APPENDIX K

Delta Passage Model

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K1

Technical Memorandum: October 2, 2009

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Technical Memorandum

TO: **Metropolitan Water District of Southern California**
FROM: Brad Cavallo (lead), Paul Bergman, and Mark Teply
SUBJECT: Preliminary assessment of the 2-Gates Project effects on Sacramento River origin salmonid smolts
DATE: October 2nd, 2009

In order to assess how salmonid smolt suvirval to Chipps Island might be influenced by the proposed 2-Gates Project, we conducted a model-based assessment using the Delta Passage Model (DPM) developed by Cramer Fish Sciences, running on DSM2-HYDRO data provided by RMA. The DPM simulates migration and mortality of juvenile Chinook salmon through the Delta and provides quantitative estimates of Delta survival to Chipps Island. Though the DPM is primarily based on studies of winter run Chinook surrogates (late fall run Chinook) it is applicable to steelhead and Chinook smolts with similar emigration timing. The biological functionality of the DPM is based upon the foundation provided by Perry et al. (2009) as well as other acoustic tagging based studies, and earlier Coded Wire Tag (CWT) analyses provided by Newman (2003), Kimmerer (2008), among others. A manuscript describing the DPM has been completed and is currently in review for publication in a peer reviewed journal. This analysis provides a useful, preliminary assessment of likely Delta-wide effects for Sacramento River origin juvenile salmonids. However, it does not provide an assessment of local, direct effects which could be associated with the 2-Gates Project. For example, the DPM as applied here does not include predation mortality occurring at the specific location of the proposed gates structure. It also important to note that this analysis does not represent likely effects to salmonid smolts entering the Delta from the Mokelumne River or the San Joaquin River; though the DPM is actively being adapted for this purpose.

Methods

The DPM is based on a detailed accounting of migratory pathways and reach-specific mortality as smolts travel through a network of Delta channels (Figure 1). Smolt movement and survival in the DPM relies on three major functional relationships (Figure 2). Consistent with the findings of Perry et al. (2009), salmon smolts arriving at distributaries enter downstream reaches in proportion to the flow diverted. Reach-specific survival estimates and associated error estimates were obtained from three separate Delta acoustic tagging studies (Burau et al. 2007; Perry et al. 2009; SJRGA 2007). Similar to the analyses of Newman (2003) and Newman and Rice (2002) reach-specific survival is calculated as a logarithmic function of flow. Smolt movement in the DPM occurs daily and is a function of reach-specific length and migration speed informed by acoustic tagging studies. Smolt migration speed is calculated as a reach-specific logarithmic function of flow. Direct loss of migrating smolts at the CVP and SWP pumps is modeled as an exponential function of Delta export flow based on Kimmerer's (2008) analysis of coded-wire tagged Chinook smolts in the Delta.

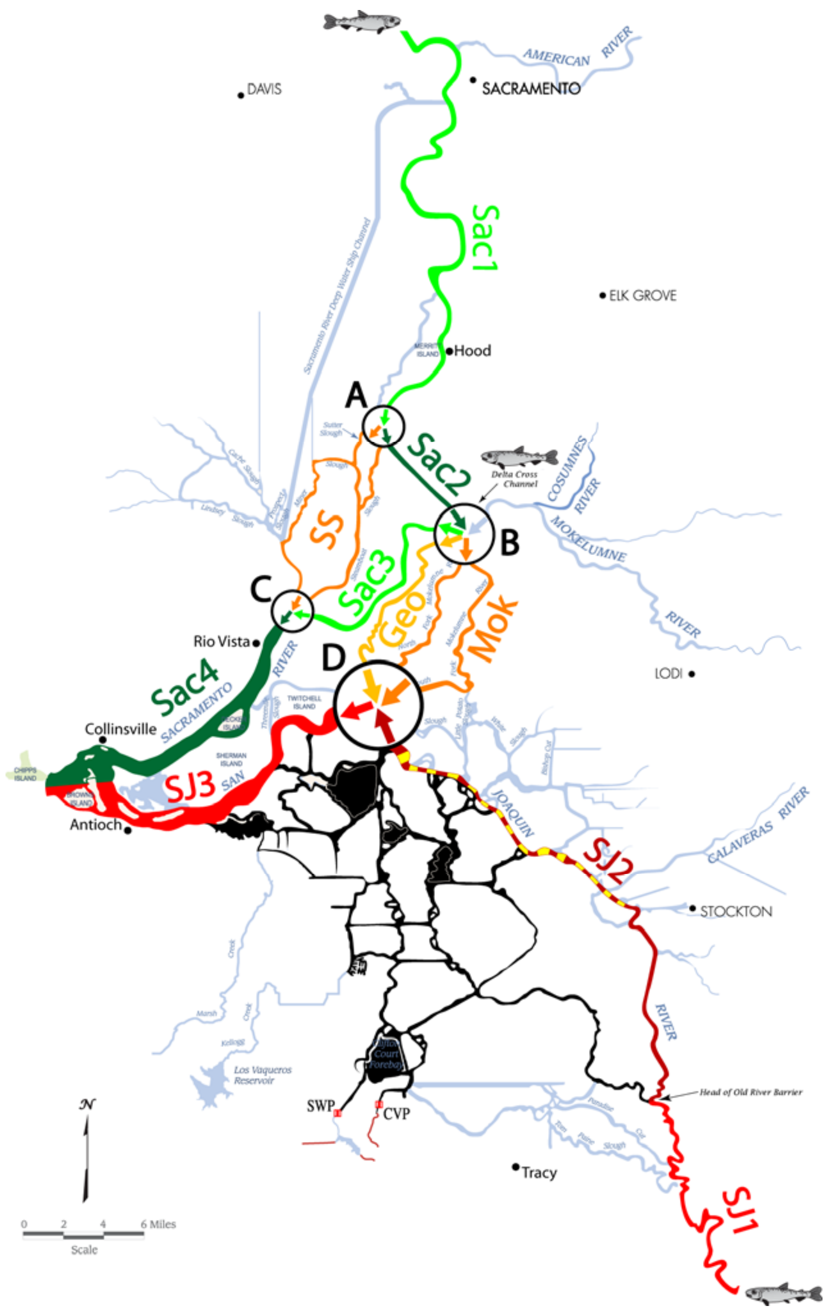


Figure 1. Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta Passage model. Reaches in the model are represented as colored segments of waterway. Reach labels are colored to match the reach. Junctions in the model are represented as circles containing arrows that correspond to the various flows entering and exiting each junction. Junctions are labeled by black letters, A-D. Salmonid symbols indicate locations where fish may be injected into the DPM.

Perry et al. (2009) describe in detail how tag detection, survival and route selection probabilities can be estimated from recovery of acoustic tagged salmon smolts. A complete mathematic expression for fish transit and survival through the Delta is provided in Appendix A. Given the complexity of the Delta, we provide a simplified example (Figure 2) to illustrate the conceptual basis for the DPM. In our simplified example, the number of smolts reaching the bay (N_B) can be calculated as:

1) $$N_B = \overbrace{(N_R - N_R*M_A)}^{\text{smolts lost in A}} - \overbrace{(N_R*1-M_A)*P_{B1}*M_B}^{\text{smolts lost in B1}} - \overbrace{(N_R*1-M_A)*P_{B2}*M_{B2}}^{\text{smolts lost in B2}}$$

$$- \underbrace{(((N_R*1-M_A)*P_{B1}*1-M_{B1}) + ((N_R*1-M_A)*P_{B2}*1-M_{B2}))}_{\text{smolts lost in C}}*M_C$$

where N_B is the number of smolts reaching the bay, N_R is the number of smolts entering from the river, M_i is reach specific smolt mortality for the i^{th} reach, and where P_i is the proportion of fish entering the i^{th} reach. In our simplified example, and in the DPM itself, M_i is a function of reach specific flow, P_i is a function of junction flow proportions, and M_C is a function of export pumping (Figure 2).

Route selection and mortality are influenced by south Delta exports, operations of the Delta Cross Channel gates (DCC), and by numerous other pathway-specific physical and biological factors. Similar to Kimmerer (2008) and NMFS (2009), we define a conceptual model where juvenile salmon migrating through the Delta are subject to one of four possible fates: background mortality (M_B), direct export mortality (M_D), indirect export mortality (M_I), or survival to Chipps Island (S_T). Total mortality (M_T) for juvenile salmon migrating through the Delta can then be defined as:

2) $$M_T = M_B + M_D + M_I$$

where M_B is mortality resulting from inflows, food, habitat, predation, water quality and disease, M_D is mortality which occurs at or near the CVP and SWP export facilities as a function of export pumping, and M_I is the additional, incremental mortality resulting from exports and DCC operations which alter Delta hydrodynamics and disrupt salmon out-migration cues.

For all of the analyses conducted in this paper, survival to Chipps Island is the response variable used to assess survival outcomes and to evaluate model function and sensitivity. Following from equation (2) survival to Chipps Island or total Delta survival (S_T) can be defined as:

3) $$S_T = 1/M_T$$

or from the example depicted in Figure 2 and equation (1):

4) $$S_T = N_B/N_R$$

Building on this conceptual framework, the DPM relies on empirical data from tagging studies of Delta salmon migration and Delta flow conditions to inform mechanisms affecting S_T. Survival estimates from acoustic tagging studies used to inform reach-specific survival parameters include all potential sources of mortality (M_B, M_D, and M_I). During experimental releases, tagged smolts were vulnerable to background mortality, and also to indirect and direct mortality associated with export facilities. Where supported by literature, functional relationships were created between Delta flow conditions (e.g. reach-specific flow, export flow) and fish survival and behavior (e.g. route selection, migration speed) to represent fish-habitat interactions as accurately as possible. Many environmental conditions besides flow (e.g. water temperature, predator densities, food availability) may influence the survival of migrating smolts, however, reach-specific data for many of these variables were not available to inform the creation of model functions.

The DPM was designed to model migration and mortality of juvenile Chinook salmon entering the Delta from one of three possible sources: the Sacramento River, the Mokelumne River, or the San Joaquin River. For simplicity, this paper focuses exclusively on salmon entering from the Sacramento River basin. The DPM depicts a simplified Delta channel network following the reaches and junctions depicted in Perry et al. (2009). Specifically, the DPM is composed of 10 reaches and four reach junctions (Figure 1). These reaches and junctions were selected to represent primary salmonid migration corridors where high quality fish and hydrodynamic data were available. For simplification, Sutter Slough and Steamboat Slough are combined as reach ***SS*** and the forks of the Mokelumne River are combined as reach ***Mok*** (Figure 1). At junction B, fish exit reach ***Sac2*** and enter either ***Sac3***, Georgiana Slough (***Geo***), or ***Mok*** (Figure 1).

The DPM operates on a daily time step using simulated daily tidally average flows, exports and DCC operations. Reach specific flow data were generated by the Delta Simulation Model II (DSM2-HYDRO) hydrology module and provided by RMA. We were provided with daily tidally averaged flows for the following six scenarios for the 2-Gates Project:

No Project, Lower Bound
No Project, Upper Bound
With Project, Gates Open, Lower Bound
With Project, Gates Open, Upper Bound
With Project, Gates Operating, Lower Bound
With Project, Gates Operating, Upper Bound

We injected smolts into the DPM at reach Sac1 using a typical emigration distribution for winter run Chinook salmon (Figure 2). For each of the six scenarios, we conducted 100 Monte Carlo simulations of smolt passage to allow for uncertainty estimates to be placed about predicted Delta survival values. Uncertainty and stochasticity associated with model parameters (reach-specific survivals, migration speeds, and route selections at junctions) are modeled using error estimates from acoustic tracking experiments. Parameter error values inform normal probability distributions that are sampled from each timestep (daily) to determine daily parameter values. For each Monte Carlo simulations we calculated survival to Chipps Island for each of the six scenarios reported mean, minimum and maximum response.

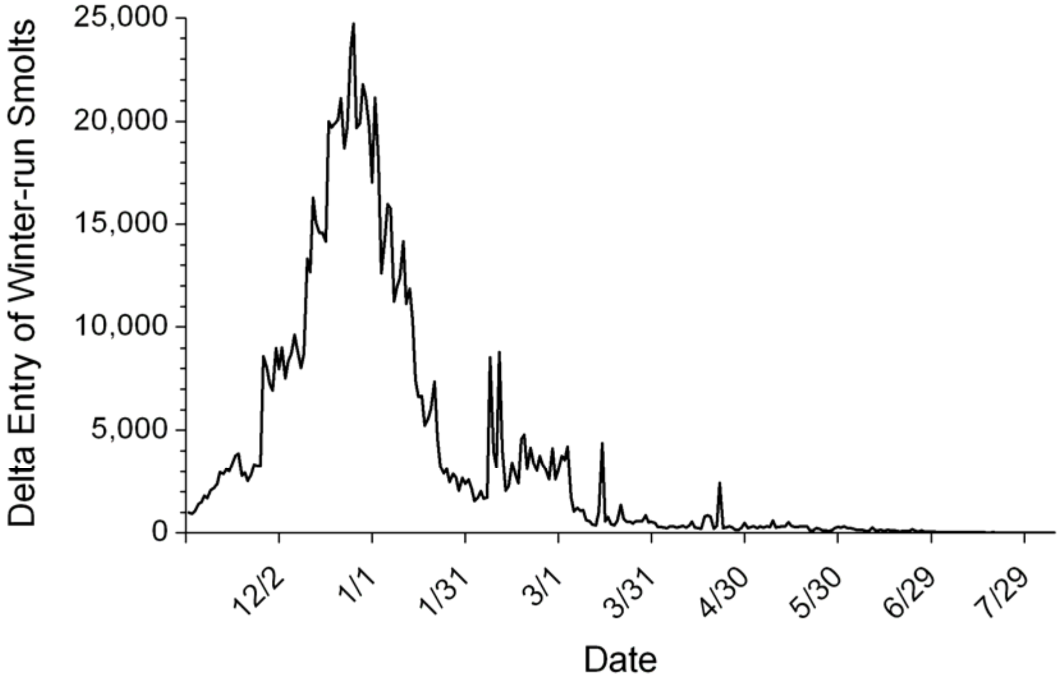
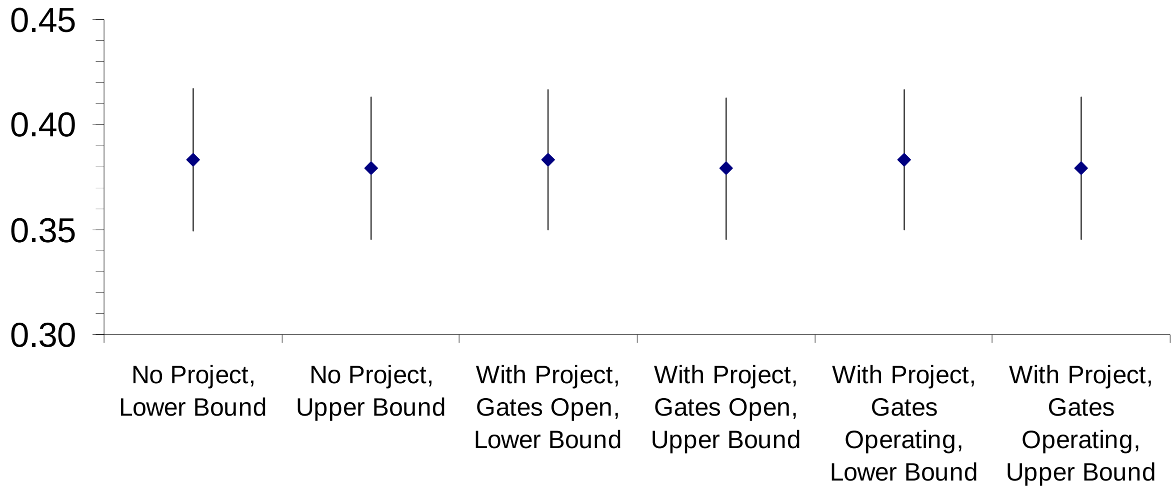


Figure 2. Estimated timing for winter run Chinook smolts reaching the Delta. Based on catch at Red Bluff Diversion Dam from 1997-2006 delayed for typical travel time to the Delta.

Results and Discussion

Our result found survival to Chipps Island for the 2003-2004 hydrology ranged between 34% and 42% for all the scenarios we evaluated. We observed only small differences in survival between any of the 2-Gates Project scenarios (Figure 3), and no significant survival differences between "No Project" and "With Project" conditions. These results are perhaps not surprising given that the proposed action scenarios have relatively little influence on flow patterns outside of the South Delta region. While the DPM cannot (at this time) address site specific effects which may occur in the immediate vicinity of the 2-Gates structure; our analysis found that roughly 20% of Sacramento River will migrate through the San Joaquin River reach where they might be exposed to direct effects of the 2-Gates Project.

These results provide a useful preliminary assessment of the 2-Gates Project likely population-level effects for Sacramento River origin juvenile salmonids. We did not observe any change in survival to Chipps Island which would be described as either biological or statistically significant. It is important to note again however, that we did not attempt to evaluate direct, site specific mortality which may be associated with the proposed project. However, our DPM runs suggest that only 1 in 5 Sacramento River origin smolts will pass through the region of the Delta where they might approach or be entrained toward the proposed project. A more detailed analysis of available acoustic tagging data from the South Delta would make it possible to better assess the local effects of the 2-Gates Project on Sacramento, Mokelumne and San Joaquin origin smolts. With additional South Delta details included in the DPM it would be possible to assess critical uncertainties related to possible Two Gate Project effects. The DPM could help identify these critical uncertainties and also provide a framework for planning and interpreting the results of new field studies and acoustic tagging experiments.



REFERENCES

Burau, J., A. Blake, and R. Perry. 2007. Sacramento/San Joaquin River Delta regional salmon outmigration study plan: Developing understanding for management and
restoration. http://baydeltaoffice.water.ca.gov/ndelta/salmon/documents/RegionalSalmonStudyPlan_2008.01.07.pdf

Kimmerer, W. 2008. Losses of Sacramento River Chinook salmon and delta smelt to
entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. 6(2).

Newman, K. B. & Rice, J. 2002. Modeling the survival of Chinook salmon smolts outmigrating through the lower Sacramento River system. Journal of the American Statistical Association 97, 983-993.

Newman, K. B. 2003. Modeling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. Statistical Modelling 3, 157-177.

Perry, R. W., P.L. Brandes, P.T. Sandstrom, A. Amman, B. MacFarlane, A.P. Klimley and J. R. Skalski. 2009. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management. In Press.

San Joaquin River Group Authority. 2007. 2007 Annual Technical Report.

K 2

Delta Passage Model

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Delta Passage Model

A system dynamics approach to integrating, understanding, and exploring salmon migration through Sacramento-San Joaquin Delta

Habitat, predators and flow conditions in the Sacramento-San Jouaquin Delta (Delta) are thought to profoundly influence Central Valley salmonid populations by impairing survival among outmigrating juveniles. Attempts to understand and quantify Delta salmonid mortality have been conducted for more than thirty years and have culminated in numerous reports (Kjelson and Brandes 1989, Baker et al. 1995, Brandes and McLain 2001, Newman and Rice 2002 , Newman 2003, Newman 2008, Kimmerer 2008, Vogel 2008, Perry and Skalski 2008). Despite the importance of Delta salmonid survival and a wealth of excellent studies, biologists and managers currently lack tools capable of integrating and illustrating patterns of salmonid behavior in relation to flow conditions and water project operations. The core purpose of the *Delta Passage* model is to provide a common, transparent framework upon which knowledge may be integrated and displayed. Most importantly, the *Delta Passage* model will serve as a "blackboard" upon which alternative hydrologies, water project operations, and fish behaviors may be evaluated for ESA compliance, water project alternatives, and to identify areas of critical uncertainty requiring further experiments.

What is the *Delta Passage* model?

- The Delta Passage model simulates migration and mortality of juvenile Chinook salmon from the Sacramento River, Mokelumne River, and San Joaquin River through the Delta.
- The model operates on a daily time step, using simulated flow through Delta channels.
    - Tidal influences on hydrodynamics and fish behavior are not addressed as we sought to represent average fish response over days, not hours.
- The model is composed of 10 reaches and five reach junctions (Figure 1).
- Fish behavior at reach junctions and mortality within reaches is modeled probabilistically using empirical estimates of variance.
- Users can select input conditions including Sacramento River flow, Mokelumne River flow, San Joaquin flow, South Delta Exports, DCC Position, Yolo Bypass flow, and Hood Bypass Diversion flow.
- For each user selected scenario, 100 Monte Carlo simulations are generated, providing estimates of salmon survival to Chipps Island and confidence intervals.

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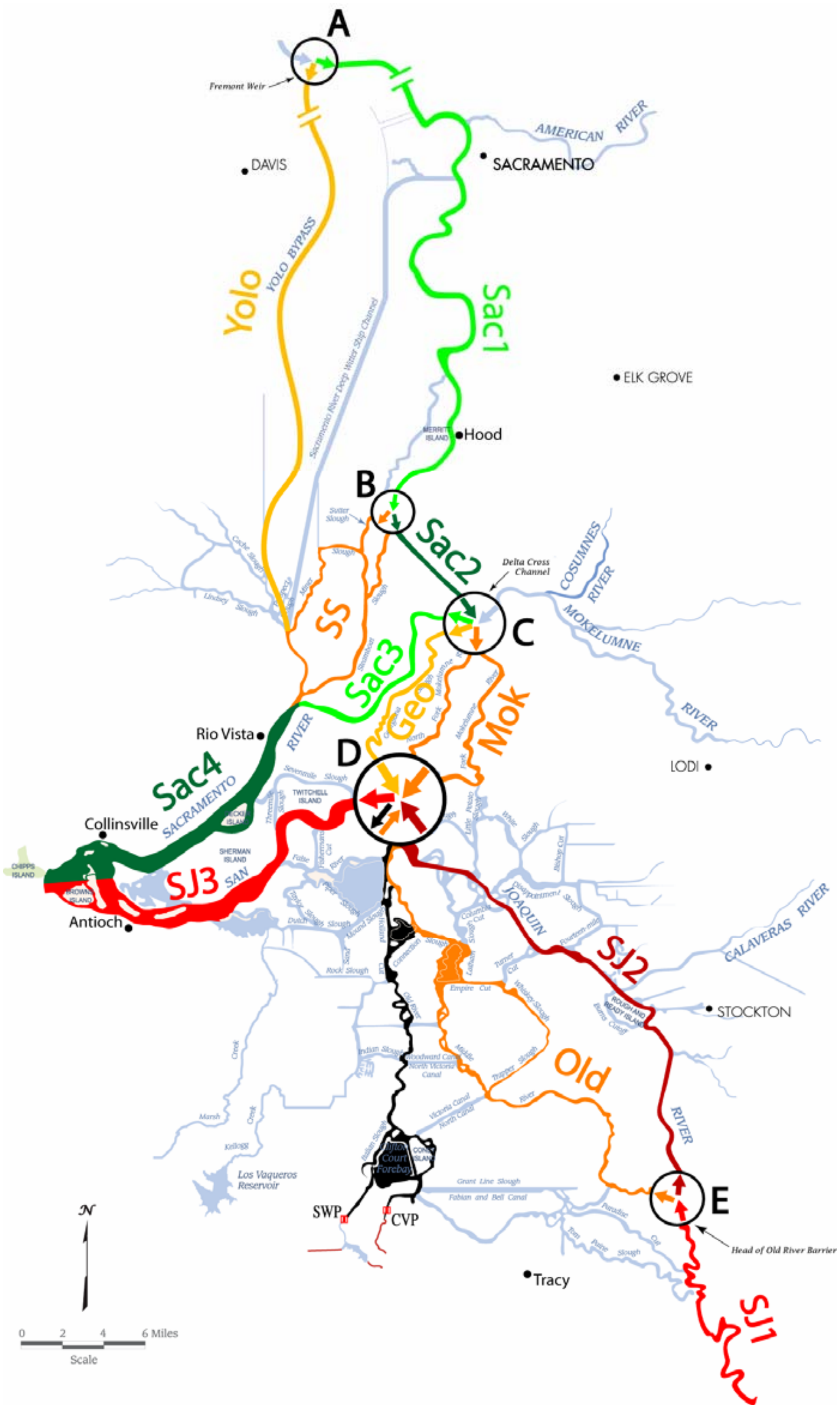

Figure 1. Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta Passage model. Reaches in the model are represented as colored segments of waterway. Reach labels are colored to match the reach. Junctions in the model are represented as circles containing arrows that correspond to the various flows entering and exiting each junction. Junctions are labeled by black letters, A-E.

Delta Flow

- Water movement though the Delta is based on empirical observations and Delta Simulation Model II (DSM2) simulations.
  - Main River inflows (Sacramento, Mokelumne, San Joaquin) provide the user-input data or user-selected conditions.
  - Moving downstream, flow allocation at each junction is determined by a function derived from empirical data and DSM2 simulated flow output (Figure 2).
    - Flow allocation is predicted as a linear function of incoming flow at the Sutter/Steamboat Sloughs, DCC, and Georgiana Slough junctions with the Sacramento River (Figure 2).
    - At the junction of the San Joaquin River and Old River, squared Old River flow (*Old River*) is predicted as a linear function of incoming San Joaquin River flow (*SJ*) and total Delta Exports (*Exports*):

      $$Old\ River^2 = B_1(SJ) + B_2(Exports) - 1839630$$

      where B_1 = 1827.67 and B_2 = 107.07. Squared Old River flow was significantly related to incoming San Joaquin flow and total Delta exports ($F_{2,299}$ = 1304, $P < 0.001$). San Joaquin River flow and total Delta exports explained 89.7% of observed variation in squared Old River flow.

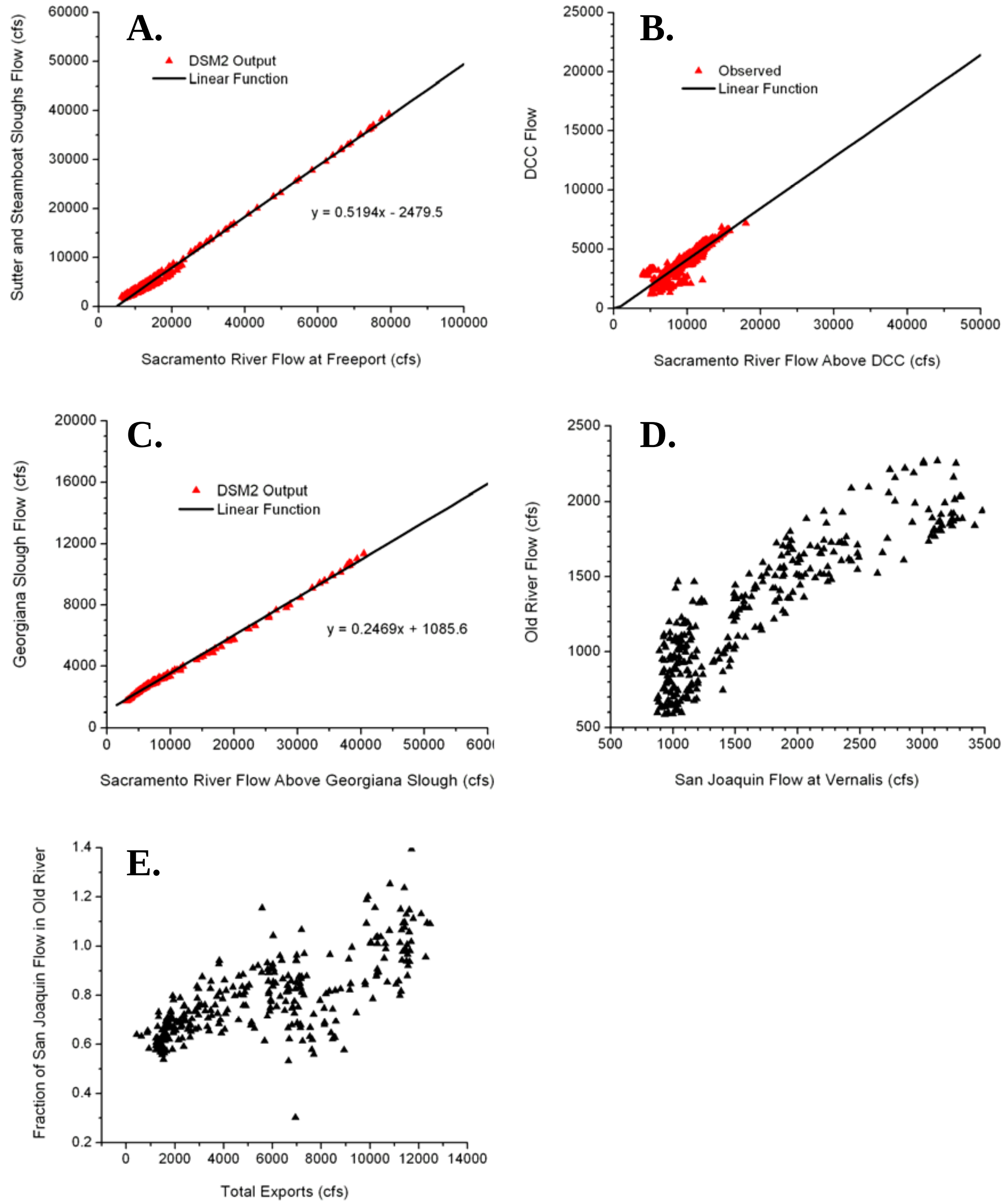

Figure 2. Flow relationships at Delta junctions used to inform flow movement in the Delta Passage model. Figures A-C depict linear functions used in the Delta Passage model to predict split flow from incoming flow at each flow junction: A) The junction of Sutter and Steamboat Sloughs with the Sacramento River, B) The junction of the Delta Cross Channel with the Sacramento River, and C) The junction of Georgiana Slough with the Sacramento River. Figures D depicts the relationship between incoming San Joaquin River flow and Old River flow. Figure E depicts the relationship between total Delta exports and the fraction of San Joaquin River flow being diverted down Old River. Incoming San Joaquin River flow and total Delta exports are independent variables in a multivariate linear function used to predict Old River flow.

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Migration Speed

- Smolt migration speed is reach-specific as informed by acoustic tagging studies.
  - For North Delta reaches **Sac1**, **Sac2**, **Sac3**, **SS**, **Geo**, and **Mok** mean migration speed is predicted as a linear function of flow (Figure 3).
    - Observed flows and migration speeds from acoustic studies for reach **Sac1** were used to create a best-fit linear relationship (Figure 3). Because migration speed data is unavailable for all other North Delta reaches, this linear function is applied North Delta-wide.
  - Due to strong tidal influences in reach **Sac4** (between Rio Vista and Chipps Island) we chose to have mean migration speed independent of reach inflow. For reach **Sac4,** mean migration speed is set constant at 22.634 km/day, the average speed of smolts in the **Sac1** reach from the acoustic study data.
  - Average migration speeds observed in acoustic studies are used to set mean migration speed for San Joaquin River reaches **SJ1** and **SJ2**. For **SJ3**, mean migration speed is set the same as **SJ2** because no migration speed data is available.
  - Stochasticity/uncertainty for migration rate is modeled using error estimates from acoustic tracking experiments.
    - Migration speed variance from acoustic study data is used along with mean migration speed to define a normal probability distribution that is sampled from each day to determine the daily migration speed in each reach (Table 1).

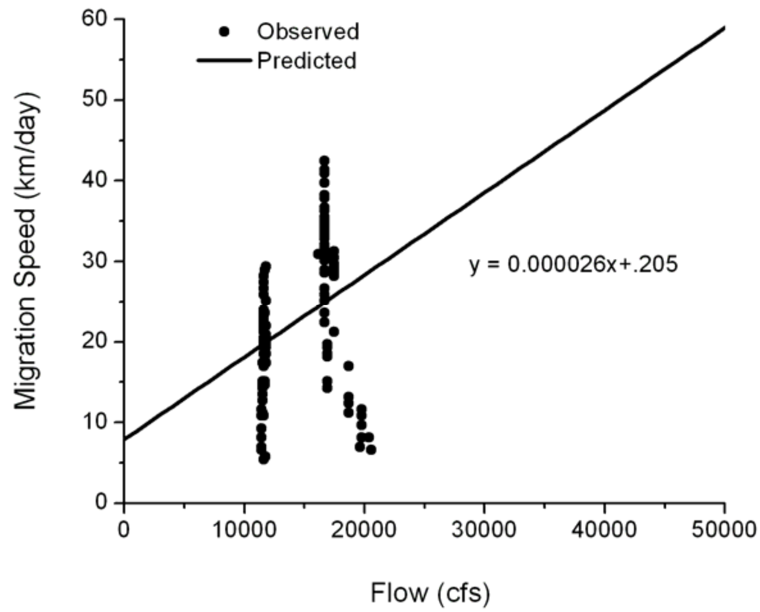

Figure 3. Linear function used to predict migration speed from flow for reaches in the North Delta. Observed data is from acoustic study data for the Sac1 reach between West Sacramento and the entrance of Sutter Slough.

Table 1. Mean and standard deviations used to define a normal probability distribution that is sampled from each day to determine the daily migration speed in each reach.

Reach	Mean (km/day)	Standard Deviation
Sac1	Linear function of flow	9.105
SS	Linear function of flow	9.105
Sac2	Linear function of flow	9.105
Sac3	Linear function of flow	9.105
Sac4	22.634	9.105
Geo	Linear function of flow	9.105
Mok	Linear function of flow	9.105
SJ1	30.938	0.266
SJ2	21.630	0.411
SJ3	21.630	0.411

Migration Pathways

- At reach junctions **A**, **B**, **C**, and **E** smolts are diverted into reaches proportional to the flow diverted. Perry and Skalski (2008) found that acoustically tagged Chinook smolts moved proportionally with flow for North Delta releases (see figure 4 from Perry and Skalski 2008). Stochasticity/uncertainty is modeled using the largest error estimates for all acoustic tracking experiments at a given reach junction.
- Movement of fish toward the state and federal pumps at junction **D** is informed by Kimmerer (2008) analysis of releases of coded wire tagged Chinook smolts in the Delta. Kimmerer (2008) found that percent salvage of Coleman National Fish Hatchery smolts increased non-linearly with export flow (see figure 9 from Kimmerer 2008). In our model, the percentage of fish moving towards the pumps is predicted from total Delta exports using Kimmerer's nonlinear function.
- The status of two migration barriers, the Delta Cross Channel (DCC) and the Head of Old River Barrier (HORB), is determined by user inputs.

Survival

- Daily smolt survival is predicted as a linear function of flow (Figure 5; Figure 6).
  - For North Delta reaches **Sac1**, **Sac2**, **Sac3**, **Sac4**, **SS**, **Geo**, **Mok,** and **SJ3** the slope of the linear relationship between flow and survival proportion was informed by the flow/survival relationship developed by Newman (2003) from CWT Chinook smolt releases in the North Delta.
    - The y-intercept of the linear relationship between flow and survival for each reach was calculated using the average of all acoustic study survival estimates (*y*), and the average daily flow during the acoustic studies (*x*):

$$Intercept = y - mx$$

where m = slope from Newman (2003).

- For San Joaquin Reaches **SJ1** and **SJ2** the linear function that predicts survival proportion from flow was created by linearly regressing flow and survival proportion data from acoustic studies (Figure 6). For each reach, a separate function was created for each HORB status (in or out).
- Stochasticity/uncertainty is modeled using error estimates from acoustic study data. The mean daily survival is used along with the reach-specific standard deviation to define a normal probability distribution that is sampled from each day to determine the daily survival rate at each reach (Table 2).

- The entrainment rate of fish at the pumps is 70%, with 30% of fish being salvaged. In our model, salvaged (saved) fish are monitored but do not re-enter the Delta system.

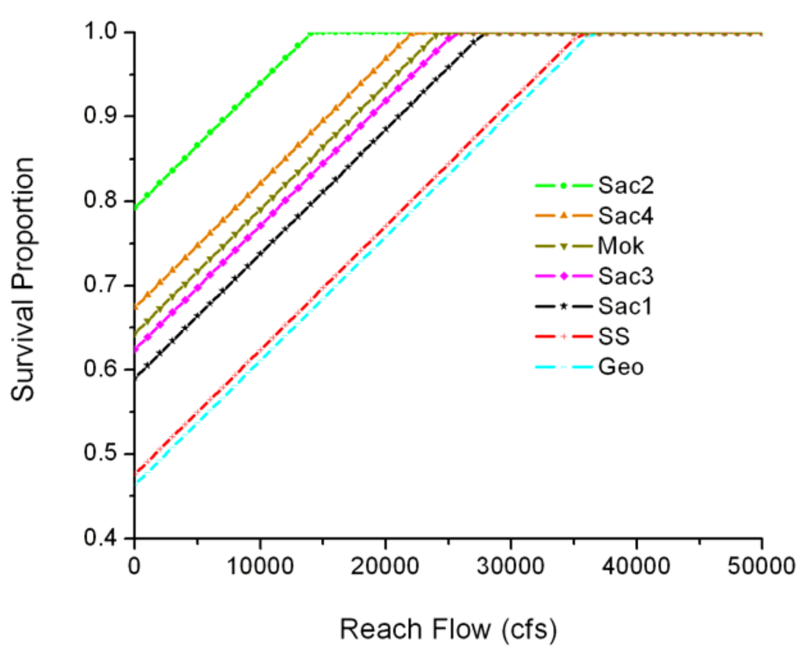

Figure 5. Reach-specific survival proportion as a linear function of flow for North Delta reaches.

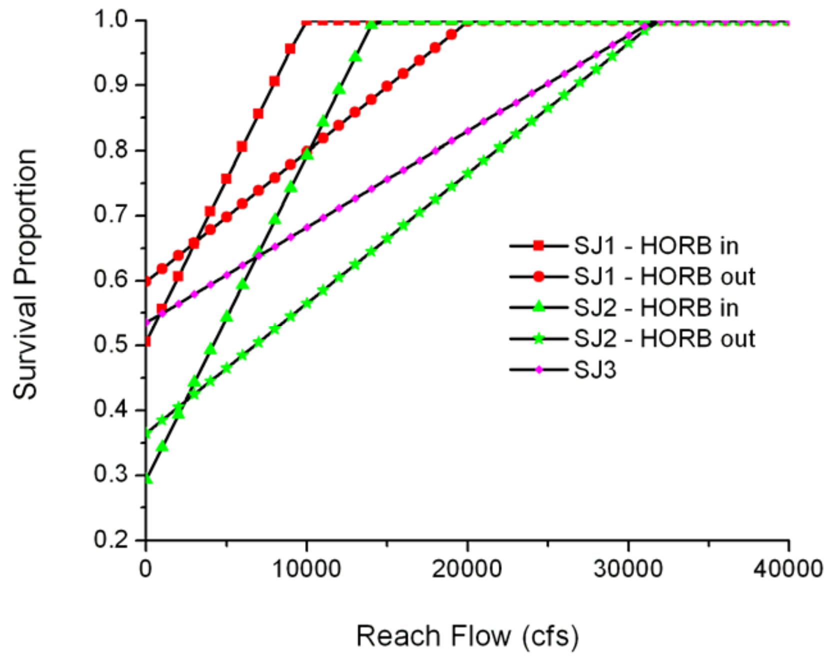

Figure 6. Reach-specific survival proportion as a linear function of flow for San Joaquin reaches.

Table 2. Slopes and intercepts used for creation of reach-specific linear functions for prediction of mean daily survival from daily flow. The mean daily survival is used along with the reach-specific standard deviation to define a normal probability distribution that is sampled from each day to determine the daily survival rate at each reach.

Reach	Intercept	Slope	Standard Deviation
Sac1	0.590	1.47E-05	0.039
SS	0.476	1.47E-05	0.120
Sac2	0.792	1.47E-05	0.045
Sac3	0.624	1.47E-05	0.108
Sac4	0.674	1.47E-05	0.235
Geo	0.464	1.47E-05	0.206
Mok	0.643	1.47E-05	0.173
SJ3	0.535	1.47E-05	0.213
SJ1 - HORB in	0.506	5.00E-05	0.057
SJ1 - HORB out	0.598	2.00E-05	0.057
SJ2 - HORB in	0.293	5.00E-05	0.220
SJ2 - HORB out	0.365	2.00E-05	0.220

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References

Baker, P. F., Speed, T. P. & Ligon, F. K. (1995). Estimating the influence of temperature on the survival of Chinook salmon smolts migrating through the Sacramento-San Joaquin River Delta of California.. *Canadian Journal of Fisheries and Aquatic Sciences* **52**, 855-863.

Brandes, P. and J. Mclain. 2001. Juvenile Chinook salmon abundance and distribution, and survival in the Sacramento-San Joaquin Exstuary. In: Brown RL, editor. Fish Bulletin 179: Contributions to the biology of Central Valley Salmonids. Volume 2. Sacramento (CA): California Department of Natural Resources.

Kimmerer, W. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science Vol. 6, Issue 2 (June), Article 2.

Kjelson, M. and P. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento San-Joaquin Rivers, California. In Levings C. et al., editors. Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105, pages 100-115.

Newman, K. B. 2003. Modeling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. *Statistical Modelling* **3**, 157-177.

Newman, K. B. & Rice, J. 2002. Modeling the survival of Chinook salmon smolts outmigrating through the lower Sacramento River system. *Journal of the American Statistical Association* **97**, 983-993.

Newman, K. B. 2008. An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon survival studies. Project number SCI-06-G06-299. U.S. Fish and Wildlife Service, Stockton, CA. Available: http://www.science.calwater.ca.gov/pdf/psp/PSP_2004_final/PSP_CalFed_FWS_salmon_studies_final_033108.pdf (November 2008).

Perry, R. W. and J. R. Skalski. 2008. Migration and survival of juvenile Chinook salmon through the Sacramento-San Joaquin River Delta during the winter of 2006-2007. U.S. Fish and Wildlife Service Report.

San Joaquin River Group Authority. 2007. 2007 Annual Technical Report.

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Vogel, D. 2008. Pilot study to evaluate acoustic-tagged juvenile Chinook salmon smolt migration in the northern Sacramento-San Joaquin Delta, 2006-2007. California Department of Natural Resources Report.

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Appendix A

Sensitivity Analysis – 10/29/08

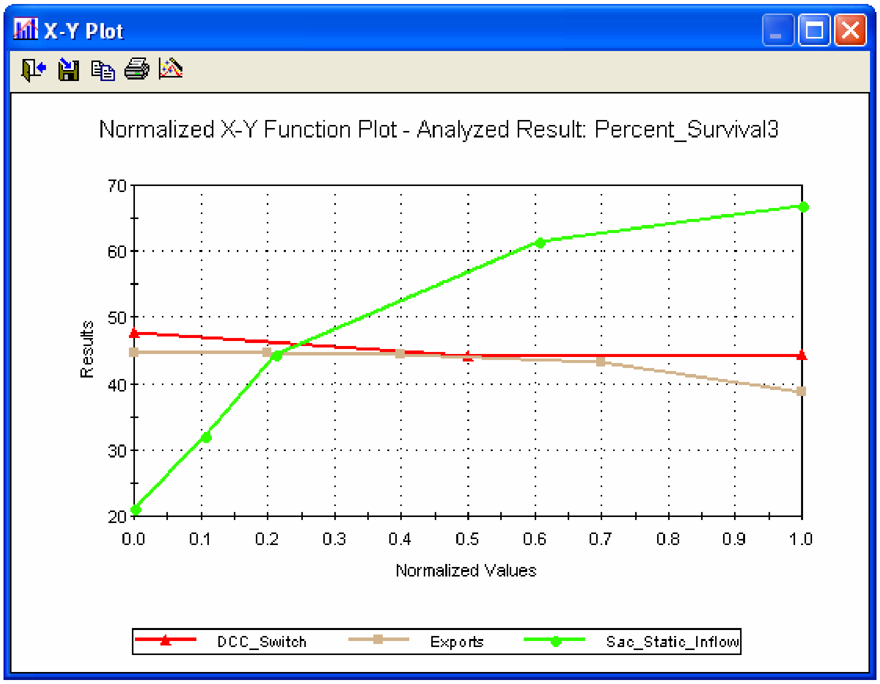
A sensitivity analysis was performed using GoldSim's sensitivity analysis application. Variation in overall passage survival was examined for each release group (Sacramento, Mokelumne, and San Joaquin) as the Delta Cross Channel (DCC) position, Delta inflow, total exports, and Head of Old River Barrier (HORB) status were varied. Each independent variable was varied from an extreme low value to an extreme high value with three additional values in between, for a total of five scenarios for each independent variable. All other model conditions remained constant as each independent variable was varied.

Sacramento Release Group

Survival of smolts released in the Sacramento River at West Sacramento were strongly sensitive to changes in Sacramento flow at Freeport, with survival varying from 20-67% as flow varied from 5,000-100,000 cfs. Survival was less sensitive to DCC gate position and total exports, with survival decreasing slightly as the DCC changed from closed to open and as total exports increased.

Sensitivity Analysis Result Data

	DCC_Switch		Sac_Static_Inflow		Exports	
	Variable Value [-]	Result Value [-]	Variable Value [1/day]	Result Value [-]	Variable Value [1/day]	Result Value [-]
Lower	0.000	47.663	5000.000	21.072	1.000	44.662
Point 2	0.333	44.130	11666.667	28.153	2000.667	44.660
Point 3	0.667	44.130	18333.334	36.214	4000.333	44.628
Central	1.000	44.495	25000.000	44.495	6000.000	44.495
Point 5	1.000	44.495	50000.000	57.466	9000.000	43.806
Point 6	1.000	44.495	75000.000	64.491	12000.000	42.222
Upper	1.000	44.495	100000.000	66.868	15000.000	38.733



Mokelumne Release Group

Survival of smolts released at the forks of the Mokelumne River were most sensitive to changes in total exports, with survival varying from 46-27.5% as total exports increased from 1-15,000 cfs. Smolts survival was less sensitive to Mokelumne River inflow and DCC position, with survival increasing slightly as Mokelumne River inflow increased and as DCC position changed from closed to open.

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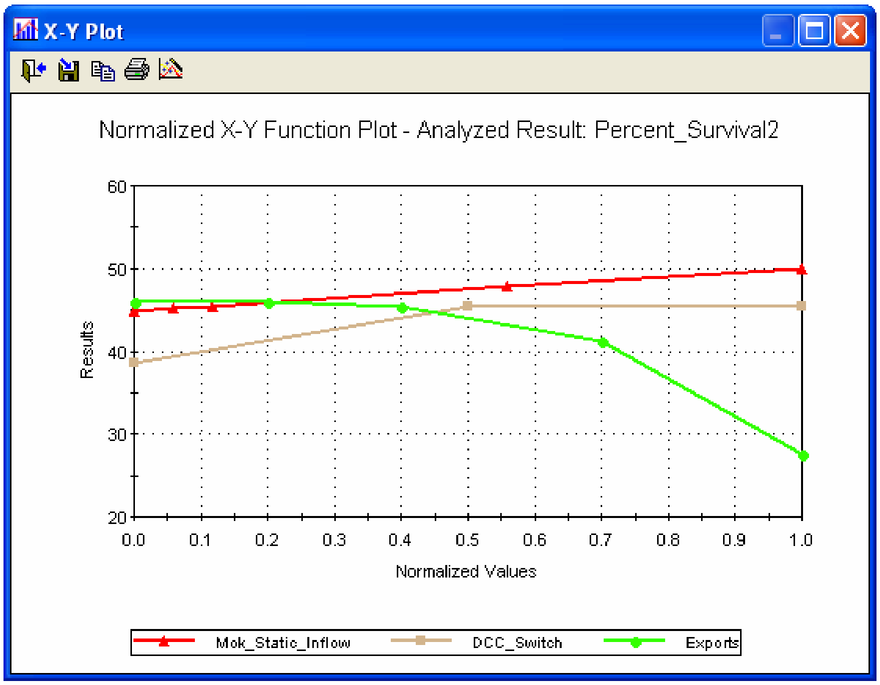
Sensitivity Analysis Result Data

	Mok_Static_Inflow		DCC_Switch		Exports	
	Variable Value [1/day]	Result Value [-]	Variable Value [-]	Result Value [-]	Variable Value [1/day]	Result Value [-]
Lower	100.000	44.869	0.000	38.641	1.000	46.007
Point 2	300.000	45.178	0.500	45.487	3000.500	45.949
Central	500.000	45.487	1.000	45.487	6000.000	45.487
Point 4	2000.000	47.783	1.000	45.487	10500.000	41.289
Upper	3500.000	50.040	1.000	45.487	15000.000	27.530



San Joaquin River

Survival of smolts released in the San Joaquin River at Durham Ferry were strongly sensitive to changes in San Joaquin flow at Vernalis, with survival varying from 23.7-64% as flow varied from 500-25,000 cfs. Survival was also sensitive to HORB status and total exports, with survival decreasing as the HORB was removed and as total exports increased.

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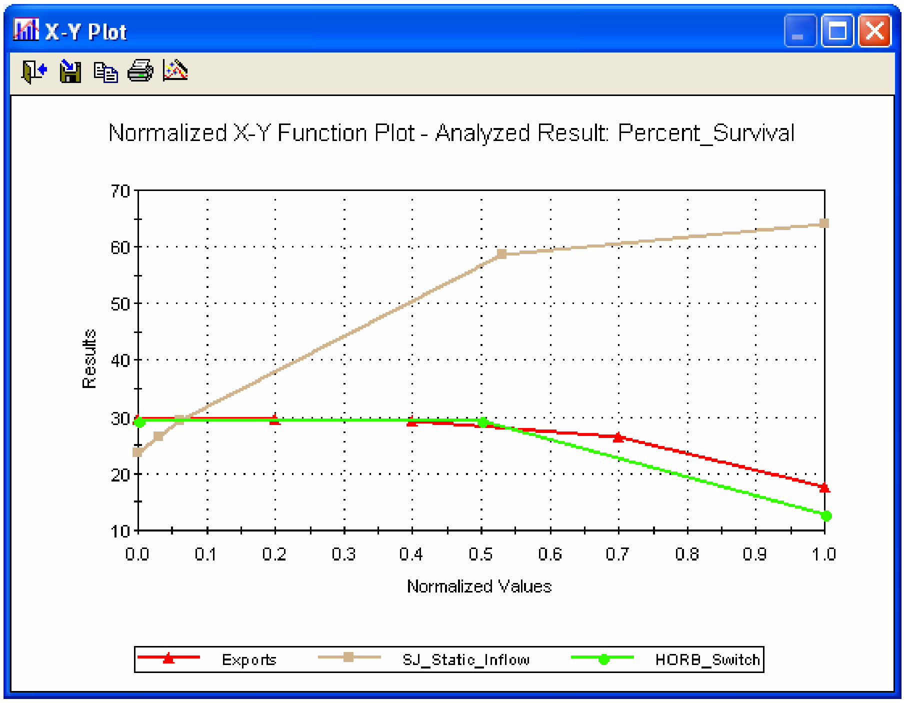
Sensitivity Analysis Result Data

	Exports		SJ_Static_Inflow		HORB_Switch	
	Variable Value [1/day]	Result Value [-]	Variable Value [1/day]	Result Value [-]	Variable Value [-]	Result Value [-]
Lower	1.000	29.622	500.000	23.775	0.000	29.287
Point 2	3000.500	29.585	1250.000	26.483	0.000	29.287
Central	6000.000	29.287	2000.000	29.287	0.000	29.287
Point 4	10500.000	26.585	13500.000	58.726	0.500	29.287
Upper	15000.000	17.726	25000.000	64.012	1.000	12.877



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Appendix B

Model Testing – 10/30/08

We tested the Delta Passage Model by validating model outcomes with results from acoustic tagging studies. We compared model outcomes to results of December 06 and January 07 Vemco acoustic tagging studies as calculated by Perry and Skalski 2008. These two studies along with the two HTI acoustic studies encompassed the dataset utilized for creation of functional relationships in the North Delta portion of the model. Delta conditions in the model were set to mimic conditions present during the two Vemco acoustic studies, including release date, flow conditions, DCC gate position, and total export level.

December 06 Vemco Study

We compared overall and reach-specific survival estimates and fish split proportions between modeled and observed results. To mimic the December 2006 Vemco acoustic study, the model was set to "release" 64 smolts in West Sacramento on December 5th, 2006, under historic flow and export conditions.

Mean overall Delta survival was slightly lower for the Delta Passage Model (0.310) than the acoustic study results (0.351; Table 1). However, the mean overall survival estimated by the model falls within the 95% confidence interval of the acoustic study estimate (Table 1). The model underestimated survival for 6 of 9 Delta reaches examined (Figure 1). Model estimates of proportional fish migration at each flow split were similar to acoustic study estimates (Figure 2).

Table 1. Estimated mean survival from Perry and Skalski 2008 and approximate mean survival from the Delta Passage Model for each Delta reach for the December 2006 release. Data in parentheses for overall survival estimates are 95% confidence intervals.

Reach	Perry and Skalski 2008	Passage Model
Sac1	0.843777	0.7928
Sutter	0.389	0.54351
Sac2	0.947	0.919
Sac3	0.6914	0.667
Sac4	0.714	0.7025
DCC	0.917	0.9196
Mok	0.707	0.6903
Geo	0.648	0.5
SJ3	0.571	0.617
Overall	**0.351 (0.2-0.69)**	**0.31(0.21-0.40)**

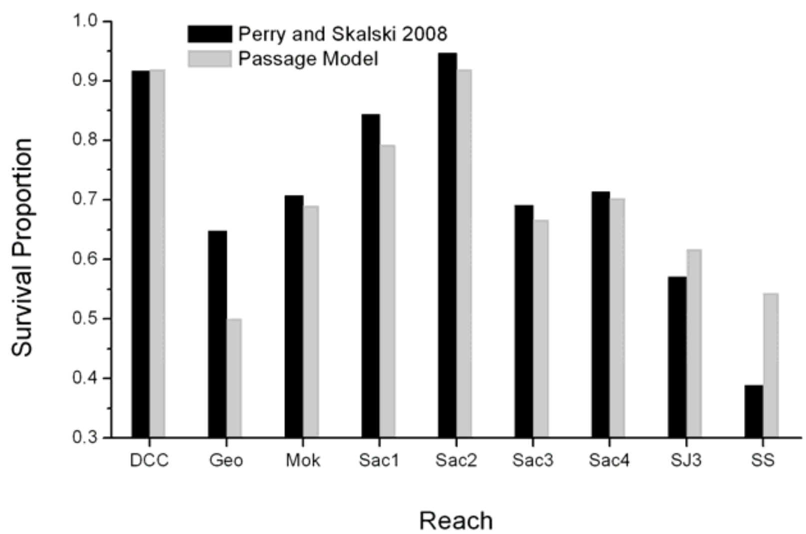


Figure 1. Estimates of the survival proportion at each reach from Perry and Skalski 2008 and Delta Passage Model for the December 2006 release.

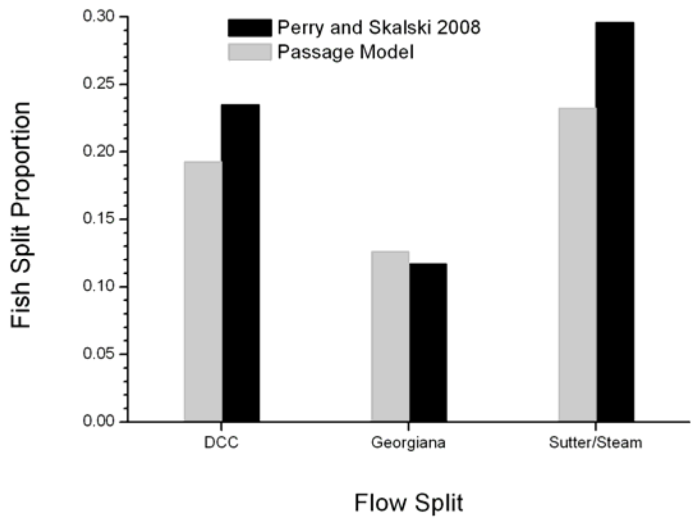


Figure 2. Estimates of proportions of fish migrating down each route from Perry and Skalski 2008 and Delta Passage Model for the December 2006 release.

January 07 Vemco Study

We compared overall and reach-specific survival estimates and fish split proportions between modeled and observed results. To mimic the January 2007 Vemco acoustic study, the model was set to “release” 80 smolts in West Sacramento on January 17th, 2007, under historic flow and export conditions.

Unlike the December 2006 comparison, mean overall survival was much lower for the Delta Passage Model (0.313) than the acoustic study results (0.543; Table 2). The mean overall survival estimated by the model did not fall within the 95% confidence interval of the acoustic study estimate (Table 2). The model underestimated survival at 5 of 6 Delta reaches examined (Figure 3). The model’s estimate of the proportion of fish migrating down Georgiana Slough was more than three times greater than the acoustic study estimate (Figure 4).

Table 2. Estimated mean survival from Perry and Skalski 2008 and approximate mean survival from the Delta Passage Model for each Delta reach for the January 2007 release. Data in parentheses for overall survival estimates are 95% confidence intervals.

Reach	Perry and Skalski 2008	Passage Model
Sac1	0.8756	0.7697
SS	0.681	0.52657
Sac2	0.976	0.9118
Sac3	0.70325	0.702
Sac4	0.8577	0.7218
Geo-Chipps	0.368	0.3031
Overall	**.543(0.42-0.69)**	**.313(0.22-0.40)**

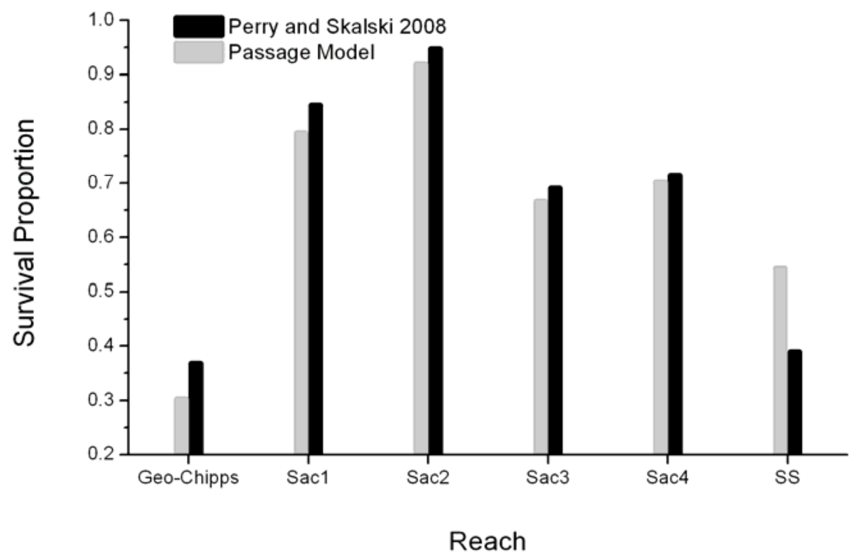


Figure 3. Estimates of the survival proportion at each reach from Perry and Skalski 2008 and Delta Passage Model for the December 2006 release.

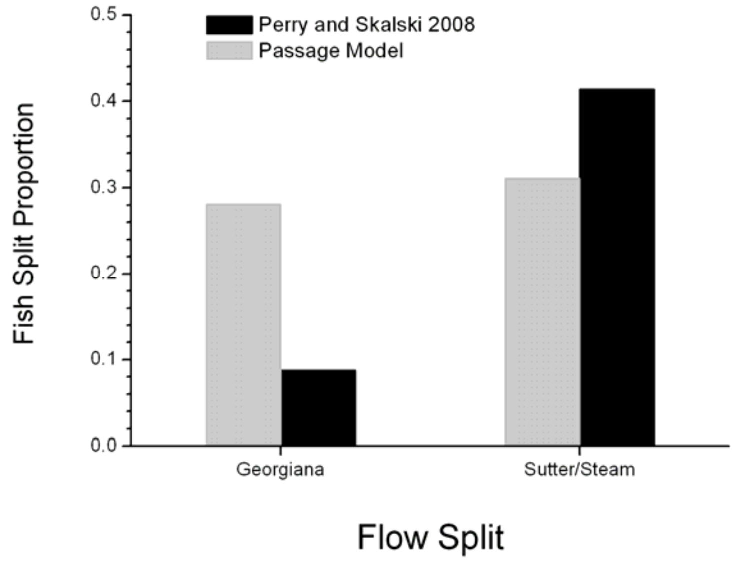


Figure 4. Estimates of proportions of fish migrating down each route from Perry and Skalski 2008 and Delta Passage Model for the January 2006 release.

Conclusion

The findings of the Delta passage model validation runs were mixed. While the Delta Passage Model estimated fish survival and movement at flow splits accurately for the December 2006 study, the model inaccurately modeled fish passage for the January 2007 study. Survival estimated for the January 2007 acoustic study was higher than average survival across all acoustic studies for four of the five reaches examined (Figure 5). Since the model uses the average survival across all acoustic studies in the calculation of mean reach-specific survival, the model consistently used reach-specific survival values lower than observed in the January 2007 acoustic study, thereby leading to a large underestimation of overall Delta survival.

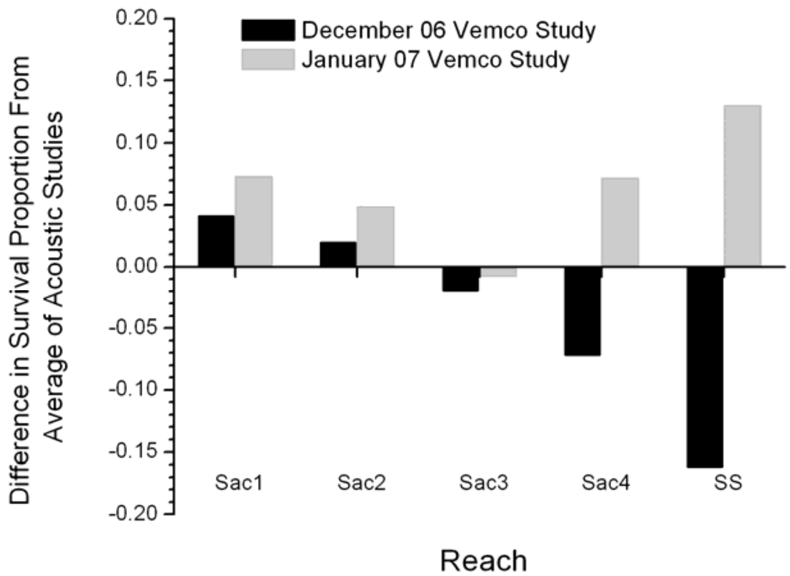


Figure 5. Reach-specific differences in survival proportion from average survival across all acoustic surveys for the December 2006 and January 2007 surveys.

Discussion

Our model-building approach has been to use the best available fish passage data to find relationships between Delta conditions and fish survival and movement to inform the creation of functional relationships in the model. Even though estimation error is present in estimates of survival and fish split proportions in each acoustic study, we believe reliable mechanisms that can predict fish survival and movement behavior will be found due to the robust sampling data used to build model functionality. Currently we are relying on a limited number of tagging studies, but intend to incorporate data from future tagging efforts to strengthen our functional relationships and provide more evidence for survival and movement mechanisms.

Because our model is built on relationships created using data from multiple acoustic tracking studies, we shouldn't expect our model to be able to accurately predict the survival and movement patterns from any individual fish acoustic study. Estimation error in passage statistics of acoustic studies and unexplained environmental variation limit our model's ability to accurately predict Delta passage. However, our model incorporates the major environmental mechanisms influencing fish survival and passage in the Delta as accurately as available data allows. Therefore, we believe our model can be useful as a learning tool for understanding how alternative water operation scenarios affect smolt survival and movement through the Delta.

K 3

Technical Memorandum: October 3, 2009

Technical Memorandum

TO: **Metropolitan Water District of Southern California**
FROM: Brad Cavallo (lead), Paul Bergman, and Mark Teply
SUBJECT: Preliminary assessment of the 2-Gates Project effects on San Joaquin River origin salmonid smolts
DATE: October 3rd, 2009

The Delta Passage Model (DPM) routes salmon smolts through Delta channels according to the proportion of tidally averaged flows taking each route. While recent acoustic tagging study analyses show that route selection is more complex, the generalized pattern is still that fish will "go with the flow" (Perry et al. 2009). We earlier applied the DPM to assess how salmonid smolt entering the Delta from the Sacramento River would likely be influenced by the proposed 2-Gates Project. Such an analysis was also desirable for salmonid smolts entering the Delta from the San Joaquin River. However, the south Delta component of the DPM is still under development and not be completed in time for this application. In lieu of a completed DPM for the San Joaquin River and south Delta, here we provide a cursory analysis of changes in tidally averaged flows at five key smolt migration junctions.

Methods

Consistent with the findings of Perry et al. (2009), we assume in this analysis (as in the DPM) that salmon smolts arriving at distributaries will generally enter reaches in proportion to the daily tidally averaged entering each reach. On the San Joaquin River (SJR) there are five key junctions wherein salmonid smolts may leave the mainstem SJR and move into the interior Delta channels (towards the export facilities). Ordered from upstream to downstream, these junctions are: Old River, Turner Cut, Columbia Cut, and what we termed Franks Tract East, and Franks Tract West. For our analyses, each of these junctions is represented by the ratio of daily tidally averaged flows within each interior Delta channel and the flow immediately upstream of the junction on the mainstem SJR. All flows were determined from DSM2 Hydro data provided by RMA. Flow ratios for each junction were calculated using the following DSM2 nodes:

Junction	Interior Delta Channel Node	SJR Mainstem Node
Old River	Ch 55	Ch 6
Turner Cut	Ch 172	Ch 22
Columbia Cut	Ch 160	Ch 31
Franks Tract East	Ch 124	Ch 42
Franks Tract West	Ch 279	Ch 48

DSM2 flow data may be either positive or negative depending on the actual direction of flow and by the standard convention used by those who constructed the DSM2 model. We used the sign (positive or negative) of the flow provided. We did not attempt to interpret the data based on the flow sign, but rather by contrasting differences in flow patterns among 2-Gates operational scenarios. We evaluated the following six scenarios for the 2-Gates Project:

No Project, Lower Bound
No Project, Upper Bound
With Project, Gates Open, Lower Bound
With Project, Gates Open, Upper Bound
With Project, Gates Operating, Lower Bound
With Project, Gates Operating, Upper Bound

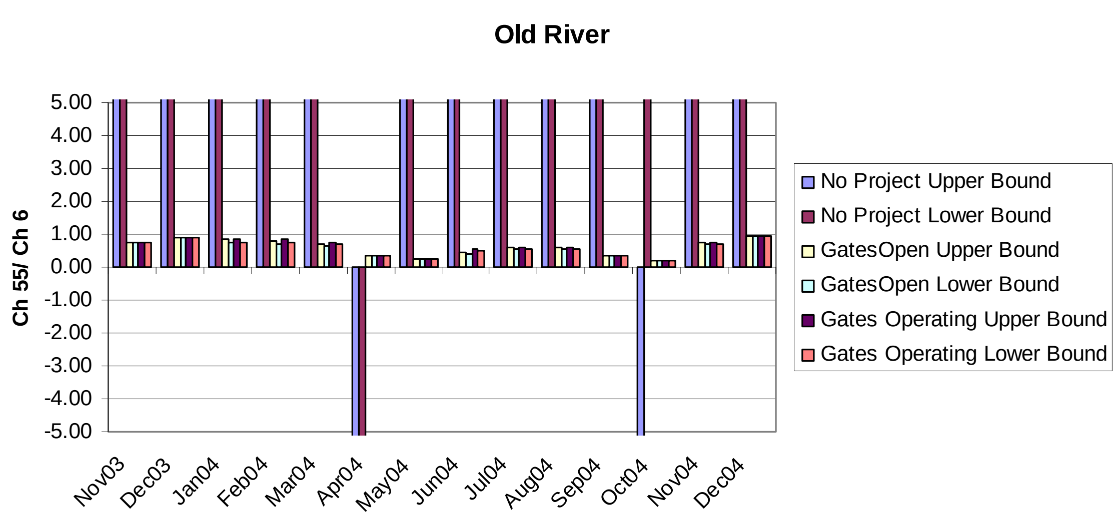
After calculating the ratio of junction flows as listed in the previous table, we further summarized the data as average monthly flows for each junction and each operational alternative.

Results and Discussion

As might be expected, results differed substantially between junctions. Reduced tidal influence and inflows from the SJR produced the largest flow ratios at the Old River junction. The flow ratios were generally positive indicating that flows going down

Old River

MonthYear	No Project Upper Bound	No Project Lower Bound	GatesOpen Upper Bound	GatesOpen Lower Bound	Gates Operating Upper Bound	Gates Operating Lower Bound
Nov03	15.31	15.31	0.75	0.75	0.75	0.75
Dec03	15.60	15.96	0.91	0.88	0.91	0.88
Jan04	16.75	19.18	0.86	0.74	0.87	0.74
Feb04	18.98	21.77	0.82	0.71	0.85	0.73
Mar04	21.38	22.56	0.68	0.63	0.74	0.68
Apr04	-27.03	-23.09	0.35	0.34	0.35	0.35
May04	112.80	100.67	0.24	0.24	0.24	0.24
Jun04	10.79	12.43	0.46	0.40	0.56	0.51
Jul04	7.68	7.64	0.58	0.57	0.58	0.57
Aug04	8.12	8.03	0.58	0.56	0.58	0.56
Sep04	30.61	5.44	0.36	0.35	0.36	0.35
Oct04	-157.16	51.38	0.20	0.19	0.20	0.19
Nov04	33.54	59.47	0.73	0.72	0.73	0.72
Dec04	15.40	15.56	0.93	0.93	0.93	0.93

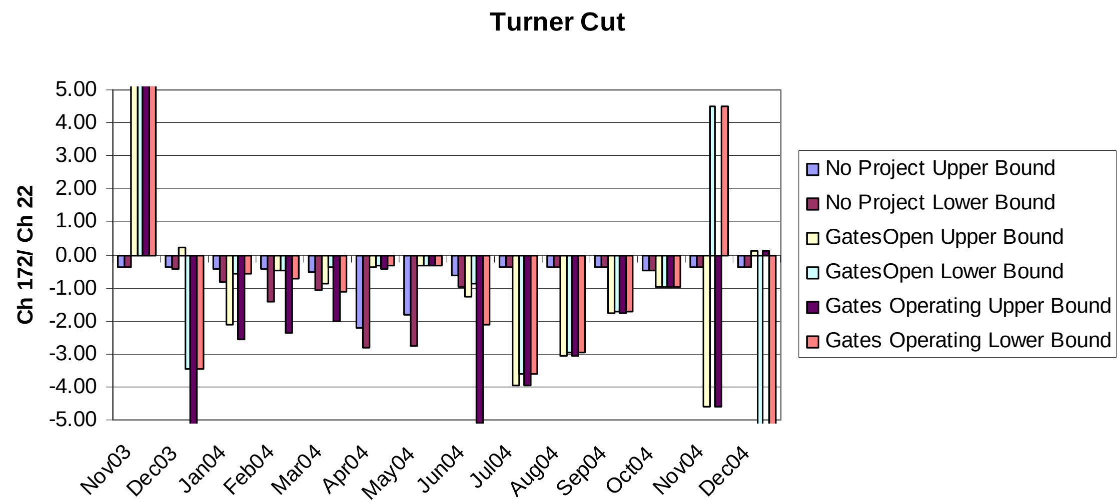


the SJR were greater than flows going into Old River. However, there were large reversals in April and October 2004 during “No Project” conditions. Under “With Project” conditions flow ratios were almost always the same sign as “No Project” conditions but the magnitude of these flow ratios were much reduced “With Project”. Understanding the meaning of these flow patterns, and possible consequences form salmonid smolts, will require a more thorough evaluation of detailed DSM2 hydro data and modeled operating conditions.

At the next downstream junction, Turner Cut, flow ratios were reduced in magnitude relative to Old River. With two major exceptions, flow ratios between “No Project” and “With Project” were generally similar. Anomalous events included a moderate magnitude, positive flow ratio in November 2003 under “With Project” conditions. In December 2004, very large negative flow ratios occurred only under “Lower Bound, With Project” conditions. As before, these trends are difficult to understand and interpret in the absence of a more thorough evaluation of the data.

Turner Cut

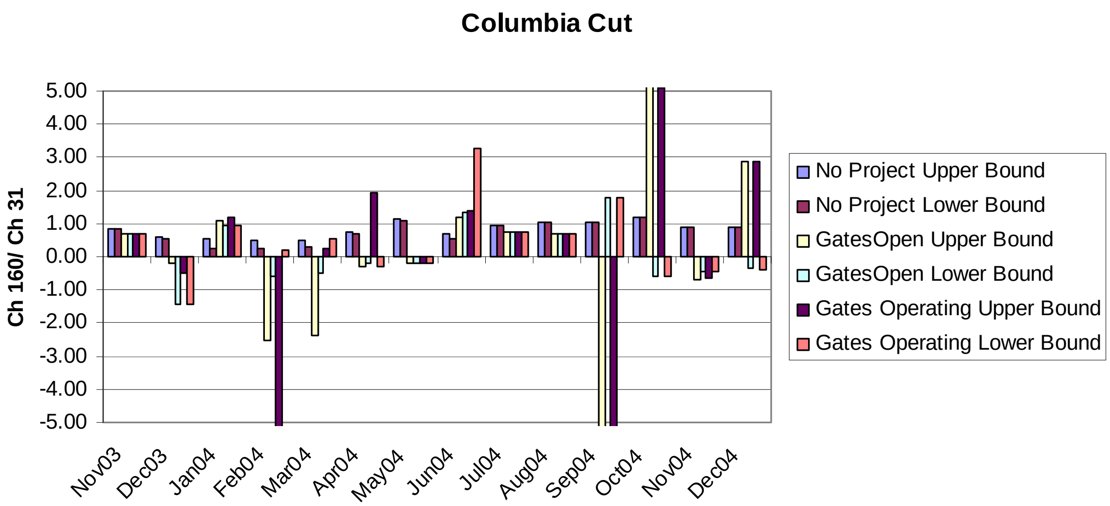
MonthYear	No Project Upper Bound	No Project Lower Bound	GatesOpen Upper Bound	GatesOpen Lower Bound	Gates Operating Upper Bound	Gates Operating Lower Bound
Nov03	-0.37	-0.37	7.71	7.71	7.71	7.71
Dec03	-0.37	-0.41	0.23	-3.48	-5.82	-3.48
Jan04	-0.43	-0.81	-2.12	-0.56	-2.58	-0.56
Feb04	-0.45	-1.43	-0.48	-0.47	-2.37	-0.73
Mar04	-0.50	-1.07	-0.86	-0.39	-2.00	-1.12
Apr04	-2.22	-2.83	-0.35	-0.32	-0.40	-0.35
May04	-1.79	-2.77	-0.32	-0.30	-0.32	-0.30
Jun04	-0.61	-0.98	-1.28	-0.85	-5.08	-2.10
Jul04	-0.38	-0.39	-3.98	-3.59	-3.98	-3.59
Aug04	-0.38	-0.38	-3.07	-2.98	-3.07	-2.98
Sep04	-0.40	-0.40	-1.76	-1.73	-1.76	-1.73
Oct04	-0.48	-0.48	-0.98	-0.98	-0.98	-0.98
Nov04	-0.39	-0.39	-4.59	4.49	-4.60	4.53
Dec04	-0.35	-0.35	0.12	-75.01	0.12	-69.07



Flow ratios at Columbia Cut were generally moderate and positive, but outlier flow ratios were observed for “Upper Bond, With Project” conditions during February and September 2004.

Columbia Cut

MonthYear	No Project Upper Bound	No Project Lower Bound	GatesOpen Upper Bound	GatesOpen Lower Bound	Gates Operating Upper Bound	Gates Operating Lower Bound
Nov03	0.85	0.85	0.68	0.68	0.68	0.68
Dec03	0.60	0.55	-0.19	-1.43	-0.48	-1.43
Jan04	0.52	0.24	1.08	0.93	1.18	0.93
Feb04	0.51	0.22	-2.52	-0.59	-6.37	0.20
Mar04	0.51	0.30	-2.39	-0.49	0.24	0.53
Apr04	0.74	0.70	-0.28	-0.19	1.93	-0.30
May04	1.13	1.10	-0.21	-0.20	-0.21	-0.20
Jun04	0.70	0.57	1.16	1.33	1.36	3.26
Jul04	0.94	0.94	0.72	0.73	0.72	0.73
Aug04	1.02	1.02	0.70	0.71	0.70	0.71
Sep04	1.05	1.05	-8.15	1.79	-7.94	1.78
Oct04	1.17	1.17	5.16	-0.58	5.12	-0.59
Nov04	0.91	0.92	-0.67	-0.46	-0.67	-0.46
Dec04	0.91	0.91	2.86	-0.37	2.86	-0.38

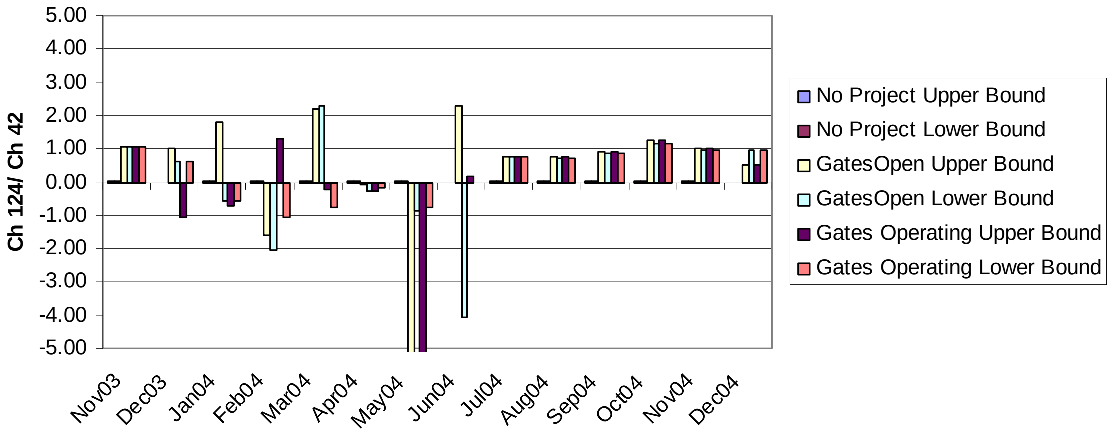


During the period of salmonid smolt outmigration (Nov-May) net flows at the junction of Franks Tract East were highly variable; ranging from both positive to negative even within "With Project" scenarios. In May 2004, very large negative flow were observed under "With Project, Upper Bound" conditions. From July through December 2004, net flows were more consistent, "With Project" conditions were generally more positive than "No Project" conditions.

Franks Tract East

MonthYear	No Project Upper Bound	No Project Lower Bound	GatesOpen Upper Bound	GatesOpen Lower Bound	Gates Operating Upper Bound	Gates Operating Lower Bound
Nov03	0.00	0.00	1.04	1.04	1.04	1.04
Dec03	0.00	0.00	1.01	0.61	-1.08	0.61
Jan04	0.00	0.00	1.81	-0.55	-0.69	-0.55
Feb04	0.00	0.00	-1.62	-2.02	1.32	-1.08
Mar04	0.00	0.00	2.18	2.30	-0.24	-0.78
Apr04	0.00	0.00	-0.09	-0.29	-0.29	-0.16
May04	0.00	0.00	-234.20	-0.88	-128.25	-0.77
Jun04	0.00	0.00	2.27	-4.05	0.16	-0.02
Jul04	0.00	0.00	0.78	0.77	0.78	0.77
Aug04	0.00	0.00	0.74	0.73	0.74	0.73
Sep04	0.00	0.00	0.90	0.87	0.90	0.87
Oct04	0.01	0.01	1.26	1.16	1.26	1.17
Nov04	0.00	0.00	0.99	0.97	0.99	0.97
Dec04	0.00	0.00	0.54	0.97	0.53	0.97

Franks Tract East

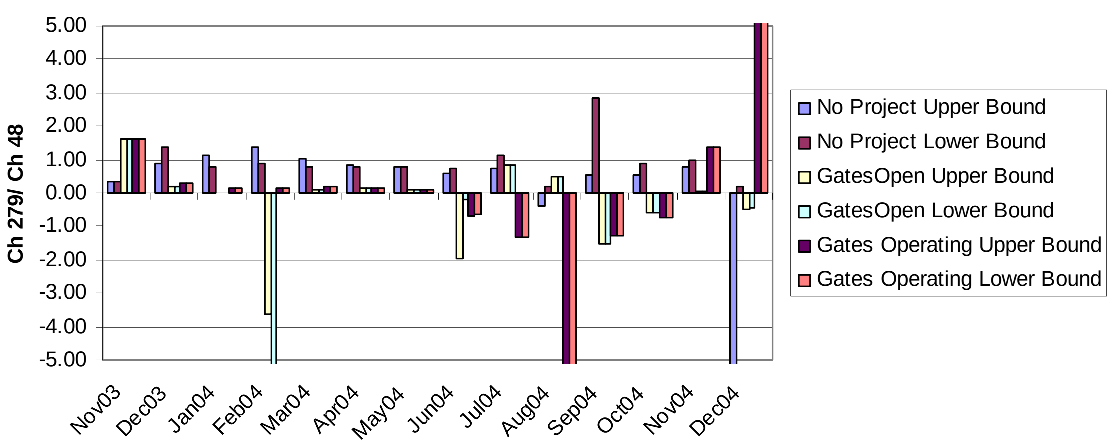


Franks Tract West exhibited a distinctly different net flow pattern from Franks Tract East. With the exception of February 2004 “With Project, Gates Open” conditions, net flows were fairly consistent during November 2003 through June 2004. The period of July through November exhibited more negative net flow conditions for “With Project, Gates Operating” conditions; however few salmonid smolts are present at this time in the Delta. Oddly, a large positive net flow event was observed in December 2004 for “With Project, Gates Operating” conditions.

Franks Tract West

MonthYear	No Project Upper Bound	No Project Lower Bound	GatesOpen Upper Bound	GatesOpen Lower Bound	Gates Operating Upper Bound	Gates Operating Lower Bound
Nov03	0.33	0.33	1.60	1.60	1.60	1.60
Dec03	0.89	1.39	0.18	0.18	0.28	0.28
Jan04	1.15	0.80	-0.01	-0.01	0.15	0.15
Feb04	1.38	0.86	-3.65	-62.68	0.14	0.14
Mar04	1.02	0.80	0.07	0.12	0.18	0.21
Apr04	0.83	0.80	0.16	0.16	0.17	0.17
May04	0.79	0.80	0.10	0.10	0.11	0.11
Jun04	0.59	0.75	-1.94	-0.21	-0.66	-0.63
Jul04	0.73	1.15	0.83	0.83	-1.33	-1.34
Aug04	-0.42	0.19	0.47	0.47	-28.57	-27.57
Sep04	0.52	2.85	-1.51	-1.52	-1.25	-1.25
Oct04	0.54	0.89	-0.58	-0.58	-0.71	-0.71
Nov04	0.80	0.96	0.06	0.06	1.39	1.38
Dec04	-9.48	0.22	-0.47	-0.46	14.67	15.96

Franks Tract West



REFERENCES

Perry, R. W., P.L. Brandes, P.T. Sandstrom, A. Amman, B. MacFarlane, A.P. Klimley and J. R. Skalski. 2009. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management. In Press.