Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 4
Adding Salmon Route Selection Behavior to DSM2 Particle Tracking Model

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4 Adding Salmon Route Selection Behavior to DSM2 Particle Tracking Model

4.1 Introduction

DSM2 Particle Tracking Model (PTM) simulates the transport and fate of individual neutrally buoyant particles through the Sacramento – San Joaquin Delta. This model has evolved since its initial development in 1993. New features, such as attaching fish-like behaviors to particles, have been added to the model. Although the model itself has been calibrated and validated using a field dye study, the adequacy of the model for simulating fish migration has never been quantitatively evaluated due to the lack of field fish monitoring data. Recent developments in the field monitoring, especially in acoustic telemetry fish tag studies, have made it possible for evaluating the adequacy of applying PTM to simulating fish behaviors.

This chapter describes the implementation of fish route selection behavior in PTM and the results of the implementation. The approach for using PTM to simulate fish behaviors and the improvements needed for PTM to better simulate fish behaviors are also discussed.

4.2 Fish Route Selection Behavior Relationship – A Generalized Linear Model

An important fish behavior is route selection when fish reaches a junction. A generalized linear model (GLM) was developed (Bowen, Hanson, & Perry, 2012) to predict the probability of late fall-run juvenile Chinook salmon route selection at a junction. This model is based on the acoustic telemetry tag data collected at the Georgiana Slough (GS) and Sacramento River (Sac. R.) junction in 2011. The fate of individual fish (whether entering GS or remaining in Sac. R.) was modeled as a Bernoulli random variable (coded as 1 for entering a particular channel and 0 for not entering). The analysis assumed the probability of entering GS has a trinomial distribution. A logit link function was used as the linear function of the covariates. The covariates included: 1) operation of the non-physical barrier; 2) time of day; 3) flow entering the river junction; 4) the cross-stream, horizontal position of each individual fish; and 5) the location of the critical streakline in the cross section. Turbidity and water velocity upstream of the non-physical barrier were considered as possible covariates at the beginning of the analysis but were not included in the model because they were found to be highly correlated with the discharge. The critical streakline is the line that divides the river channel into two water parcels entering either GS or Sac. River. Fish in the GS water parcel have a higher probability of entering GS, and those in Sac. River parcel have a lower probability. The streakline was estimated by channel width multiplied by the flow split ratio of the flow entering GS to the total inflow. The values of the covariates were obtained when fish were closest to the junction. The model was selected according to the best fit and Bayesian Information Criterion, a model selection criterion widely used for model identification in linear regression.

4.3 PTM Implementation and Results

The GLM discussed above was implemented in PTM. The implementation only applied for the environmental conditions that the GLM is based on– that is, the GLM was only used for the simulation when a particle reached the GS and Sac. River junction and under the unidirectional flow condition. The purpose of this implementation was to assess whether the implementation of the behavior relationship (behavior vs. environment) in PTM could substantially improve the model's prediction of fish behavior.

The values of the GLM hydrodynamic covariates (flow, depth, width, etc.) in the model were simulated by DSM2 Hydro. A DSM2 Hydro run from 2/1/2011 to 5/20/2011 was performed. DSM2 historical flow and stage boundary conditions for the period were used in the simulation. Figure 4-1 through Figure 4-3 show simulated versus observed flows entering the junction (Figure 4-1), downstream of the junction at Sac River (Figure 4-2), and GS (Figure 4-3), respectively. The simulated flows matched the field data well, except for the period with the maximum flows. During this period, the model underestimated the flows. However, the mismatch could have been caused by the uncertainty in the field data as there were many missing data points in the observed time series. Non-physical barrier operation was obtained for the model input. All simulations assumed daylight conditions because light intensity data are currently not available. The night condition will be simulated in the future when light intensity data become available.

Four PTM runs were performed for high/low flow and barrier on/off conditions. For each run, 1000 particles were inserted at 13,989 feet (DSM2 node 341) upstream of the junction node (DSM2 node 343) on 3/20/2011 and 4/16/2011, respectively. The 1,000 particles were released randomly across the cross-section within a day. The positions of the particles approaching the junction were simulated by the PTM. The simulated cross channel distributions of the particles at the junction are shown in Figure 4-4. From the simulation, the simulated distributions showed two peaks, one near the GS side and the other near the Sac. River side under both the high and low flow conditions. For the high flow condition, the simulation showed that particles were more evenly spread over the channel. These simulated particle distribution patterns were somewhat different from the field observed fish distribution patterns (Figure 4-5) in which fish were more concentrated near the center of the channel on the Sac. River side. The difference could have been caused by the original fish release locations. In the field study, the fish were released at the center of the channel while the particles in the simulation were released randomly across the channel, which is the way PTM is set up. The fish released at the center might not have enough time to spread out over the channel when they approached the junction.

Table 4-1 lists the simulated versus observed percentage of fish/particles entering GS. The simulation with the GLM implementation agreed reasonably well with the field observation, especially under the low flow conditions, which indicates that the PTM is able to predict certain fish behavior as long as an adequate fish behavior relationship is implemented. Under the high flow condition, the PTM with GLM appeared under-predict the probability of fish entering GS. This could have been caused by the initial fish release positions as explained above. Table 4-1 also shows the comparison between the PTM simulations with and without the GLM implemented. By implementing the GLM, the PTM improvement on predicting the behavior was substantial, especially under the low flow conditions.

4.4 Further Improvement

Many other fish behaviors could affect fish migration through the delta. For example, swimming behavior determines fish travel time, residence time, and the timing of reaching important locations such as a crucial junction. Survival behavior determines fish survival through the Delta. To make PTM more scalable/flexible so it can incorporate these important behaviors for different fish species, the PTM recently has been redesigned and is currently going through a major code rewriting. An open source project website is also under development to allow other public agencies and private consultant firms to contribute to the PTM behavior development.

Field fish monitoring and data collection are also crucial to improve the model's fish behavior prediction. More acoustic telemetry tag data will be needed to cover a wider spectrum of environmental conditions throughout the delta so that various behavior relationships can be established and the PTM can be calibrated and validated. Fortunately, more field fish monitoring studies have been planned for important delta junctions and channels. Furthermore, the data that have been collected are being analyzed to establish statistical behavior relationships. When these relationships become available, they will be implemented in PTM.

The PTM flow field simulation can also be improved. A computer interpolation program for a finer resolution flow field in the delta will be available later this year. The program will interpolate DSM2 Hydro outputs for a higher resolution grid using sophisticated interpolation schemes. The improvement to the quasi-three-dimensional velocity profiles is also taken under consideration.

4.5 Conclusion

The Delta is a complex system as river and tidal forces alternately dominate. Manmade structures and their operations add more complexities to the system. When fish migrate through this complex system, they interact with the system and display seemingly uncertain and unpredictable behaviors. Because of the limitations in our understandings of fish behaviors and their relationship to the system, oftentimes it is difficult to mechanistically simulate the behaviors. However, with the accumulation of field monitoring fish tag data, it is possible to statistically describe the relationships between fish behaviors and the system. PTM, as a surrogate tool to evaluate fish behaviors, can utilize those statistical relationships to improve its representation of fish behaviors in the model. The results from the current implementation of the GLM indicate that the model's prediction of certain fish behaviors can be improved substantially when the relationship between the behavior and environmental conditions is statistically described and implemented in the model. It is expected that when more behavior relationships are established for wider ranges of environmental conditions and are implemented in PTM, the model can predict behavior patterns more accurately and help to identify the factors that affect fish behaviors and survival in Delta.

4.6 Reference

Bowen, M., Hanson, D., & Perry, R. (2012). *2011 Georgiana Slough Non-Physical Barrier.* Draft, California Department of Water Resources, Sacramento.

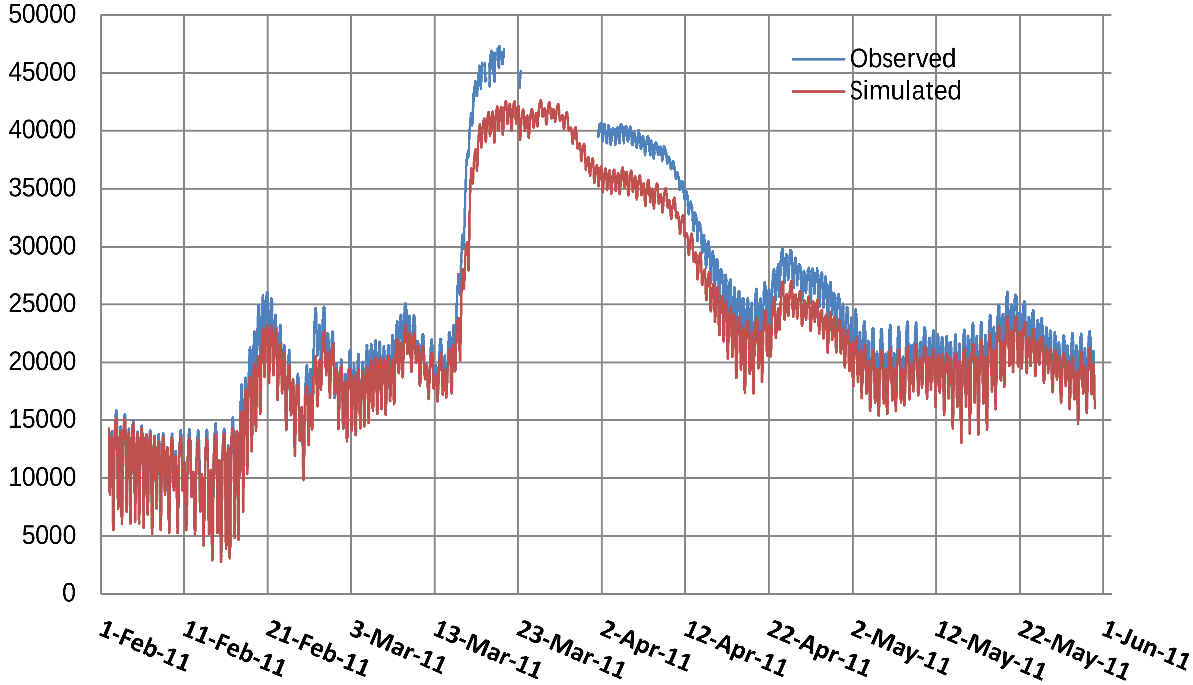

Figure 4-1 Simulated vs. Observed Flows (CFS) at GS and Sac. R. Junction

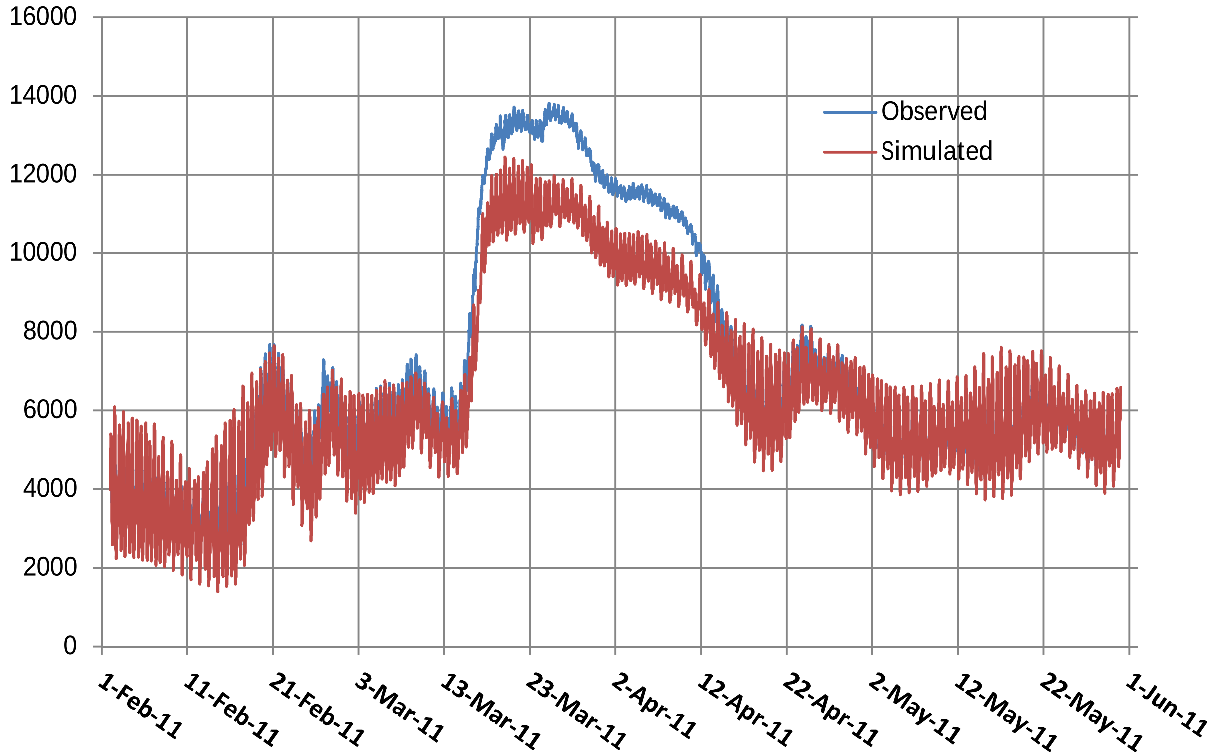

Figure 4-2 Simulated vs. Observed Flows (CFS) Entering Georgiana Slough

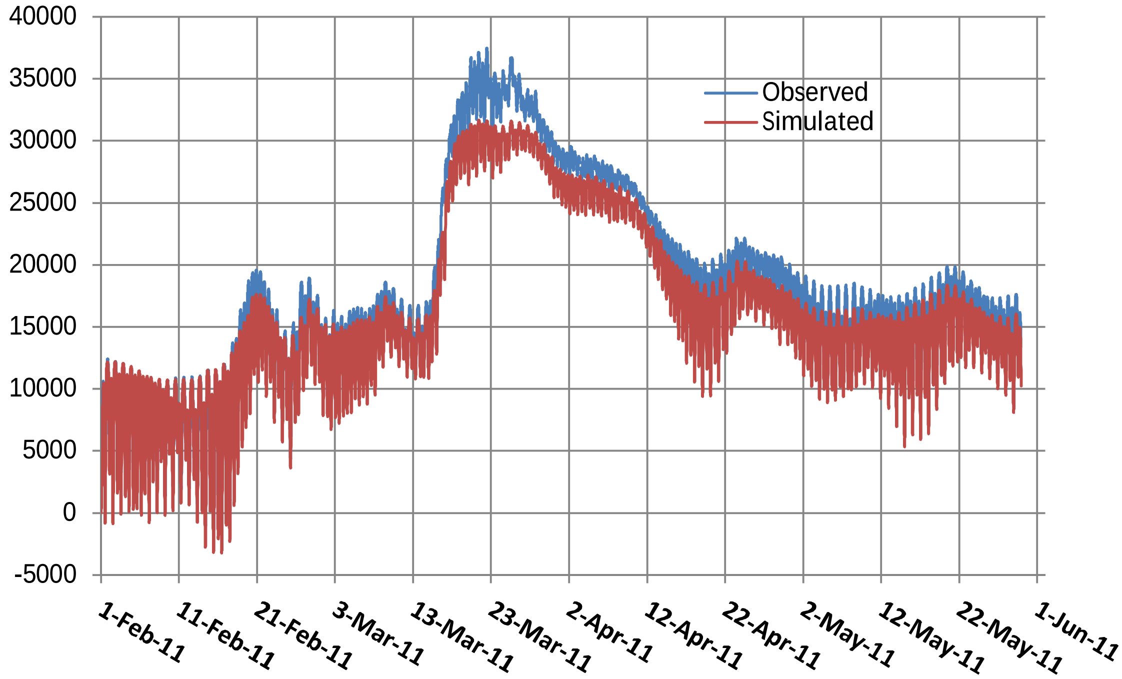

Figure 4-3 Simulated vs. Observed Flows (CFS) Entering Downstream Sac. R.

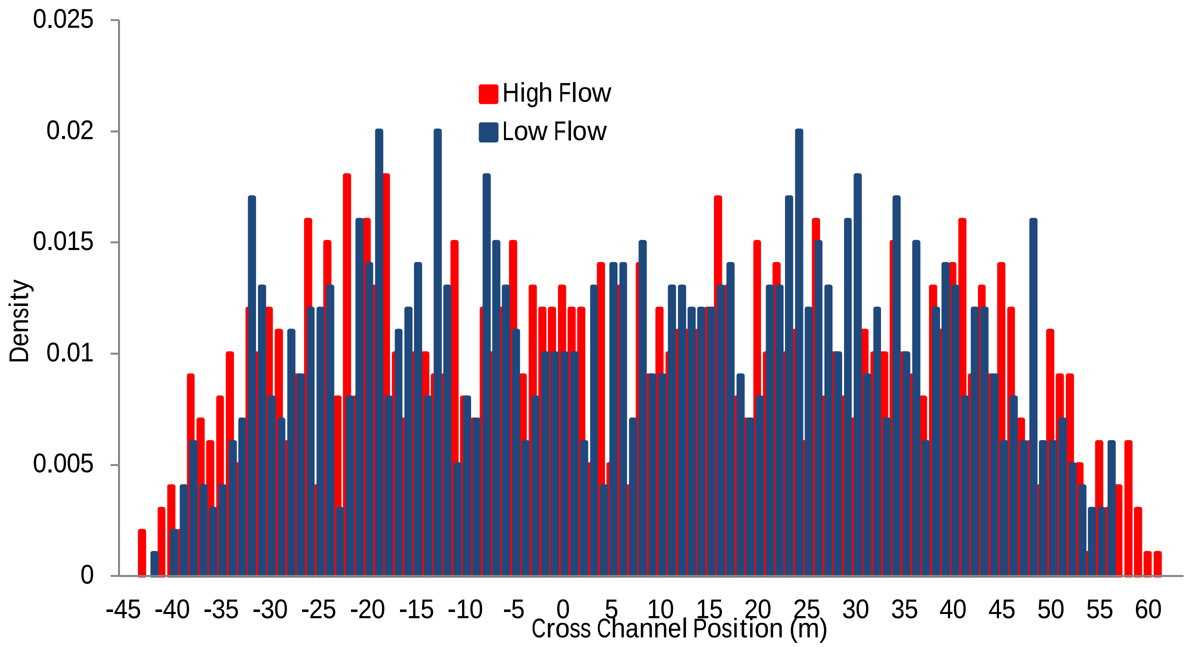

Figure 4-4 Simulated Particle Cross Sectional distribution at the Junction

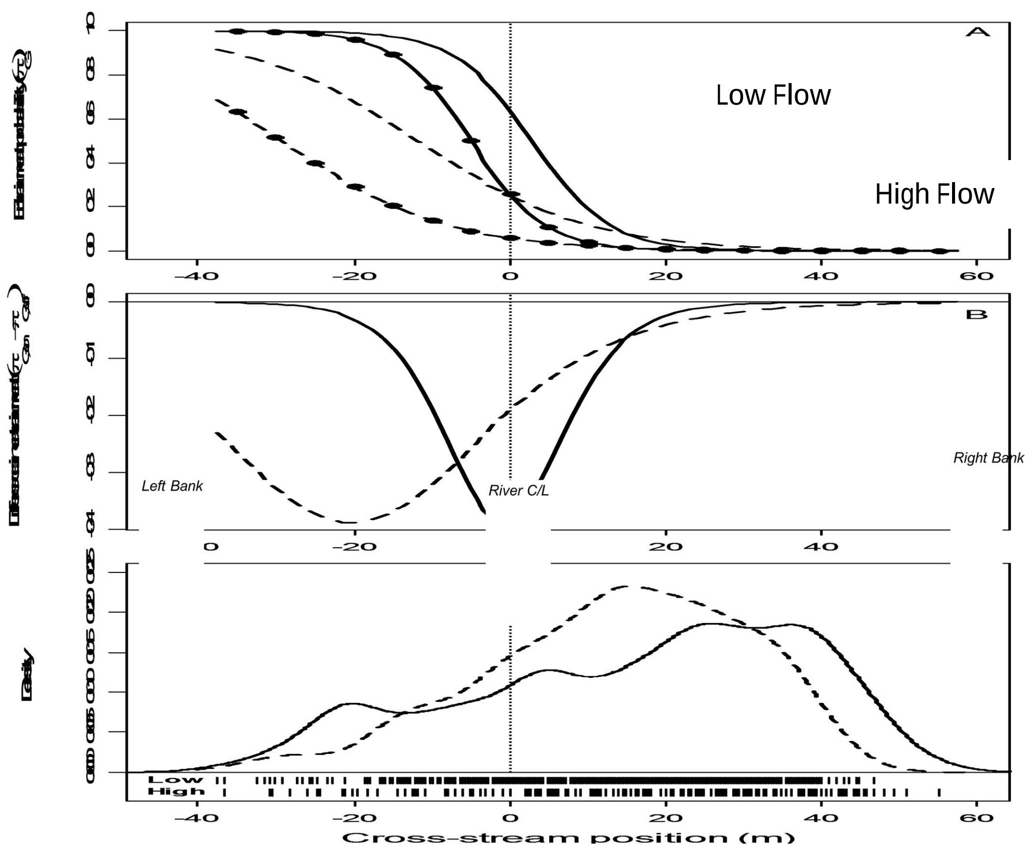

Figure 4-5 Observed Fish Cross Sectional Distribution at the Junction

Table 4-1 Particle Fraction Entering Georgiana Slough (%)[1]

Flow	Barrier	Observed	GLM	PTM W/ GLM	PTM W/O GLM
Low	On	1.7 (SE* 0.007)	4.7 (SE 0.015)	5.2 (SE 0.003)	30.0
	Off	19.3 (SE 0.023)	16.7 (SE 0.012)	15.9 (SE 0.007)	30.0
High	On	21.1 (SE0.048)	14.9 (SE 0.034)	14.6 (SE 0.009)	29.9
	Off	29.5 (SE 0.045)	32.2 (SE 0.039)	25.0 (SE 0.012)	29.9

* SE: standard error.

[1] In the field study, 1500 acoustically tagged late fall-run Chinook salmon were released into the Sacramento River at 29,199 feet upstream of the Georgiana Slough junction from March 15 to May 16, 2011. The fish were released to the center of the channel in a small group about every 3 hours (due to the weather and equipment conditions, the release interval was not strictly 3 hours).

Table 4-2 Flow Category

Inflow Category	Data Type	Barrier Operation	Flow (cfs x 1000)
Low	Observed	On	24.3 (SD* 3.1)
		Off	24.9 (SD 3.2)
	PTM W/GLM	On	24.0 (SD 1.5)
		Off	24.0 (SD 1.5)
High	Observed	On	44.6 (SD 1.2)
		Off	43.0 (SD 4.0)
	PTM W/GLM	On	41.0 (SD 1.0)
		Off	41.0 (SD 1.0)

* SD: standard deviation