CHAPTER VI. MODEL DESCRIPTIONS

A number of models are available to estimate the water supply, water quality, and aquatic resource impacts of alternative physical and regulatory conditions in the Bay-Delta Estuary. This chapter provides a brief discussion of the models that were used by the SWRCB to analyze the effects of the alternative standards.

A. DWR's PLANNING SIMULATION MODEL (DWRSIM)

DWRSIM is a generalized computer simulation model designed to simulate the operation of the CVP and the SWP system of reservoirs and conveyance facilities. The model accounts for system operational objectives, physical constraints, legal requirements, and institutional agreements. These parameters include requirements for flood control storage, instream flows for fish and navigation, allocation of storage among system reservoirs, hydropower production, pumping plant capacities and limitations, the COA, and required minimum Delta operations to meet water quality and Delta outflow objectives. A description of both the DWRSIM model and its operations criteria has been prepared by the DWR (Barnes and Chung 1986; DWR 1986, 1992a, 1992b).

DWRSIM studies use the historical 71-year hydrologic sequence of flows from water years 1922 through 1992 as input, adjusted to reflect the effect of estimated 1995 level land use patterns. This adjustment is developed using two other models: the Consumptive Use model and the Depletion Analysis model. The hydrology is also modified to account for current operations of local upstream reservoirs. The entire San Joaquin River system, except for New Melones Reservoir and the Stanislaus River, and local reservoir operations on the Sacramento River are treated as pre-modeled inputs to DWRSIM and are not operated to meet flow or water quality requirements in the Delta.

The CVP and SWP export demand south of the Delta is also based on a 1995 level of development and is adjusted to account for the different hydrologic conditions in central and southern California.

In summary, the model simulation results estimate how the entire system would perform when trying to meet project demands, assuming recurrence of the historical 71-year sequence of hydrology at the 1995 level of development.

DWRSIM has a number of limitations which require that caution be exercised when analyzing or interpreting model results. Many of these limitations are due to lack of information or objective criteria, and would be limitations of any similar model. Some of the more important limitations are discussed below.

1. DWRSIM operates on a monthly time step. Therefore, assumptions must be made to model any standard that is not formulated on a monthly basis. Additionally, peak

storm flows, which are usually considerably higher than monthly average flows, cannot be modeled.

2. The ESA limitations on Delta export pumping based on actual "fish take" cannot be modeled.

3. The CVPIA mandates that 600 to 800 TAF of CVP yield be allocated annually for environmental purposes. The USBR has not yet established criteria on how this obligation will change CVP operations, or how much additional Delta inflow or outflow this mandate will provide. Until such criteria are established, interpretation of modeling results are subject to the uncertainty of the CVPIA allocation.

4. The effect of the ESA requirements or other proposed standards on the sharing formula in the COA is unknown. This sharing will affect relative reservoir levels and available water for delivery between the CVP and SWP.

5. DWRSIM primarily simulates the CVP and SWP system of reservoirs and conveyance facilities. This system is, therefore, used as a surrogate to estimate water supply impacts throughout the Central Valley. Actual responsibility to meet Bay-Delta standards might be allocated among other water users as well. Operations criteria for these other water users must be incorporated into DWRSIM before more detailed modeling can proceed.

6. The Depletion Analysis model accounts for use of ground water, but ground water itself is not physically modeled.

7. DWRSIM is not capable of analyzing the water supply impacts of water quality objectives for the interior stations in the southern Delta because of a lack of adequate understanding of relationships between the San Joaquin River flow and southern Delta water quality.

B. DELTA HYDRODYNAMICS AND WATER QUALITY MODEL (DWRDSM)

DWRDSM is a mathematical model developed to simulate the hydrodynamics and water quality in the Sacramento-San Joaquin Delta. The model is a variant of the Fischer Delta Model, which was developed by Hugo Fischer and is currently under the proprietorship of Flow Science Inc. DWR incorporated a number of modifications to the Fischer Delta Model and created DWRDSM. DWRDSM was specifically designed to simulate salinity changes in the Delta as affected by changes in geometry and hydrology (DWR 1995).

The hydrodynamics of the Delta are described in the model by governing equations for long wave, non-uniform, unsteady flow in prismatic channels. These equations coupled with continuity equations are solved by different numerical schemes for flows, stages, and velocities at discrete locations. The fundamental assumptions made in deriving the governing equations for the hydrodynamics of the Delta are:

1. The flow is assumed to be one dimensional, i.e. the flow in the channel can be approximated with uniform velocity over each cross-section and the free surface is taken to be a horizontal line across the section. This implies that the centrifugal effect due to channel curvature and Coriolis effect are negligible.

2. The pressure is assumed to be hydrostatic, i.e. the vertical acceleration is neglected and the density of the fluid is assumed to be homogeneous.

3. The effects of boundary friction and turbulence can be accounted for through the introduction of a resistance force which is described by the empirical Manning or Darcy Weisbach Friction Factor equations.

The movement of water quality constituents, currently total dissolved solids, is explained in the model by two distinct processes: advection and dispersion. The advection process is largely dependent on flow velocities, which are obtained by solving the hydrodynamics equations. The dispersion process is dependent on the concentration gradient and the dispersion coefficient. The dispersion coefficients vary from one location to another and are commonly used as calibration parameters.

C. RELATIONSHIP BETWEEN OUTFLOW AND X2

There are two models that establish relationships between Delta outflow and X2, the position of the 2 ppt bottom isohaline. The first model was developed by Kimmerer and Monismith (SFEP 1993). This model predicts the location of X2 as a function of the antecedent flows. Isohaline position is a function of net Delta outflow on a particular day and the isohaline position on the previous day, as specified in the following equation:

$$X2_{(t)} = 10.16 + (0.945\ X2_{(t-1)}) - (1.487 \log(\text{Delta outflow}))$$

where $X2_{(t)}$ and $X2_{(t-1)}$ are the 2 ppt positions, in kilometers eastward from the Golden Gate Bridge, at time t and t-1 in days, respectively; and Delta outflow is the net daily mean Delta outflow in cfs.

The second model was developed by Denton (CCWD 1994). This model predicts salinity at a fixed position as a function of the antecedent flows, as specified in the following equations:

$$S(t) = (S_0 - S_b)e^{-\alpha G(t)} + S_b$$

where G(t) is a functional of the antecedent flows; and α, S_0, and S_b are empirically determined constants for the specified position. The functional, G, can be expressed in the following form:

$$dG/dt = (Q - G)G/\beta$$

where Q is the flow rate; and β is an empirically determined constant for the specified position.

D. STRIPED BASS MODEL

Three striped bass models have been developed, using outflow and export or X2 parameters, one by the DFG and two by Jassby. The DFG's model uses the variables of Delta outflow and CVP and SWP exports, and a series of life stage relationships, to predict annual survival from the egg to the 38 mm stage (YOY index) and adult striped bass abundance (DFG 1992a). The two models developed by Jassby predict survival from the egg to both the YOY index and the fall mid-water trawl index, based on X2 (SFEP 1992, 1993). The DFG's striped bass model is used in this document.

The DFG examined the relationships individually between the adult striped bass abundance, the YOY index, export losses, and the loss rate index. A positive correlation between adult abundance and YOY indices, and a negative correlation between adult abundance and both losses and the loss rate index indicate that high adult abundance results from initial strong year classes that experience only minor late summer though winter losses due to export pumping. Impacts of losses vary, depending on time of year and size of entrained fish because survival increases with age and size. Losses of large YOY fish late in the year are potentially more damaging than losses of smaller fish in summer (DFG 1992a).

The model is provided below:

Total YOY = Delta YOY + Suisun YOY + Residual YOY . . . . **Eqn. (1)**

Delta YOY = 69.33 - 0.005058 mean April-July diversion (cfs) . . . . **Eqn. (2)**

Suisun YOY = -158.86 + 46.61 $\log_{10}$ mean April-July outflow (cfs) . . . . **Eqn. (3)**

Residual YOY = [1/(0.0093 + (2.70/eggs))] - 60 . . . . **Eqn. (4)**

Egg production (billions) = 49.27 + 88.01(adult population(millions))^2 . . . . . . **Eqn. (5)**

Log_{10}(loss rate) = 4.482 + 0.00015252 mean August-March export - 0.00000594 mean August-March outflow . . . . **Eqn. (6)**

Legal-sized adults = 3,801,443 + 14,182 weighted mean YOY index - 625,944 $\log_{10}$(weighted mean loss rate) . . . . **Eqn. (7)**

The DFG's striped bass model illustrates the factors affecting adult striped bass abundance. The model indicates that freshwater outflow and water exports during the initial year of life are the primary factors controlling adult striped bass abundance in the Sacramento-San Joaquin Estuary. The model also serves to evaluate relative impacts on striped bass of alternative combinations of outflows and exports (DFG 1992a).

In order to graphically illustrate the information contained within this model, the model was simplified by assuming a constant adult striped bass population, a constant loss rate, and constant YOY indices set at 4, 8, 16, 32, and 64. The export/outflow relationships during the April through July and the August through March periods were then plotted in Figures VI-1 and VI-2, respectively. Figure VI-1 shows that, assuming a constant population, the YOY index is established based on the export/outflow relationship from April through July. Figure VI-2 then shows the export/outflow relationship that must be maintained from August through March, once the YOY index is established, in order to sustain the adult target population. The model indicates that, when the YOY index in the spring is high, larger exports can be tolerated later in the year to achieve the same adult population.

The statistical validity of the DFG's striped bass model has been reviewed (DWR 1992c). This review concluded that the model has poor predictive ability. Statistical criticisms of the model include multicollinearity, autocorrelation, averaging, and propagation of errors.

E. ESTUARINE RESOURCES MODELS

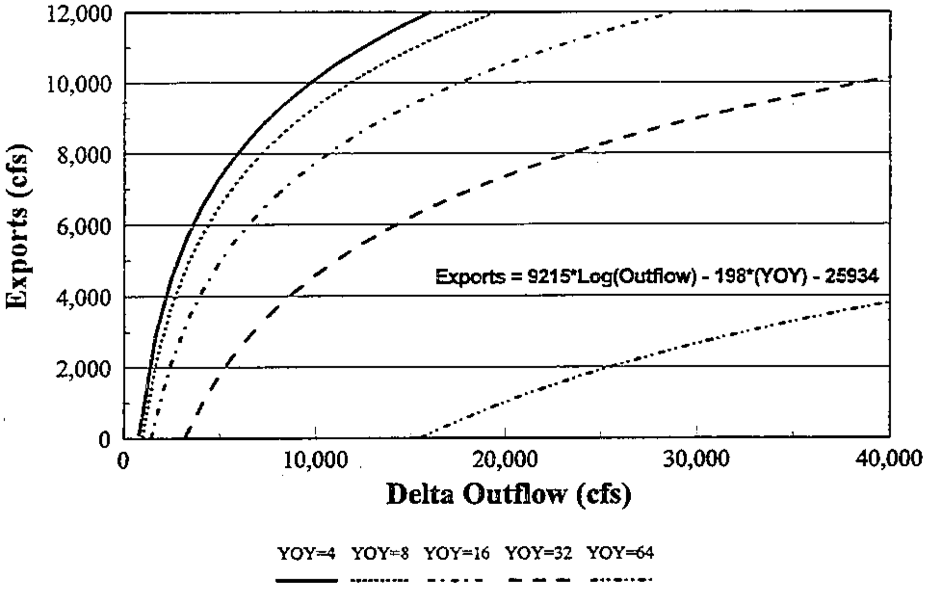
The DFG has sampled the abundance of estuarine and bay fish species for many years. Since 1980, as part of the Interagency Ecological Program (IEP), the DFG has undertaken a specific study to investigate the relationship between Delta freshwater outflow and the abundance and distribution of fish and invertebrates. Factors other than flow can affect fish and invertebrates, but the major objective of this study was to consider outflow as it influences bay fish resources (DFG 1987).

The abundance of 70 species of fish, shrimp, and crabs were analyzed for the years since 1980. A majority of the species (55.6 percent) showed no difference in their abundance between wet and dry years. Most of the species that showed no significant difference in abundance between wet and dry years were marine. In contrast, over two-thirds of the species in the study considered to be estuarine, anadromous, or freshwater were significantly

Figure VI - 1

Striped Bass Model[1]

April-July Average Exports vs. Delta Outflow

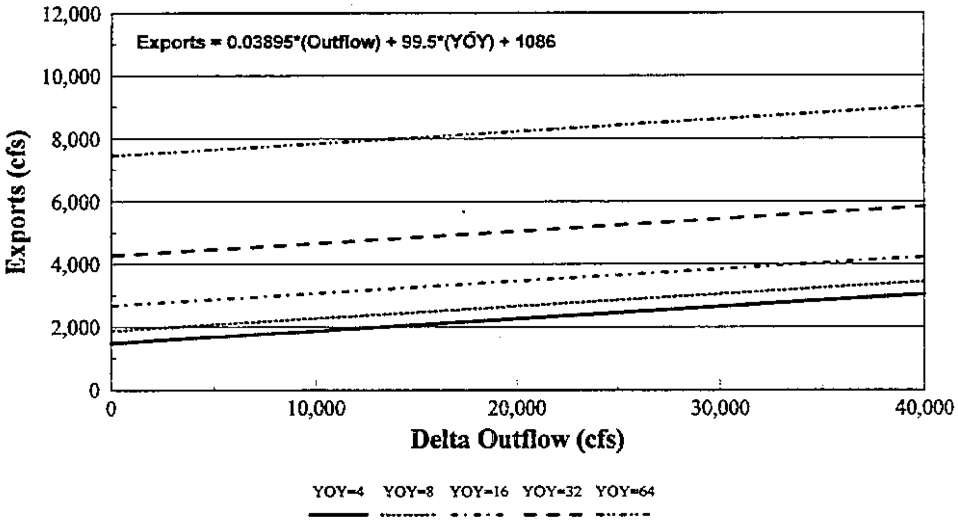


1 - assuming constant population of adult striped bass of 1,000,000 and constant loss rate

Figure VI - 2

Striped Bass Model[1]

August-March Average Exports vs. Delta Outflow



1 - assuming constant population of adult striped bass of 1,000,000 and constant loss rate

more abundant in wet years. Significant positive relationships between Delta outflow and abundance were found for four of these estuarine species: a bay shrimp, *Crangon franciscorum*; longfin smelt; starry flounder; and Sacramento splittail (DFG 1987, 1992a).

In addition to these outflow/abundance relationships, Jassby developed relationships between X2 and several aquatic resources in the Estuary, including: POC; a small mysid shrimp, *Neomysis mercedis*; *C. franciscorum*; starry flounder; longfin smelt; striped bass; and mollusks (SFEP 1992). These aquatic resources were selected because they were found by the DFG to correlate well with outflow, and because they are representative of various trophic levels in the Estuary. The regression equations and the data used to develop the equations are plotted in Figures VI-3 to VI-8. For consistency, the regressions have been expressed as outflow/abundance relationships. A brief discussion of each of the plots is provided below.

1. Particulate Organic Carbon

POC is an expression of food and energy sources at the base of the estuarine food web. Because the upstream areas can be a major source of organic carbon, it follows that flow will influence the amount of organic carbon in the Delta. A positive linear regression was calculated between increasing POC in gigagrams per year (Gg/yr) and increases in the log of average annual outflow (Figure VI-3). Although there is a great deal of variability in the data at lower outflows, at higher Delta outflows, the relationship is fairly strong.

2. *Neomysis mercedis*

The small mysid shrimp, *Neomysis mercedis*, is an important prey item for a number of fish species in the Delta. A positive linear relationship was calculated between the abundance index for the years 1972 and 1990 and average March through November outflow (Figure VI-4).

3. *Crangon franciscorum*

The DFG has developed statistical relationships between the annual abundance of mature *C. franciscorum* and freshwater outflow the previous spring (March through May), and between immature *C. franciscorum* and outflow from March through May of the same year (DFG 1992b, 1994). The DFG selected the March through May period as the most critical for freshwater outflow in the establishment of a strong year class of *C. franciscorum* in the bay because, in this period, the juveniles are recruited into the estuarine nursery areas and grow rapidly. Figure VI-5 illustrates the positive significant relationship between the abundance of immature *C. franciscorum* and the log of the March though May outflow. This model, a logarithmic versus linear relationship, indicates that large increments of increased outflow correlate with small but progressively higher abundance indices of immature *C. franciscorum*.

Figure VI - 3

Particulate Organic Carbon (POC) vs. Delta Outflow

(1975-1989)

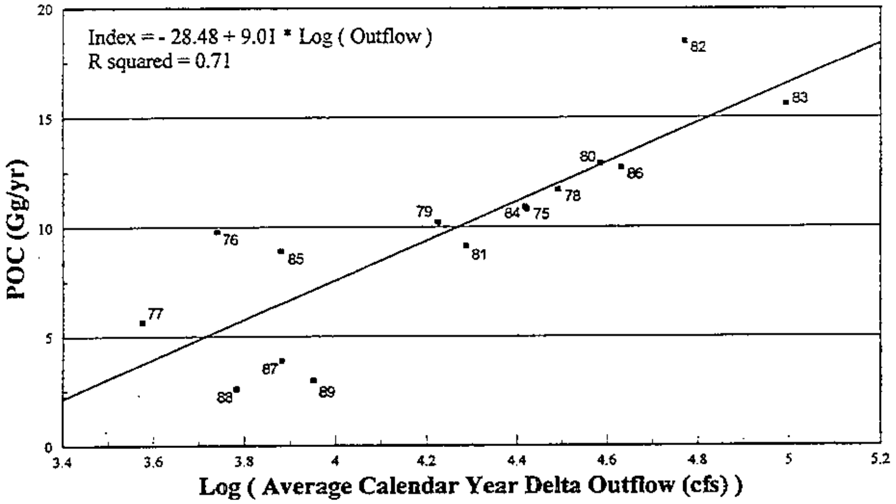


Figure VI - 4

Neomysis Abundance Index vs. Delta Outflow

(1972-1990)

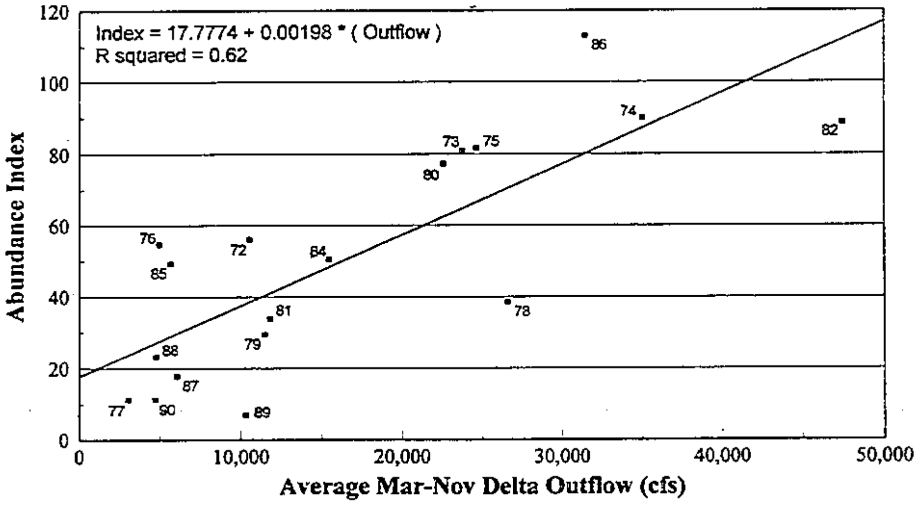


Figure VI - 5

Immature *Crangon franciscorum* Abundance vs. Delta Outflow

(1980-1993)

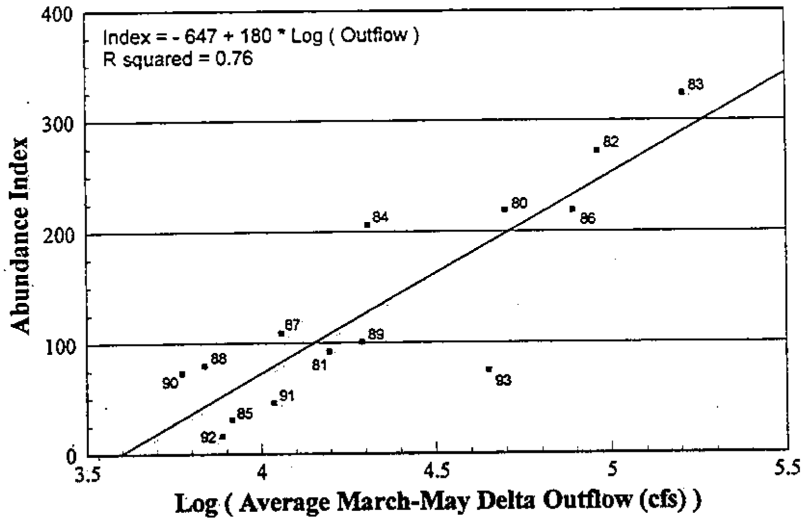
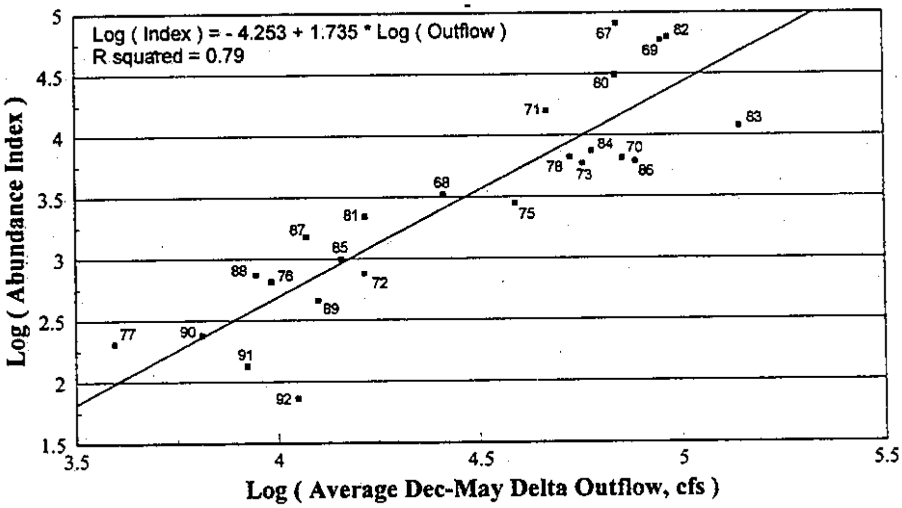


Figure VI - 6

Longfin Smelt Abundance Index vs. Delta Outflow

(1967-1992)



4. Longfin Smelt

The DFG's model for longfin smelt is based upon a significant positive relationship between the log of the abundance index and the log of December through May outflow for the years 1967-1992 (Figure VI-6). Initially, a shorter time period, the February though May period, was considered critical to the success of the longfin smelt year class because larval dispersal, first feeding, and establishment of the brackish nursery habitat all occur during this time. However, the conditions in December and January, months prior to the young moving downstream, have also been found to be important (DFG 1992b). The correlation coefficient for the December through May period is greater than for the February through May period (r^2 of 0.77 and 0.67, respectively) (DFG 1994).

5. Starry Flounder

The DFG developed an abundance index for starry flounder, and compared the log of the March through June outflow at Chipps Island with the log of the 1-year-old starry flounder abundance index for the brood years 1979-1992 (Figure VI-7). This comparison yielded a significant positive relationship. The DFG found that good recruitment of starry flounder is possible during both high and low outflow years, but only poor recruitment occurs when outflow is low. This observation indicates that increased outflow in the Delta does not necessarily guarantee a high abundance index of 1-year-old starry flounder the following year, but it would be more likely than with lower outflows (DFG 1992b).

6. Splittail

The DFG developed an abundance index from the young Sacramento splittail captured in the fall mid-water trawl survey. The DFG then developed a statistical relationship between the juvenile splittail abundance index and March through May outflow, the period in which spawning occurs, for the years 1967-1993 (Figure VI-8). The data are not log transformed, and the model indicates that increased outflow in the spring corresponds with increased splittail abundance index (DFG 1992b). Increases in the splittail abundance index are more apparent when the outflow is greater than 50,000 cfs.

F. SALMON MODELS

The USFWS has developed models for both the Sacramento and San Joaquin rivers which describe survival of fall-run chinook salmon smolts as they migrate through the Delta. For the Sacramento River, the factors that the USFWS believes best describe smolt survival are: water temperature at Freeport; percent flow diverted through the Delta Cross Channel gates and Georgiana Slough; and CVP and SWP exports from April through June (USFWS 1992a, 1992b). On the San Joaquin River, the corresponding primary factors are: percent flow diverted into upper Old River; percent flow remaining in the river at Stockton; temperature at Jersey Point; and CVP and SWP exports in April and May (USFWS 1994). In order to

Figure VI - 7

One-Year-Old Starry Flounder Abundance vs. Previous Year Delta Outflow

(1979-1992)

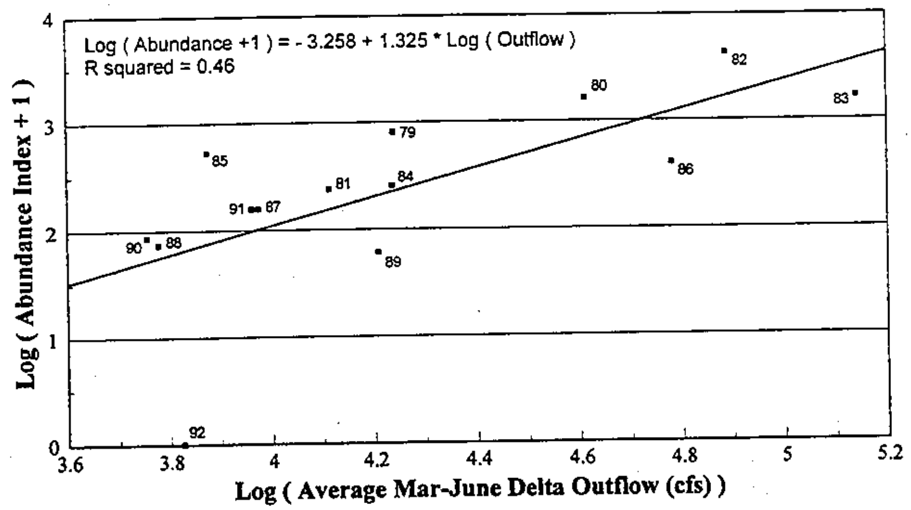
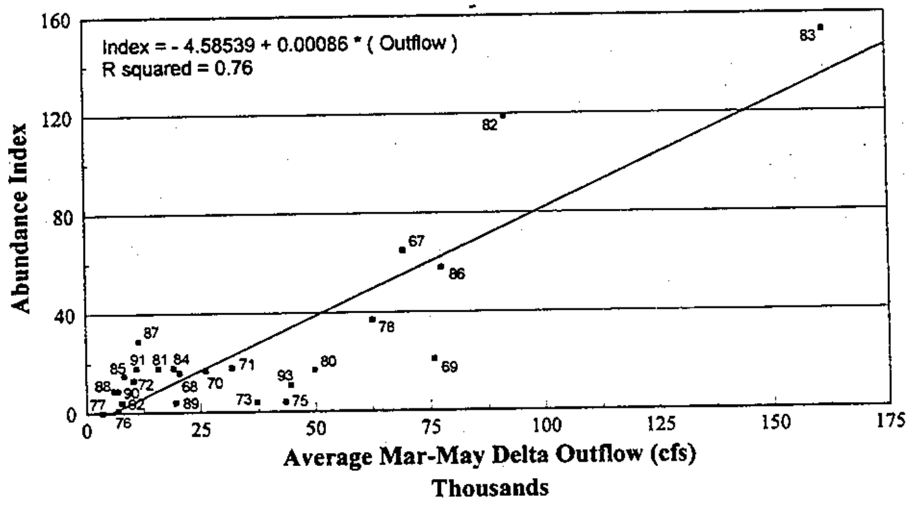


Figure VI - 8

Sacramento Splittail Abundance Index vs. Delta Outflow

(1967-1993)



illustrate the information contained within these models, the models are graphed in Figures VI-9, VI-10, and VI-11.

The model for smolt survival on the Sacramento River illustrates the importance of keeping the migrating salmon smolts on the mainstem of the Sacramento River and minimizing their diversion into the central Delta. Figure VI-9 shows the effect of temperature and export rates on smolt survival when both the Delta Cross Channel gates and Georgiana Slough are open, assuming a flow of 10,000 cfs in the Sacramento River at Sacramento. Under this circumstance, both export rates and temperature have a significant effect on survival. Figure VI-10 shows the corresponding effect of temperature and export rates when the Delta Cross Channel gates are closed and Georgiana Slough is open, with a flow of 10,000 cfs in the Sacramento River. Under these conditions, the effect of export rates on survival is significantly reduced. For example, with the Delta Cross Channel gates and Georgiana Slough open and a temperature of 64°F, exports would need to be maintained at 2,000 cfs in order to achieve a survival index of 0.2. With the same conditions but the Delta Cross Channel gates closed, a survival index of 0.2 could be achieved at an export rate of approximately 5,000 cfs. If both the Delta Cross Channel gates and Georgiana Slough are closed, the lines of constant survival become vertical, and smolt survival becomes independent of export rates.

Similarly, the model for smolt survival on the San Joaquin River illustrates the importance of keeping the migrating salmon smolts on the mainstem of the San Joaquin River and minimizing their diversion into Old River. The San Joaquin River smolt survival model incorporates flows at Vernalis, and mathematically incorporates the flow split at upper Old River and the resulting flow at Stockton, which changes with Old River flow and whether or not the barrier is assumed to be installed. The smolts that migrate down upper Old River and survive are assumed to have gone though the export salvage facilities and then been released into the Delta. The amount of flow in upper Old River substantially affects the survival index. For those smolts that migrate down the mainstem of the San Joaquin River, factors affecting survival include flow, temperature at Jersey Point, and exports. Figure VI-11 shows the effect of temperature, exports, and flow at Vernalis on salmon smolt survival when there is a barrier at the head of Old River.

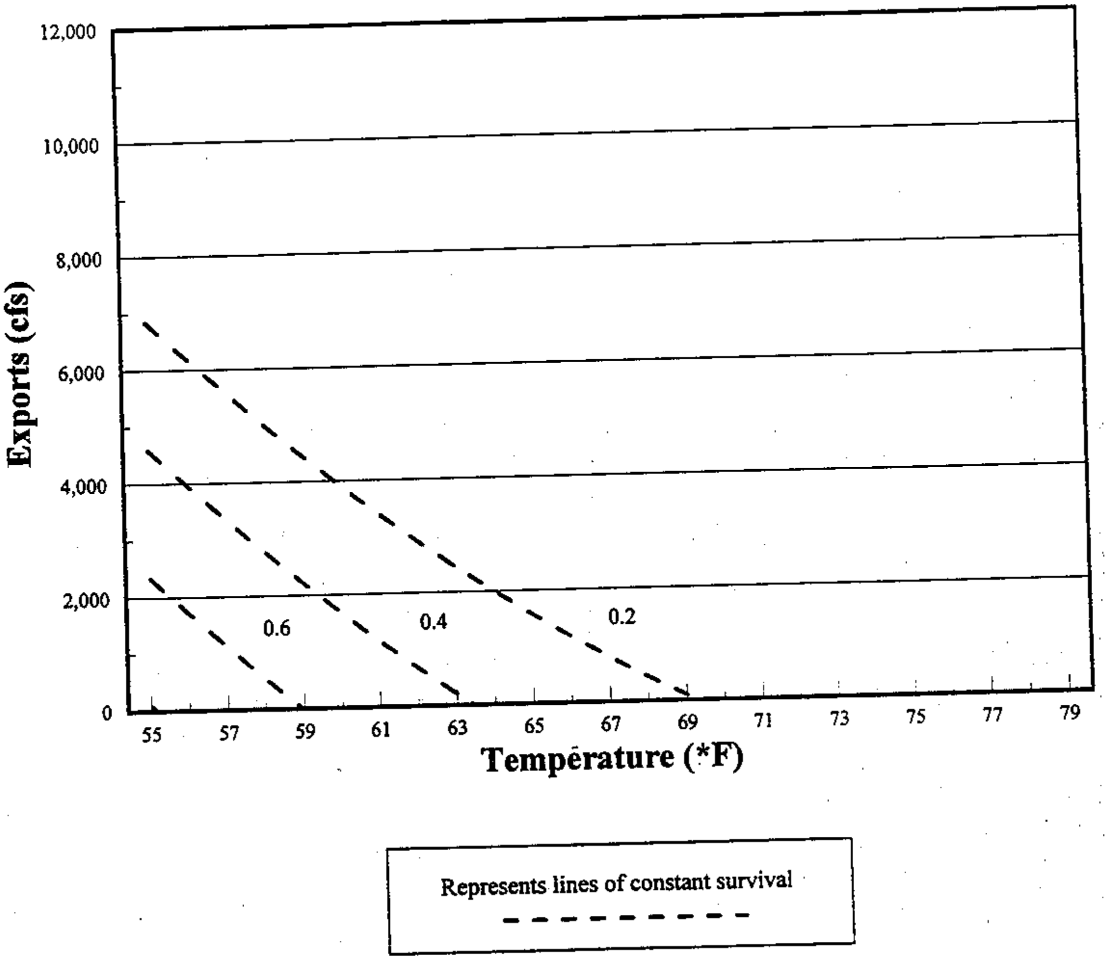
The models can be used to estimate the relative benefits of implementation measures or operations of controllable parameters in the Delta, specifically, flows, exports, and Delta Cross Channel gate operation, and construction of the Old River barrier. A number of other implementation measures may also beneficially affect smolt survival, but the effects of those other measures have not been modeled.

The statistical validity of the USFWS' smolt survival model has been disputed (Kimmerer 1994). A peer review analysis facilitated by Kimmerer concluded that the models are too complex, contain too many parameters, and inappropriately convert smolt survival index values to probabilities to calculate survival through successive reaches of the Delta.

Figure VI-9

Sacramento Salmon Smolt Survival Index

Delta Cross Channel and Georgiana Slough Open
(Sacramento River Flow 10,000 cfs at Sacramento)



$$Y = 1\text{-}[(-2.46 + 0.04T) + (-0.59 + 0.02T + 4.3E\text{-}05X)(P1) + (-1.61 + 0.03T)(P2) - (-2.46 + 0.04T) * (-0.59 + 0.02T + 4.3E\text{-}05X)(P1) - (-2.46 + 0.04T) * (-1.61 + 0.03T)(P2)$$

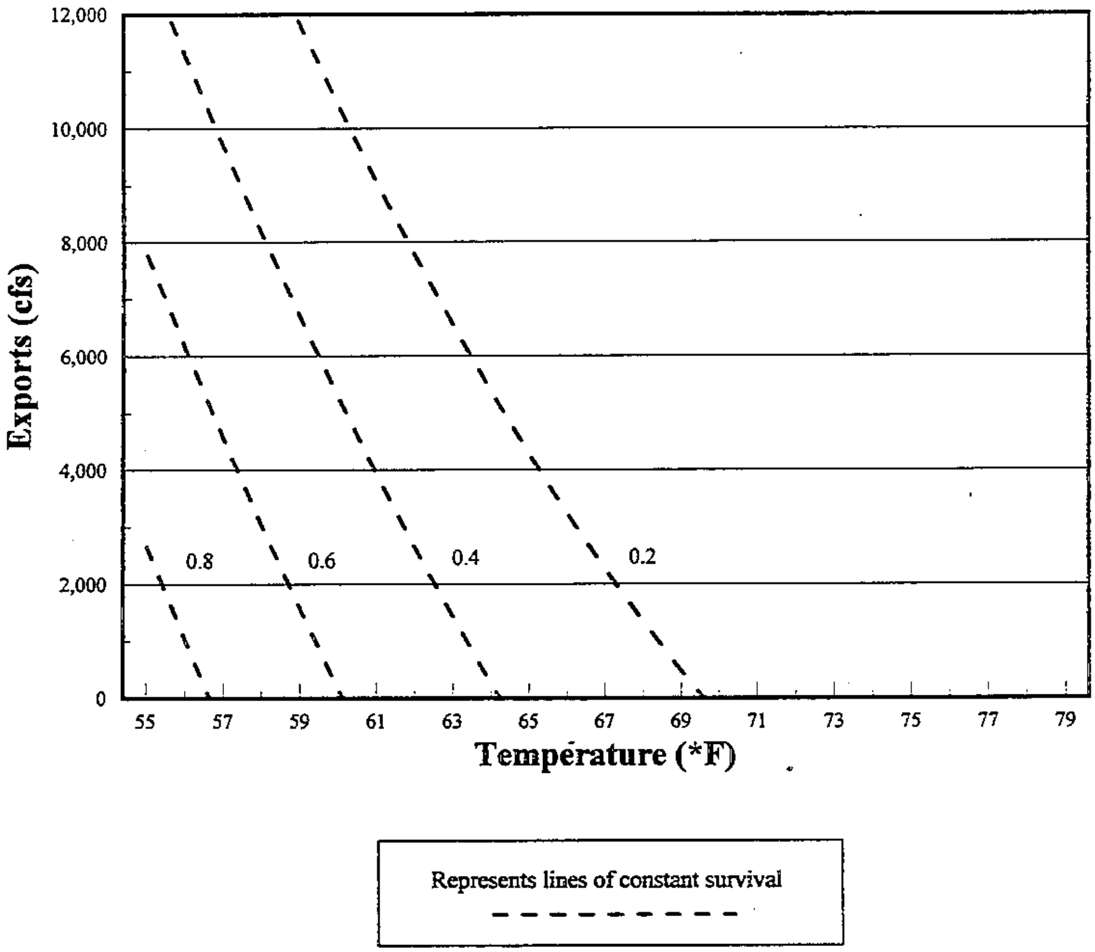
Y = Sacramento Smolt Survival Index
T = Mean monthly water temperature at Freeport (*F)
X = Mean monthly CVP+SWP exports (cfs)
P1 = Percent of water diverted into Delta Cross Channel and Georgiana Slough at Walnut Grove (flow at Sacramento-Steamboat and Sutter Sloughs)
P2 = Percent of water remaining in Sacramento River downstream of Walnut Grove (1-P1)

Figure VI-10

Sacramento Salmon Smolt Survival Index

Delta Cross Channel Closed and Georgiana Slough Open

(Sacramento River Flow 10,000 cfs at Sacramento)



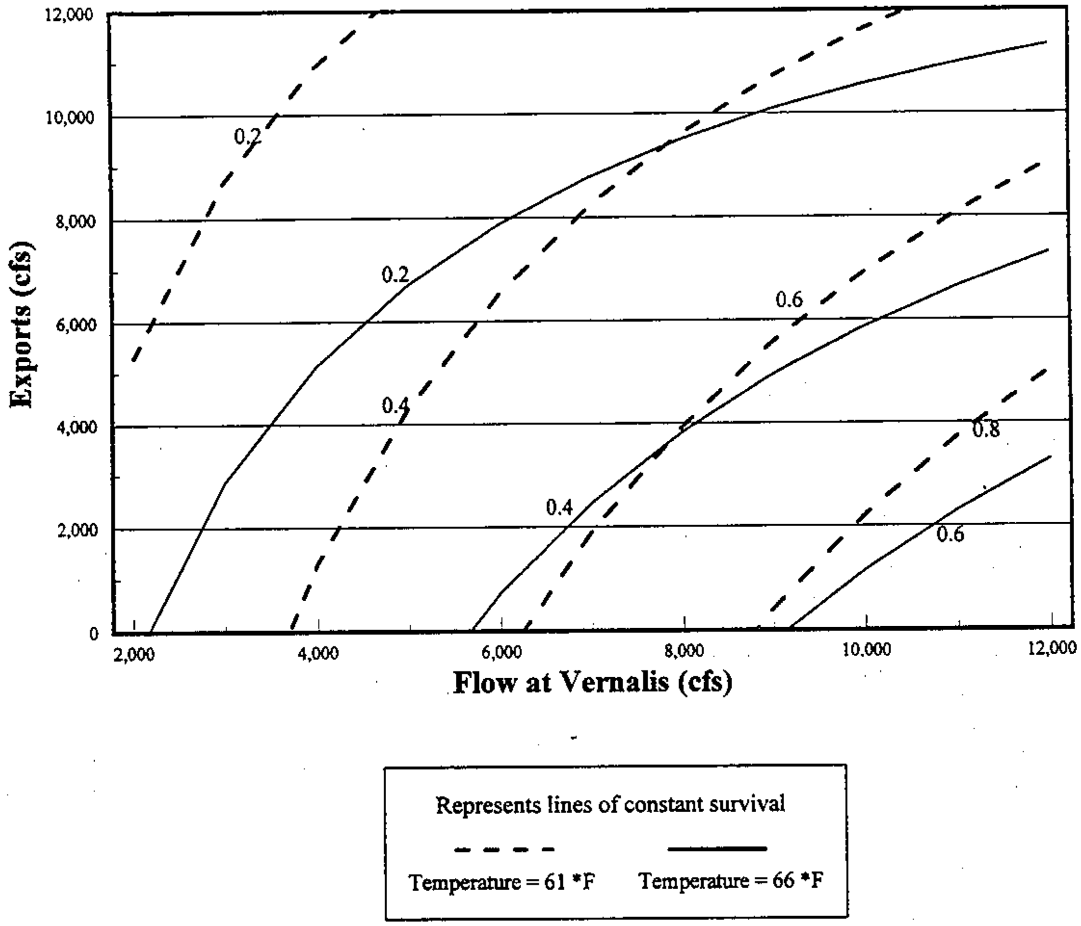
$$Y = 1-[(-2.46 + 0.04T) + (-0.59 + 0.02T + 4.3E\text{-}05X)(P1) + (-1.61 + 0.03T)(P2) - (-2.46 + 0.04T) * (-0.59 + 0.02T + 4.3E\text{-}05X)(P1) - (-2.46 + 0.04T) * (-1.61 + 0.03T)(P2)$$

Y = Sacramento Smolt Survival Index
T = Mean monthly water temperature at Freeport (*F)
X = Mean monthly CVP+SWP exports (cfs)
P1 = Percent of water diverted into Delta Cross Channel and Georgiana Slough at Walnut Grove (flow at Sacramento-Steamboat and Sutter Sloughs)
P2 = Percent of water remaining in Sacramento River downstream of Walnut Grove (1-P1)

Figure VI-11

San Joaquin Salmon Smolt Survival Index

with a Barrier at the Head of Upper Old River
San Joaquin River Flow at Vernalis



$$Y = 1-[((P2)(1.01-0.0003(X1))+(P3)((0.876-0.00007(X2))+(3.66+.058(X3)+0.00005(X4))-(0.876-0.00007(X2))(-3.66+0.058(X3)+0.00005(X4)))]$$

Y = San Joaquin Salmon Smolt Survival Index
X1= Mean daily flow in Upper Old River (cfs)
X2= Mean daily flow at Stockton (cfs)
X3 = Mean monthly water temperature at Freeport (*F)
X4 = Mean monthly CVP+SWP exports (cfs)
P2 = Percent of water diverted in Upper Old River
P3 = Percent of water remaining in San Joaquin River (1-P2)

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