

The flow independent migration rate is driven by two parameters, b_{min} and b_{max}. bmin is the flow independent migration rate at the time of release (T_{RLS}), and b_{max} is the maximum flow independent migration rate. In the equation above, it is easier to express migration rate in terms of b0 and b1 with the following relationships:

$$b_{MIN} = b_0 + b_1/2$$
$$b_{MAX} = b_0 + b_1 \qquad (2)$$

With $ß_{max} > ß_{min}$, the $_{fish}$ have a tendency to migrate faster the longer they have been in the river. This tendency can be "turned off" by setting $ß_{max} = ß_{min}$. Also, flow independent migration can be turned off entirely by setting $ß_{max} = ß_{min} = 0$.

The magnitude of the flow dependent term is determined by $ß_{flow}$. This term determines the percentage of the average river velocity that is used by the fish in downstream migration. The flow term has a seasonal component determined by T_{SEASN}, which is expressed in terms of Julian date. This has the effect of the fish using less of the flow early in the season and more of the flow later in the season. Values of T_{SEASN} that are relatively early in the season mean that the fish mature relatively early. The a parameter determines how quickly the fish mature from early season behavior to later season behavior. Setting a equal to 0 has the effect of "turning off" the flow/season interaction, resulting in a linear relationship between migration rate and river flow.

These parameters are estimated using a calibration program that is, in effect, a stripped-down version of CRiSP that only encompasses the travel time component. The migration rate parameters and river flow information are provided to the program, and it returns average travel times to several points along the river. These model-predicted average travel times are then compared to observed average travel times. The migration rate parameters are selected that provide the best fit of the model to the data.

Several criteria are used to select appropriate data sets. First, because migration rate is related to date in season and date of release, it is essential that the calibration data sets have fish released over long periods of time so these effects can be measured. Also, it is desirable to have fish released from the same site over multiple years so that a variety of river conditions are encountered. Sufficient numbers of fish must be observed at downstream observation sites, and fish must be observed at multiple sites. Finally, data sets are selected to represent as many stocks of fish and sections of the river as possible.

The procedure is to first organize fish into cohorts, which comprise fish released on the same day or on several consecutive days. Based on these cohorts, the following equation is minimized with respect to the migration rate parameters:

$$\sum\sum(tt_{model} - tt_{daata})^2 \qquad (3)$$

where the summation is over is the total number of cohorts and the total number of observation sites. The terms inside the summation are the model predicted average travel times and the observed average travel times.

For each stock, the travel time data are compared to a nested sequence of migration rate models, beginning with a simple model that incorporates only a constant migration rate. Behavioral factors (such as flow effects, seasonal effects or experience effects) are added one at a time to determine their importance. The concept of parsimony is used to select the simplest model to adequately explain the observed behavior.

Travel time data sets for spring chinook

Snake River spring chinook

These are PIT tagged fish released at the Snake Trap (top of Lower Granite Pool) and observed at Lower Granite, Little Goose, and McNary Dams. The release period is from early April to early May, with separate releases occurring daily. Although these fish are classified as run-of-the-river fish, it is likely that the vast majority of these fish are spring chinook based on the distribution of lengths (most fish longer than 110 millimeters) and the timing of migration (early spring). This is consistent with other treatments of these fish (e.g., Fish Passage Center, 1991).

The migration rate equation was fit to all three of the observation points simultaneously over a seven year period (1989-1995). Plots of the results for 3 of the migration rate models are contained in Figure C6 A5-9, and the parameter estimates are in Table C6 A5-6. For these fish, the most complex model is supported; strong seasonal and experience effects exist. It is clear from the plots in Figure 1 that a linear flow model is not adequate to describe the data, and the more complex models fit the data substantially better.

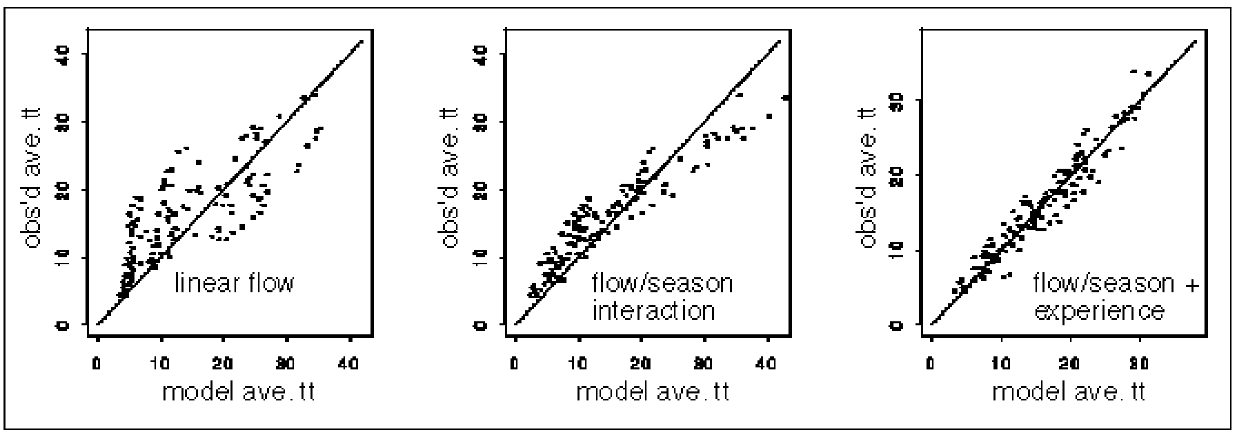

Figure C6 A5-9: Observed travel times versus model predicted travel times for spring chinook released at Snake River trap and observed at Lower Granite, Little Goose, and McNary Dams. For each of the plots, a different migration rate model is used to generate the predicted travel times. As more complexity is added to the models, the fit is substantially improved.

Table C6 A5-6: CRiSP migration rate parameters for the Snake Trap yearling chinook data.

rls site	b_{min}	b_{max}	b_{flow}	a_1	a_2	T_{seasn}
Snake Trap	1.34	20.2	0.71	0.10	0.10	119.8

Because of the seasonal effects, the relationship between river flow and travel time depends on when fish are released. Fish released later in the season are more mature and tend to use more of the river velocity for migration — either by spending more of the day in the flow or by migrating in regions of higher river velocity. Figure C6 A5-10 depicts this effect by showing the relationship between fish travel time and water travel time for fish released at four different dates over a month long period. The fact that fish released later in the season migrate at a faster rate relative to water velocity is consistent with several photoperiod studies (e.g., Muir, et al., 1994) where fish subjected to advanced photoperiods experienced faster travel times.

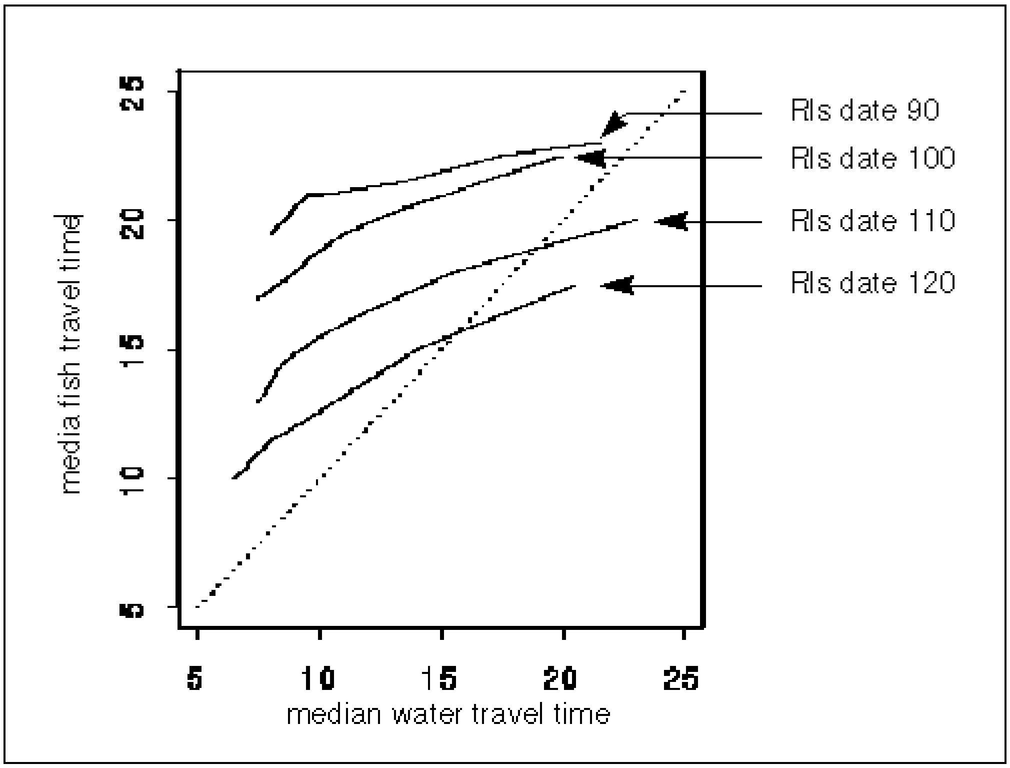

Figure C6 A5-10: Modeled relationship between fish travel time and water travel time for spring chinook released at the head of Lower Granite Pool and migrating to McNary Dam. Model parameters were based on Snake Trap PIT tagged fish. Modeled fish were released on four different dates.

For comparison with the FLUSH model, we selected one release date (Julian date 110 or April 20), and plotted fish travel time versus water travel time over several reaches (see Figures C6 A5-12 and C6 A5-13). Included in these plots are the data for fish released on this date over several years. Note that this is a reduced set of data compared to the plots above, and the model was fit to the larger data set over several reaches simultaneously. For these release groups, the model predicts the travel times from the head of Lower Granite Reservoir to Lower Granite Dam and McNary Dam within one to two days.

Downstream travel time data for CRiSP

Previous to 1995, very few PIT tagged fish were detected at John Day or Bonneville dams from Snake River releases. Our approach with the CRiSP model was to calibrate migration rates through McNary and then use McNary pool migration rates to move fish through the lower reservoirs. In 1995, enough fish were detected at John Day so that we could compare our predictions to observations at this site. In 1996, we were able to compare our predictions to observations at both John Day and Bonneville. Figure C6 A5-11 shows observed average travel times versus predicted average travel times to six observation sites for fish released at Snake trap in 1996. The model parameters used for the predictions were the standard CRiSP Snake River yearling migration rate parameters. The fish were released on April 20, which an intermediate date that has been used for CRiSP/FLUSH comparisons.

For these fish, the model accurately predicts travel times to the downstream observation sites. For future applications, we will use data from the downstream observation sites to calibrate the migration rate parameters.

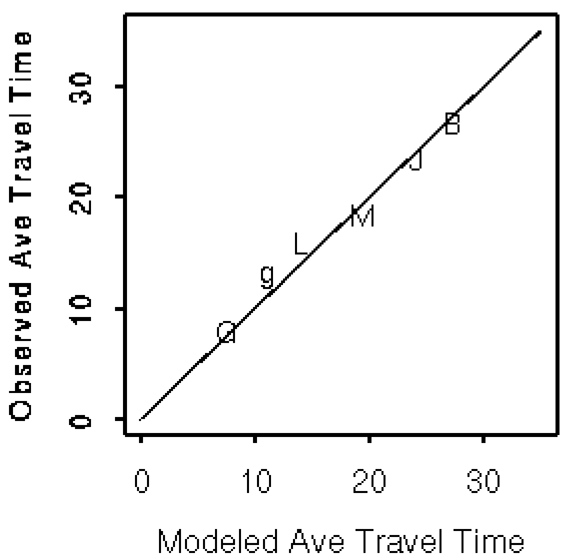

Figure C6 A5-11: Observed versus expected average travel times from Snake Trap to six observation sites. The fish were released on April 20, 1996, and the predictions were based on standard CRiSP migration rate parameters for Snake River yearling chinook. G = Lower Granite; g = Little Goose; L = Lower Monumental; M = McNary; J = John Day; B = Bonneville.

Other spring chinook data sets that have been analyzed for CRiSP calibration and validation are:

- Sims and Ossiander brand data.

- UW/NMFS survival study PIT tag data.
- Rock Island PIT tag data for Run-of-the-river-fish
- Several stocks of wild spring chinook originating from tributaries in Idaho.

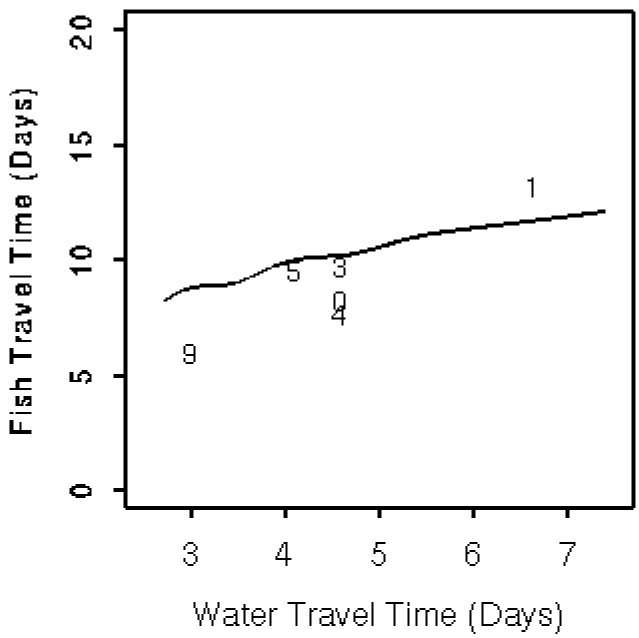

Figure C6 A5-12: Fish travel time versus water travel time from Lewiston to Lower Granite Dam for fish released on April 20. The solid line represents model predictions. 9 = 1989; 0 = 1990; 1 = 1991;3 = 1993; 4 = 1994; 5 = 1995. There was not an adequate sample size of fish released on this date in 1992.

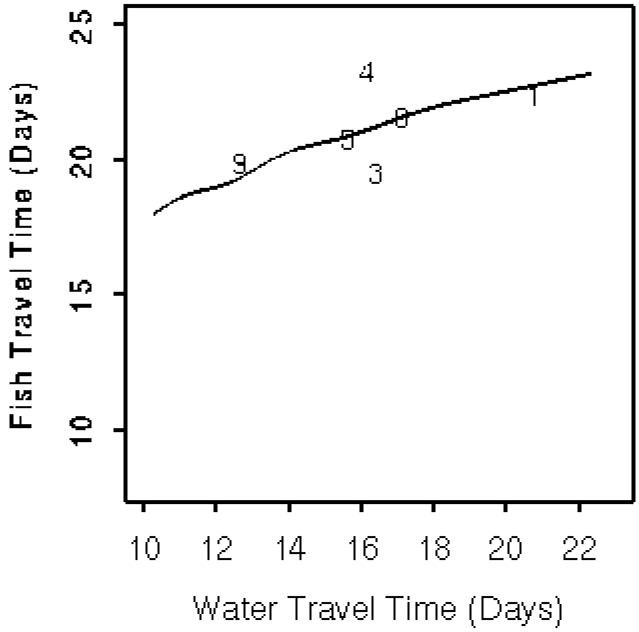

Figure C6 A5-13: Fish travel time versus water travel time from Lewiston to McNary Dam for fish released on April 20. The solid line represents model predictions. 9 = 1989; 0 = 1990; 1 = 1991;3 = 1993; 4 = 1994; 5 = 1995. There was not an adequate sample size of fish released on this date in 1992.

6.0 Survival-Travel Time Relationship In Spring FLUSH

Paul Wilson

In Spring FLUSH, the function determining survival of fish as they migrate through the reservoirs is based on data from a NMFS study reported in Sims and Ossiander (1981) and Sims et al. (1981). The study produced estimates of mainstem system survival for juvenile spring chinook and steelhead for the years 1970 and 1972-80. Survival of smolt releases from the uppermost dam on the Snake River to John Day or The Dalles dams on the lower Columbia River were measured. Over the study period, the upper dam changed as hydropower projects were completed and brought on line. The total number of reservoirs in the reach studied therefore changed from 5 to 6 during the study period. The survival estimates reflect smolt mortalities both in the reservoirs and from dam passage. Sources of reservoir mortality include predation by fish and birds, temperature-induced physiological stress, cumulative effects of exposure to nitrogen supersaturation, and residualism and loss of energy reserves (Raymond 1979).

For the first three years of the NMFS study for which we use data on survival (1970, 73, 74), the reach spanned five reservoirs, since Lower Granite Dam had not been completed, and fish were released from Little Goose Dam. Consequently, the five pool survivals for these years had to be expanded to six-pool values to be comparable to the other years. To do this, we first determined the survival-per-day for the five reservoir reach from the calculated fish travel time for this reach. We then estimated fish travel time for the sixth reservoir (Little Goose) and calculated a survival for this reach from the survival-per-day raised to the power equal to the number of days to traverse that reservoir. This is then multiplied by the five pool survival to get a new reach survival, as if the sixth reservoir had been impounded during the early years.

State and Tribal passage analysts have reviewed the 1993-95 NMFS/UW PIT tag studies. These data, although interesting, do not by themselves provide the best basis for a passage model because of the short reaches and short time series involved. The chief concern in extrapolating the results of this study is that studies in shorter reaches, high in the system, are less likely to detect either mortality due to cumulative impacts or delayed mortality than longer reach studies. In particular, the 1993-95 reach survival estimates do not include survival through the lower Columbia River. This is important in part because John Day Reservoir's volume alone is greater than all four Snake River reservoirs combined. Reservoir volume, along with flow, determines water velocity, which, in turn, strongly influences fish migration rates (Appendix 5, Section 4.0); and mortality can be expected to increase with increased fish travel time. In addition, predator composition and density is different in the lower reservoirs than in the Snake River. Reach survival studies in general provide an incomplete picture of success of the migration, because smolt timing and condition (e.g., depleted energy reserves, delayed mortality) are likely important to subsequent estuary and early ocean survival. However, studies over longer reaches can be expected to better approximate migration success than short reach studies.

Before using the 1970-1980 data in developing the relationship used in FLUSH, system survival estimates for 1972 were excluded because an additional mortality was caused that year by passage through slotted bulkheads installed at skeleton bays at two dams (Raymond 1979). Prolonged exposure to lethal concentrations of dissolved gases caused by spilling at dams was also a source of reservoir mortality in high flow years prior to installation of spill deflectors in the 1970s. The procedure used to determine reservoir mortality in a six project reach (Little Goose through The Dalles) is to estimate the survival through the reach in each study year and then relate the values to estimated fish travel times for the corresponding years (estimation of fish travel time is described in Section 4.0 of this appendix).

To isolate the mortality in the reservoirs from the overall survival data, it is necessary to remove the component of mortality associated with the dams. Dam passage includes mortality through the three alternative means of traversing the dams: turbine mortality, direct spill mortality, and mortality of fish guided through bypass systems. Data on proportion of flow spilled, estimates of project fish guidance efficiencies (FGEs) from fyke net studies, and estimates of survival through each passage route are used to estimate each year's dam passage mortality. After the mortality each year due to dam passage is estimated, the reach reservoir survival is calculated as the overall survival divided by the cumulative dam passage survival.

The form of the relationship between survival and travel time ideally would fit the data well while behaving in a manner that is biologically realistic. The survival function should equal 1 at zero travel time, and approach 0 as travel time approaches infinity. A constant survival per day (constant mortality rate) would meet these criteria, as would a negative exponential function with the intercept constrained to equal one. However, the fit of both functions to the survival vs. fish travel time data is poor, as they under-predict all of the data from moderate-high flow years and greatly over-predict the survival in the low flow years.

A functional form that meets the biological criteria and fits the data better is an "upside-down logistic". This form can be created by taking the standard logistic equation, subtracting it from a constant, and scaling it so that it has a maximum value of 1 and a minimum value of zero. A common form of the logistic is

$$y = \frac{C}{1 + A\exp(-Bx)}, \quad A,B,C > 0.$$

Reservoir survival (S) as a function of fish travel time can then be described by

$$S(t) = D - \frac{C}{1 + A\exp(-Bt)}$$

where t is fish travel time, and A, B, C, and D are parameters.

The number of parameters can be reduced to two by setting the limiting conditions

$$S(0) = 1,\ S(\infty) = 0.$$

Solving for the second condition gives $D = C$. Substituting for D and solving for the first condition gives

$$C = \frac{1 + A}{A}.$$

The equation for reservoir survival as a function of fish travel time then becomes, after substituting for C and simplifying,

$$S(t) = \frac{(1 + A)\exp(-Bt)}{1 + A\exp(-Bt)} \qquad (1)$$

with A, $B > 0$.

Table C6 A5-7 shows the data points upon which the relation is based, along with corresponding flows and water travel times for the assumed migration period for each point. Turbine mortality was assumed to be 15%, and bypass and spill mortality 2%, at all projects. Spill efficiency was assumed to be 1:1 at all projects, except The Dalles Dam, where it was set to 2:1.

Table C6 A5-7: FLUSH reservoir survival relationship data, for six pools (LGO to TDA).

Year	Snake Flow (kcfs)	Columbia Flow (kcfs)	WTT (Days)	FTT (Days)	Survival
1970	100	230	14.49	16.24	32.4%
1973	55	140	24.60	23.55	8.1%
1974	135	349	9.95	12.58	63.6%
1975	119	288	12.02	14.26	42.9%
1976	144	336	10.00	12.79	41.8%
1977	41	131	30.52	27.33	5.5%
1978	95	260	13.86	15.45	75.6%
1979	90	232	15.07	16.44	53.1%
1980	104	246	13.72	15.62	62.3%

Equation (1) can be fit to the data using an iterative procedure minimizing the sum of squared deviations (or the sum of absolute value of the deviations). The least-squares fit of this relation to the estimated six-pool survival for years 1970 and 1973-1980 gives

$$A = 14.07,\ B = 0.1822$$

with an R-square of 0.59. The fit of the relationship to the data is shown in Figure C6 A5-14.

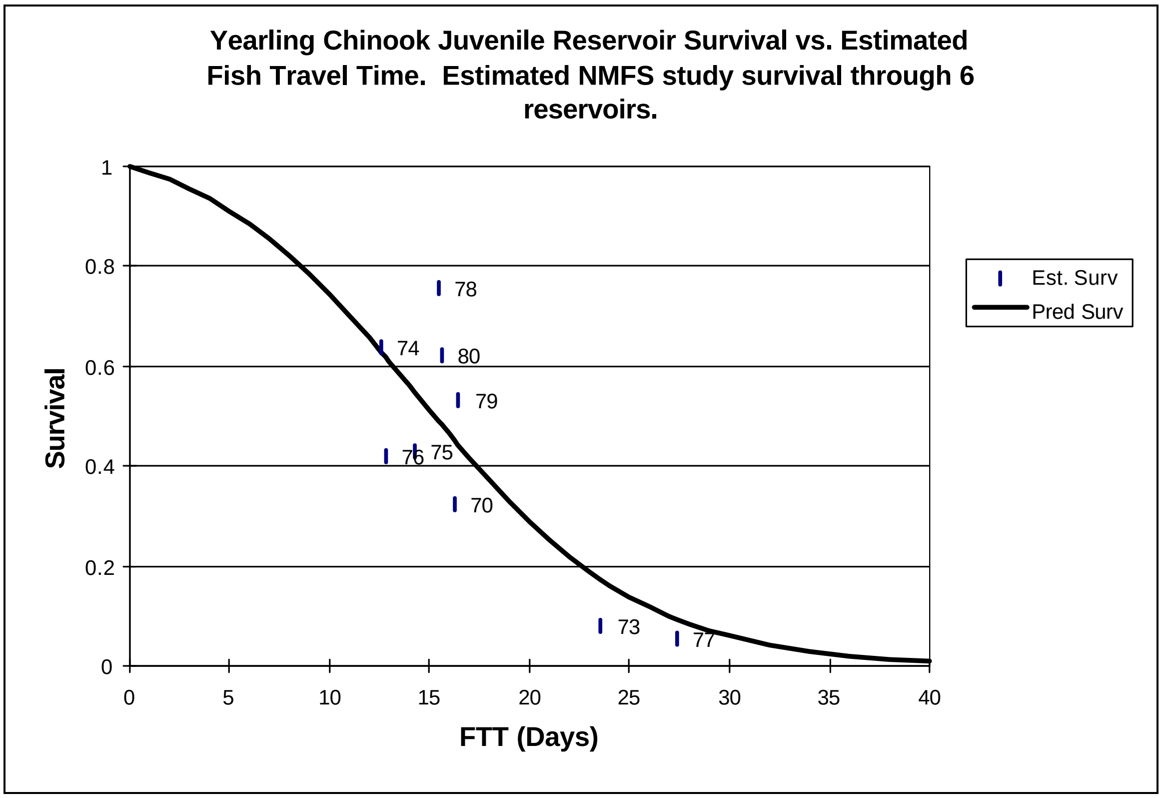

Figure C6 A5-14

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7.0 Calculation Of Survival In CRiSP

Unlike FLUSH and other models, CRiSP does not have an explicit travel time-survival relationship. Instead, the model includes modules for estimation of fish travel time, predation rates in various portions of the reservoir, losses due to gas bubble disease, and mortality suffered in dam passage. Travel time for spring chinook stocks is a function of intrinsic stock-specific migration velocities as well as a separate stock-specific flow-dependent portion. Mortality in the system occurs as a function of three different mechanisms:

1. Direct mortality suffered in dam passage (turbines, bypass, etc),
2. Predation mortality in reaches, and
3. Nitrogen supersaturation-related gas bubble trauma.

The second and third mortality sources are related to, among other things, residence time in the reach(es) in question: mortality caused by either mechanism is a rate-related process. To that extent, reductions in travel time will result in decreased exposure and decreased mortality in CRiSP.

Calibration of the flow-travel time portion of CRiSP is described elsewhere [Zabel, section 5.0 of this Appendix]. Predation mortality modeling is based on consumption studies carried out in John Day reservoir (Vigg et al. 1991), and predator densities are based on indexing studies. Gas mortality is estimated based on early work by Dawley et al. (1976) and more recent studies by Fidler and Miller (1994); nitrogen concentrations are estimated using the Corps' "gasspill" model, calibrated to saturation data from the CROHMS database.

When taken as a whole, the travel time and mortality components of CRiSP produce excellent fits to observed travel time and mortality estimates from a variety of studies in the Snake River, mid-Columbia and lower Columbia River [Table C6 A5-8; Figure C6 A5-15].

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Table C6 A5-8: Observed and modeled survival and travel time for yearling chinook through various reaches in the Columbia/Snake system.

	Survival (%)		Travel Time (days)		
Year	**Observed**	**Modeled**	**Observed**	**Modeled**	**Reference**
1966	85	86	14	14	1
	63	61	--	--	1
1967	85	86	15	15	1
	64	61	--	--	1
1968	95	84	16	15	1
	62	59	--	--	1
1969	75	88	--	--	1
	62	64	--	--	1
	46	56	--	--	1
1970	28	27	23	17	1
	33	39	--	--	1
	67	53	--	--	1
	22	21	--	--	1
1971	50	33	17	14	1
	48	48	--	--	1
1972	32	31	19	13	1
	39	44	--	--	1
	42	30	--	--	1
	15	13	--	--	1
1973	10	11	26	27	1
	12	18	7	10	1
	42	45	15	14	1
	5	8	22	24	1
1974	41	50	11	11	1
1974	50	65	5	5	1
	71	45	7	9	1
	34	29	12	14	1
1975	36	35	14	14	1
	36	51	4	8	1
	69	53	8	8	1
	25	27	12	16	1
1976	63	64	7	7	2,3
	69	69	10	8	2,3
	30	45	17	15	2,3
1977	4	3.5	38	45	2,3
	17	13	17	24	2,3
	20	31	22	15	2,3
	3	4	39	39	2,3
1978	69	65	6	7	3,4
	64	75	7	8	3,4
	44	48	13	15	3,4
1979	43	45	7	7	3,4
	72	75	8	8	3,4
	30	31	15	15	3,4

	Survival (%)		Travel Time (days)		
Year	**Observed**	**Modeled**	**Observed**	**Modeled**	**Reference**
1980	46	70	--	--	5
	49	51	--	--	5
	74	85	--	--	5
	36	39	13	14	5
1982	56	56	22	22	6
1982	43	41	--	--	6
	34	54	9	8	6
	68	88	6	4	6
	23	41	15	12	6
1983	69	42	12	10	7
	90	87	2	4	7
	62	36	14	14	7
1985	45.1	54.2	32	34	8
1986	46.8	45.9	27	30	9
1993	90.2	90	9.7	8.3	10
	86.2	90	4.9	5.6	10
	78	81	14.6	13.9	10
1994	92.3	92	9.1	9.1	11
	82.7	83	5.4	5.5	11
	94.4	83	--	--	11
	76	76	14.5	14.6	11
	72.8	63	--	--	11
	72.5	90.8	2.5	3.7	12
	77.5	89.9	2.0	3.2	12
1995	93.7	94	9.0	7.3	13
	82.6	89	5.0	4.5	13
	94.1	91	2.1	2.5	13
	77.4	84	14.0	11.8	13
	72.8	76	16.1	14.3	13

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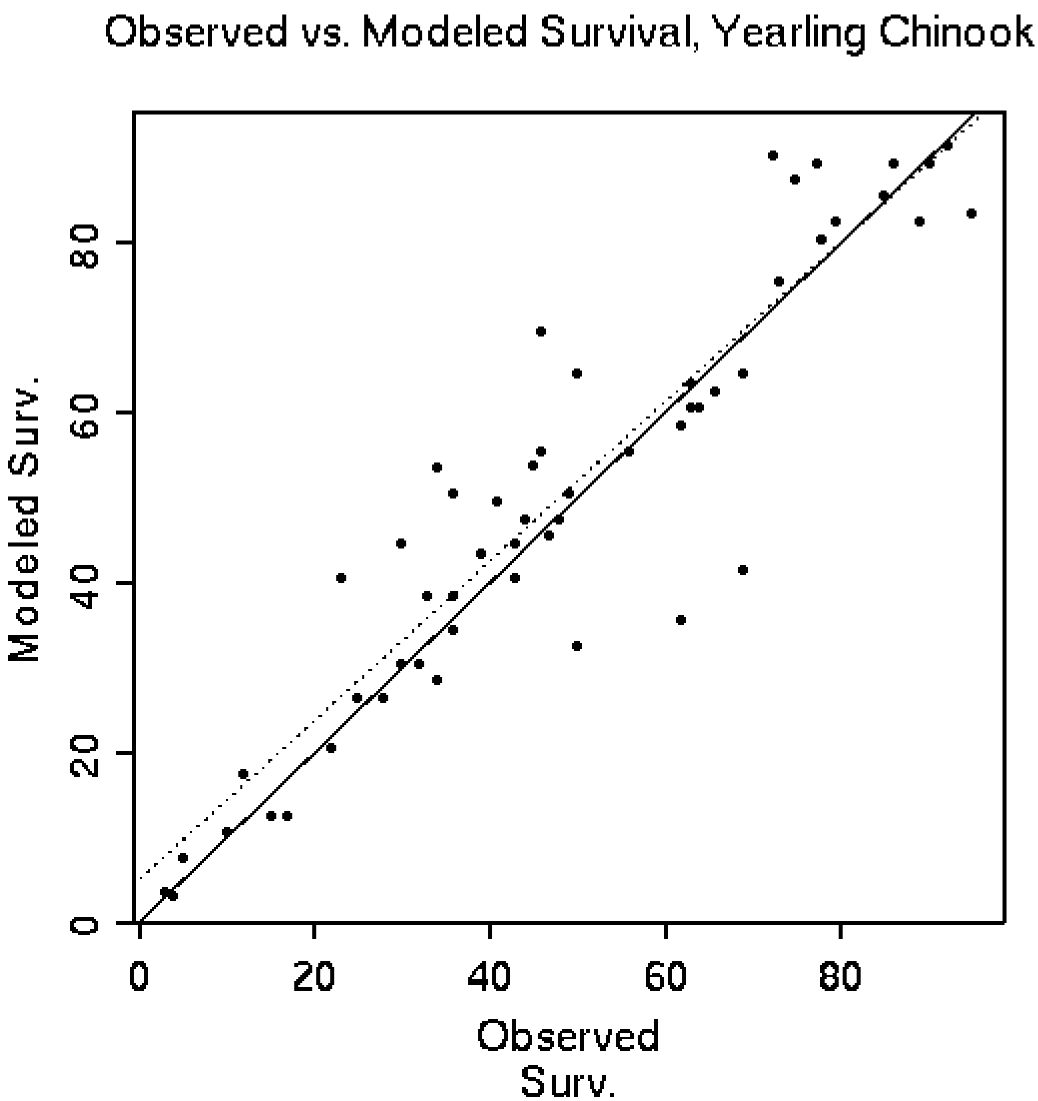

Figure C6 A5-15: Graph of all yearling chinook survival efforts. The solid line is a 1:1 line; the dotted line is a regression line.