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

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Chapter 4:
Validation of Dispersion Using the Particle Tracking Model in the Sacramento-San Joaquin Delta

Author: Ryan Wilbur

4 Validation of Dispersion Using the Particle Tracking Model in the Sacramento-San Joaquin Delta

[Editor's Note: The following report is a condensed version of Ryan Wilbur's M.S. Thesis (2000). It has been reformatted to be consistent with this progress report. A complete copy of his thesis is on file with University of California, Davis. This validation did not use the DSM2 geometry that was discussed in Chapter 2 because the calibration was not yet finished.]

4.1 Introduction

The Particle Tracking Model (PTM) was developed by DWR's Delta Modeling Section. The purpose of the model is to simulate the transport and fate of individual, neutrally buoyant "particles" through the Sacramento – San Joaquin Delta.

The PTM model is a component of the Delta Modeling Section's DSM2. DSM2 simulates the hydrodynamic, water quality, and particle movement throughout the Sacramento – San Joaquin Delta in three models: HYDRO, QUAL, and PTM, respectively. Figure 4-1 shows the location of major cities on a schematic for the Delta region. Figure 4-2 shows significant inflows and outflows in the Delta. The Delta is the confluence of the Sacramento River, San Joaquin River, East Side Tributaries, and the open water of San Francisco Bay. The western boundary condition used by DSM2 is the stage at Martinez. The tidal motion influences the entire Delta. Flow reverses direction due to the tidal motion throughout most of the Delta.

The PTM model uses the hydrodynamics determined by HYDRO to extrapolate the average velocity in a channel to a pseudo 3-dimensional velocity cross-section. Assumed velocity profiles are used for this extrapolation. The velocity profiles assume the zero slip condition at the bottom and sides of the channel; while the fastest areas are the center of the transverse profile and the top of the water column. The selection of velocity profiles is equivalent to setting the longitudinal dispersion coefficient. In addition, movement due to mixing (in the transverse and vertical) is superimposed on the advective motion. Data collected by USGS are used to guide the selection of the velocity profiles. These new profiles are then compared to a tracer study to determine if the accuracy of the PTM is improved.

The PTM was originally developed in 1992 by Gilbert Bogle, a consultant working for Water Engineering and Modeling. Several modifications have been made by DWR and Bogle to this model to account for such particular phenomena as tidal effects and channel branches. The model was rewritten by Nicky Sandhu of DWR in Java and C++ to take advantage of object-oriented programming. Input-output was also updated to be consistent with the DSM2 model. Calibration of the advective characteristics was performed by Tara Smith of DWR. A limited investigation of dispersive characteristics of the Delta was performed by Bogle, but a full calibration was not completed. The goal of this study: is to calibrate the dispersive characteristics of HYDRO-PTM.

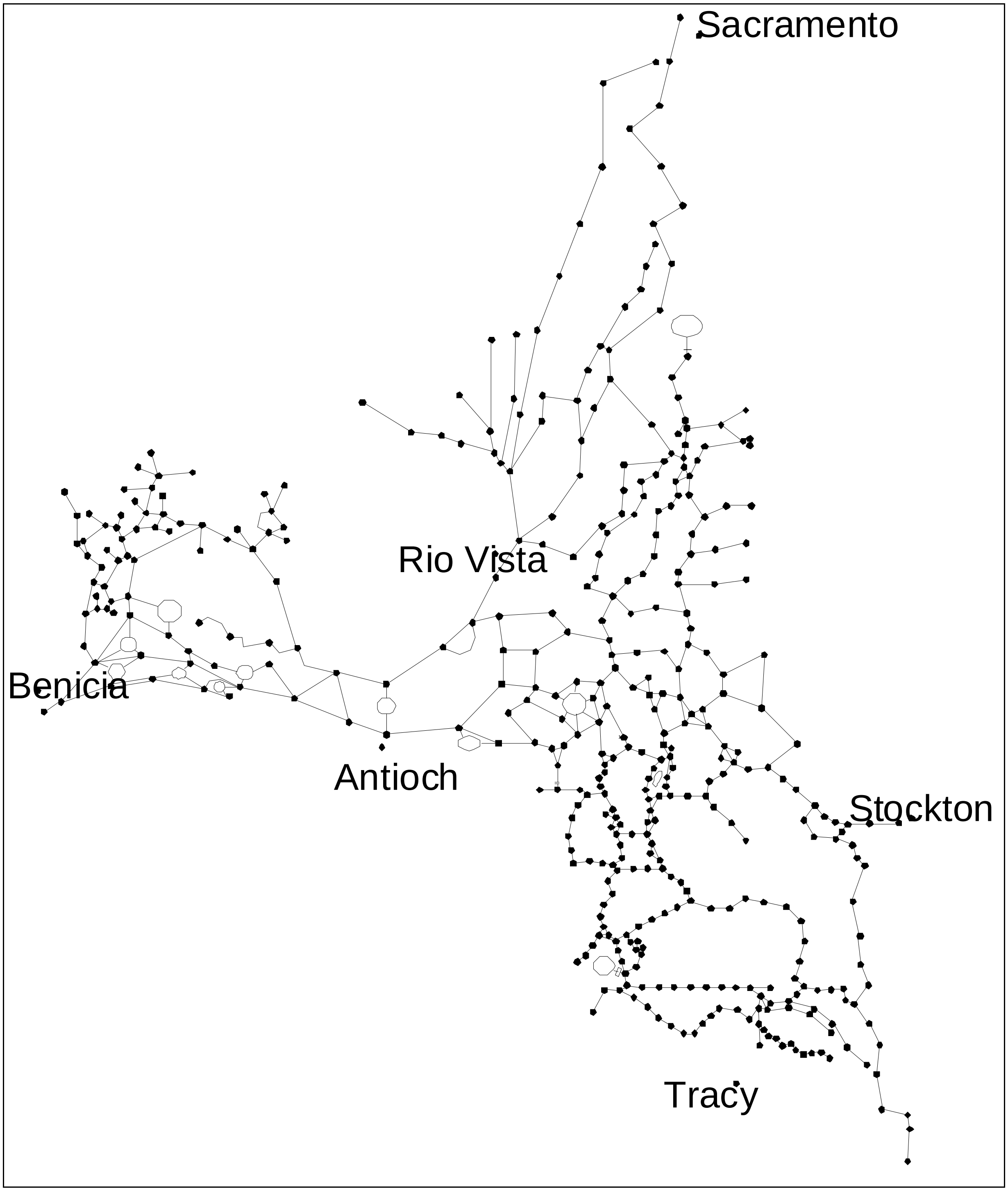

Figure 4-1: DSM2 Schematic of the Sacramento – San Joaquin Delta.

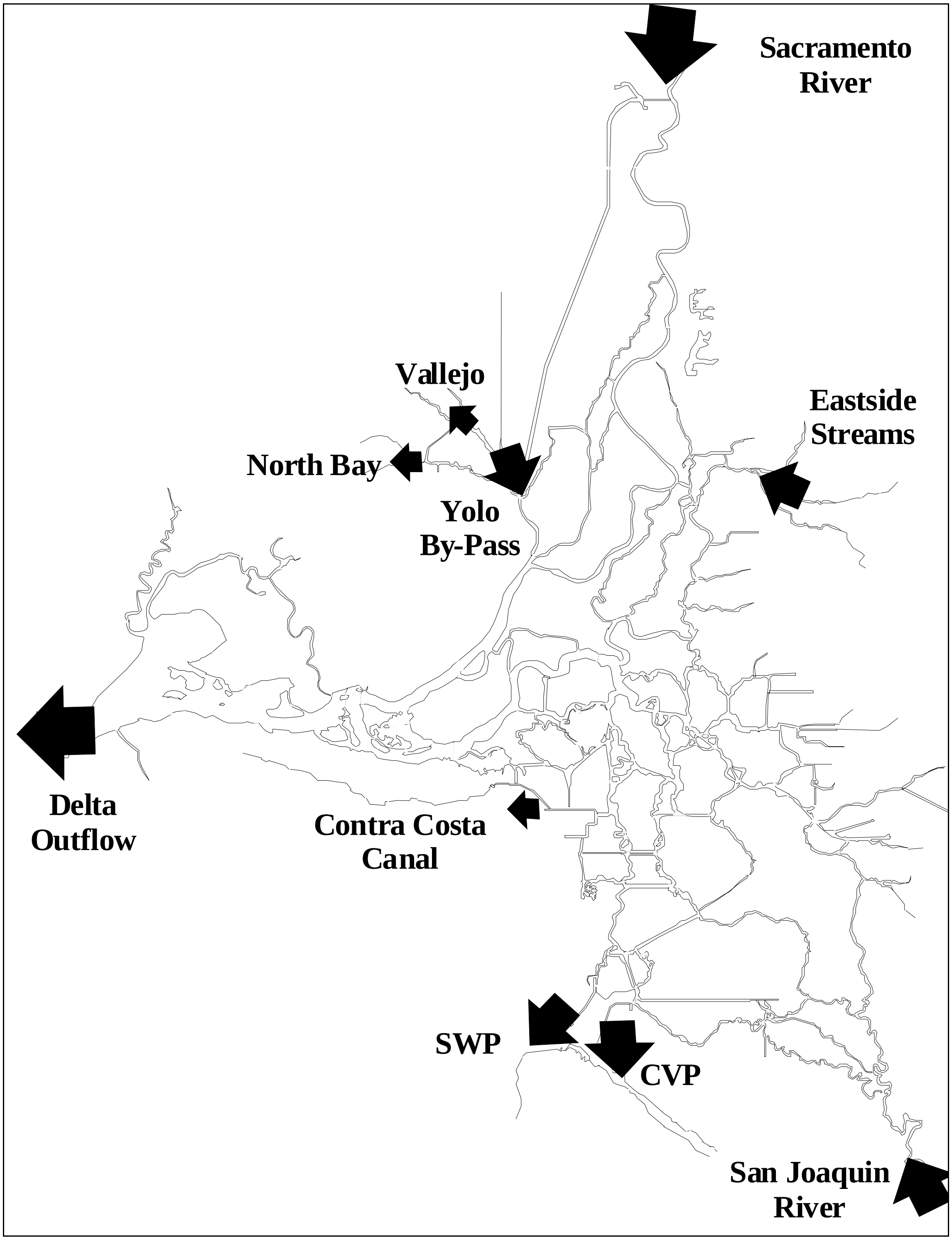

Figure 4-2: Major Sacramento – San Joaquin Delta Boundary Flows.

4.2 PTM Model

4.2.1 PTM Introduction

The DSM2 is the simulation model used by DWR's Delta Modeling Section. There are three components: HYDRO, QUAL, and PTM. HYDRO is a 1-dimensional, unsteady hydrodynamic model. HYDRO originated from the FourPt model developed by Lew Delong of USGS (DeLong 1995). It is a fully implicit unsteady flow model and is based on the 1-dimensional Saint Venant equations:

$$\frac{d}{dt}(\rho M_a A)+\frac{d}{dx}(\rho Q)-\rho_q q=0 \qquad \text{[Eqn. 4-1]}$$

$$\frac{d}{dt}(\rho M_q Q)+\frac{d}{dx}\left(\beta\rho\frac{Q^2}{A}+\rho g I_1\right)+\rho g A(s_o+s_f)-\rho g I_2=0 \qquad \text{[Eqn. 4-2]}$$

where t is time, ρ is density, A is a cross-sectional area, M_a is the area-weighted sinuosity coefficient, x is downstream distance, Q is the flow rate, q is the lateral inflow, ρ_q is the density of the lateral inflow, M_q is the flow-weighted sinuosity coefficient, β is the momentum coefficient, g is gravity, s_o is the channel bottom slope, s_f is the friction slope, and I_1 and I_2 are integrals for averaging the depth over the cross-section.

FourPt has been adapted for accommodating simulations in the Delta. These changes provide for inclusion of reservoirs, gates, and an entirely different input system. DSM2-HYDRO Version 6.1 and DSM2-PTM Version 1.10 were used for this thesis. Output from the HYDRO component is used by the other two modules for determination of the velocity and stage conditions throughout the Delta. Thus, the water quality parameters determined by QUAL and the particle movement from PTM do not affect the hydrodynamics of the Delta system. The schematic representation of the Delta is represented in Figures 4-1 and 4-2. This representation of the Delta is modeled as a network of channel segments and open water areas. The HYDRO setup currently used is being updated by the Delta Modeling Section. This new calibrated Delta setup will improve on the current one with new geometric information. This is not available for implementation in this study due to time restraints. *[Editor's Note: Since the time of original writing, the Delta Modeling Section has adopted a new DSM2 geometry as was discussed in Chapter 2.]*

4.2.2 PTM Theory

The PTM simulates the movement of particles in a channel by imposing a velocity field and random mixing across the channel. The mean channel velocity is found by the DSM2-HYDRO model. The dispersive characteristics are determined by PTM. Velocity profiles are used to extrapolate the calculated 1-dimensional velocity into a more realistic representation of velocity. This simulation of shear flow dispersion, along with random mixing coefficients, simulates the particle movements.

4.2.3 Longitudinal Dispersion

Longitudinal dispersion in the PTM is simulated by extrapolating the mean channel velocity from DSM2-HYDRO into a pseudo 3-dimensional velocity cross-section. This representation allows the simulation of shear flow dispersion in which a particle traveling in the center of the channel (or the top of the water column) will be subjected to a higher velocity than if it were at the sides of the channel (or at the bottom of the water column). This formulation does not directly use a longitudinal dispersion coefficient typically found in the literature. Instead, this is represented in the PTM as the standard deviation or variance of the distance of all the particles from the center of mass of the particles.

The transverse velocity profile is represented by a fourth order polynomial of the form developed by Bogle (1997):

$$F_T = A + B\left(\frac{2y}{W}\right)^2 + C\left(\frac{2y}{W}\right)^4 \qquad \text{[Eqn. 4-3]}$$

where A, B, and C are constants, y is the depth of water, and w is the width of the rectangular channel. The three constants must be restricted such that the velocity at the sides of the channel is zero and to maintain a constant mean velocity. This is accomplished by satisfying the two equations:

$$A + B + C = 0 \qquad \text{[Eqn. 4-4]}$$

$$A + \frac{B}{3} + \frac{C}{5} = 1 \qquad \text{[Eqn. 4-5]}$$

When one constant value is selected, the other two are determined through solution of these two equations. Thus, selection of one constant determines the value of the others. Figure 4-3 shows the transverse velocity profile with various coefficients determined by A. The current transverse profile used by PTM is A = 1.62, B = -2.22, C = 0.6. Selection of this profile was achieved by matching the dispersion generated by these profiles to the dispersion predicted by the longitudinal dispersion coefficient equation, as is shown below in Equation 4-6 (Wilbur 2000). Higher A values yield stronger peak velocity, while lower A values yield a flatter profile.

$$K = \frac{0.11\bar{u}W^2}{d} \qquad \text{[Eqn. 4-6]}$$

where W is width, d is depth, and $\bar{u}$ is average velocity. Inclusion of the uncertainty over the transverse mixing coefficient results in a range of coefficient values of 0.06 and 0.229.

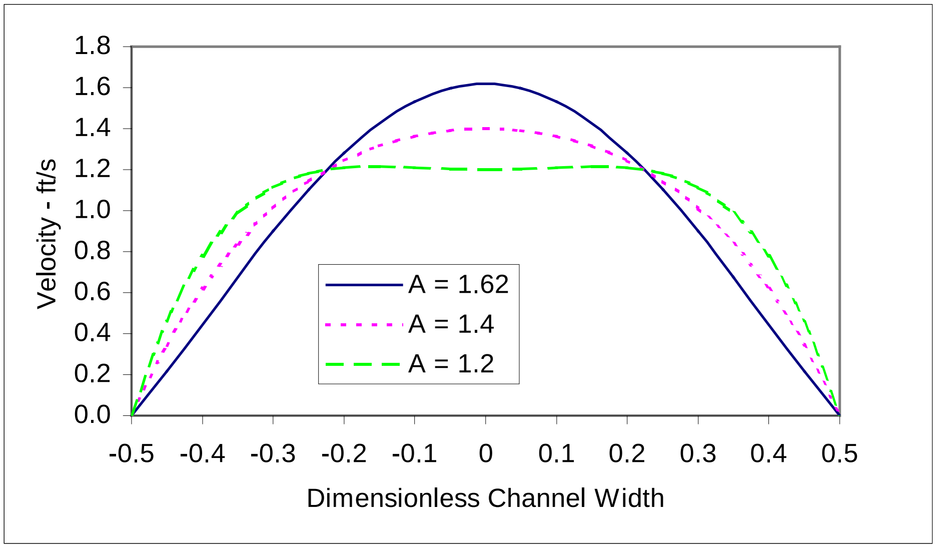

Figure 4-3: Transverse Velocity Profiles.

The vertical velocity profile is represented as the von Karman logarithmic equation:

$$F_v = 1 + \frac{0.1}{k}\left[1 + \log\left(\frac{z}{d}\right)\right] \qquad \text{[Eqn. 4-7]}$$

where k is the von Karman constant, z is vertical position in the water column, and d is the depth of water. Inclusion of a shape factor s, multiplying the von Karman constant, allows the modification of the shear induced by the velocity profile:

$$F_v = 1 + \frac{0.1}{s\,k}\left[1 + \log\left(\frac{z}{d}\right)\right] \qquad \text{[Eqn. 4-8]}$$

Changing the shape factor yields different peak velocities. Figure 4-4 shows various vertical velocity profiles with different shape factors. The current PTM model uses an s of 1.0. Increasing this constant reduces peak velocity.

One set of velocity profile coefficients is used for the entire Delta. The set does not change with time or location. The transverse and vertical velocity profiles are scaled by the mean velocity in each channel. This results in the velocity at any point in the channel cross-section represented in Equation 4-9:

$$V(y,z) = \underline{u}\, F_T\, F_V \qquad \text{[Eqn. 4-9]}$$

Here, V is the velocity at any point in the cross section and $\underline{u}$ is the mean velocity simulated by HYDRO. The profiles used in the initial model development were selected purely on a theoretical basis. The coefficients will be selected based on data presented later.

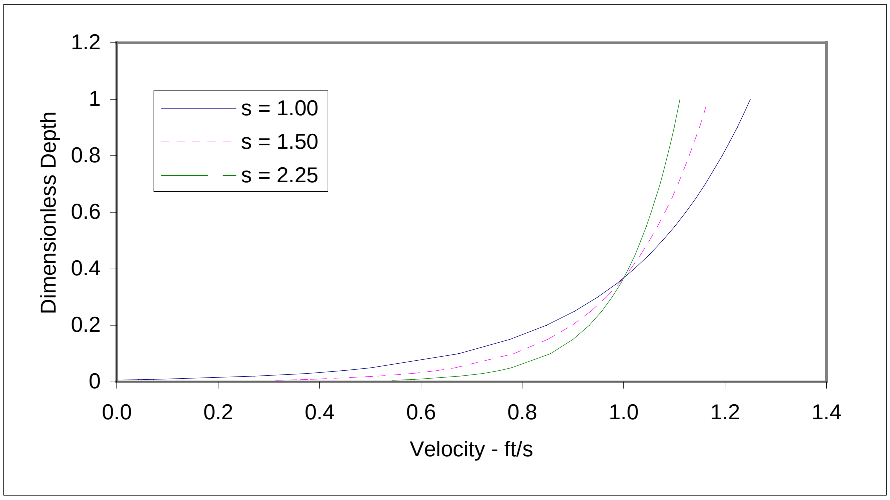

Figure 4-4: Vertical Velocity Profiles.

Comparison of the effective dispersion generated by selection of the velocity profiles to the theoretical longitudinal dispersion predicted by Equation 4-6 is performed by determining the simulated longitudinal dispersion. The variance of the longitudinal displacement of particles is found by:

$$\sigma^2 = \frac{1}{N}\left[\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{N}\right] \qquad \text{[Eqn. 4-10]}$$

Here, σ^2 is the variance, N is the number of particles, and x_i is the longitudinal location of particle i. The effective longitudinal dispersion is then found by:

$$K(t) = \frac{\sigma^2(t) - \sigma^2(t - dt)}{2\,dt} \qquad \text{[Eqn. 4-11]}$$

PTM determines the position of each simulated particle as the longitudinal distance from the beginning of each channel, the vertical distance from the bottom of the channel, and the transversal distance from the centerline of the channel. The output may be modified to allow the results to be compared to concentrations of dissolved substances, such as data from a tracer study. The number of particles in a channel segment is scaled by the volume of water in that segment. This may be represented as:

$$C = f\,\frac{(\#\text{ of particles})}{AL} \qquad \text{[Eqn. 4-12]}$$

where A is the cross-sectional area, L is the length of the channel segment, and f is a scaling factor used to adjust to appropriate magnitude. The area changes with time as the stage and flow oscillate due to the hydrodynamics of the Delta.

4.3 Data

Two sets of data collected by USGS are used for this calibration study. These consist of channel cross-sectional velocity profiles and tracer (rhodamine WT) data.

4.3.1 ADCP

Acoustic Doppler Current Profiler (ADCP) data are used to measure the flow and velocity in the cross-section of a channel. The ADCP instrument is an advanced acoustic device that sends signals into the water column. These signals reflect off particles moving with the water and return to the instrument. The ADCP measures the change in frequency in the signal and determines particle velocity. The ADCP divides the depth of water into a series of vertical bins and returns each bin's average velocity. The depth of each bin is approximately 0.3 meters. A series of these depth readings is made as the boat carrying the ADCP travels across the channel. The speed of the boat is removed from the velocity by using “bottom tracking.” This results in a cross-sectional view of the velocity field (RD Instruments 1996).

ADCP data were collected at 16 sites in the Delta over a period of 3 years starting in 1997. The typical collection pattern consists of between two and seven hours of cross-section transverses at one location. This enables the collection of data to include a portion of the tidal motion. One transverse takes between five and 15 minutes, depending on width of cross-section. Table 4-1 lists the locations and dates of this data.

Table 4-1: Location and Dates of Collected ADCP Data

	1997			**1999**					
Location	April	May	June	March	April	May	June	July	August
Connection Slough					x	x	x	x	
Dutch Slough below Jersey Island Road @ Jersey Point									x
False River					x	x	x	x	
Grantline Canal @ Tracy Road	x	x	x			x	x	x	
Middle River @ Middle River									x
Middle River South of Columbia Cut	x	x	x		x	x	x	x	
Old River @ Bacon Island									x
Old River @ Clifton Court Ferry	x	x	x						
Old River Near Webb Tract						x	x		
Sacramento River above Delta Cross Channel									x
San Joaquin River @ Jersey Point									x
San Joaquin River bet. Columbia & Turner Cuts	x	x	x						
San Joaquin River below Garwood Bridge @ Stockton				x					
Threemile Slough @ San Joaquin River						x			
Turner Cut	x	x	x		x	x			
Victoria Canal	x	x	x						

Figures 4-5 and 4-6 show the measured data for Turner Cut. Figure 4-6 shows the transverse and vertical velocity profiles measured on April 9, 1997 at 1:30 p.m. Figure 4-5 shows the tidal influence on the flow at this location. Averaging the velocity profile data allows the irregular data (due to turbulence) to be smoothed, as Figure 4-6 shows. The averaging was done as a running mean of 5 to 15 data points. The general trend of the velocity profiles does correlate with the vertical and transverse profiles assumed in the PTM model. Comparisons with the PTM profiles are presented in a later section.

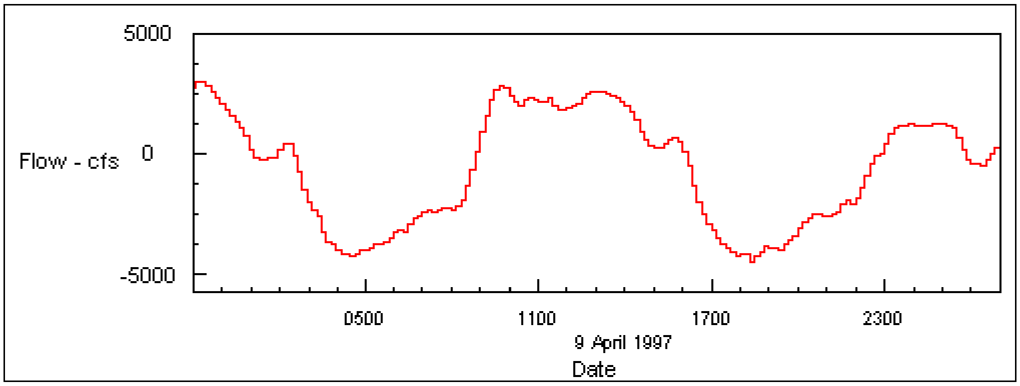

Figure 4-5: Historical Flow at Turner Cut.

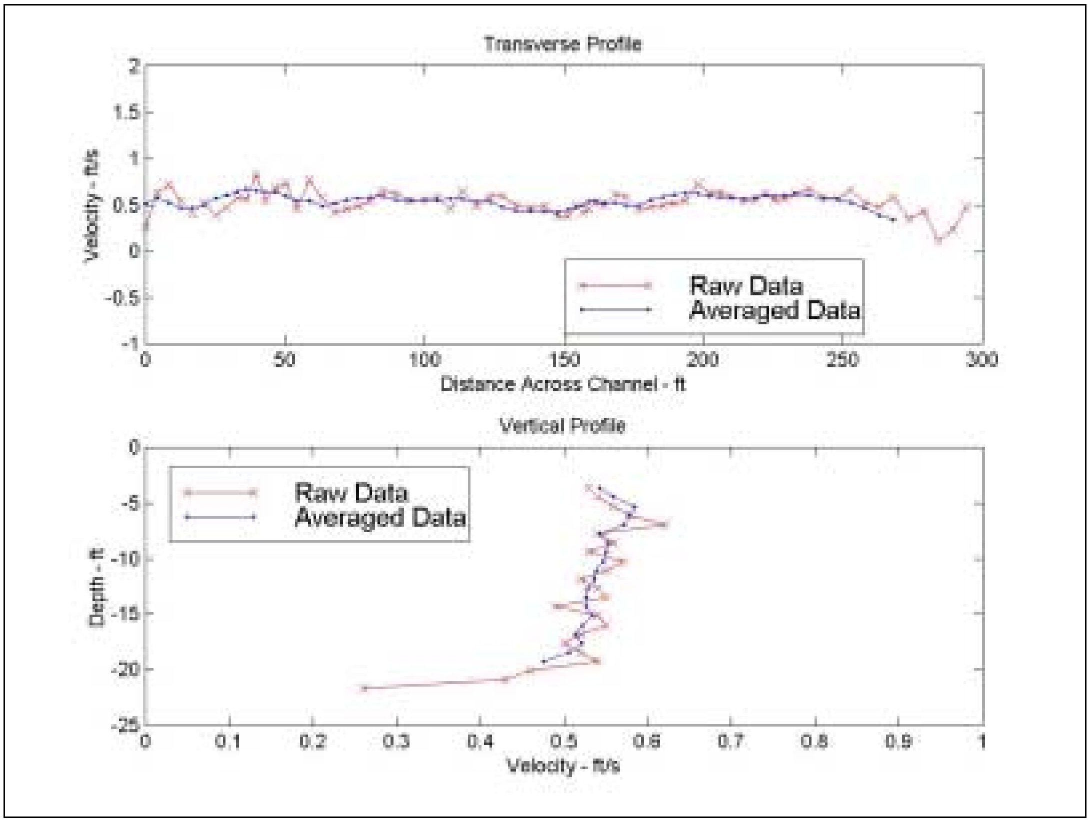

Figure 4-6: Turner Cut ADCP Profile Data (1:30 p.m., April 9, 1997).

Similar characteristics are found at the San Joaquin River between Columbia and Turner Cuts. Figures 4-7 and 4-8 show the flow and ADCP velocity profile data on April 4, 1997 at 10:30am.

Additional locations showing cross-sectional velocity magnitudes are shown in Wilbur (2000) for different stages in the tidal sequence. The stage data corresponding with these times are also provided. Inspection of these figures shows a great deal of heterogeneity in the channel cross-section and velocity magnitudes.

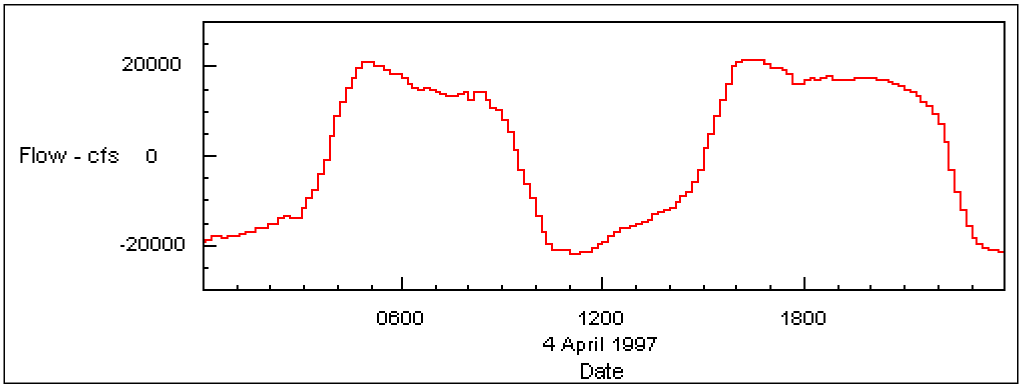

Figure 4-7: Historical Flow of SJR between Turner and Columbia Cuts.

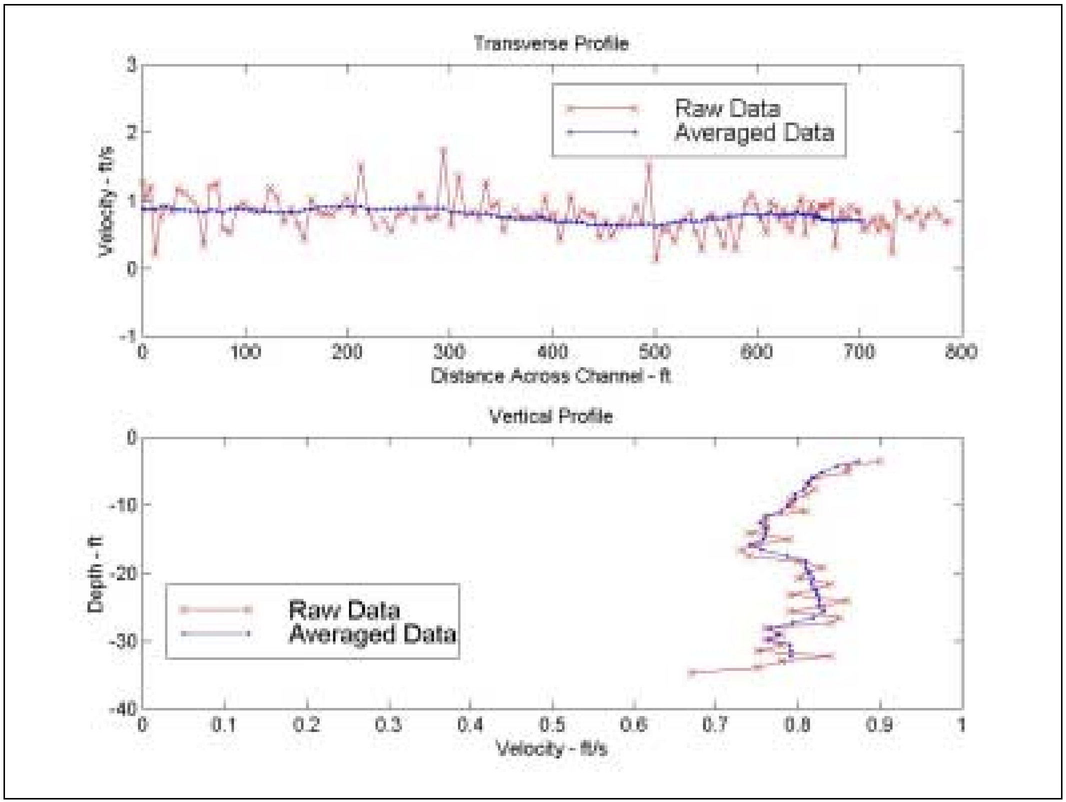

Figure 4-8: SJR between Turner and Columbia Cuts ADCP Profile Data (10:30 p.m., April 4, 1997).

4.3.2 Tracer

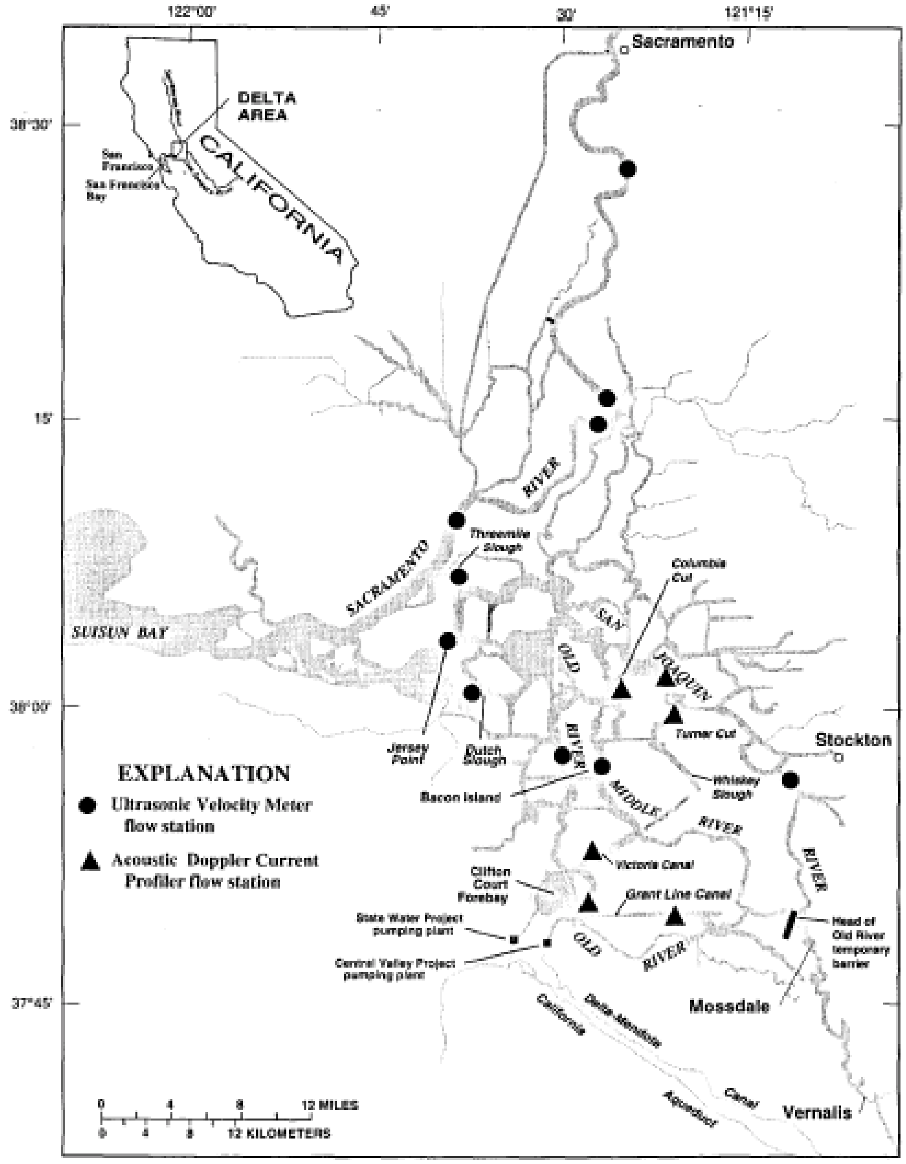

Figure 1. Locations of tidal-flow monitoring stations, Sacramento-San Joaquin Delta, California. UVM, ultrasonic velocity meter; ACDP, acoustic Doppler current profiler.

2 Measured Flow and Tracer-Dye Data Showing Anthropogenic Effects on the Hydrodynamics, south Sacramento-San Joaquin Delta

Figure 4-9: Location of Tracer Study Data Collection Sites.

The tracer study used in this project was conducted and presented by Oltmann (1998) and is summarized here. A Rhodamine WT tracer study was performed in April and May 1997 to track the movement of water into which tagged salmon smolts were released. The tracer was released at noon on April 28, 1997 near Mossdale on the San Joaquin River one hour prior to the release of 50,000 salmon smolts by the U.S. Fish and Wildlife Service and California Department of Fish and Game. Forty-eight liters of 20% Rhodamine WT were released over a 15- minute period. Nine automatic sampling measurement sites in the Delta were used to record the concentration of the tracer. These took samples on an hourly basis and were retrieved and transported to a laboratory where a fluorometer was used to measure the tracer concentration. Figure 4-9 shows the locations of the tracer data collection sites. The locations are: Grantline Canal at Tracy Blvd bridge, Jersey Point, Middle River at Middle River, Middle River South of Columbia Cut, Old River at Bacon Island, Old River at Clifton Court Ferry, Turner Cut, San Joaquin River at Stockton UVM site, and San Joaquin River at Mandeville Ranch.

The tracer was released during the Vernalis Adaptive Management Plan's (VAMP) pulse-flow period on April 28, 1997. The flow on the San Joaquin River near Mossdale is shown in Figure 4-10. The tracer traveled from the release point to the Stockton UVM sampling site (about 13 miles) in about 10 hours (mean velocity of 1.9 ft/sec). Figure 4-11 shows the tracer concentration for the Stockton UVM site. This shows the peak concentration reached 10.5 ug/L and took about four hours to pass the site.

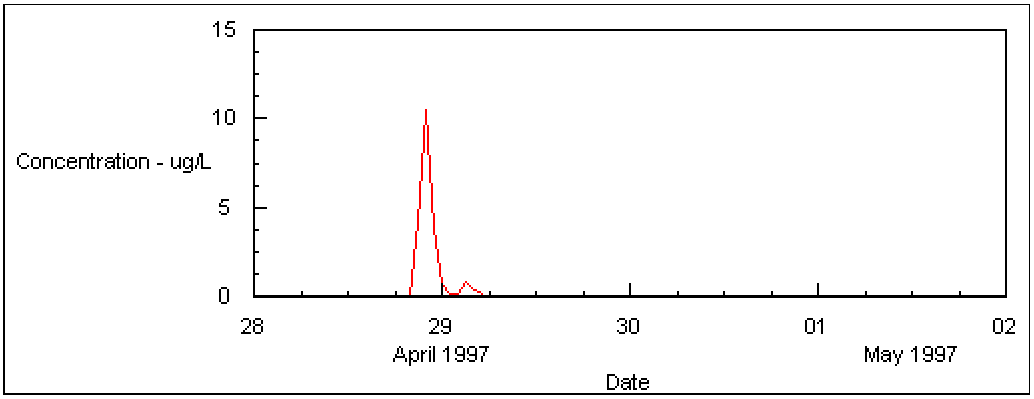

Figure 4-10: Tracer Concentration at Stockton UVM Site.

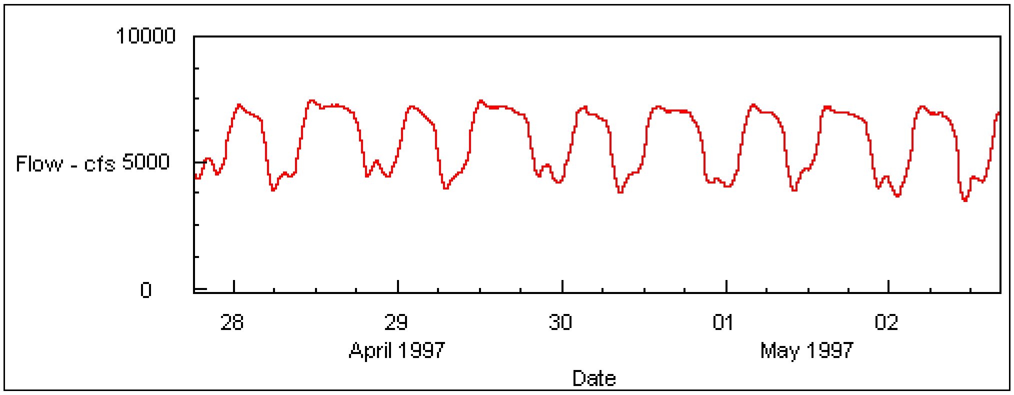

Figure 4-11: Measured Flow at Stockton UVM Site.

Turner Cut tracer concentration and flow are shown in Figures 4-12 and 4-13. Turner Cut is approximately 10 miles downstream from the Stockton UVM site. Travel time for the tracer to reach Turner Cut was about 25 hours (mean velocity 0.6 ft/sec). As Figure 4-13 shows, this portion of the Delta is influenced much more by tidal forces than the Stockton UVM site, resulting in the tracer taking more time to pass this site due to the reversing flow conditions. The peak concentration reached about 0.8 ug/L and the tracer took just over two days to pass the site.

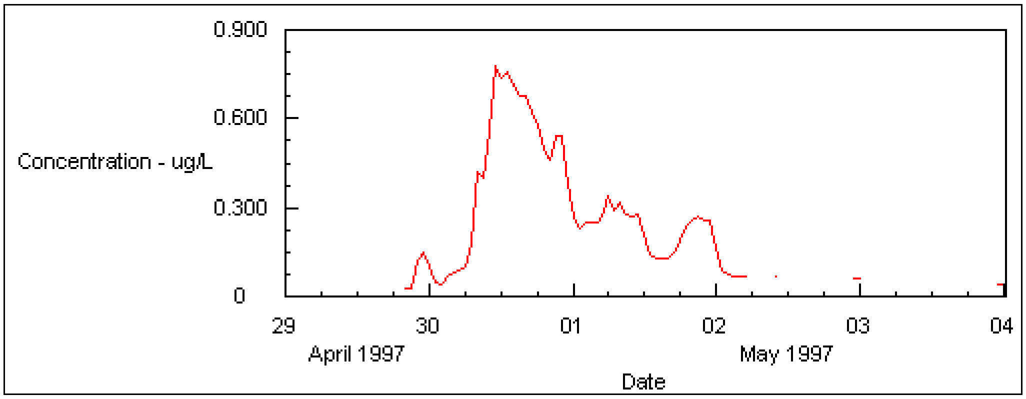

Figure 4-12: Tracer Concentration at Turner Cut.

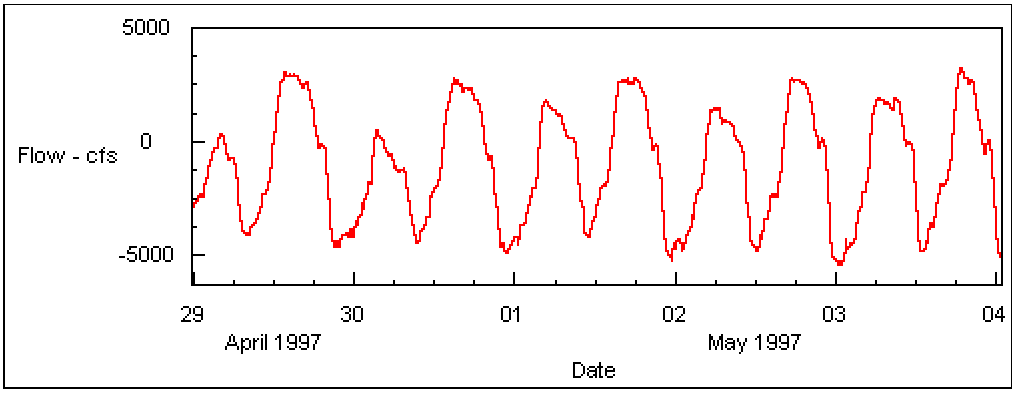

Figure 4-13: Measured Flow at Turner Cut.

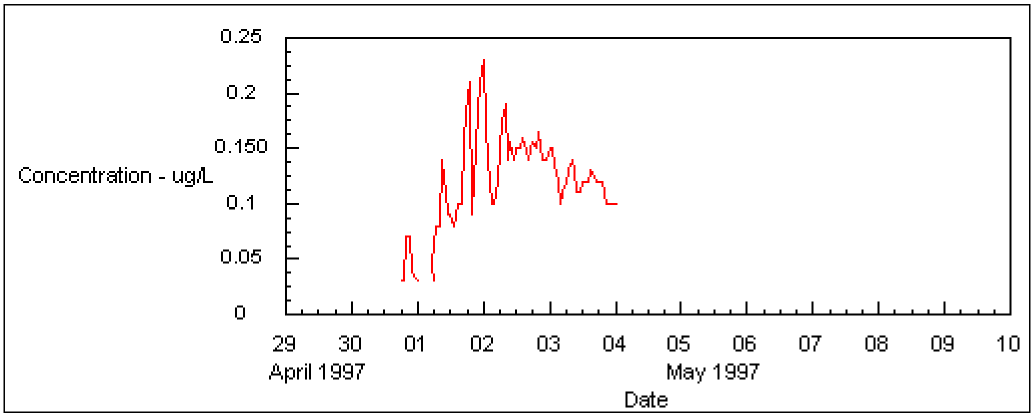

Figure 4-14: Tracer Concentration at San Joaquin River near Mandeville Ranch.

Figure 4-14 shows the tracer concentration at San Joaquin River near Mandeville Ranch. No measured flow data were available for this location. The peak concentration is reduced and the length of time passing the site is increased compared to the previous two locations. This is due to the increased mixing caused by tidal forces in the Delta. Similar results were found at Middle River South of Columbia Cut, shown in Figures 4-15 and 4-16.

Figures 4-17 and 4-18 show the tracer and measured stage at Grantline Canal near the Tracy Blvd Bridge. This shows some flow was able to pass through the barrier and culverts installed at the head of Old River. The concentrations measured at Grantline are fairly small compared to the other locations.

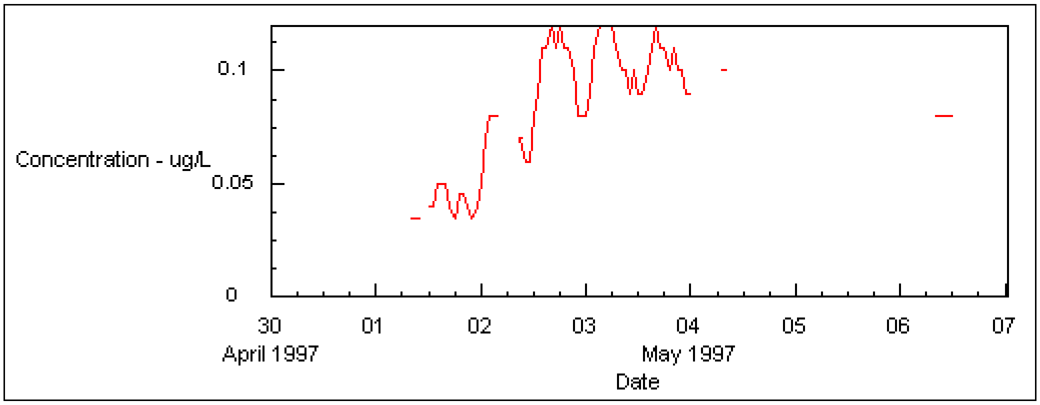

Figure 4-15: Tracer Concentration at Middle River near Columbia Cut.

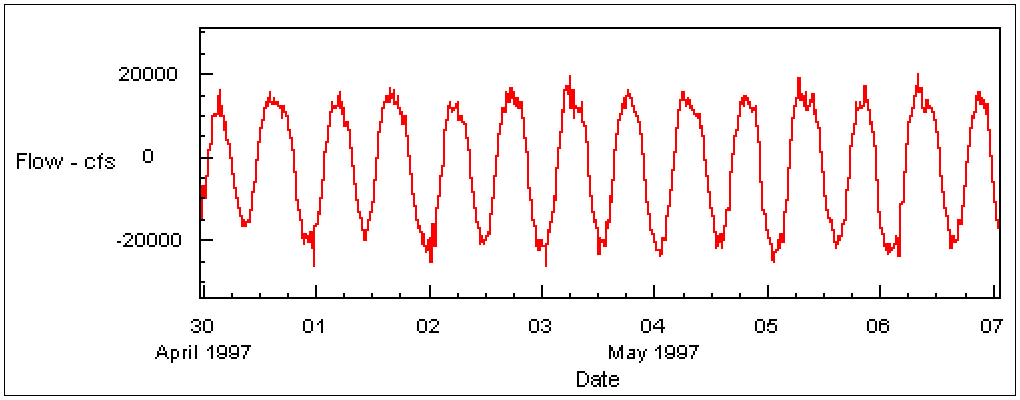

Figure 4-16: Measured Flow at Middle River near Columbia Cut.

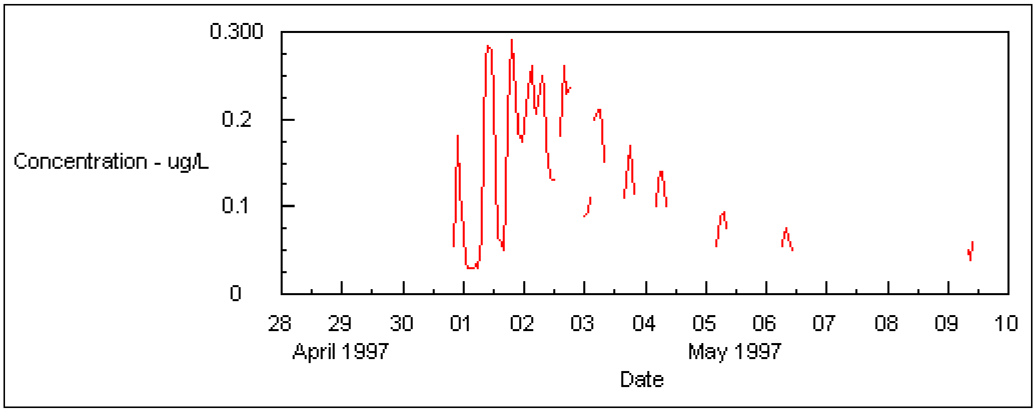

Figure 4-17: Tracer Concentration at Grantline Canal near Tracy Blvd. Bridge.

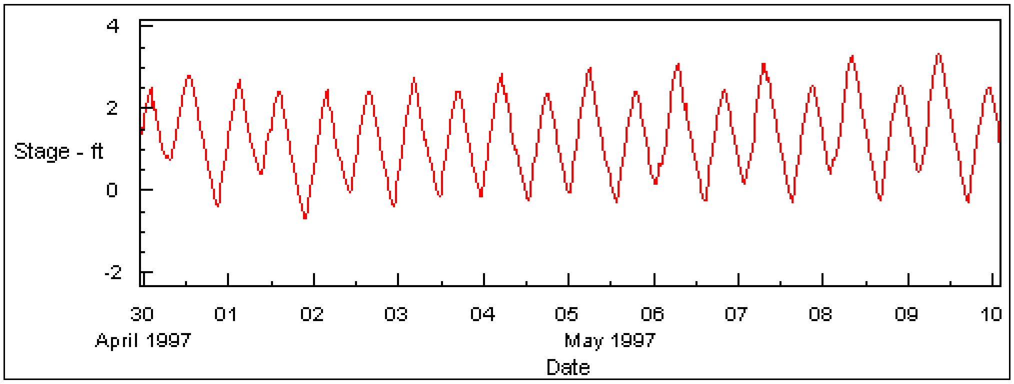

Figure 4-18: Measured Stage at Grantline Canal near Tracy Blvd. Bridge.

Other tracer sample recording locations experienced difficulties, making the data inapplicable for the purpose of this project. All collected at Old and Middle River UVM sites showed concentrations no higher than background concentrations (about 0.04 ug/L). The Old River UVM (near Clifton Court Forebay) measured the tracer arriving prior to the arrival at Grantline Canal – this shows something was interfering with the measurement. The Jersey Point station did not record any data.

4.4 Modeling Results

4.4.1 Profile Comparisons

Comparison of velocity profiles between the ADCP data and those used by the original PTM profiles show some inconsistencies. The profiles used by the PTM model have the same mean velocity, but consistently over-predict variation in peak velocity across the channel. This leads to the overestimation of shear flow dispersion calculated by PTM. Modification of the velocity profile coefficients yields an improved representation of the velocity fields.

Adjustments of the coefficients for the transverse and vertical velocity profiles make it possible to improve the representation of these idealized profiles to better approximate the profiles measured by the ADCP data. Figures 4-19 and 4-20 show the velocity data for Turner Cut. These now have additional information including the original and modified profiles. The modified profiles, obtained by inspection, were found to better represent the transverse and vertical velocities. Coefficients selected for the transverse profile are A = 1.2 and for the vertical profile the shape factor s = 1.25. Figures 4-21 and 4-22 show similar graphs for San Joaquin River between Columbia and Turner cuts.

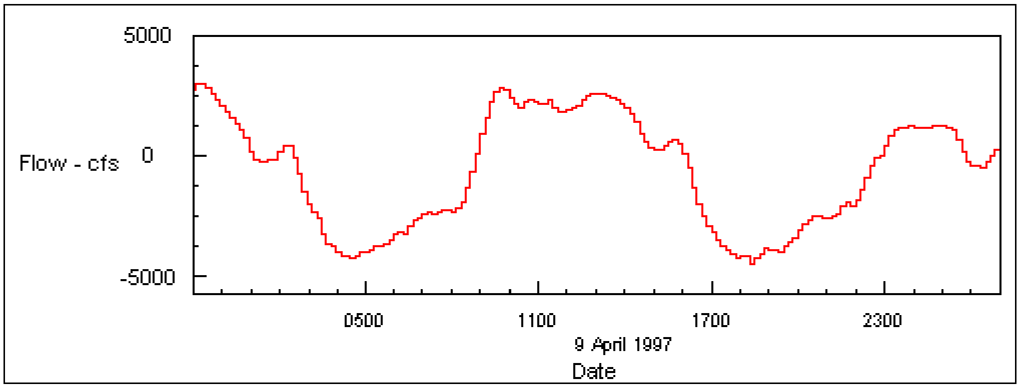

Figure 4-19: Turner Cut Flow.

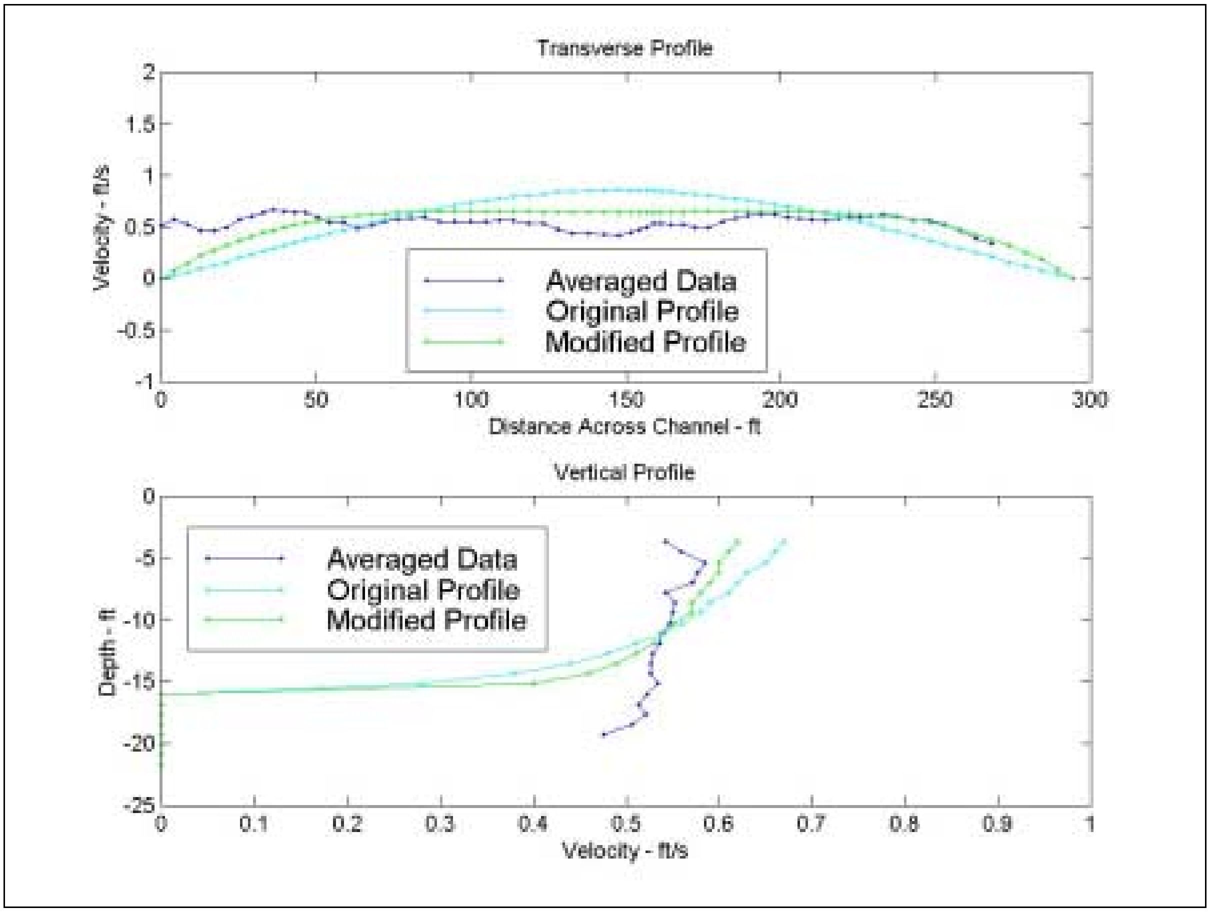

Figure 4-20: Turner Cut Profile – ADCP Comparison (1:30 p.m., April 9, 1997).

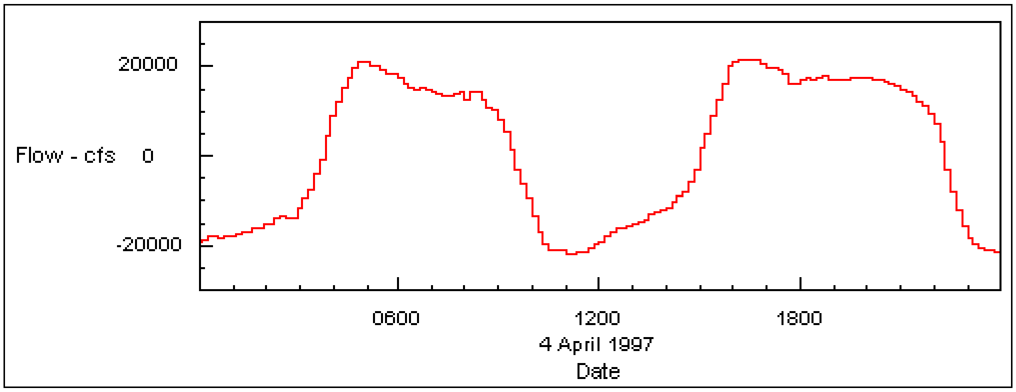

Figure 4-21: SJR between Columbia and Turner Cuts Flow.

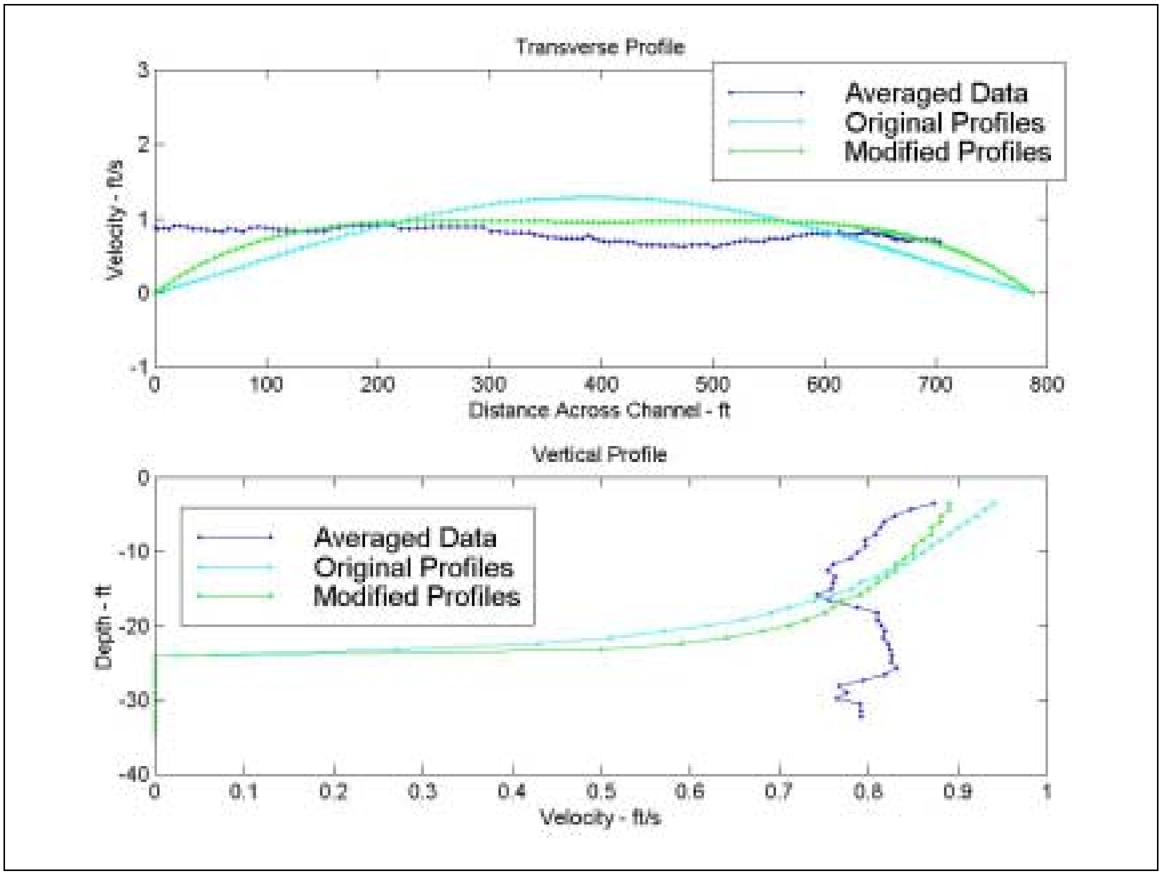

Figure 4-22: SJR between Columbia and Turner Cuts Profile – ADCP Comparison (10:30 p.m., April 4, 1997).

Additional figures presented by Wilbur (2000) show the comparisons between the ADCP data and the theoretical transverse and vertical velocity profiles for both the original and the modified profile coefficients. The vertical velocity profile shows more inconsistencies when compared to the ADCP data than the transverse profile. Several of the figures show that a uniform vertical velocity profile may better represent the observed data. In a later section, a uniform vertical velocity profile, as well as a uniform transverse velocity profile, will be compared to the modified velocity profiles shown in the figures.

4.4.2 Longitudinal Dispersion

A single hypothetical channel was represented in DSM2 in order to investigate the behavior of the Particle Tracking Model's implementation of longitudinal dispersion. Modification of the velocity profile coefficients controls the amount of dispersion superimposed on the advection of a mass of particles. Velocity profile coefficients used for this simulation were both the original ($A = 1.6$, $s = 1.0$) and the modified profiles ($A = 1.2$, $s = 1.25$). The channel has a width 500 feet, an average depth of 40 feet, and an average velocity of 1.6 ft/sec. Ten thousand particles were inserted instantaneously at the furthest upstream location.

Figure 4-23 shows the particle concentration for the original and modified velocity profiles. Three locations are shown (at 5, 20, and 35 miles downstream of the beginning of the channel), which demonstrate how, under steady flow conditions, the different dispersion scenarios transport the particles. The original profiles produce more dispersion. This is shown in the figure by the smaller peak concentration and the longer time it takes to pass a single site. The modified profiles, having less dispersion, have higher concentrations and behave more advectively.

Equation 4-6 may be used to predict theoretical longitudinal dispersion. The range of theoretical longitudinal dispersion for this channel is 165 to 4,900 ft^2/s as determined by the uncertainty of Equation 4-6. Figure 4-24 shows the variance for the longitudinal displacement of particles produced by the original velocity profiles. The linear nature, once dispersion has fully developed, reflects the steady state condition. Figure 4-25 shows the effective longitudinal dispersion coefficient based on the original profiles. The steady state range approaches 1,200 ft^2/s, which is in the range of theoretical dispersion in Equation 4-6. This figure shows the first 3 hours of simulation time. A period of about 2 hours is needed for the dispersion to fully develop. The fluctuations in the curve are due to the randomness of the random mixing coefficients.

Figures 4-26 and 4-27 show the variance of longitudinal displacement and the effective longitudinal dispersion coefficient using the modified velocity profiles. The steady-state value of dispersion for the modified profiles is about 300 ft^2/s, which is also in the range of theoretical longitudinal dispersion. The modified velocity profiles yield a smaller longitudinal dispersion coefficient. This value is still within the range of acceptable values, as compared to those from Fischer (1979).

Inclusion of a tidal influence at the downstream end of the channel allows for the investigation of how longitudinal dispersion behaves in the Delta. A repeating 25-hour oscillating stage was added to the downstream boundary condition. Figure 4-28 shows a segment of the historic tide used for this example. Predicting a longitudinal dispersion coefficient by Equation 4-6 in a tidally influenced system becomes difficult because a steady state condition never develops – the dispersion coefficient is always changing. Additionally, in real systems with many branches, such as the Delta, the mass of particles becomes separated into different channels as the tide forces the flow throughout the system. Each channel typically experiences different flow and tidal conditions at different times, producing different dispersion coefficients for each.

Figure 4-29 shows the tidal influence on the stage for different locations in the channel. The upper reaches (5 and 20 miles downstream) are slightly influenced while the lower reaches (34 and 45 miles downstream) are significantly affected by the tide. Figure 4-30 shows the particle concentration for three locations in the channel. The tide at the various locations has delayed the arrival time of the particle cloud by almost 12 hours and reduced the peak concentrations.

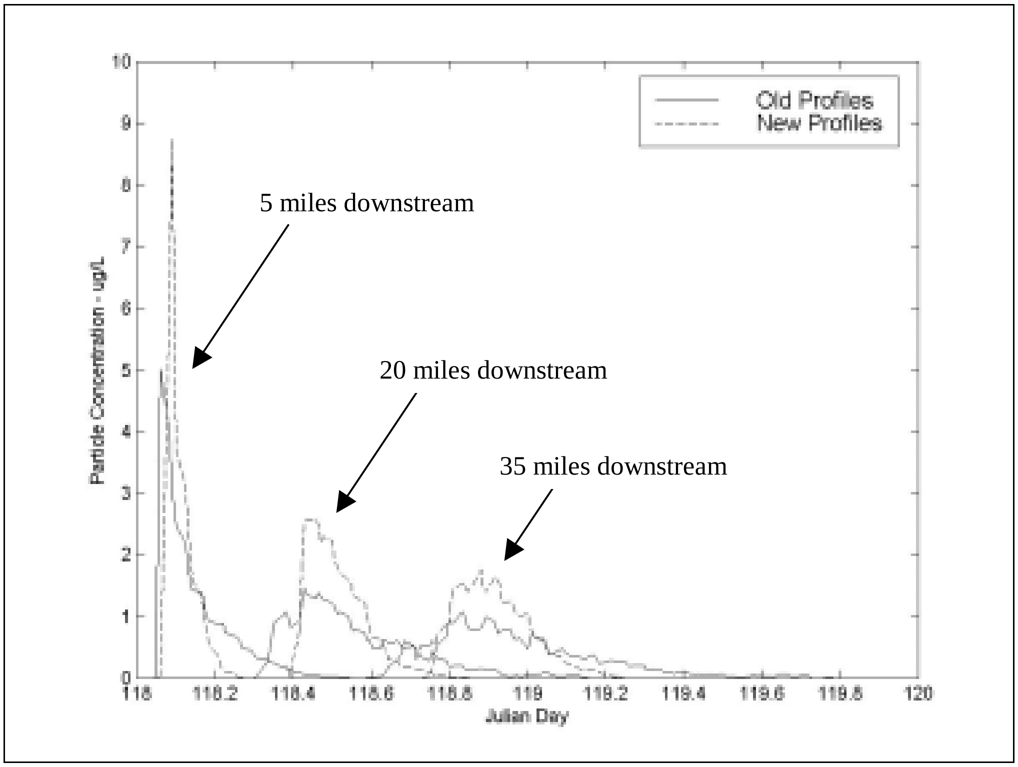

Figure 4-23: Velocity Profile Differences for a Single Long Channel.

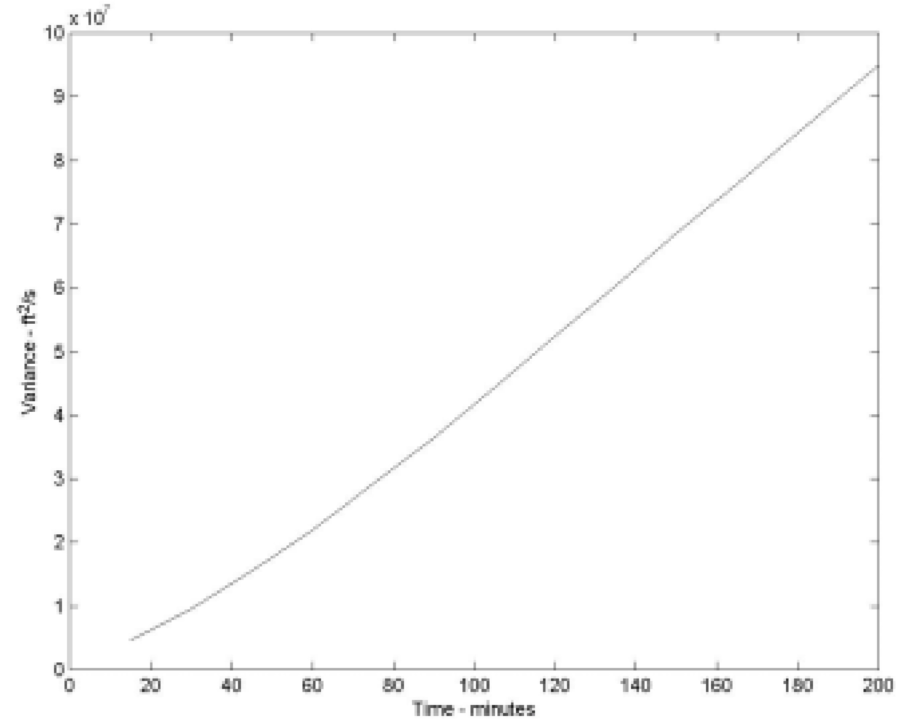

Figure 4-24: Variance of Longitudinal Displacement for Original Profiles.

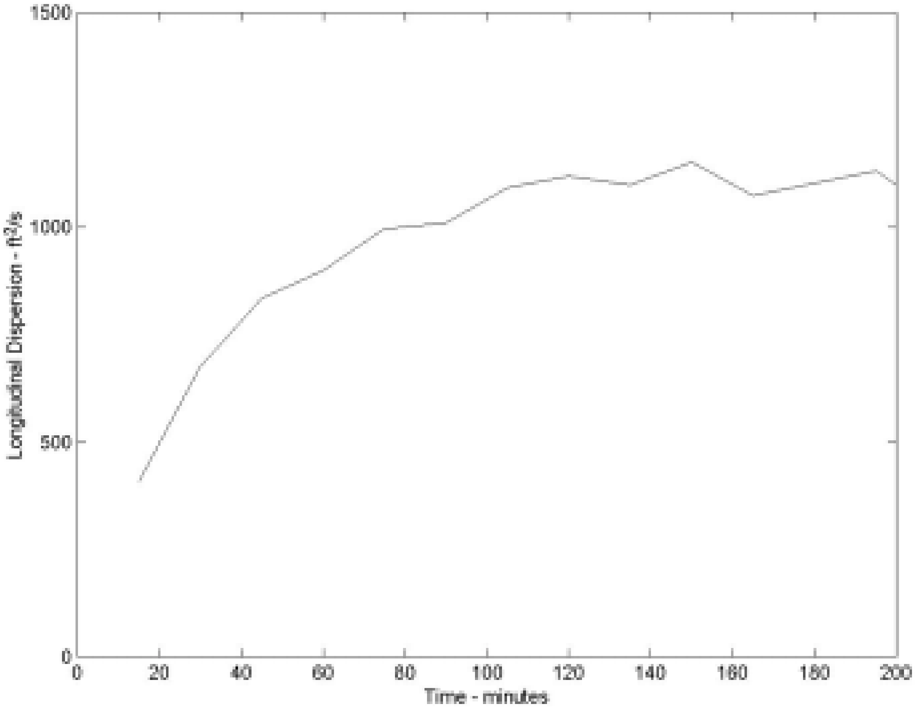

Figure 4-25: Effective Longitudinal Dispersion for Original Profiles.

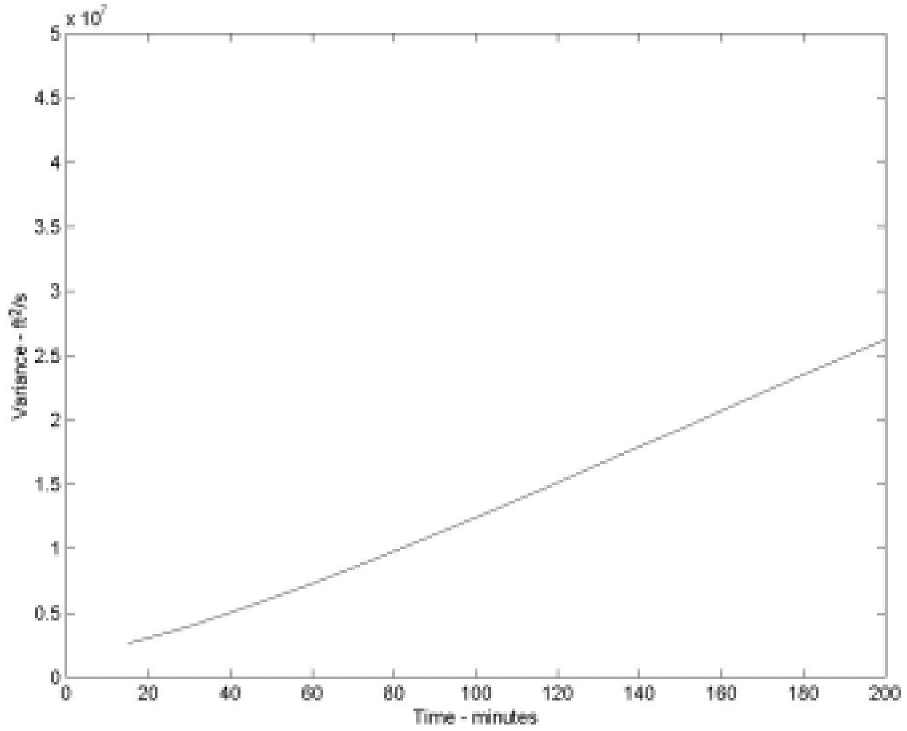

Figure 4-26: Variance of Longitudinal Displacement for Modified Profiles.

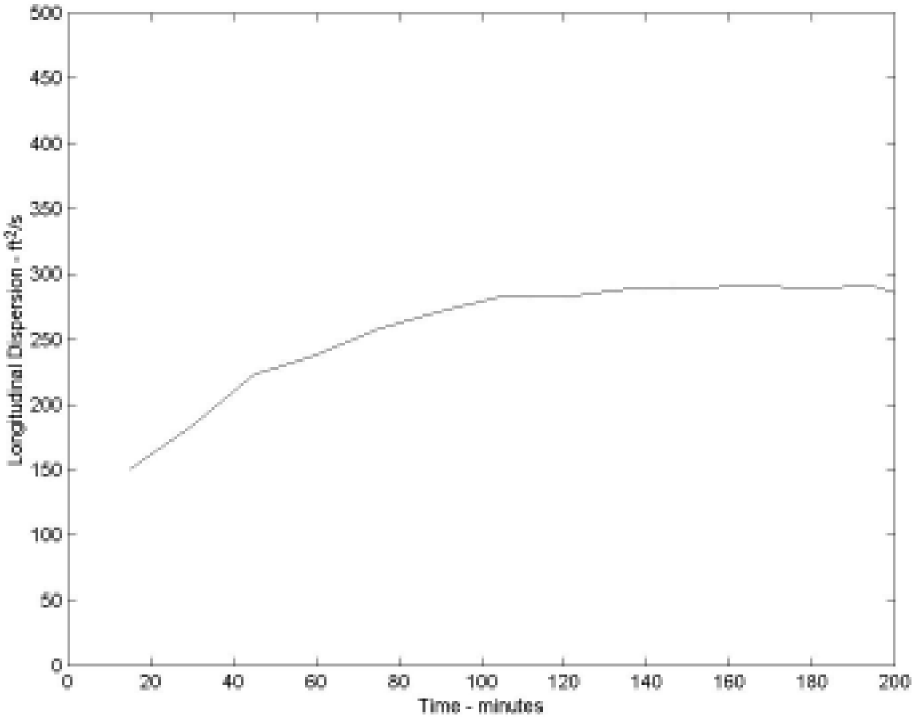

Figure 4-27: Effective Longitudinal Dispersion for Modified Profiles.

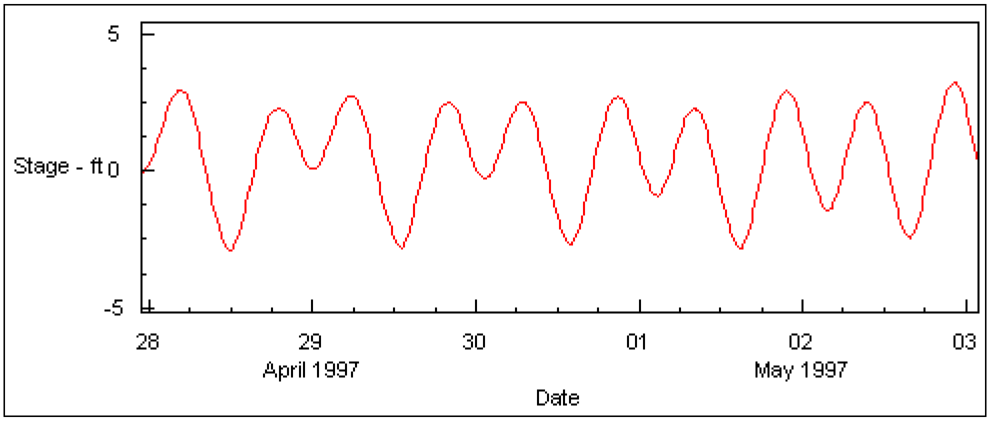

Figure 4-28: Stage Boundary Condition for Long Channel.

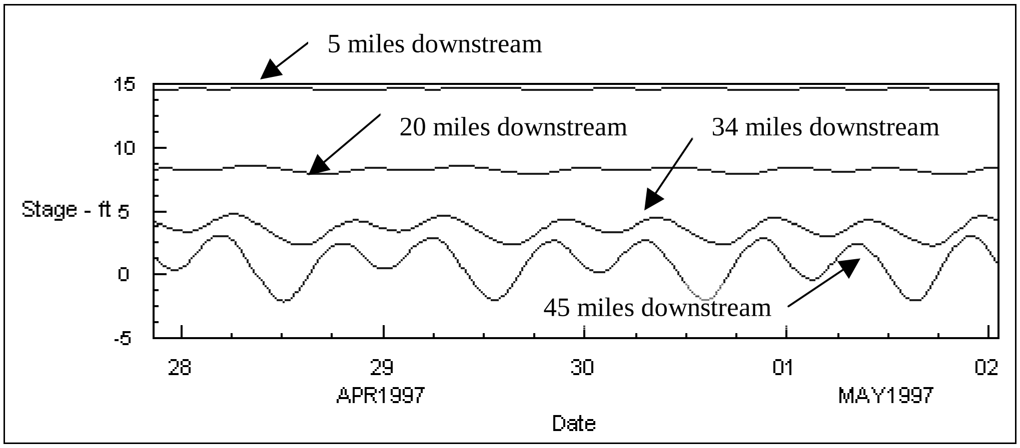

Figure 4-29: Stage at Various Locations influenced by Tidal Boundary Condition.

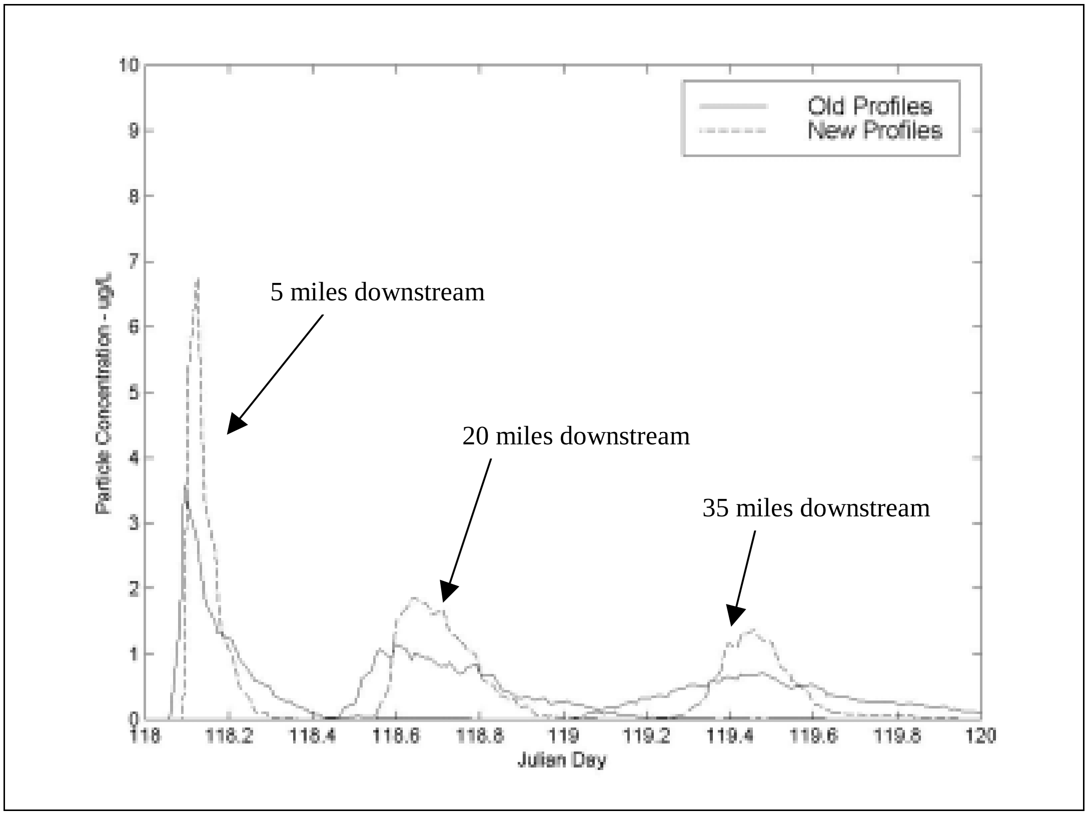

Figure 4-30: Particle Concentration for Long Channel with Tidal Boundary Condition.

4.5 DSM2 Results

[Editor's Note: The results presented below were not based on the most recent geometry that is currently in use, because this new geometry had not been verified at the time of this study. The current DSM2 geometry is discussed in Chapter 2.]

4.5.1 Hydrodynamics

The hydrodynamics of the Delta are important for the PTM model to give accurate results. While the hydrodynamics are not the focus of this investigation, they are presented here for completeness.

The simulations use a historical real tide for the westernmost boundary at Martinez. The stage used as a boundary condition is shown in Figure 4-31 for the duration of the tracer study. There is a 25-hour repeating tide sequence. This includes a 12.5-hour period between each high tide (also for low tide).

Gate operations are accounted for in such places as the Delta Cross Channel and temporary barriers at the head of Old River. Documented gate installation and operations come from DWR (1998).

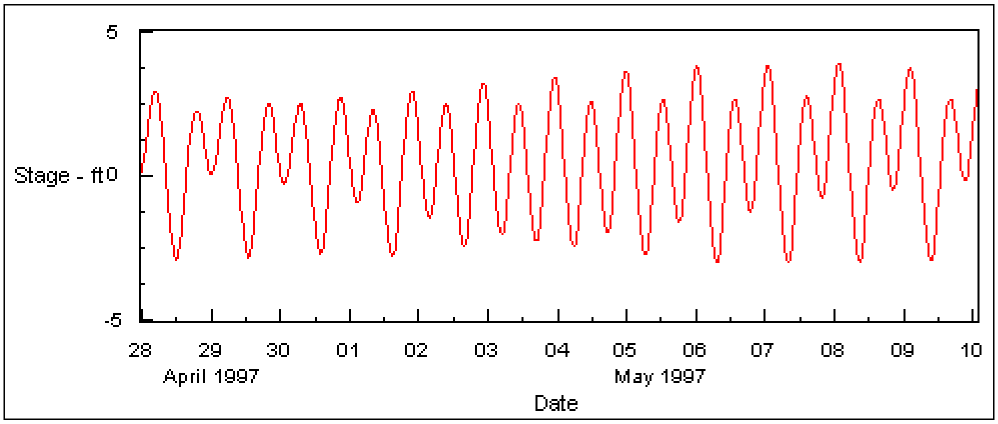

Figure 4-31: Martinez Stage Boundary Condition.

Stage and flow results are presented with historical data at various locations. Locations of interest for the tracer study are shown. Figures 4-32 – 4-35 show HYDRO simulation results with historical data for Turner Cut, Jersey Point, Old River near Bacon Island, and Middle River south of Columbia Cut.

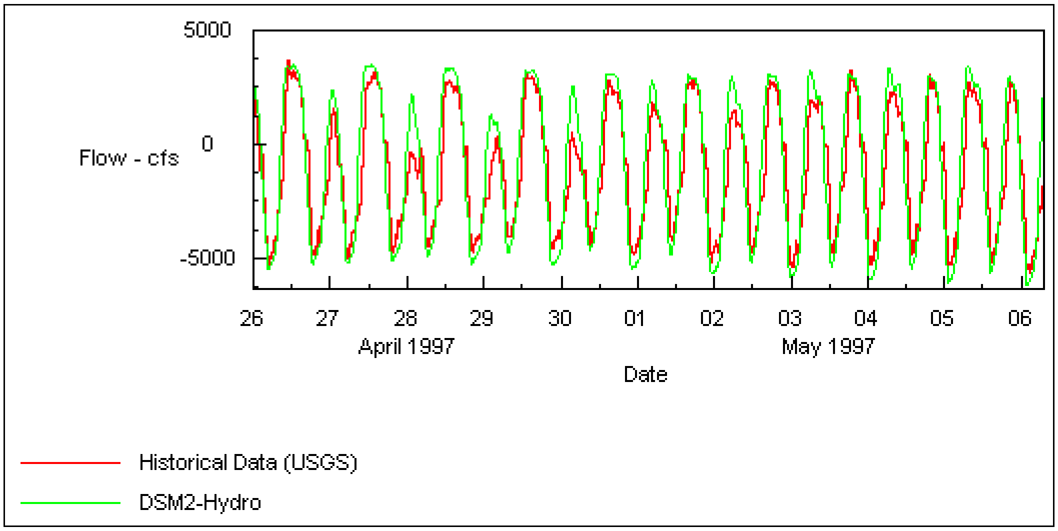

Figure 4-32: DSM2 and Measured Flow at Turner Cut.

Figure 4-32 shows the simulated flow at Turner Cut. HYDRO represents fairly well the measured flow. The extreme magnitudes on the tidal oscillation show the greatest amount of problems for this and other sites. The largest inconsistencies are about 600 cfs, while the majority of the time these measure less than 200 cfs.

Figure 4-33 shows the simulated and measured flow for Jersey Point. This also shows that the majority of the inaccuracies with HYDRO have to do with simulating the peak flows. Due to the magnitude of the flow at Jersey Point the small differences shown on the figure are approximately 2,000 cfs.

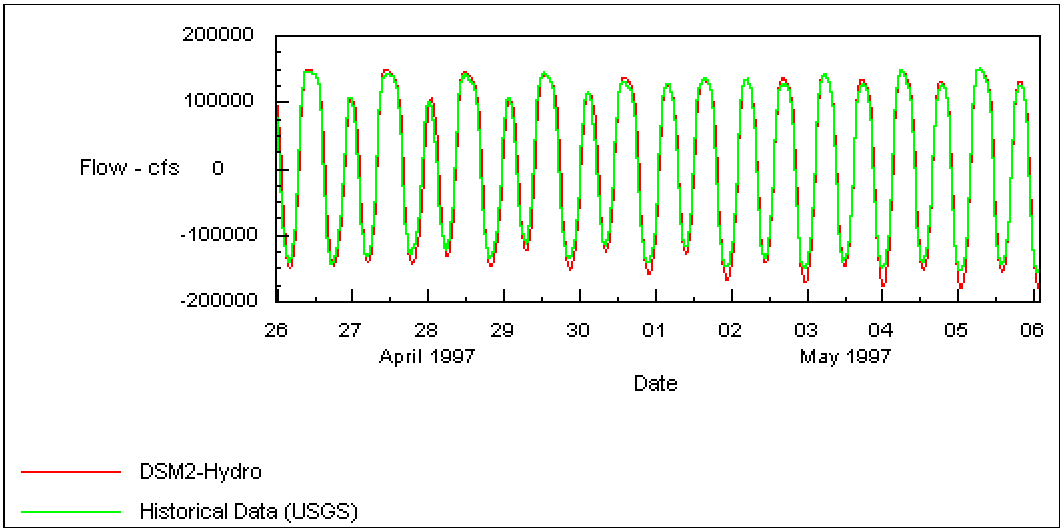

Figure 4-33: DSM2 and Measured Flow at Jersey Point.

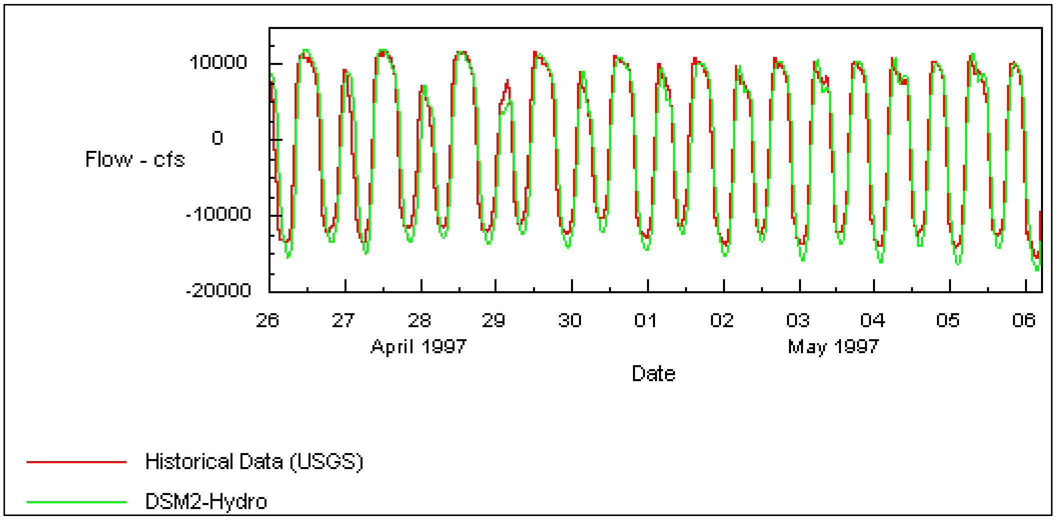

Figure 4-34: DSM2 and Measured Flow at Old River near Bacon Island.

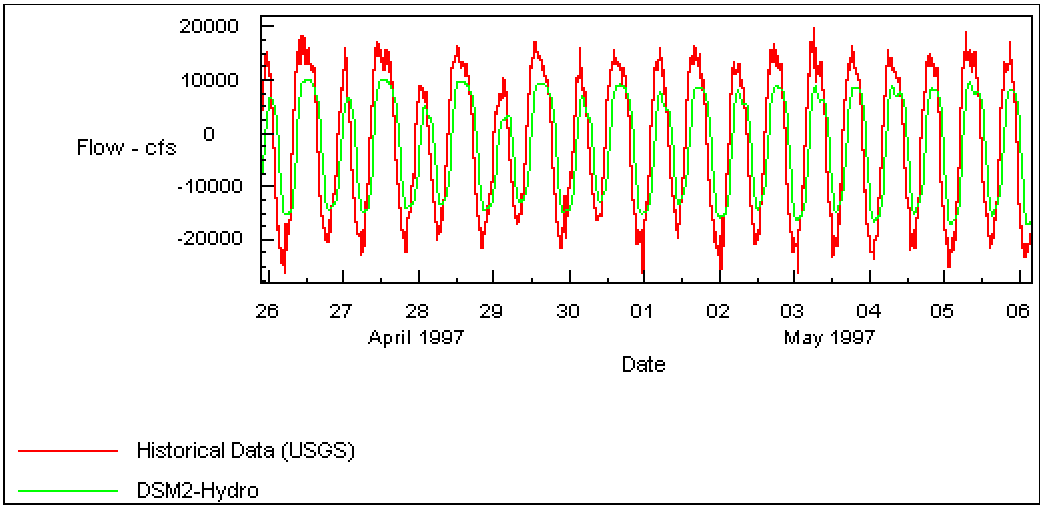

Figure 4-35: DSM2 and Measured Flow at Middle River South of Columbia Cut.

Flow at Old River near Bacon Island is shown in Figure 4-34. Similar results are found comparing the measured and simulated flow. Differences between the two are less than 1,000 cfs.

Simulated and measured flow for Middle River South of Columbia Cut shows a large amount of disagreement. Figure 4-35 shows differences of nearly 10,000 cfs. This mismatch is probably due to poor representation of the bathymetry.

4.5.2 PTM – Tracer Comparisons

The original velocity profiles are used in the first simulation to compare it to the collected tracer data. An additional simulation was performed with modified velocity profiles that more accurately represent the velocity profiles found in the ADCP data.

As discussed earlier, the concentrations for the tracer study are reliable at only a few sites. The PTM simulations and tracer data are compared at these locations only. Three locations in particular have high enough concentrations to be used in testing the PTM model. These are Turner Cut, Mandeville Ranch, the UVM site near Stockton, and Middle River south of Columbia Cut.

The PTM simulations compared here use the velocity profile coefficients listed in Table 4-2. The PTM results (position of each particle) are converted to a concentration through use of Equation 4-12. The factor used to scale the particles to micro-grams per liter is 318,000.

Table 4-2: PTM Velocity Profile Coefficients

	A	B	C	Shape Factor
Original Profile	1.62	-2.22	0.6	1.0
New Profile	1.2	0.3	-1.5	1.25

The first location, Stockton UVM, is shown in Figure 4-36. This figure shows the tracer data, and PTM simulation results with original and modified profile configurations. It appears the original profiles more accurately represent the tracer data. It should be kept in mind that the distance of the Stockton UVM site is close to the particle injection point. The modified profiles do not mix across the channel to simulate full mixing of particles.

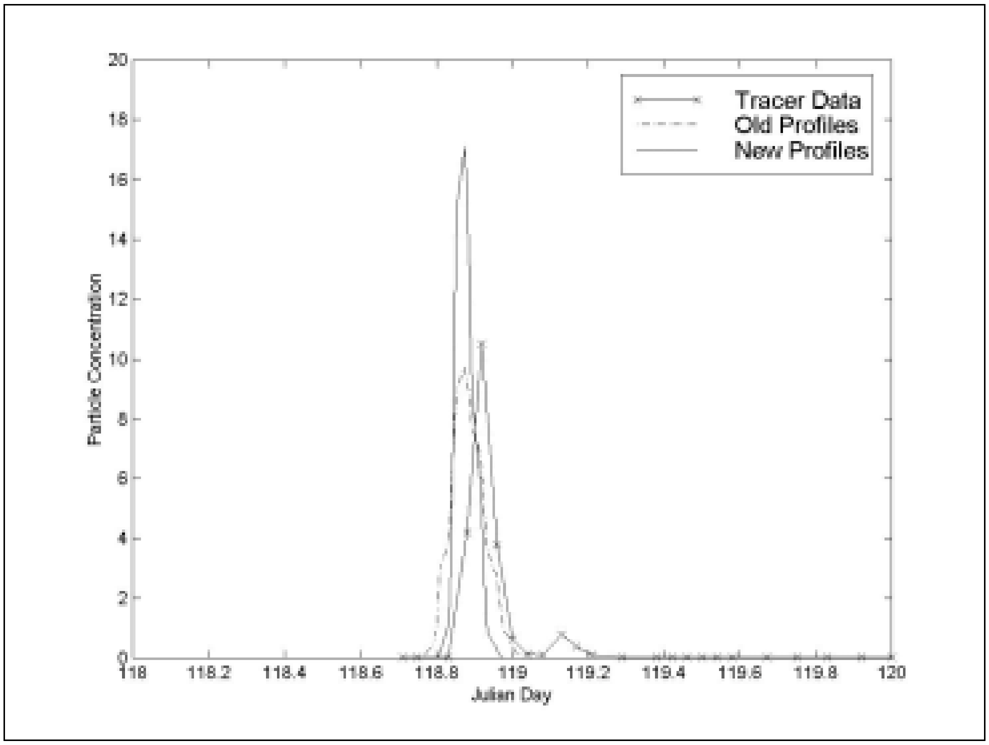

Figure 4-36: PTM and Tracer Comparison at Stockton UVM Site.

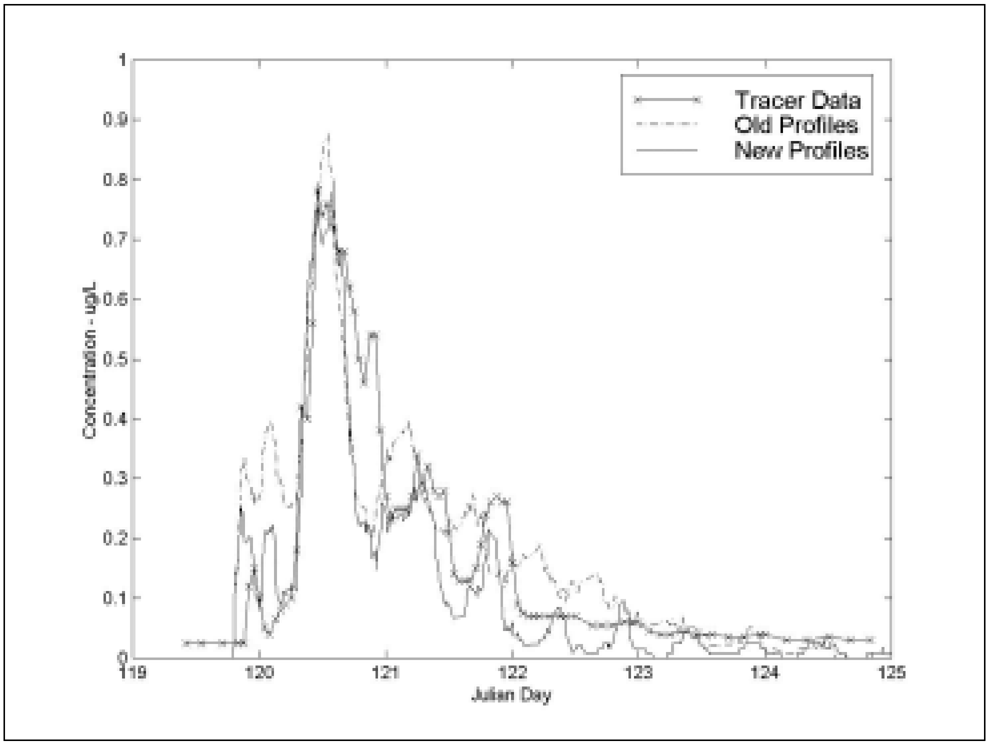

Figure 4-37: PTM and Tracer Comparison at Turner Cut.

Figure 4-37 shows the tracer data and PTM results for the Turner Cut location. This shows the clearest difference between the two sets of profiles in their effects on the particle dispersion.

While both profiles simulate the main peak concentration (at time 120.5) the new profiles better simulate the arrival of particles at the first (time 120), third (120.2), and fourth (120.9) peaks. The new profiles simulate a lower concentration at the first spike and arrives closer to the time the tracer data does. The original profiles do a poorer job at predicting the arrival time of these particles. Following the fourth concentration spike, both PTM profiles predict more oscillations in the concentration than exist in the data. This is possibly due to inaccuracies in the hydrodynamics or when recording of tracer at low concentrations close to background levels.

Figure 4-38 shows the same PTM – tracer comparisons at the San Joaquin River near Mandeville Tract. This location experiences much more oscillations, in both PTM and in the tracer data, than the other locations. Both profiles demonstrate they over-predict as well as under-predict concentrations at different times. Because of this, it is difficult to determine which one simulates the tracer data more accurately. The possible causes of these extreme oscillations include hydrodynamic problems and the method of converting the PTM output to concentrations.

Figure 4-39 shows different results for Middle River south of Columbia Cut. The PTM model does not simulate the tracer movement through this location very accurately. It is believed the problem is associated with the hydrodynamic model not properly simulating the flow (Figure 4-35).

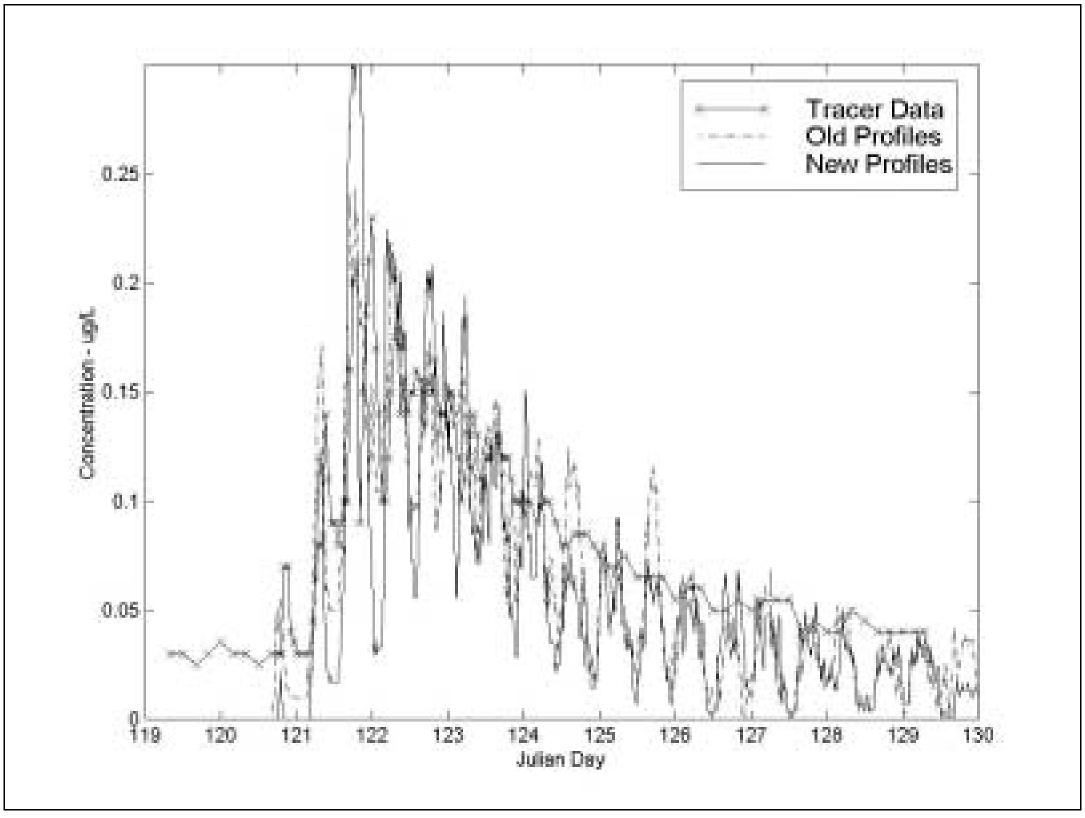

Figure 4-38: PTM and Tracer Comparison on SJR at Mandeville Reach.

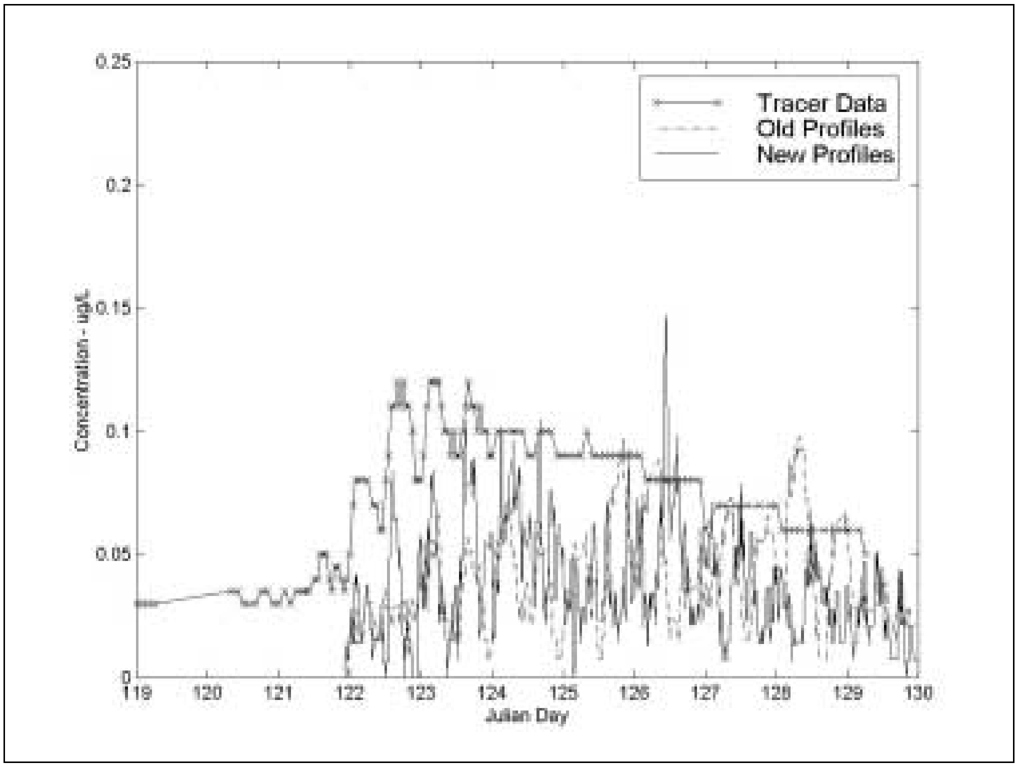

Figure 4-39: PTM and Tracer Comparison on Middle River South of Columbia Cut.

4.5.3 No Dispersion

Investigation of the importance of dispersion to the movement of particles throughout the Delta is now investigated with comparisons to the new velocity profiles discussed earlier. The first condition compared is the case where the system is only subjected to advective forces. The flow in both the vertical and transverse directions are uniform, thus the velocity across the entire channel is equivalent to the mean velocity.

Figure 4-40 displays the tracer study data, the simulated tracer concentration using the new profiles, and the no-dispersion condition at Turner Cut. The arrival time of particles under the no-dispersion case matches fairly well with both the tracer and new profiles. This suggests the dominance of advection in the Sacramento – San Joaquin Delta over the effects of dispersion. However, it is obvious the no-dispersion condition does a poorer job at simulating the tracer concentration than either the original or modified velocity profiles used for representation of dispersion. While the general timing of particles is similar to the previous results, the large oscillations in particle concentration are unrepresentative of the tracer data. The movement of particles with this advection-only situation shows how the particles do no spread longitudinally – they maintain their original distribution and are controlled by the hydrodynamics of the Delta.

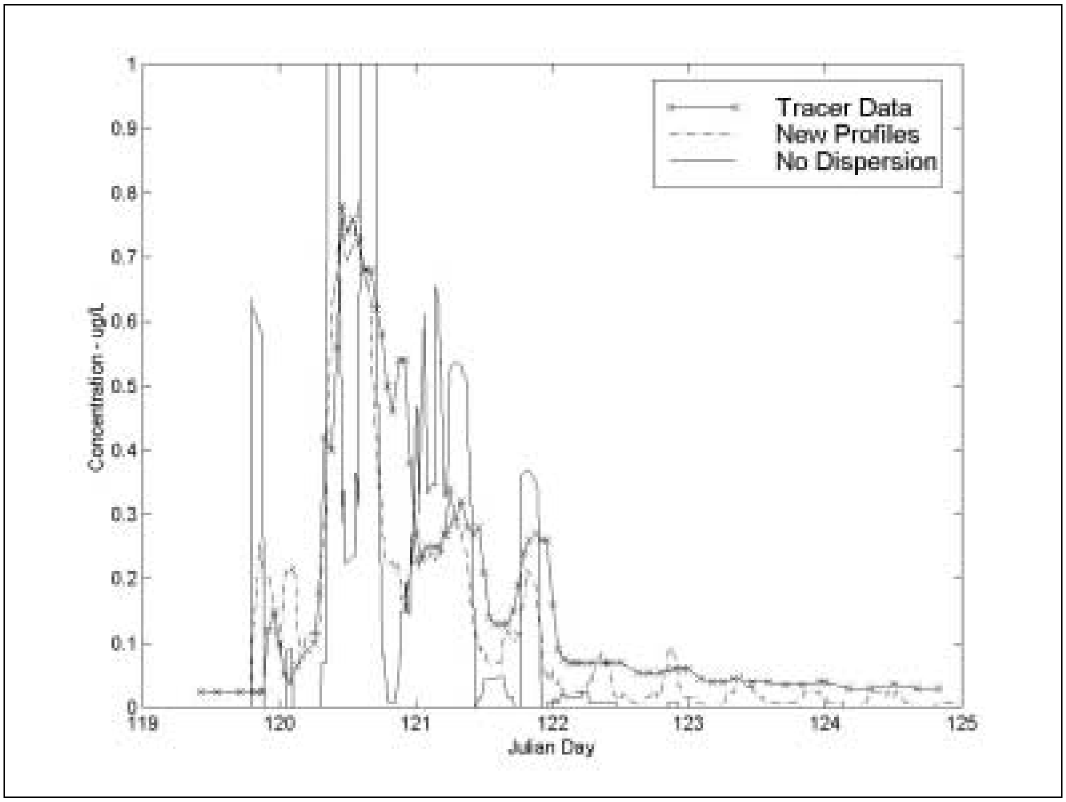

Figure 4-40: PTM and Tracer Comparison with No Dispersion at Turner Cut.

4.5.4 No Vertical Shear

Removal of the vertical velocity profile from the "best fit" PTM simulation shows how particles travel with a uniform vertical profile. All dispersion with this scenario is generated from the transverse velocity profile. Figure 4-41 shows the results of this simulation for Turner Cut. This shows a slight difference between the "best" profiles and the uniform vertical profile. The trend shows the particle arrival time as slightly earlier than the "best" profile results. While the differences are slight, it does not compare well with the tracer data. Without the vertical distribution, dispersion is slightly underestimated.

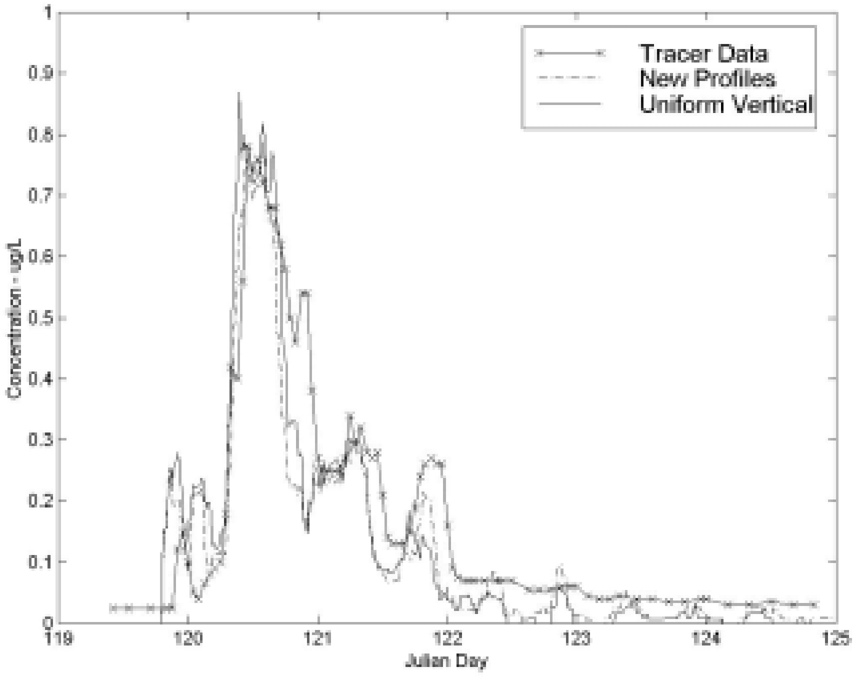

Figure 4-41: PTM and Tracer Comparison with Uniform Vertical Velocity Profile at Turner Cut.

4.5.5 No Transverse Shear

Following a similar examination of a uniform vertical velocity profile, removal of the transverse velocity profile is now presented. The dispersion generated with this condition is only from that produced by the vertical velocity profile. Figure 4-42 shows the PTM results with the tracer data for Turner Cut. This shows the PTM model, without the transverse velocity profiles, predicts a much more advective particle movement than the tracer and “best” fit profiles. This also may be compared to the uniform vertical velocity profile. These show the transverse velocity profile is more important to the dispersion process than the vertical velocity profile. This observation was discussed by Fischer (1979) and supported here with the PTM results.

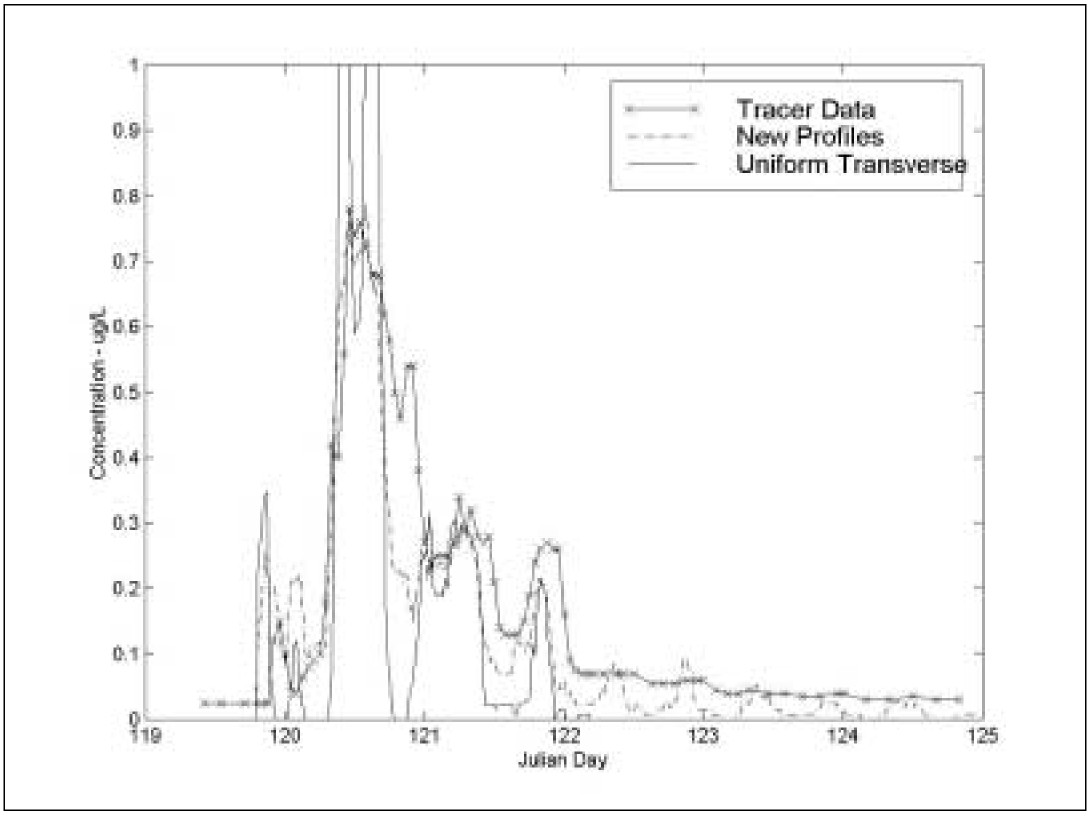

Figure 4-42: PTM and Tracer Comparison with Uniform Transverse Velocity Profile at Turner Cut.

4.6 Conclusions

The following conclusions may be made based upon the previous discussion and analysis:

- As discussed in the literature, the dispersal cloud is proportional to the square-root of the longitudinal dispersion coefficient. Addition of an oscillating flow condition reduces the dispersion by about one half. These lead to the conclusion that the modeling results are rather insensitive to slight changes in the mechanisms causing dispersion.

- The existing velocity profiles used in the Particle Tracking Model consistently over-predict the peak velocities found in the ADCP data. The mean velocity is accounted for, but the shear created by the excessive velocity profiles overestimates the dispersion in the system.

- Modification of the transverse and vertical velocity profile coefficients allow for an improved representation of the velocities found by the ADCP data. Channel irregularity can be attributed to the inconsistencies between the idealized profiles and those shown in the data.

- Simulation of the tracer study conducted by USBR with the Particle Tracking Model yields fair results with the original profiles. Even though the original profiles overpredict the peak velocities, the movement of particles is rather insensitive to the dispersive processes.

- Incorporation of the modified velocity profile coefficients into the Particle Tracking Model results in improved simulation of the tracer study. While the particle movement is rather insensitive to the amount of dispersion in the system, it is nonetheless an important process and cannot be ignored.

- The "no-dispersion" simulation by PTM shows the importance of including dispersion in the model. The overall dominance of advection in the system is shown by the fairly accurate arrival time of particles corresponding with peak tracer concentrations. The lack of dispersion, however, produces particle distributions that do not correspond to the tracer data.

- The comparison between the uniform vertical velocity profile and the uniform transverse velocity profile show the relative importance of the transverse profile to the production of dispersion in the Delta.

- The vertical velocity profile plays a minor role in the development of dispersion in the Delta. Two very different approximations of the vertical velocity profile, uniform and either the original or modified von Karman representations, result in fairly similar simulations of the tracer study. This lessens the concerns about inconsistencies between the von Karman approximation of the vertical velocity profile and the ADCP data.

- Inspection of the HYDRO and PTM results show the importance of accurate simulation of the hydrodynamics of the Delta prior to the simulation of PTM. If any error exists in HYDRO, it will be carried through to the PTM model results.

4.7 Future Directions

The following suggestions are made based upon the previous discussion and analysis:

- Incorporate the new geometry files used for the DSM2-HYDRO simulation. These include updated bathymetry data for most of the Delta. More accurate determination of the hydrodynamics of the Delta will improve the simulations of PTM. The process of calibrating these new geometry files has yet to be completed. A similar investigation of the PTM simulation of the 1997 tracer study should be performed once the calibration process is completed.

- Improve the tracer study to compare the PTM simulations. The number of locations useful for this simulation study was limited to four. The data collection stations should include more stations located throughout the entire Delta. Also, the concentration levels should be high enough as to not become lost to background noise to ensure the collected data are valid.

4.8 References

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