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

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Chapter 4:
Particle Tracking

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4 Particle Tracking

[Editor's Note: This is an electronic reprint of the original report. Electronic copies of the figures, tables, and final report were unavailable, thus the figures and tables are not included in this reprint. A scan of the original paper can be found using this link.]

This chapter gives a brief overview of the Particle Tracking Model (PTM) and then focuses on the development of the model over the past year. The PTM was described in the Thirteenth and Fourteenth Annual Progress Reports to the State Water Resources Control Board.

General Description

PTM is a physically based model that simulates the transport and fate of particles throughout the San Joaquin Delta. PTM uses one dimensional velocity results from a hydrodynamic model and then applies vertical and transverse velocity profiles to the individual particles traveling through the channels. In order to fully represent the physical processes that determine three dimensional movement of neutrally buoyant particles, the model also simulates transverse and vertical mixing. These dispersion processes are illustrated in Figure 1. For modeling non-neutrally buoyant particles such as biological species, other factors such as settling velocity and mortality are also simulated.

New Developments

Addition of Smaller Time Steps

In the previous version of the model, during a 15-minute time step particles traveled distances in the x, y and z directions. (The x direction is defined as lengthwise down the channel, the y direction is defined as across the channel, and the z direction is defined as vertically up and down in the channel.) When moving in the y or z directions, a particle could encounter a boundary before it was able to travel its entire distance. These boundaries include the sides, bottom and top of the channel. When the particle encountered the boundary, it reflected back into the channel the remaining distance it was supposed to move. This presented a problem with modeling accurately the mixing of particles when distances became large during a time step. To solve this problem, time steps were reduced to a user specified time step. However, there was no easy way to know if the time steps were reduced enough to limit the "bouncing". To remedy this, (with the aid of the contractor Water Engineering and Modeling (WEM)) smaller sub-time steps were created. The sub-time steps were calculated based on the distance traveled by particles during a time step. If the particles travel a distance larger than ten percent of the width or the depth, then the time step is reduced so that the distance traveled is equal to or less than the limiting distance. The distance traveled is based on a Gaussian distribution.

New Dispersion Calculations

Estimates of dispersion for PTM were taken from Fischer et al. (1979). Because some of the dispersion values were based on idealized laboratory experiments, WEM did some additional research on dispersion in the Delta using velocity profiles measured by USGS in a few locations in the Delta. WEM came to the conclusion that the previous estimates of dispersion overpredicted actual dispersion. This new information will be included in future enhancements of DSM2-PTM.

Channel Grouping

Currently the model produces output that counts the number of particles that remain in the delta, that are lost to exports, that are lost to agricultural diversions, and that make it past Chipps Island. The model can also produce output counting how many particles pass specified locations. The new channel grouping development allows the user to specify a group of channels where he or she would like to know the number of particles residing during a time period. Previously, the user could see the movement of particles through the Delta using the Delta Graphical User Interface (DGUI). Now the user can also have a count written to a file of the number of particles in locations such as the South Delta or Suisun Marsh.

Interfacing with DSM2

Major changes within the code are underway to allow PTM to interface with DSM2. The code currently uses flow, velocity and stage output from the DWRDSM hydrodynamics. The code also calls the geometry subroutine from DWRDSM to define channel numbers and geometry. PTM will be modified to received flow information from the hydrodynamics module of DSM2 (DSM2-HYDRO) and the geometry subroutine will no longer be used. The DWRDSM geometry subroutine will be replaced with the new input system subroutines discussed in Chapter 6.

Additional changes to the program include eliminating the hardwired coding of the tidal day time periods and modifying the geometry. The user now specifies the time period for which output is desired. Previous Delta geometry was defined by one rectangular cross section. Channels are now defined by different rectangular cross sections at each end of the channel. Future changes will include adapting the model to irregular cross sections (see Chapter 10).

Future Modeling of Behavior

PTM currently models some behavior characteristics of biomass. In previous studies, settling and mortality rates were applied to particles to better simulate their movement and fate. Plans to expand behavior modeling are underway. These plans include having the option of allowing particles to react to the following:

- Position – Particles will move towards a certain location within the channel.

  Example: Inland Silversides tend to move towards the shore. A transverse velocity component could be added to simulate the swimming.

- Time – PTM models the age of particles. As a result of age the particles' behavior will change.

  Example: Stripped Bass eggs are heavier than larvae. Settling rate changes when the eggs hatch.

  Particles will also react to changes in the diurnal cycle.

- Flow – Particles will rise and fall in the water column depending on tidal velocity and direction.

  Example: Longfin and Stripped Bass move up in the water column to ride the flood tide in. Vertical velocity components could be added to simulate that behavior.

  Particles will also move with or against the flow.

- Quality – Simple Bioenergetics will be added so that the growth rate and mortality of particles will be a function of temperature, dissolved oxygen, and food.

  Particles will swim towards a certain quality.

  Example: Salmon swim towards fresh water.

Channel Grouping: An Illustration

PTM studies were requested by Jim Cowan of the University of South Alabama in support of his work on a Striped Bass model for the Sacramento-San Joaquin Delta and San Francisco Bay. The PTM provides hydrology specific transport of individuals between computational compartments of the striped bass model.

The COMPMECH striped bass model is an individual based model of young-of-year striped bass population dynamics. It is used as a framework for synthesizing available food chain information and for evaluating the interactive effects of factors which influence various life stages of striped bass. The model begins with spawning and simulates daily growth and mortality of individual fish as they develop through the life stages of egg, yolk-sac larva, feeding larva, and juvenile during their first year of life in a single, well-mixed compartment.

Cowan divides the Bay-Delta into four computational compartments on the basis of temperature, zooplankton, and striped bass survey data. Compartment one is the Sacramento River spawning are from approximately Grimes to Sacramento, compartment two is the lower Sacramento from Freeport to the confluence, compartment three is the San Joaquin River spawning area from Rindge Tract to the confluence, and compartment four is Suisun Bay.

While the model comprehensively simulates striped bass bioenergetics on a daily basis, there is no mechanism for determining the transport of individuals between compartments. On the basis of channel velocity determined by a hydrodynamics model, the PTM tranports individual particles three-dimensionally within the water column by deterministic and stochastic motions.

For this application, the PTM was used to determine the daily probability that a particle in a given compartment would remain within that compartment, move to another compartment, or be entrained by an agricultural diversion or export pump. Probabilities were determined from the transport history of one-hundred individual particles.

Eight separate steady-state hydrology studies were requested including all permutations of high versus low Delta outflow index, Delta Cross-Channel open versus closed, and Sacramento River spawn versus San Joaquin River spawn. Output is in the form of a matrix of probabilities that an individual particle will move between all possible compartments and sinks for each day of a sixty-day period. Cowan will read these matrices directly into his model as input. Specifics of the high and low flow hydrologies were chosen to be nominally consistent with current draft Delta standards for above normal and critical year classifcations.

This study demonstrates a succesful linkage between biological and hydrodyanmics models. The remainder of this chapter details the approach and assumptions used, presents model output, and provides observations about the results with suggestions for further investigation.

Study Request

Jim Cowan requested a simulation period of sixty days with steady-state hydrology. Eight steady-state hydrologies were designed to provide information on the daily probability that a given particle will move between defined geographical areas of the Delta (or into agricultural diversions or export pumps). Table 4-1 summarizes the eight PTM studies.

Methodology and Assumptions

Cowan defined four Delta compartments according to temperature, zooplankton, and spawning and rearing habitat characteristics. DFG striped bass survey data is the basis for the habitat delineations (Figure 4-2). Obtaining time histories of individual particles without gaps requires that all Delta channels are assigned to one of the four compartments. However, since some areas of the Delta are not sampled by the sruvey (e.g. Mokelumne river forks, south Delta area), an agreement was needed on how to apportion the remaining area to compartments. After personal communication with Cowan, compartments were delineated as shown in Figure 4-3.

This request was intended to provide screening level estimates of striped bass transport between geographical areas of the Delta. As such, while inflow and export magnitudes are nominally typical of the April 15 through May 15 period under the current draft standards, the hydroliges are applied constantly for the requested 60-day simulation period (that is, steady-state).

All particles are assumed to be neutrally buoyant for the duraction of the 60-day simulation; this does not suggest that simulation of striped bass eggs and larva as neutrally buoyant entities is a particularly good assumption beyond about seven days. The simulations are carried out for 60 days for purposes of sensitivity analysis only. It is expected that as more data about life-stage behavior of striped bass becomes available, PTM settling and dispersion parameters can be adjusted to mimic larva behavior.

The upstream boundary of the DWRDSM model is Sacramento. Since Sacramento River striped bass spawn upstream of Sacramento, the upper Sacramento compartment is somewhat truncated. Particle travel times from the spawning area to Sacramento will be estimate from flow. Particle release locations for the San Joaquin River spawn are shown in Figure 4-4. The spawning distribution was determined from long-term average striped bass survey data. Of one-hundred individual particles released, thirteen were released near Antioch, thirty-eight near Jersey Point, twenty-five near Prisoner's Point, twenty-three at the San Joaquin-Mokelumne River confluence, and one near Rindge Tract.

The goal of the study is to provide daily probabilities that any individual particle will move between compartments or enter an agricultural diversion or project pump. To obtain these probabilities, the time histories of individual particles must be recorded. Currently the PTM is capable of tracking bulk activity within user defined sub-areas of the Delta.

However, individual time-histories of all particles are not yet available. The approach was to conduct 60-day simulations of one particle at a time in order to exactly track movement between compartments or into sinks. For each study, one-hundred such individual particle simulations were made, changing only the random number seed to begin the simulation.

An example output file showing the time history of one particle is shown in Table 4-2. In this example the particle is initially released at Sacramento under a high flow condition. At the end of day 1, the particle is still in the upper Sacramento compartment (usbox). The particle then spends days 2 through 4 in the lower Sacramento compartment (lsbox). Days 5 and 6 are spent in the Suisun Bay compartment (sbbox). One day is spent in the San Joaquin compartment (sjbox) before spending three more days in the Suisun Bay compartment. On day eleven, the particle moves downstream of Martinez, beyond the downstream boundary condition of the model. For the purposes of the striped bass model, all particles which are transported downstream of Martinez are considered to reside in the Suisun Bay compartment (pers. comm., J. Cowan).

For a given one-hundred-particle PTM simulation, one hundred such output files are generated. A postprocessing routine was written to summarize these files, and determine the probability that an individual particle will move from one compartment to another compartment or sink on any given day.

Conclusions

An approach for accurately simulating particle transport between computational compartments of Cowan's striped bass model has been demonstrated. The technique is quite flexible, and can be easily modified to test more specific hypotheses about factors influencing the growth and mortality of striped bass in the future.

Opportunities for Further Investigation

Improvements in the approach to particle tracking include:

- Extend the upstream boundary of the DSM2 to the striped bass spawning area so that residence time in the upper Sacramento compartment can be directly modeled (see Chapter 10).

- Time-dependent settling rates could be applied to particles to simulate larva behavior. Some life-stage settling rate data has been experimentally determined [Meinz, 1979].

- Additional studies could be done to isolate the impact of exports and agricultural diversions on striped bass mortality.

Improvements in the striped bass model might include:

- If the data will support it, increase the resolution of the model by including more compartments. Currently, the striped bass model does not explicitly consider bioenergetics processes in the Mokelumne River area and the south Delta area.

- Ultimately, the striped bass model should be explicitly integrated with the PTM to create a comprehensive model of striped bass dynamics.

References

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