RMA

RESOURCE MANAGEMENT ASSOCIATES, INC.

SUISUN CITY, CALIFORNIA

Newport Bay Toxics Modeling

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1 INTRODUCTION

The existing 3-D and 2-D water quality models of Newport Bay have been used to perform simulations to evaluate transport in Newport Bay and to quantify the mass of contaminants that remains in the Bay relative to the mass supplied to the Bay under a range of inflow conditions.

1.1 Background

The RMA-10 stratified flow model for the Upper Newport Bay was configured and calibrated for the Upper Newport Bay Water Quality Model Development project funded by the State Water Resources Control Board (Agreement 8-064-258-0). The stratified flow model was calibrated to salinity measurements in the Bay (RMA, 2001).

The calibrated model was used to analyze conservative and settleable constituents under large storm, medium storm and low flow conditions, and evaluate the impact of stratification on transport of the constituents.

A numerical model of Newport Bay based on the RMA series of finite element models was originally developed as part of the Upper Newport Bay Feasibility Study conducted by the U.S. Army Corps of Engineers, Los Angeles District in close cooperation with the County of Orange (RMA, November 1999, October 1998, July 1998, October 1997). It includes the Upper and Lower Newport Bay using a two-dimensional depth-averaged representation. Boundaries of the model are located at the harbor entrance, San Diego Creek, and Santa Ana Delhi Channel.

The focus of the Feasibility study was on the long-term sediment deposition patterns under alternative dredging plans and for the no-project condition. As part of the study the model was calibrated for hydrodynamics, sediment transport, and salinity with emphasis on the Upper Bay.

The calibrated hydrodynamic and salinity transport models were built upon to develop the capability for simulation of a full range of water quality constituents for the first phase of the Regional Water Quality Control Board Upper Newport Bay Water Quality Model Development Study.

The 2-D depth averaged water quality model was originally calibrated for dry weather periods. To more accurately simulate low flow neap tide, and wet weather periods during which vertical stratification is present in the Bay, it was determined that three-dimensional simulations were necessary. The 3-D stratified flow model was thus developed, calibrated and used to examine stratification in the Upper and Lower Bay under three different flow conditions representing low flow neap tide, and wet weather periods.

1.2 Objectives

The objective of this modeling study was preliminary evaluation of transport in Newport Bay to quantify the mass of contaminants that remains in the Bay relative to the mass supplied to the Bay under a range of flows. This was accomplished using three different modeling scenarios: (1) 3-D simulations using a conservative tracer, (2) 3-D simulations using a settleable tracer, and (3) 2-D sediment simulations with deposition and scour. Simulations were performed for low flow and three different storm flow conditions.

2 MODELING APPROACH

Three-dimensional hydrodynamics were simulated using RMA-10, and 3-D water quality transport was simulated using RMA-11. The 3-D transport simulations were performed with a conservative and a settleable tracer for low flow and three different storm conditions. The conservative tracer represents a dissolved constituent with no settling. The settleable tracer uses a constant settling rate with no resuspension. Once the tracer has settled it is permanently removed from the system. Inflow concentrations for both the conservative and settleable tracer were set constant at 100 for San Diego Creek and Santa Ana Delhi Channel, with no other sources entering the Bay and initial concentrations set to zero throughout the Bay. The results were analyzed to quantify the mass of constituent remaining in the bay under each of the different flow conditions. Simulations were performed for low flow, small storm, medium storm and large storm conditions. The low flow condition used the tide from July 30 – August 10, 1999 (Figure 2.1) and constant average summertime tributary flows. The small storm (100 cfs) simulation was performed using artificial tributary inflow hydrographs and the tide from January 19 – 24, 1999 (Figure 2.2). The simulated San Diego Creek inflow hydrograph includes a peak storm flow of 100 cfs for one full tidal cycle on January 20 – 21 (San Diego Creek hydrograph shown in Figure 2.3). The medium storm (1,160 cfs) simulation was performed using tide (Figure 2.4) and hourly tributary flows for January 25 – 29, 1999. Three storms occur during this period, however only the first storm was included in the simulations. The actual flows and altered hydrograph for San Diego Creek are shown in Figure 2.5. The large storm simulation (4,500 cfs) was performed using tide and hourly tributary flows from November 21 – 27, 1996 (Figures 2.6 and 2.7).

Additional simulations were performed for the same three storm flows using the 2-D depth-averaged model. The 2-D hydrodynamic simulations were performed using RMA-2, and sediment transport was simulated using RMA-11. Sediment transport was simulated, including deposition and scour based on critical shear stress. Sediment inflow concentrations in San Diego Creek and Santa Ana Delhi are dependent on flow according to the relationship shown in Figure 2.8. The 2-D sediment model results are used to show deposition patterns and to quantify the mass of constituent remaining in the bay under each of the different flow conditions.

Table 1 summarizes the differences among the three simulation types discussed above.

A 2-D low flow hydrodynamic run was also simulated for analysis of residual currents. The 2-D low flow simulation was performed using average summertime tributary inflows and a repeated mean tide.

Table 1. Summary of simulations.

<table>
<tr><th colspan="2"></th><th>Conservative Tracer</th><th>Settleable Tracer</th><th>Sediment</th></tr>
<tr><td colspan="2">Inflow concentration</td><td>Constant (100)</td><td>Constant (100)</td><td>Flow dependent</td></tr>
<tr><td colspan="2">Settling rate</td><td>None</td><td>Constant</td><td>Concentration dependent</td></tr>
<tr><td colspan="2">Resuspension</td><td>N/A</td><td>No</td><td>Yes</td></tr>
<tr><td rowspan="4">Simulations performed</td><td>Low Flow</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Small Storm</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Medium Storm</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Large Storm</td><td>X</td><td>X</td><td>X</td></tr>
</table>

2.1 Sediment Properties

Fine silts and especially clays have a large particle surface area to weight ratio. This is important for two reasons: 1) The large surface area can adsorb toxic contaminants from the water, and 2) under certain conditions (salinity > 1-3 ppt and concentration > 300 mg/l) clay particles become mutually attracted and can form aggregates with settling velocities much higher than individual particles.

For low concentrations (< 300 mg/l) a typical settling velocity for cohesive sediments in a saline environment is about $2.3x10^{-5}$ m/s (2 m/day), equivalent to a particle fall diameter of 0.007 mm. This would be appropriate for summer conditions. During a large storm event, the storm flow transporting the sediment load flushes saline water out of much of the Upper Bay. For low salinity (< 1 – 3 ppt) the flocculation of clay particles is not expected to occur. However, the calibration of the 2-D sediment transport model (discussed in "Upper Newport Bay Final Model and GUI Development and Implementation Report", RMA, October 1997) showed that a weak coupling of suspended sediment concentration to settling velocity could be used to reproduce the historical sediment deposition patterns in the Upper Bay. This concentration dependent settling simulates the deposition of coarser particles in the Unit I/III area and the deposition of finer sediment particles further downstream.

For this study, a single settling velocity was used for each of the 3-D model simulations. The settling velocity for the storm simulations was 6.9×10^{-5} m/s (6 m/day). The equivalent particle fall diameter is about 0.012 mm, representative of fine silt. For the low flow simulation the settling velocity was 2.3×10^{-5} m/s as discussed above. A concentration dependent settling rate was used for the 2-D simulations.

A more comprehensive study would include the simulation of several particle size fractions calibrated to suspended sediment concentrations observed in the Upper and Lower Bay. However, such measurements were not available for a large storm event.

2.2 2-D Model

The finite element mesh used for the 2-D simulations is shown in Figure 2.9.

Two-dimensional sediment transport is simulated using the finite element water quality model, RMA-11, which solves the mass transport equation in divergence or non-divergence form for multiple non-linearly coupled constituents. Velocities and water depths obtained from hydrodynamic model results are used to solve the advection-dispersion equation for each constituent simulated.

RMA-11 includes relationships for simulation of cohesive and non-cohesive sediment transport based upon concepts developed by Ariathurai and Krone (1976). Processes that are represented include aggregation of cohesive sediments, settling, and surface and bulk erosion. Shear stresses calculated for settling or resuspension are dependent on surface wind stress and current velocity in the overlying water column.

Consolidation of deposited material and burial to deep sediments are included in the bed layer component of the sediment transport simulation model.

Sediment is supplied to the Upper Newport Bay during storm events. It is then resuspended and redistributed due to tidal circulation and wind-generated waves. During storm events, significant deposition occurs over the course of hours or days, equivalent to the length of a storm. During dry weather periods, significant movement of sediments by resuspension and redistribution occurs much more slowly, on the order of months. In both cases, however, it is the inter-tidal flow that affects transport, deposition, and scour of sediments.

The 2-D depth-averaged hydrodynamic model RMA2 and the water quality/sediment transport model RMA11 are used in concert to perform the simulations. A controller program is used to run RMA2 and RMA11 to perform a hydrodynamic simulation for a wet weather deposition event, and then perform a sediment transport simulation for the corresponding time period with sediment loading applied at the San Diego Creek inflow and Santa Ana-Delhi Channel.

2.2.1 REPRESENTATION OF SEDIMENT BED

The parameters required by the sediment transport model include the number and thickness of sediment bed layers, critical shear stress for erosion for each layer, sediment density for each layer, critical shear stress for deposition, and sediment particle settling rate.

Sediment bed properties are a function of depth. Newly deposited sediment is generally less dense and more easily scoured than sediments that have been covered and have begun to consolidate. The variation in sediment properties is often significant over the first few centimeters of the bed. RMA11 represents the variation in bed properties as series of thin fixed layers over a variable thickness layer. Sediment is always deposited into the top layer. As the top layer fills, sediment is shifted down to the lower layers. The bottom layer can grow indefinitely. When scour occurs, the upper layers are removed first. A six-layer model was used for the Newport Bay. The set of sediment properties for each layer is shown in Table 2. Sediment property values were developed for the Newport Bay Feasibility Study (RMA, 1998) sponsored by the US Army Corps of Engineers, and are representative of clay and silt.

Table 2. Sediment model parameter values at current level of calibration.

Previously Existing (Old) Bed						
Layer	1	2	3	4	5	6
Layer Thickness (m)	0.005	0.015	0.020	0050	0.200	---
Critical Shear Stress for Erosion (N/m^2)	0.18	0.38	0.68	0.82	1.00	2.00
Bulk Density (kg/m^3)	1126	1155	1224	1269	1310	1350

Newly Deposited Bed						
Layer	1	2	3	4	5	6
Layer Thickness (m)	0.010	0.010	0.020	0.043	0.127	---
Critical Shear Stress for Erosion (N/m^2)	0.16	0.35	0.55	0.68	0.82	1.5
Bulk Density (kg/m^3)	1105	1126	1143	1164	1269	1310

Critical Shear Stress for Deposition (N/m^2)	0.11
Bulk Density (kg/m^3) bottom consolidated layer	1430
Settling Velocity, $v_s = KC^{\alpha}$	
Wet weather simulation:	
v_s at C < 300 mg/l (m/s)	4.44x10-5
α	1.0
v_s at C > 3000 mg/l (m/s)	4.44x10-4
Dry weather simulation:	
v_s at C < 300 mg/l (m/s)	2.22x10-5
α	1.33

Table 2 presents two sets of bed properties. The existing or "Old" bed properties represent sediments deposited before the current simulation period and are the bed sediments available for scour if sufficient bed shear stress develops. The critical shear stresses for erosion of the old bed layers were calibrated during the Newport Bay Feasibility Study.

The concept of the sediment bed growing from the bottom-most layer is important when performing the update of the bottom bathymetry from one simulation period to the next. The density used to convert the mass of sediment deposited to a thickness value should be representative of the total depth of sediment deposited over the time of simulation. The density for the bottom most consolidated layer was calibrated to 660 kg/m^3 (1430 kg/m^3 bulk density) during the Feasibility Study.

Deposition can only occur when the shear stress on the bed is less than the critical shear stress for deposition. The critical shear stress for deposition is only a function of the uppermost bed layer so only one value is required.

2.3 3-D Model

RMA11 is used to simulate conservative and settleable tracer constituents for the 3-D simulations. The 3-D settleable tracer simulations, however, only address removal of sediment from the water column by settling, and do not simulate scour, resuspension, or net deposition.

Figure 2.10 shows the finite element mesh used for the 3-D simulations. The model was configured to represent the current Upper Bay bathymetry with the completed Unit III basin. The mesh is a combination of 3-D, 2-D laterally averaged and 2-D depth averaged elements. Compute times are generally long for stratified flow modeling. To greatly reduce the computation time, 2-D laterally averaged elements are used to simulate stratified flow in channels where possible. The 2-D laterally averaged elements have a trapezoidal cross-section, and are a computationally efficient way of simulating stratified flow in a channel geometry. Two-dimensional depth averaged elements are used for the marsh and upper mudflat areas where the depth of water is shallow (less than 0.6 m at high tide) and expected to be vertically uniform.

Generally 2-D laterally averaged elements are used below the Unit II area. A three-dimensional section is used in the Lower Bay to connect the main channel with East and West Lido Channels. In the Upper Bay above Upper Island, the mesh uses a combination of 3-D and 2-D depth averaged elements. This region of the Bay has a complex geometry, which would not be well represented using 2-D laterally averaged elements. Those areas with bed elevations above +0.2 m to +0.5 m MSL (mean sea level) are represented with 2-D depth averaged elements. Areas below +0.2 m to +0.5 m MSL are represented with three-dimensional elements.

The marsh above the salt dike has been included in the network. This area has a significant impact on the tidal prism for the Upper Bay. Except at the very highest tidal elevations, water flows from the main channel into the marsh through incised channels just above the salt dike. In the mesh used for the 3-D model, the marsh is isolated from the main channel except for the connecting channels near the salt dike. This differs somewhat from the 2-D depth averaged network, where water could also overtop the main channel bank above 0.9 meters MSL and flow into the marsh. Excluding this overbank flow, the current network simplifies the 3-D geometry and significantly reduces the computational bandwidth and thus the computer run time.

Up to eight element layers are used in the 3-D and 2-D laterally averaged sections of the mesh. Layers are set at +1 m, 0 m, -1 m, -2 m, -4 m, -6 m, -8 m and –10 m MSL. An example of element layer construction is shown in Figure 2.11. There are nine nodes that make up the four layers shown: five corner nodes and 4 mid-side nodes. Values are computed not just for four layers, but at each of the nine nodes. The model uses a quadratic fit across each layer so variation in salinity is smooth.

Only density stratification due to salinity was considered, as observed data indicate that salinity stratification is about five times more important than stratification due to temperature.

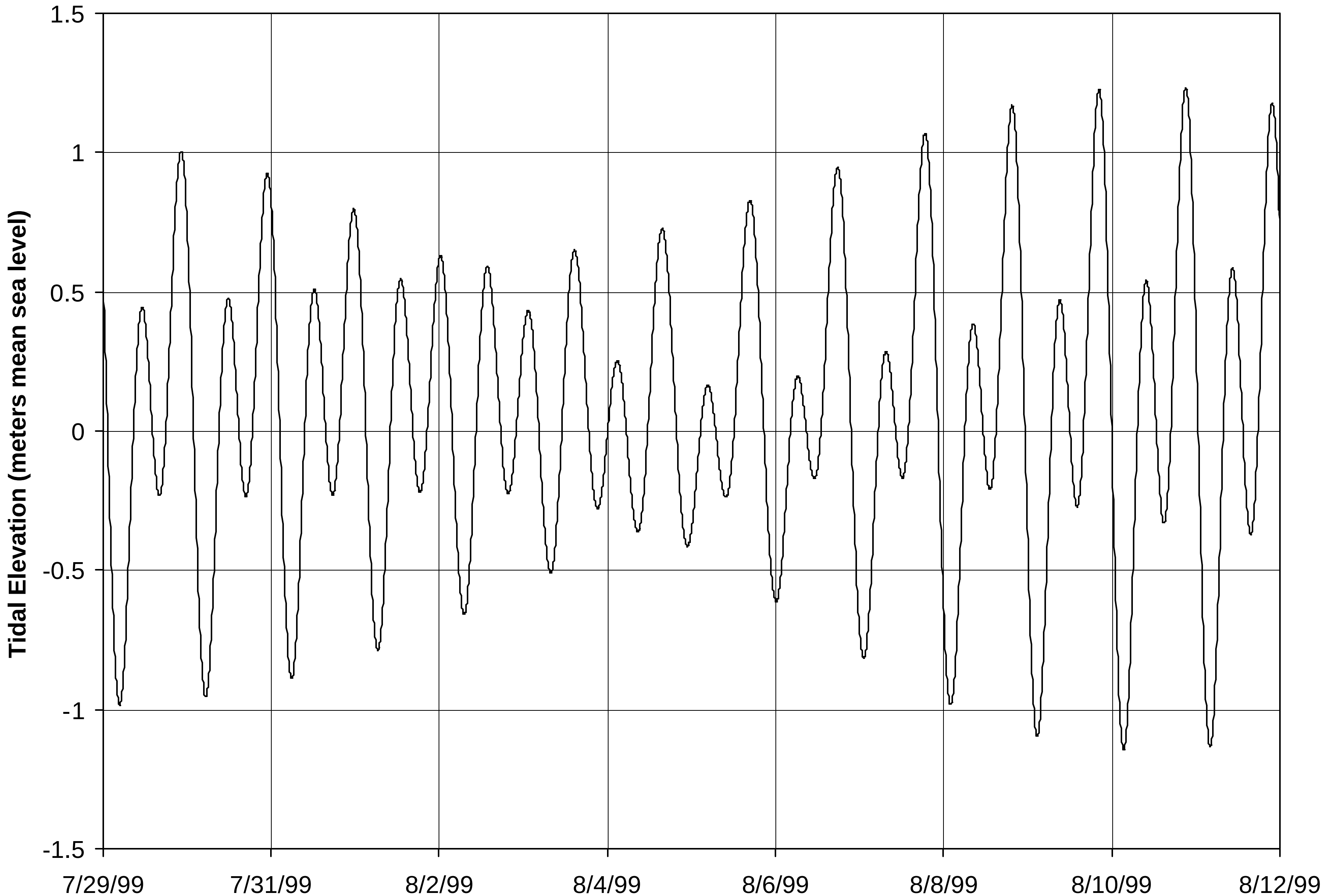

Figure 2.1 Tidal elevations at Newport Harbor entrance for the August 1999 low flow simulation.

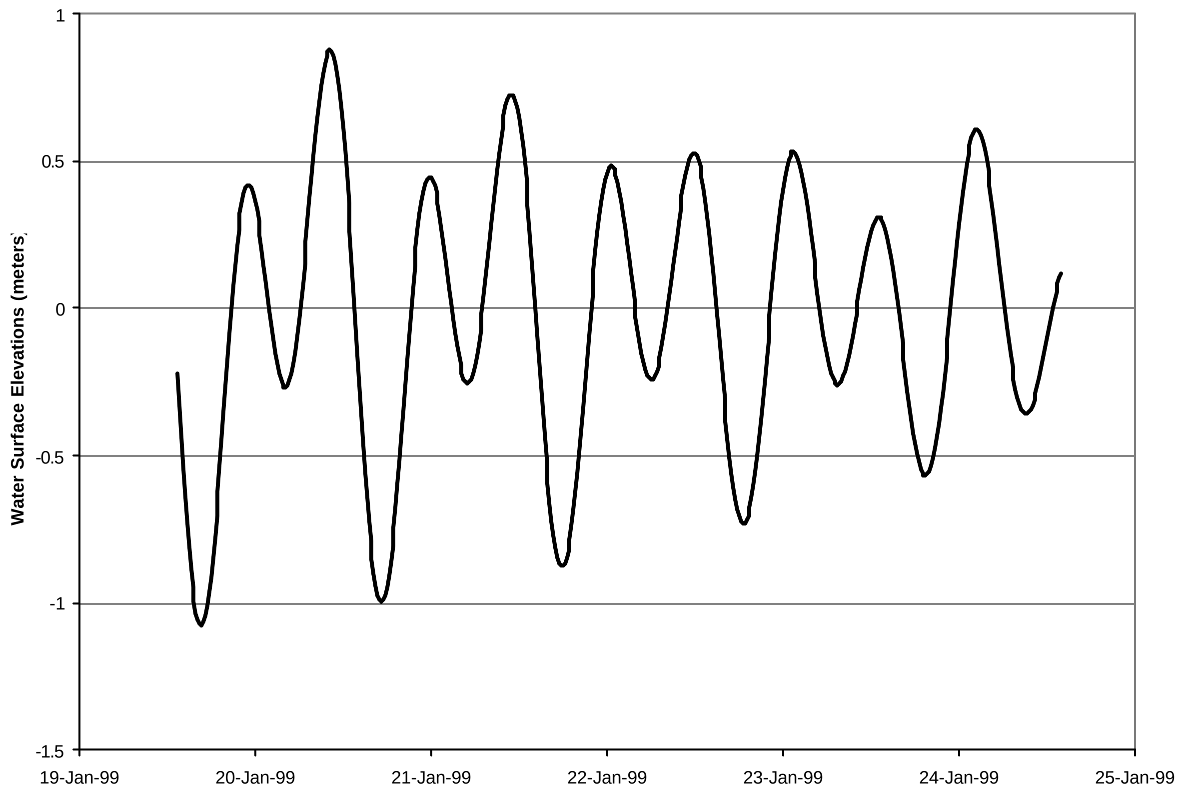

Figure 2.2 Tidal elevations at Newport Harbor entrance for the 100 cfs small storm simulation.

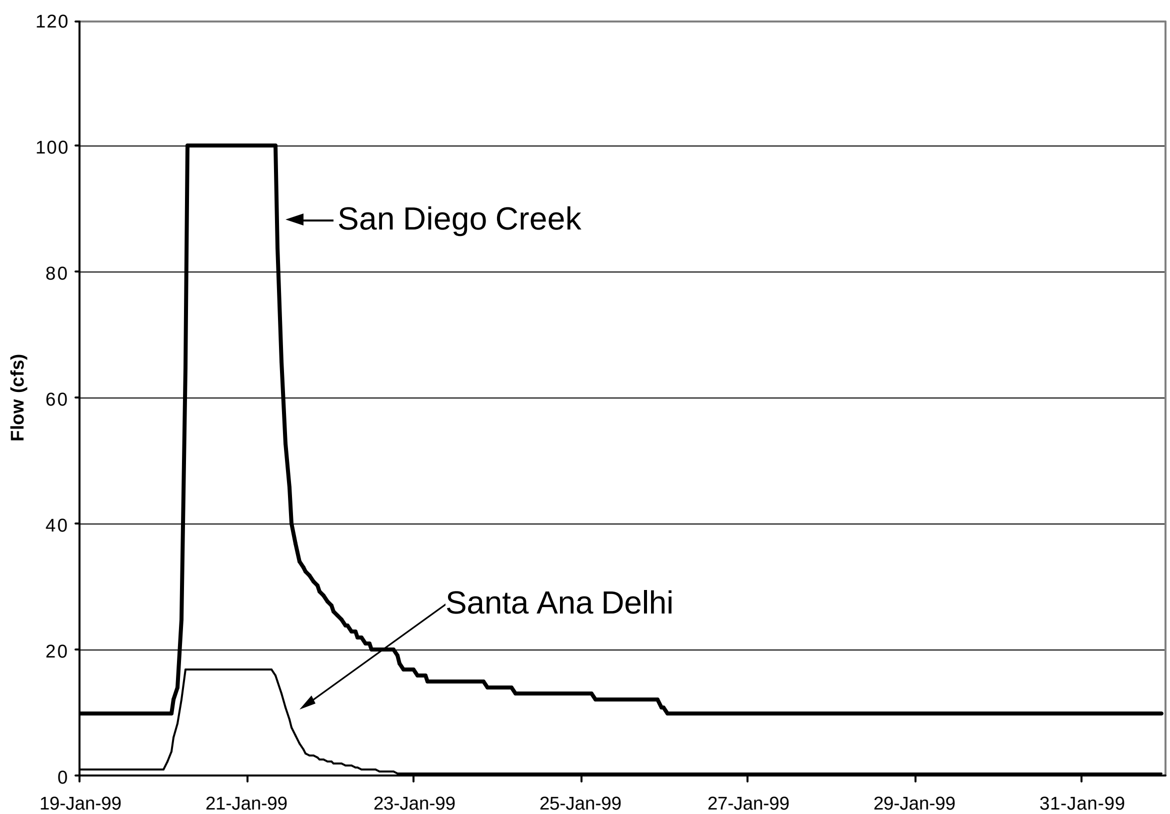

Figure 2.3 San Diego Creek and Santa Ana Delhi artificial inflow hydrographs for the 100 cfs small storm simulation.

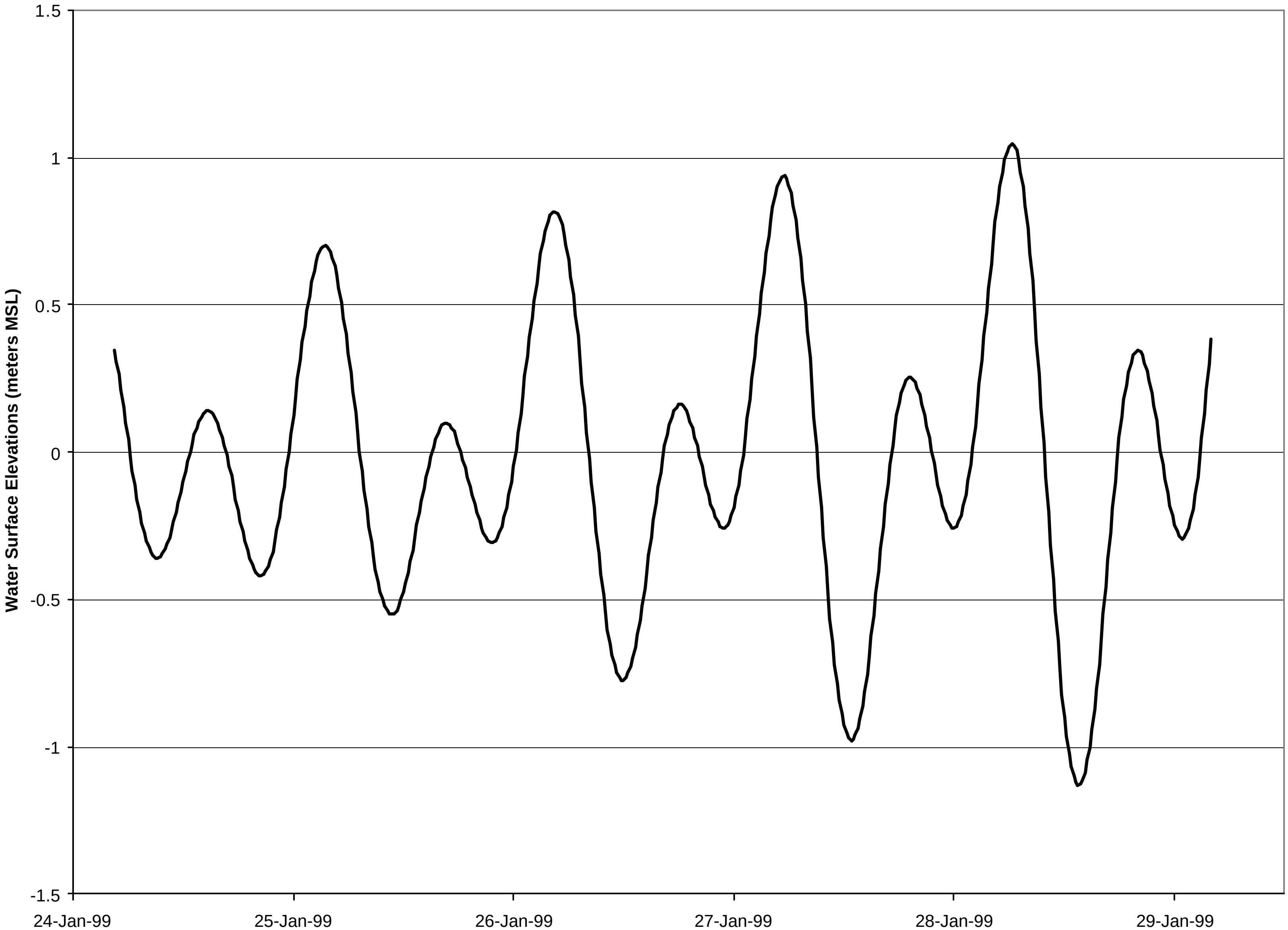

Figure 2.4 Tidal elevations at Newport Harbor entrance for 1,160 cfs medium storm simulation.

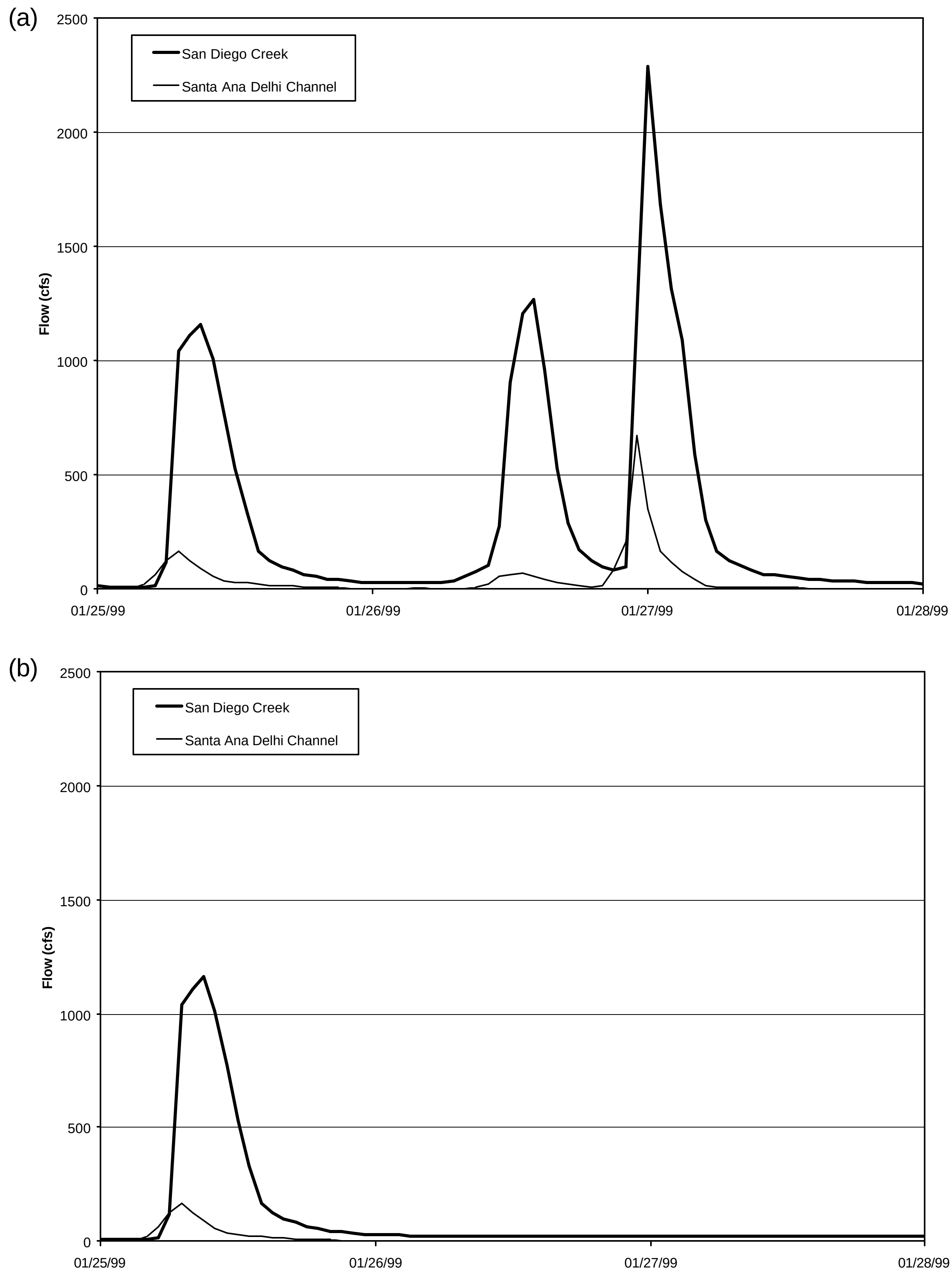

Figure 2.5 San Diego Creek and Santa Ana Delhi hydrographs with (a) actual flows, and (b) manipulated flows for January 1999 1,160 cfs medium storm simulation.

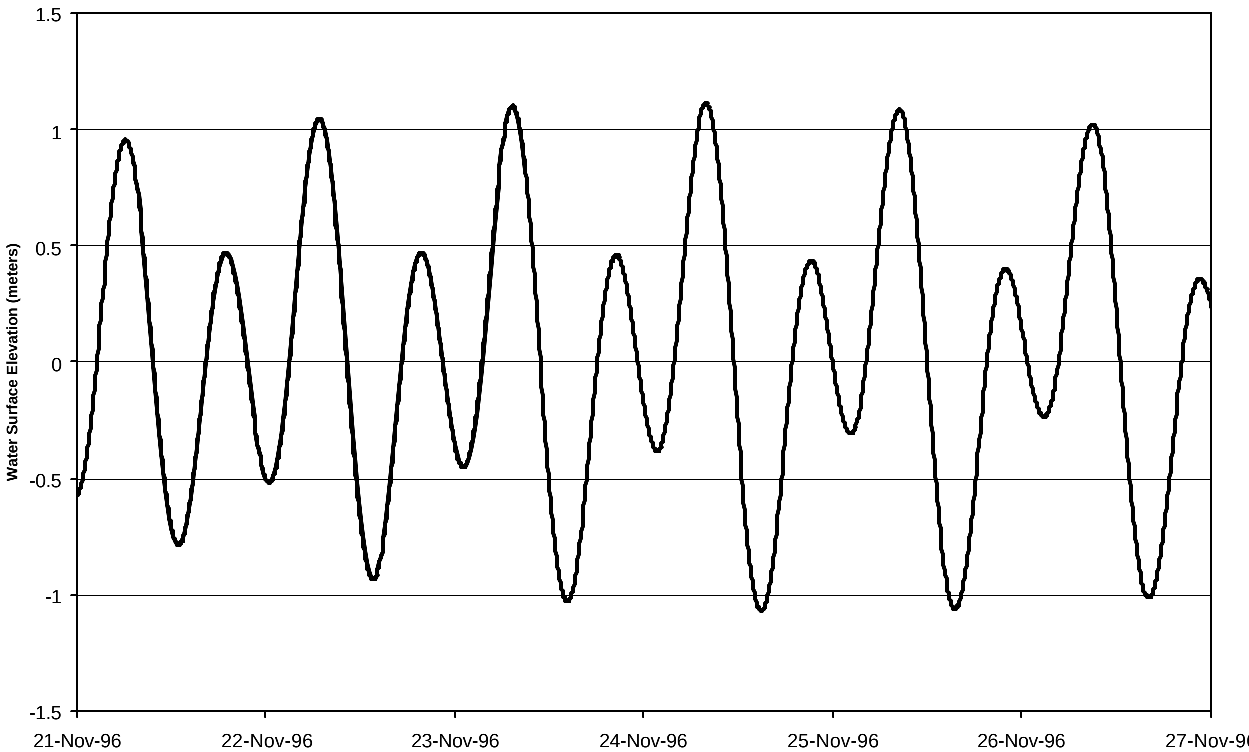

Figure 2.6 Tidal elevations at Newport Harbor entrance for 4,500 cfs large storm simulation.

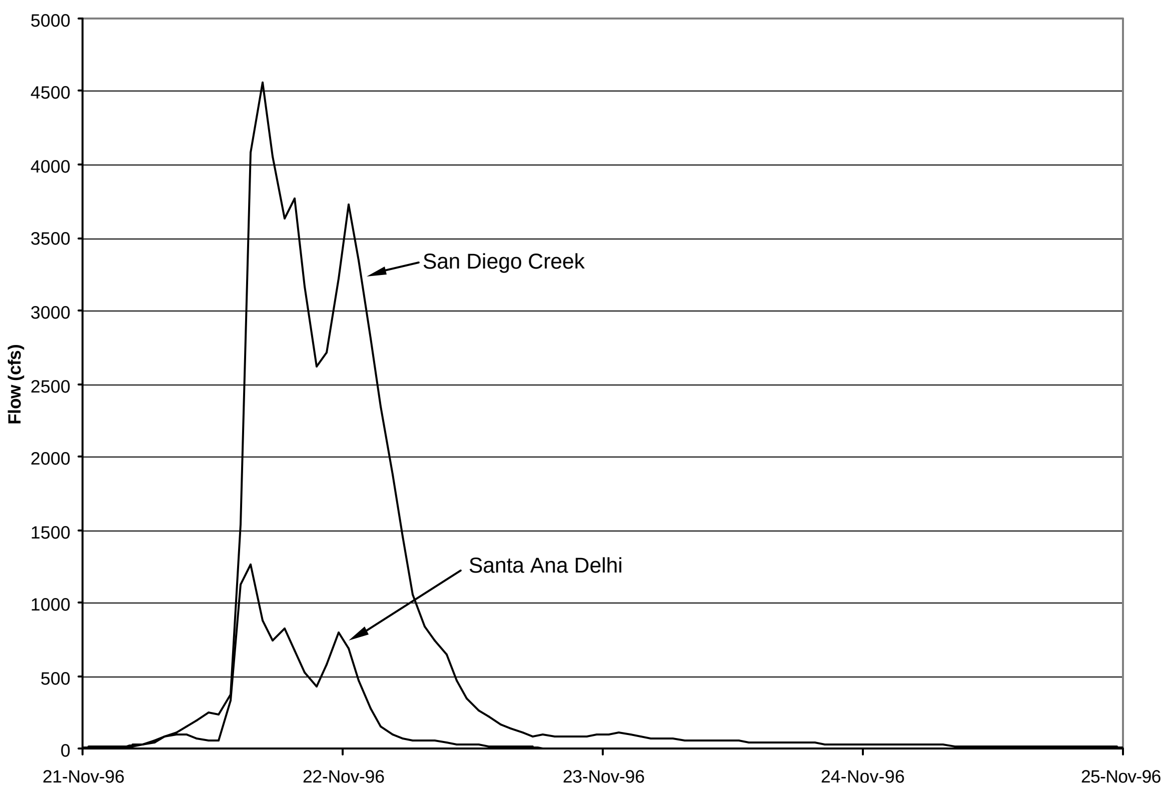

Figure 2.7 San Diego Creek and Santa Ana Delhi inflow hydrographs for 4,500 cfs large storm simulation.

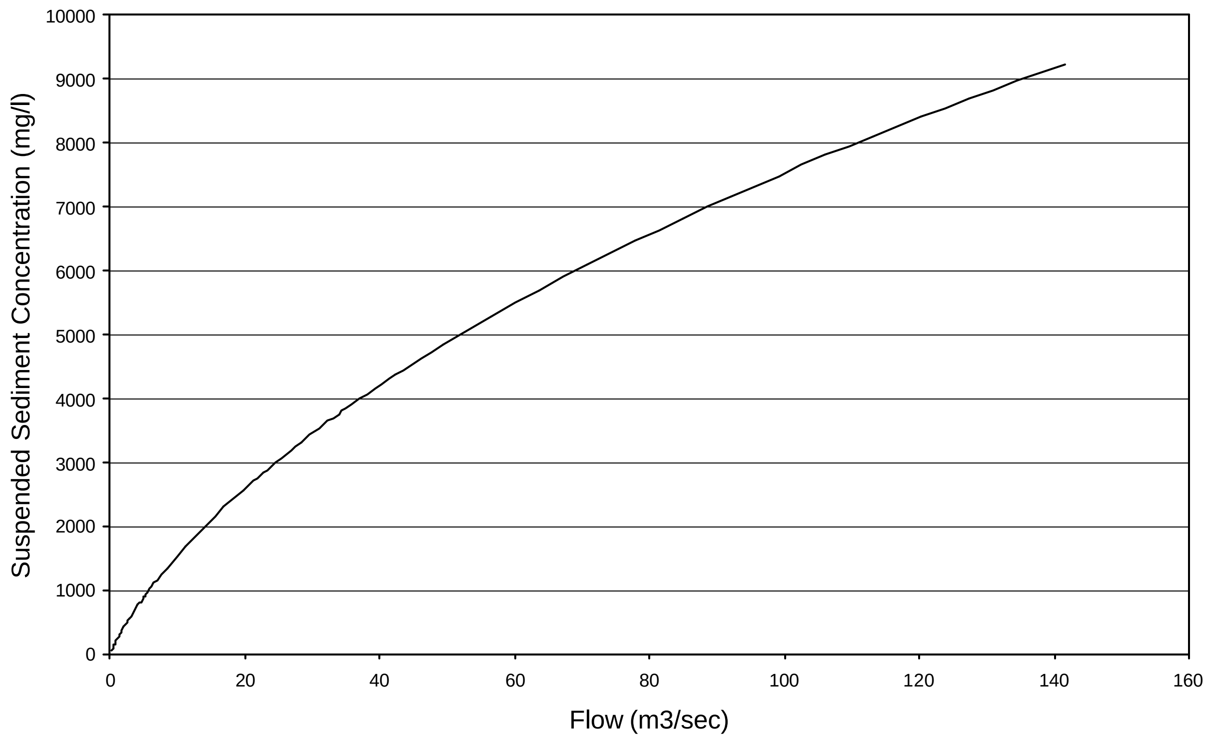

Figure 2.8 Suspended sediment concentration versus flow for San Diego Creek inflow in 2-D sediment simulations.

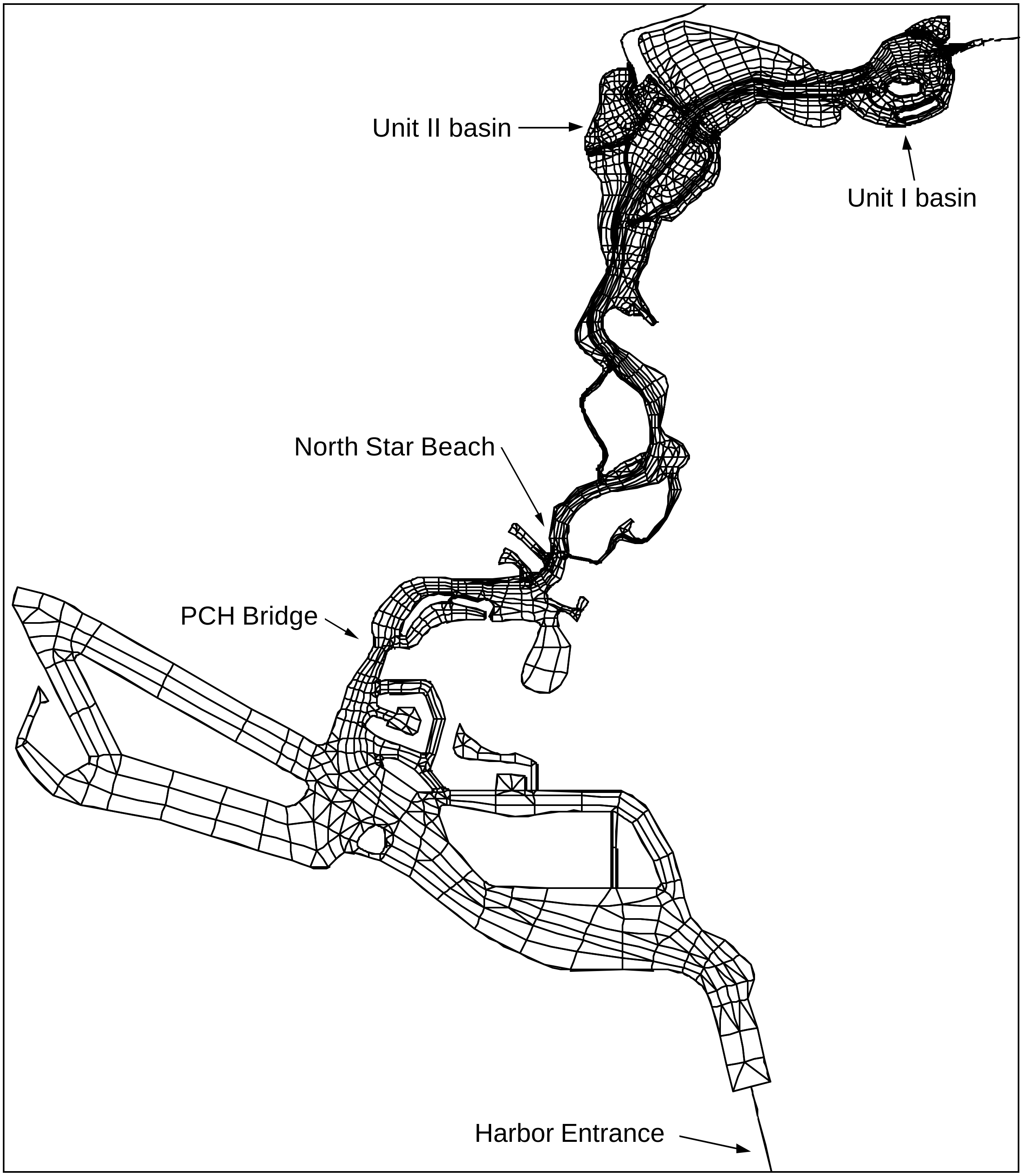

Figure 2.9 Finite element mesh for 2-D simulations.

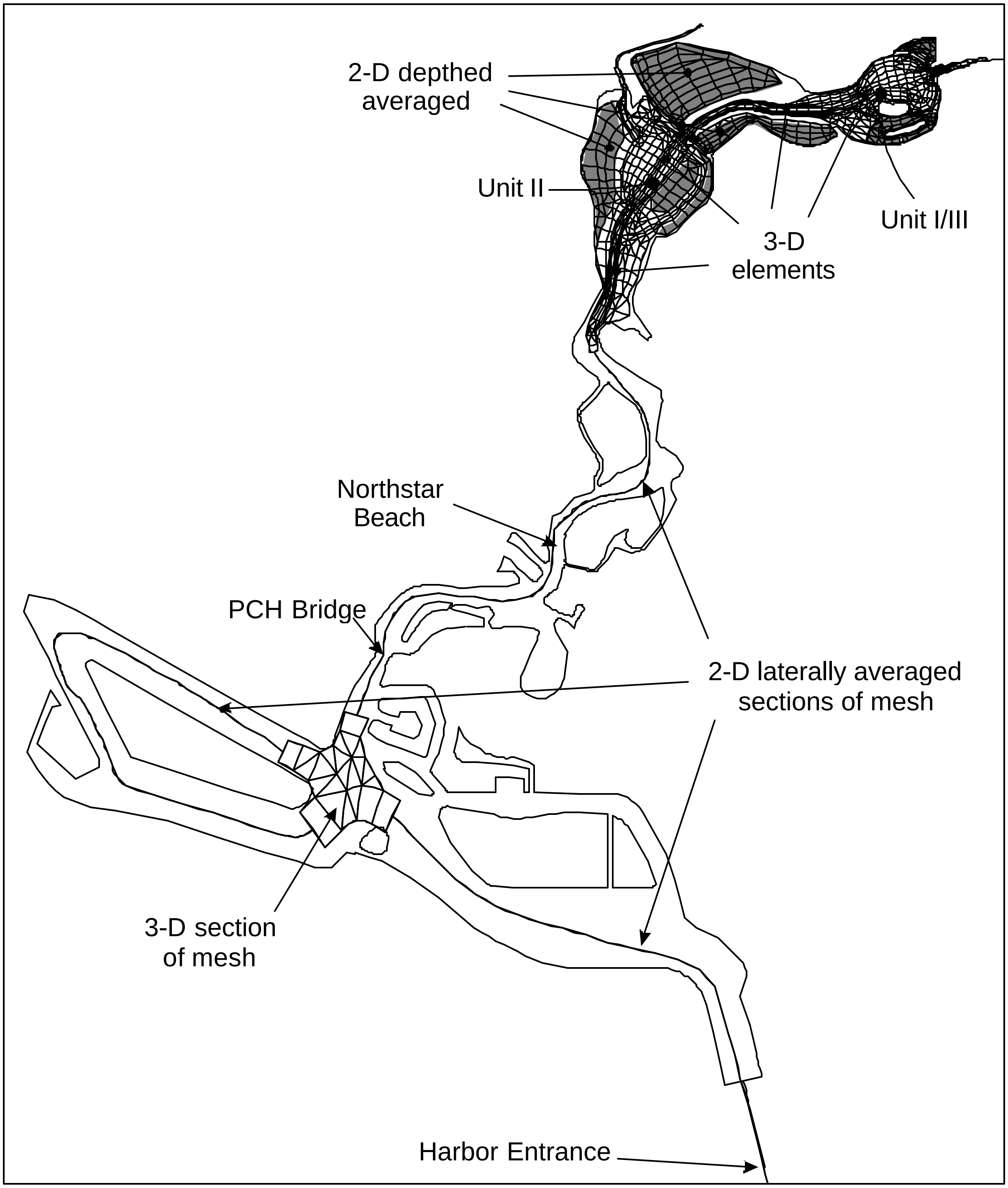

Figure 2.10 Finite element mesh for 3-D simulations.

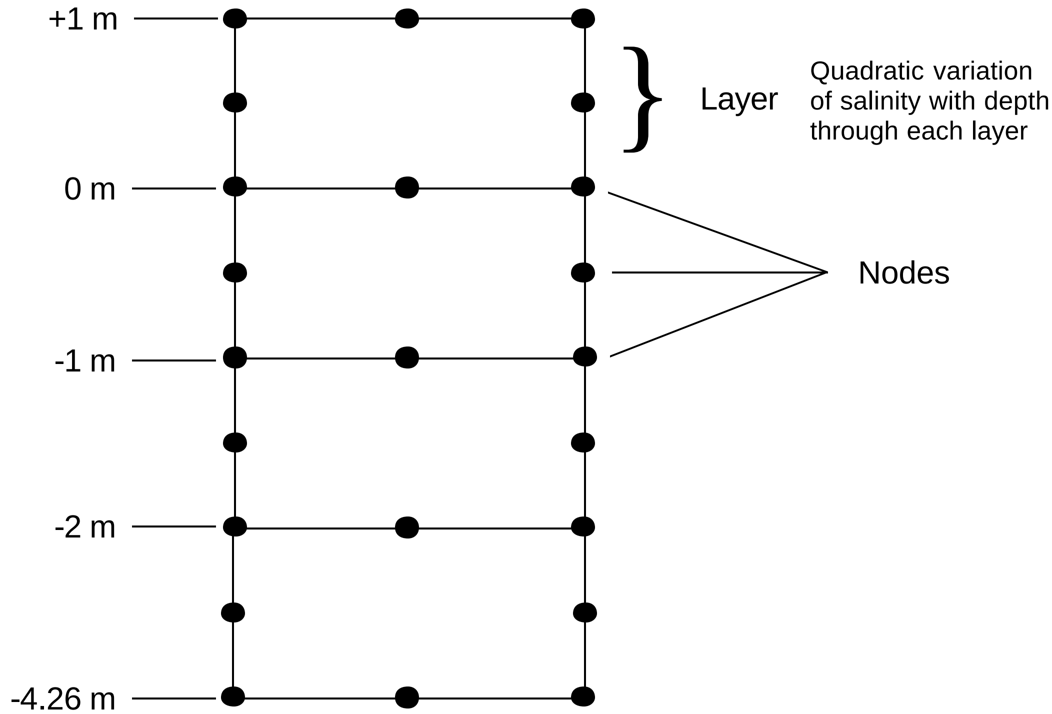

Figure 2.11 Example of 3-D element layer construction.

3 RESULTS

Cumulative mass time series are plotted for each of the simulation results to indicate the mass of contaminants that remains in the Bay relative to the mass of contaminants that is supplied from San Diego Creek and Santa Ana Delhi Channel during different inflow conditions. These time series plots include cumulative constituent mass in the Upper Bay, in the Lower Bay, and the mass that has exited the Bay. For the settleable tracer and 2-D sediment simulations, the Upper and Lower Bay mass is divided into settled and suspended mass. Plot scales in Figures 3.1 – 3.10 facilitate viewing of individual results. Plots in Figures 3.12 – 3.22 use a common scale allowing comparison of the different storm simulations. In the common scale plots some of the series are too small to see and are therefore not labeled.

Summaries of the cumulative constituent distributions for the storm simulations are shown in Tables 3 and 4. Because the low flow simulation does not represent an event in which the total cumulative load is important, it is more useful to look at loading rates, rather than at cumulative loads. Therefore, the low flow simulation results are not addressed in these tables. Distributions in Tables 3 and 4 are computed as averages over one tidal cycle starting on the third day following the storm peak. Values in Table 3 are listed as percent of total cumulative inflow in each location and Table 4 lists the total cumulative mass in each location. The storm simulations were run for different lengths of time ranging from 4 to 5 days. The third day following the storm peak was chosen for some consistency in the table, however given the variety of factors affecting tracer/sediment distribution (e.g. the shape of the hydrograph, post-storm base flow, tide, etc.) there is no perfect time for comparing all of the results. The simulations are all near steady state by the third day after the storm peaks. Steady state occurs when the storm flows have subsided, the sediment loads from the storm have been deposited or exited the ocean boundary and suspended sediment concentrations return to normal throughout the Bay.

The cumulative total constituent mass continues to grow for as long as the simulations are run because there is always sediment entering the Bay from San Diego

Creek and Santa Ana Delhi Channel. The cumulative mass exiting the ocean boundary constantly increases. The suspended mass will decline following a storm and level off as it approaches equilibrium, slightly fluctuating only with the tide when the tributary inflow is constant (this fluctuation is most visible in the conservative tracer simulations since the entire mass load remains suspended). For the settleable tracer and sediment simulations, the settled mass generally continues to grow, although some scour of the sediment is also occurring. This increase is not noticeable in the large storm results because the rate of increase is very small compared with the mass that is deposited during the storm. The increase in cumulative settled mass is obvious in the low flow results plotted in Figure 3.2.

Note that the percentages listed in Table 3 will constantly change over time when accounting for cumulative mass because, as discussed above, the mass exiting the ocean boundary is always increasing, as is the settled mass, while the suspended mass levels off. This constant change is unimportant in the large storm simulation, as the mass settled during the storm event is so dominant. It is more important in the small storm case. The large storm simulations, which are nearest equilibrium in terms of mass distribution percentages, are the most important for total deposition, as the large storms are responsible for the majority of the sediment input to the system throughout the year. Figures 3.23 and 3.25 show bar graphs comparing the total sediment input after 4 days for each simulation. The total sediment mass for the large storm is much larger than the smaller storms or the low flow simulation. In particular, for the sediment simulations, which use flow dependent sediment inflow concentrations, the large storm sediment mass is an order of magnitude larger than the medium storm, and two orders of magnitude larger than the small storm.

A 2-D low flow simulation was performed for analysis of residual velocities. Results are shown in Figures 3.29 – 3.32.

Table 3. Summary of constituent mass distribution by percentage for each simulation.

Constituent Type	**Constituent Location**	**Average % of cumulative constituent mass during the third day following the storm peak**		
		Small Storm S.D. Crk 100 cfs	Medium Storm S.D. Crk 1160 cfs	Large Storm S.D. Crk 4500 cfs
Conservative Tracer (3-D)	Upper Bay	55.1%	43.6%	10.8%
	Lower Bay	22.3%	26.3%	11.4%
	Out ocean boundary	22.5%	30.2%	77.8%
Settleable Tracer (3-D)	Upper Bay settled	95.5%	92.9%	53.1%
	Upper Bay suspended	3.5%	3.7%	0.8%
	Lower Bay settled	1.0%	1.8%	16.0%
	Lower Bay suspended	0.1%	0.5%	0.8%
	Out ocean boundary	0.0%	1.1%	29.4%
Sediment (2-D)	Upper Bay settled	91.8%	93.1%	73.3%
	Upper Bay suspended	7.6%	5.8%	1.1%
	Lower Bay settled	0.4%	0.6%	20.2%
	Lower Bay suspended	0.2%	0.5%	2.0%
	Out ocean boundary	0.0%	0.1%	3.4%

Table 4. Summary of constituent mass distribution for each simulation.

Constituent Type	Constituent Location	Cumulative constituent mass (grams) during the third day following the storm peak		
		Small Storm S.D. Crk 100 cfs	Medium Storm S.D. Crk 1160 cfs	Large Storm S.D. Crk 4500 cfs
Conservative Tracer (3-D)	Upper Bay	2.76E+7	3.95E+7	7.61E+7
	Lower Bay	1.12E+7	2.82E+7	7.98E+7
	Out ocean boundary	1.14E+7	2.74E+7	5.47E+8
	Total tracer inflow	5.01E+7	9.06E+7	7.02E+8
Settleable Tracer (3-D)	Upper Bay settled	4.79E+7	8.42E+7	3.73E+8
	Upper Bay suspended	1.74E+6	3.39E+6	5.42E+6
	Lower Bay settled	4.92E+5	1.63E+6	1.12E+8
	Lower Bay suspended	4.95E+5	4.25E+5	5.33E+5
	Out ocean boundary	0.0	9.60E+5	2.07E+8
	Total tracer inflow	5.01E+7	9.06E+7	7.02E+8
Sediment (2-D)	Upper Bay settled	1.56E+8	1.73E+9	2.71E+10
	Upper Bay suspended	1.29E+7	1.07E+8	4.06E+8
	Lower Bay settled	6.48E+5	9.66E+6	7.45E+9
	Lower Bay suspended	2.57E+5	1.04E+7	7.24E+8
	Out ocean boundary	2.70E+3	1.06E+6	1.25E+9
	Total sediment inflow	1.70E+8	1.85E+9	3.69E+10

3.1 3-D Low Flow Simulation

Three-dimensional low flow simulations were performed for the period of July 30 through August 10, 1999 (approximately 12 days). Cumulative mass time series plots are shown in Figures 3.1 and 3.2.

The conservative tracer simulation (Figure 3.1) has not quite reached equilibrium by the end of the simulation period. Over the last tidal cycle, average suspended mass continues to increase in the Lower Bay, and an average of 85% of the mass load (1.3×10^5 grams/hr) exits the ocean boundary per time step. When the system has fully reached steady state, the average suspended mass will be steady and on average 100% of the inflow mass will be exiting the ocean boundary.

For the low flow settleable tracer simulation (Figure 3.2), steady state has been reached by the end of the simulation period. During the last tidal cycle of the simulation the average suspended sediment mass is constant. On average, 88.2% of the mass load ($1.4x10^6$ grams/hr) is deposited in the Upper Bay, 6.1% ($9.4x10^3$ grams/hr) is deposited in the Lower Bay, and 5.6% ($8.7x10^3$ grams/hr) exits the ocean boundary during each time step of the last tidal cycle.

3.2 3-D 100 cfs Small Storm Simulation

Three-dimensional small storm simulations were performed with simulated tributary inflow hydrographs, and predicted tide for January 19 – 24, 1999 (approximately 5 days) shown in Figures 2.2 and 2.3. Mass time series plots for the model results are shown in Figures 3.3 and 3.4.

The Upper Bay cumulative conservative tracer mass in Figure 3.3 peaks and begins to decline following the 100 cfs storm. Cumulative mass in the Lower Bay continues to generally increase throughout the simulation as the tracer moves from the Upper Bay toward the ocean boundary. During the third tidal cycle following the storm peak, an average of 55.1% of the tracer mass remains in the Upper Bay, 22.3% is in the Lower Bay, and 22.5% has exited the ocean boundary.

In Figure 3.4, most of the settleable tracer mass settles in the Upper Bay. The Upper Bay cumulative suspended mass continually decreases following the storm peak. During the third tidal cycle after the storm peak, an average of 95.5% of the mass has settled in the Upper Bay and 3.5% is suspended in the Upper Bay. Only 1.0% has settled in the Lower Bay, 0.1% is suspended in the Lower Bay, and virtually no mass has exited the ocean boundary.

3.3 2-D 100 cfs Small Storm Simulation

The small storm 2-D sediment simulation results shown in Figure 3.5 are similar to the 3-D settleable tracer results. By the third tidal cycle after the storm peak, an average of 91.8% of the cumulative mass has settled in the Upper Bay, 7.6% is suspended in the Upper Bay, 0.4% is settled in the Lower Bay, 0.2% is suspended in the Lower Bay, and virtually no mass has exited the ocean boundary.

Figure 3.26 shows net deposition patterns at the end of the 100 cfs storm simulation. Deposition depths greater than 0.005 meters have occurred only in the Upper Bay in Unit I near the mouth of San Diego Creek. Maximum depth of deposition is less than 0.02 meters. Recall that 92% of the total mass settles in the Upper Bay, thus the small depth of deposition is simply a function of a relatively small inflow mass.

3.4 3-D 1,160 cfs Medium Storm Simulation

The medium storm simulation was performed for the period of January 25 – 29, 1999 (approximately 4 days). Mass time series plots are shown in Figures 3.6 and 3.7.

In Figure 3.6, cumulative conservative tracer mass in the Bay peaks after the storm peak and begins to decrease as flows recede and mass washes out the ocean boundary. During the third tidal cycle after the storm peak, an average of 43.6% of the mass remains in the Upper Bay, 26.3% remains in the Lower Bay, and 30.2% has washed out the ocean boundary.

Much of the settleable tracer mass in Figure 3.7 is suspended in the Upper Bay during the storm peak, but the majority of the mass (average 92.9%) has settled in the Upper Bay during the third tidal cycle after the storm. Only 3.7% remains suspended in the Upper Bay, 1.8% has settled in the Lower Bay, 0.5% is suspended in the Lower Bay, and 1.1% has exited the ocean boundary.

3.5 2-D 1,160 cfs Medium Storm Simulation

The medium storm sediment simulation results are similar to the 3-D settleable tracer simulation. As seen in Figure 3.8, during the third tidal cycle following the storm peak, the majority of the sediment (average 93.1%) settles in the Upper Bay. The Upper Bay cumulative suspended mass declines slightly as the mass moves into the Lower Bay and an average of 5.8% remains suspended in the Upper Bay. In the Lower Bay 0.6% is settled and 0.5% is suspended during the third tidal cycle after the storm. Only 0.1% of the cumulative sediment total exits the ocean boundary.

Figure 3.24 shows net deposition patterns at the end of the 1,160 cfs storm simulation. Deposition depths greater than 0.01 meters have occurred only in the Upper Bay in Unit I and Unit II basins, with the most deposition (approximately 0.08 meters) occurring at the mouth of San Diego Creek.

3.6 3-D 4,500 cfs Large Storm Simulation

The large storm simulation was performed for the period of November 21 – 26, 1996 (approximately 5 days). Mass time series plots are shown in Figures 3.9 and 3.10.

For the conservative tracer simulation in Figure 3.9, cumulative suspended tracer mass in the Bay peaks after the storm peak and begins to decrease as flows recede and mass washes out the ocean boundary. During the third tidal cycle after the storm peak, an average of 10.8% of the mass remains in the Upper Bay, 11.4% remains in the Lower Bay, and 77.8% has washed out the ocean boundary.

In Figure 3.10, much of the settleable tracer mass is suspended in the Bay during the storm peak, but the cumulative suspended mass declines to 0.8% each in the Upper Bay and Lower Bay by the third tidal cycle following the storm peak. The majority of the cumulative mass (average 53.1%) has settled in the Upper Bay by this time, while 16% has settled in the Lower Bay and 29.4% has exited the ocean boundary.

3.7 2-D 4,500 cfs Large Storm Simulation

The results of the large storm sediment simulation are similar to the 3-D settleable tracer simulation. As seen in Figure 3.11, during the third tidal cycle following the storm peak, the majority of the cumulative sediment mass (average 73.3%) settles in the Upper Bay, and 20.2% settles in the Lower Bay. The cumulative suspended mass declines to 1.1% in the Upper Bay and 2.0% in the Lower Bay, while 3.4% has exited the ocean boundary.

Figure 3.28 shows net deposition patterns at the end of the large storm simulation. Deposition depths greater than 0.01 meters have occurred throughout the Upper and Lower Bay, with up to 0.3 meters of deposition occurring in Unit I basin and up to 0.2

meters of deposition occurring in Unit II basin. Depths of deposition in the Lower Bay are generally less than 0.06 meters. Note that the scale differs from the previous plots.

3.8 Mass Distribution Summary

With the large storm a significant difference is apparent between the 2-D and 3-D simulations. A much larger percentage of the mass exits the ocean boundary early in the simulation with the 3-D model than with the 2-D model. By the third tidal cycle following the storm peak, the 2-D sediment simulation shows 3% exiting the ocean boundary, while the 3-D settleable tracer simulation shows 29% exiting. Stronger density stratification is present with the large storm as the high fresh water flow volumes flow out over the denser salinity wedge at the bottom. The 3-D model is able to simulate this while the 2-D model maintains constant concentrations over depth. Therefore, in the 3-D model, more of the settleable tracer remains near the surface and reaches the ocean boundary before settling out. It is expected that the 2-D model would predict more deposition of sediment in the Bay than the 3-D model would. The 2-D model has been calibrated for sediment transport in the Upper Bay and proven to produce good results. The 3-D model has not been calibrated and uses simpler relations, e.g. a constant settling rate, constant inflow and sediment concentration, and no resuspension of deposited sediment. Intuitively it seems that the 3-D model representation would be more accurate in its prediction of more mass exiting the ocean boundary due to stratification, however there should not be too much reliance placed on these numbers relative to the 2-D model until the 3-D model has been calibrated for sediment transport using flow varying sediment input, and concentration dependent settling rates.

By the end of the large storm conservative tracer simulations, most of the tracer mass has passed out of the system following the storm peak. The high flows have forced 78% of the tracer mass out the ocean boundary by the third tidal cycle following the storm peak, with only 11% remaining in the Upper Bay and 11% remaining in the Lower Bay. The medium storm simulation flows are not large enough to have washed as much tracer out of the system in the three days following the storm, so that 44% of the tracer remains in the Upper Bay, 26% in the Lower Bay and 30% has washed out the boundary.

Similarly for the small storm simulation, only 23% has washed out the boundary, with 55% remaining in the Upper Bay and 22% in the Lower Bay.

Because the mass is slowly accumulating in the low flow simulation, it is useful to look at mass on a per time step basis, rather than cumulatively. On the per time step basis, tidally averaged conservative tracer mass in the Bay becomes constant after steady state is reached, and on average 100% of the mass inflow is exiting the ocean boundary. For the settleable tracer simulation, after steady state is reached the suspended mass in the Bay is constant while 44% of the incoming mass is deposited in the Upper Bay, 3% is deposited in the Lower Bay, and 53% exits the ocean boundary.

When viewing all of the conservative tracer results on the same scale, it is clear that regardless of the storm size, the suspended mass concentrations in the Upper and Lower Bay are approaching the same equilibrium values as the tributary inflows return to normal flow conditions. Equilibrium occurs when the rate of increase in total cumulative mass equals the base flow times the tributary tracer concentration of 100 and tracer concentrations have leveled off throughout the Bay. The low flow simulation is building up slowly to that equilibrium condition, while the storm flow simulations are gradually returning to the equilibrium condition following the storm peaks. Viewing the settleable tracer results on the same scale, and the sediment results on the same scale, however, shows that although the suspended settleable tracer mass and the suspended sediment mass approach the same equilibrium values regardless of the storm size, the settled mass is very much dependent on storm size. In the time frame considered in this study, very little scour and resuspension of the sediment occurs so that the settled mass rapidly increases during the storm events and remains stable. Material may be resuspended later however, during normal tidal action.

3.9 2-D Low Flow Simulation – Residual Velocities

Residual velocities were computed by running a low flow simulation with repeated mean tide and average summertime flows for San Diego Creek and Santa Ana Delhi Channel. Residual velocity vectors for the 2-D low flow simulation are shown in Figure 3.29 for the entire Bay. Figures 3.30 – 3.32 show closer views of the upper, mid, and lower areas of the Bay. Ebb flows dominate the side channel areas in Unit I and Unit II basins in Figure 3.30, and the side channels in Figure 3.31. A counterclockwise flow pattern around Lido Island in the Lower Bay is apparent in Figure 3.32. No strong ebb or flood patterns are apparent in the main channel of the Bay.

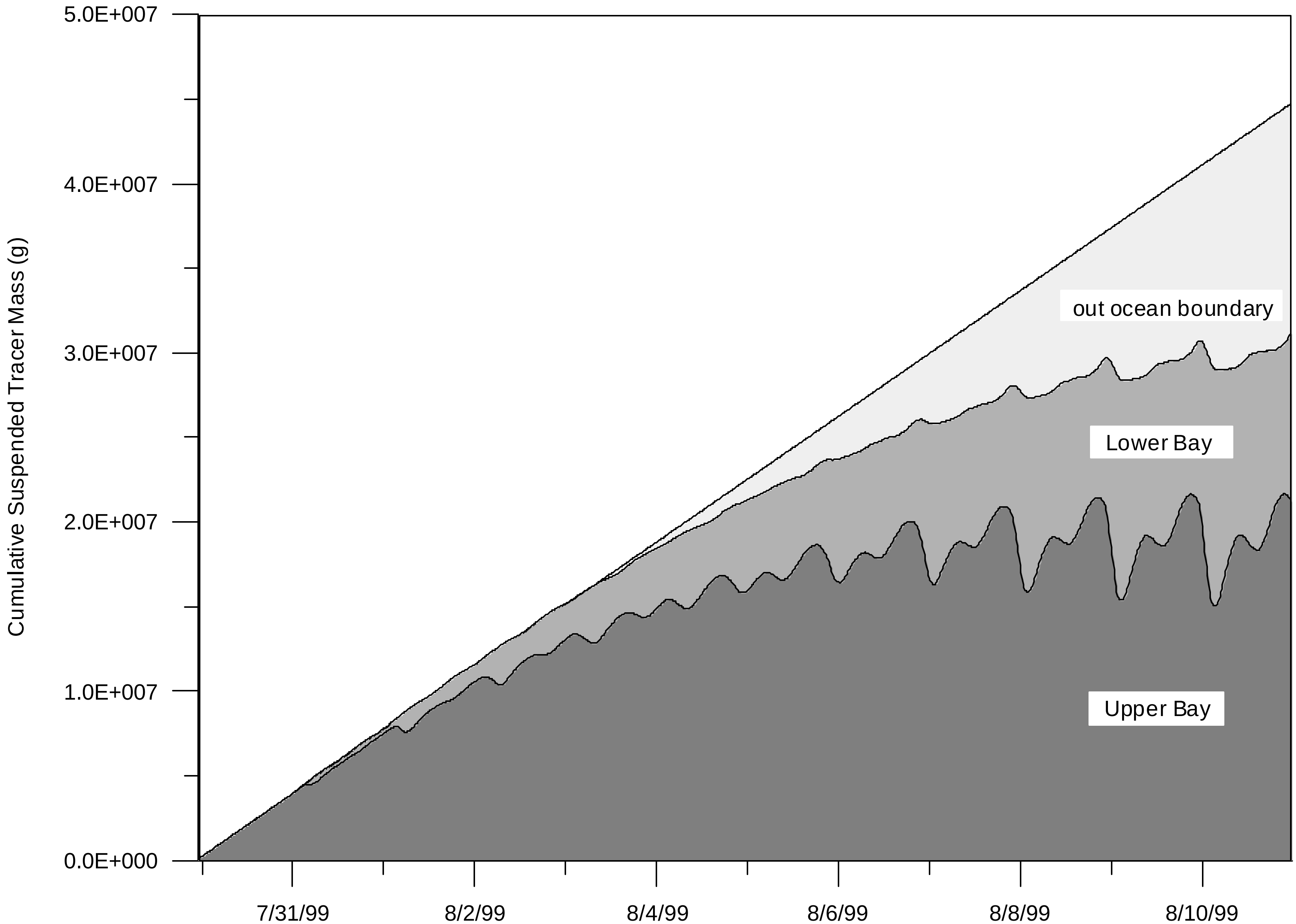

Figure 3.1 Cumulative suspended conservative tracer mass for the 3-D August 1999 low flow simulation.

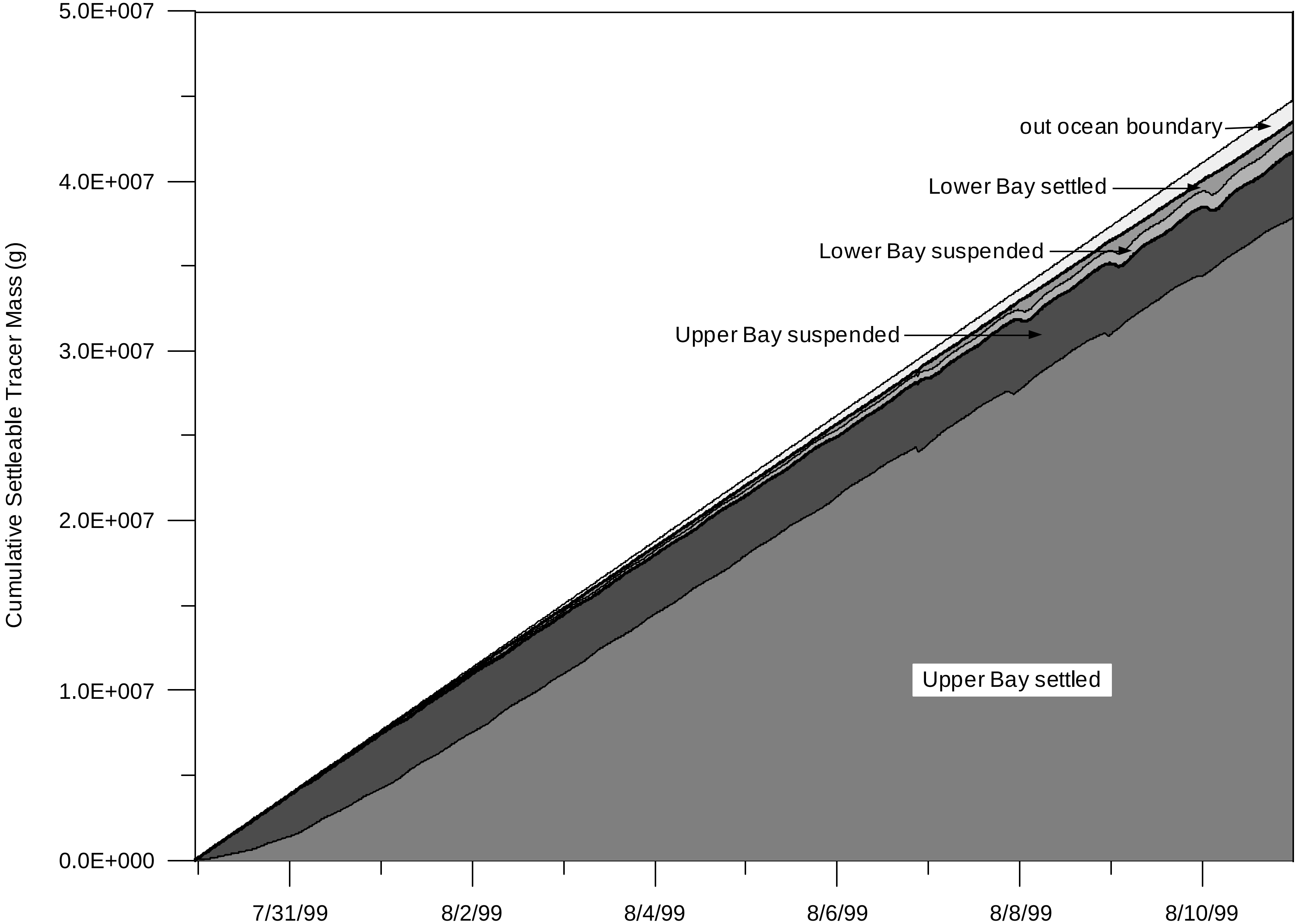

Figure 3.2 Cumulative settleable tracer mass for the 3-D August 1999 low flow simulation.

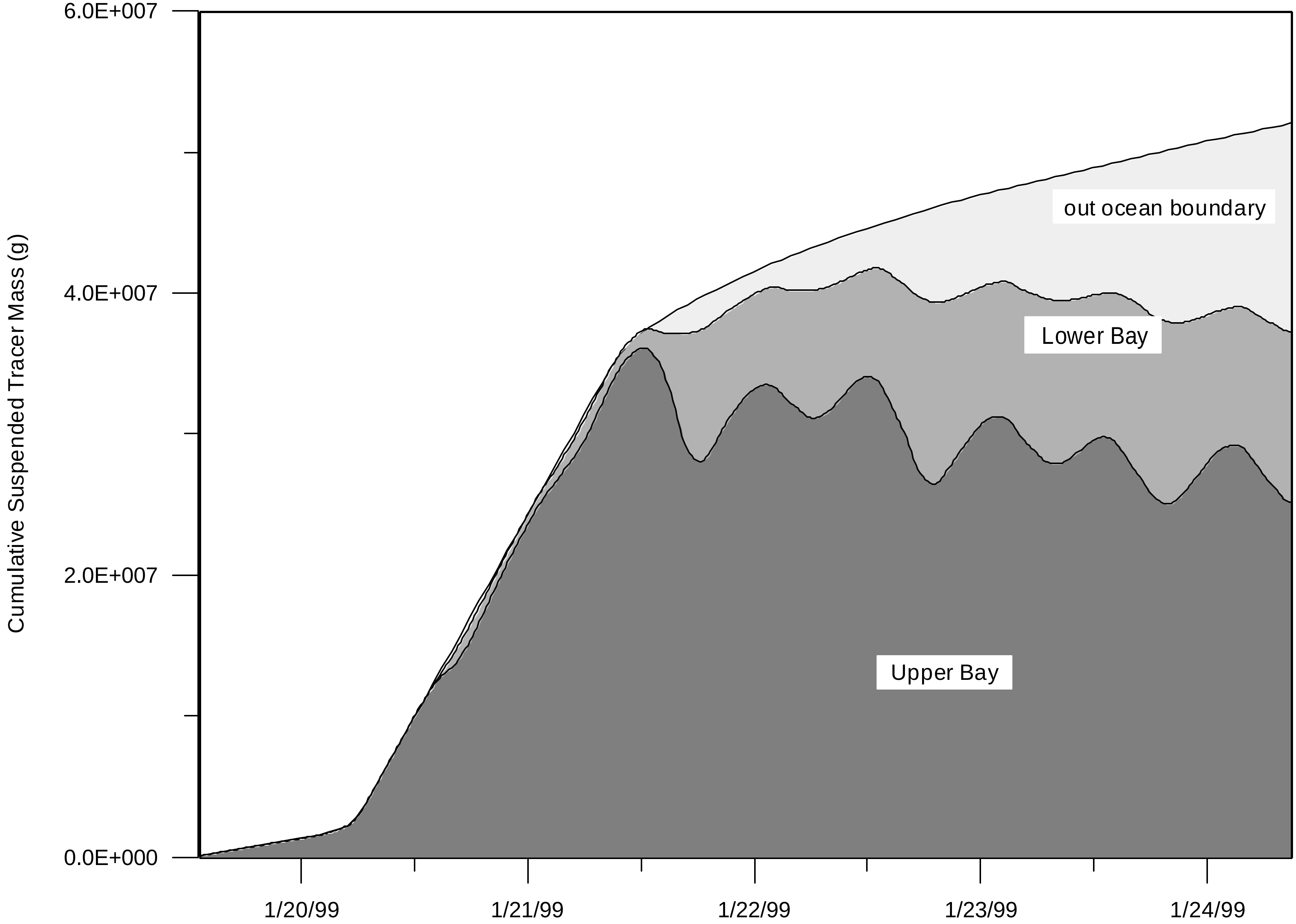

Figure 3.3 Cumulative suspended conservative tracer mass for the 3-D small storm simulation (100 cfs peak San Diego Creek flow over one tidal cycle).

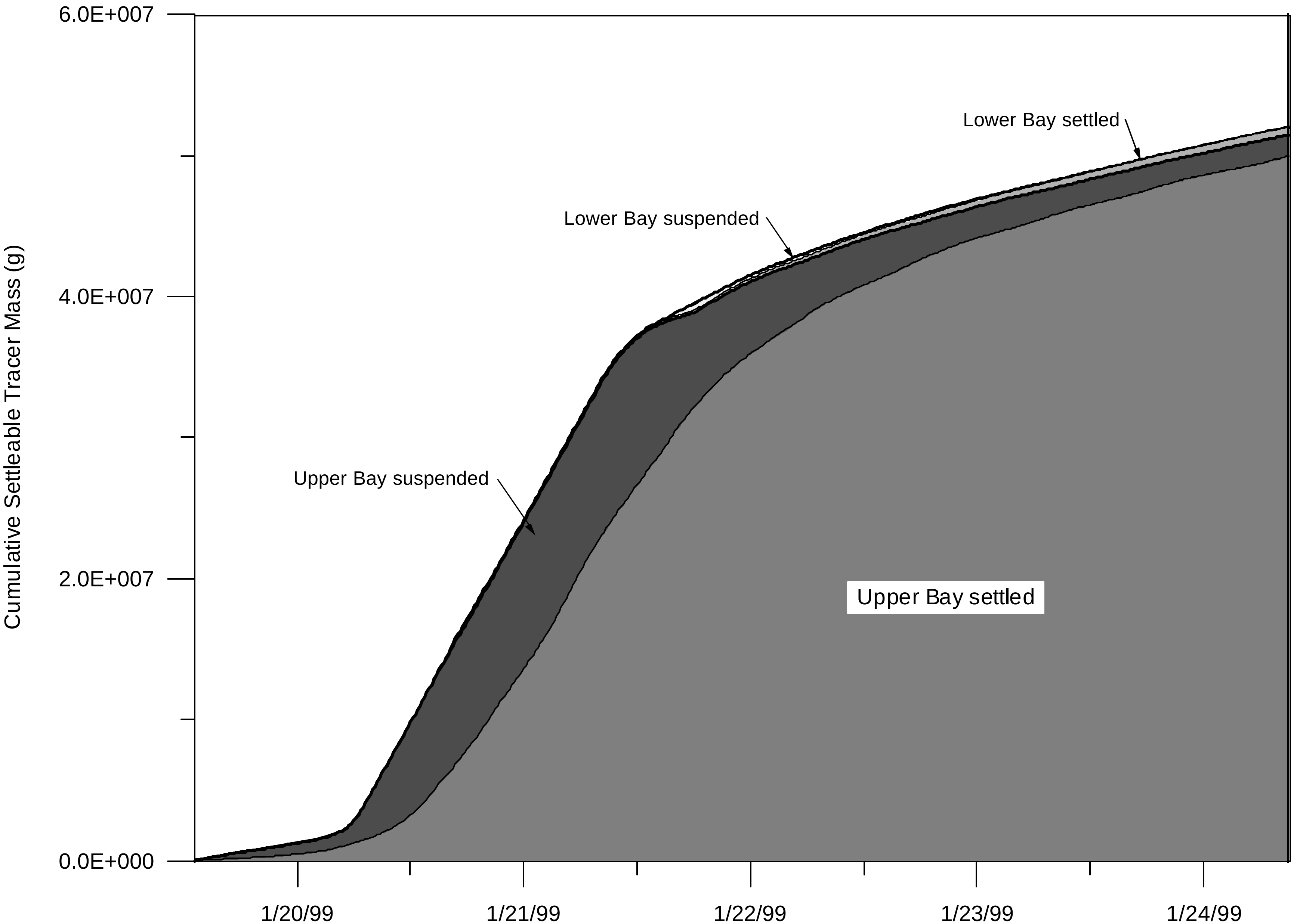

Figure 3.4 Cumulative settleable tracer mass for the 3-D small storm simulation (100 cfs peak San Diego Creek flow over one tidal cycle).

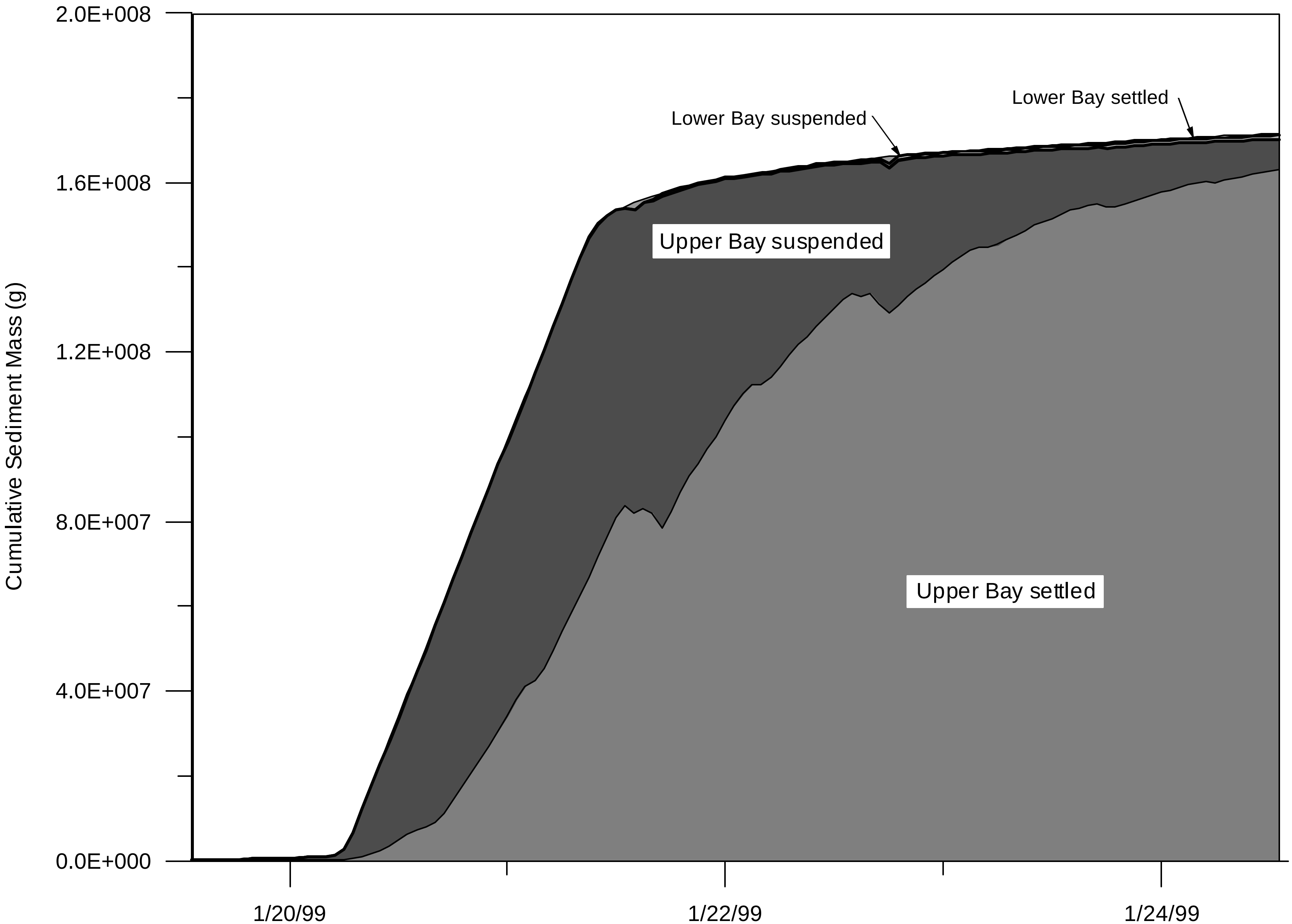

Figure 3.5 Cumulative sediment mass for the 2-D small storm simulation (100 cfs peak San Diego Creek flow over one tidal cycle).

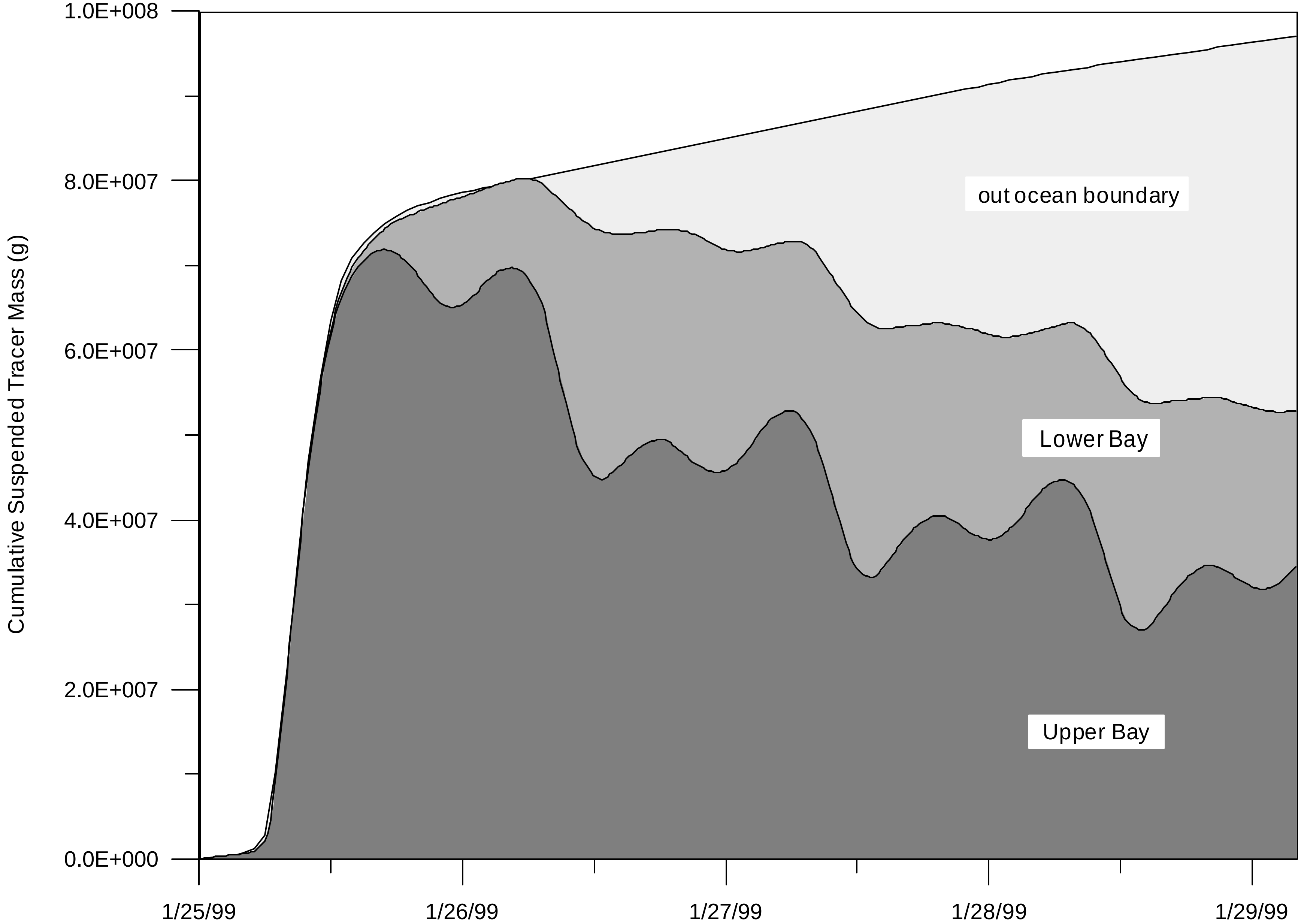

Figure 3.6 Cumulative suspended conservative tracer mass for the 3-D January 1999 medium storm simulation (San Diego Creek peak hourly flow 1,160 cfs).

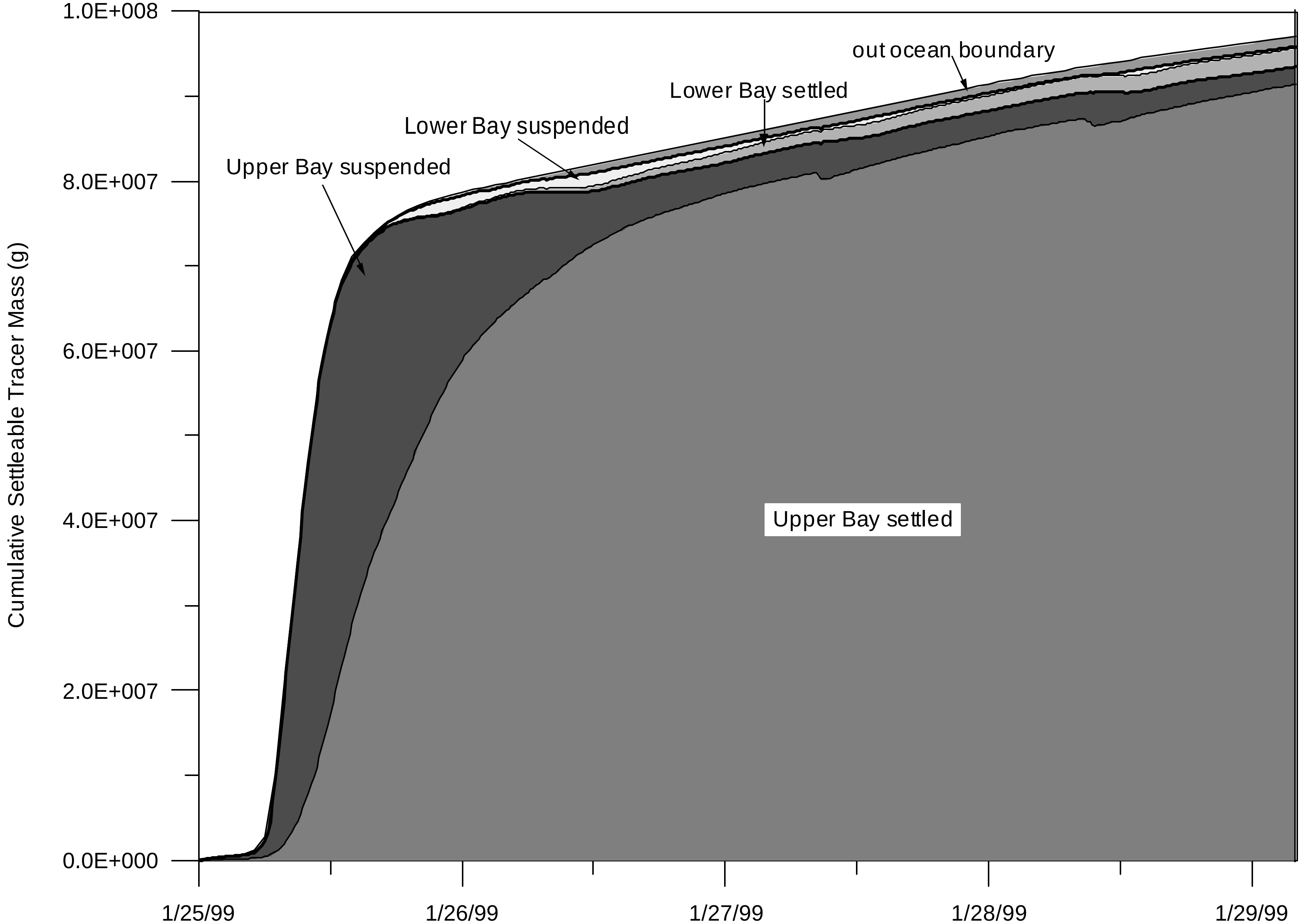

Figure 3.7 Cumulative settleable tracer mass for the 3-D January 1999 medium storm simulation (San Diego Creekpeak hourly flow 1,160 cfs).

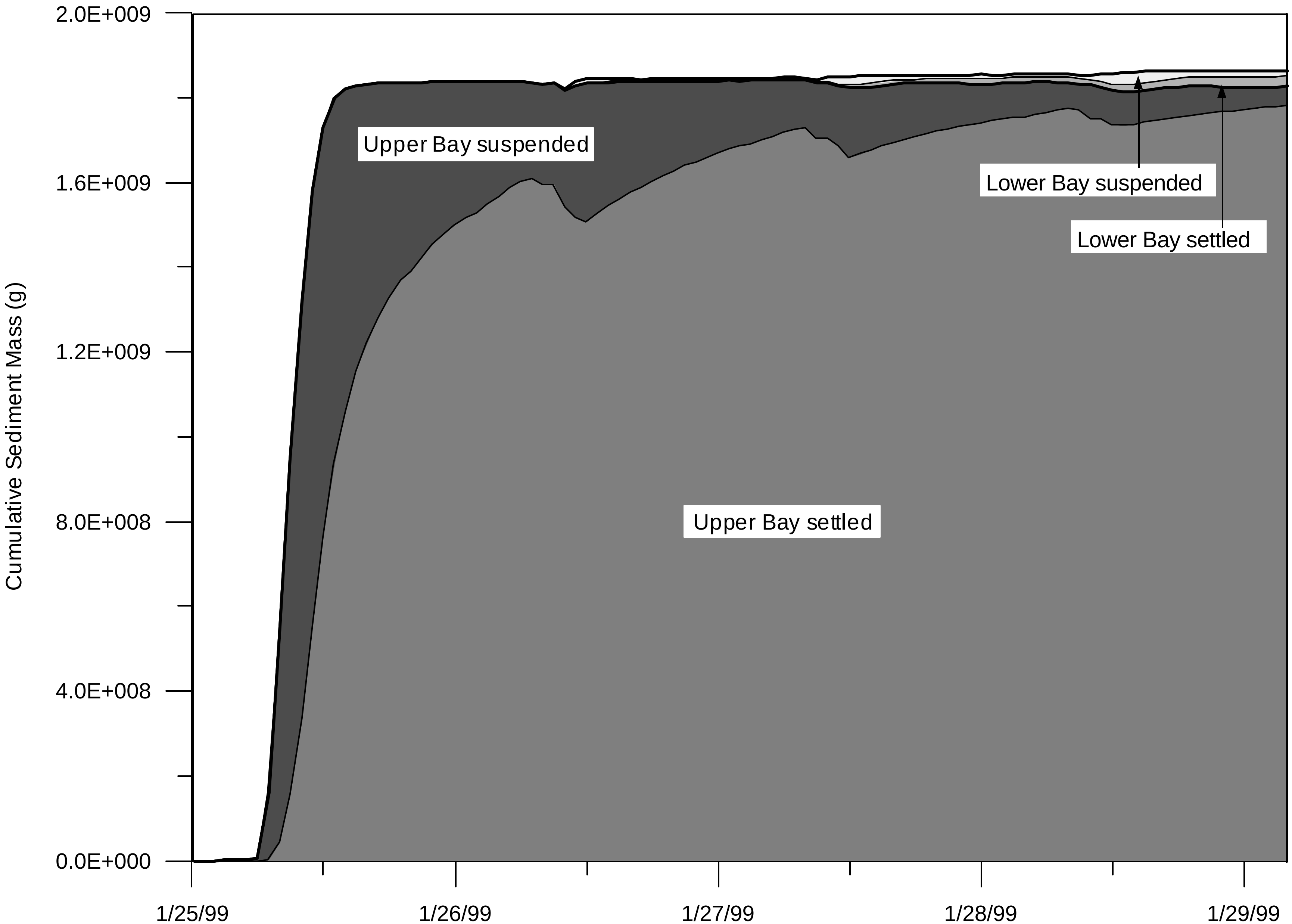

Figure 3.8 Cumulative settleable tracer mass for the 2-D January 1999 medium storm simulation (San Diego Creek peak hourly flow 1,160 cfs).

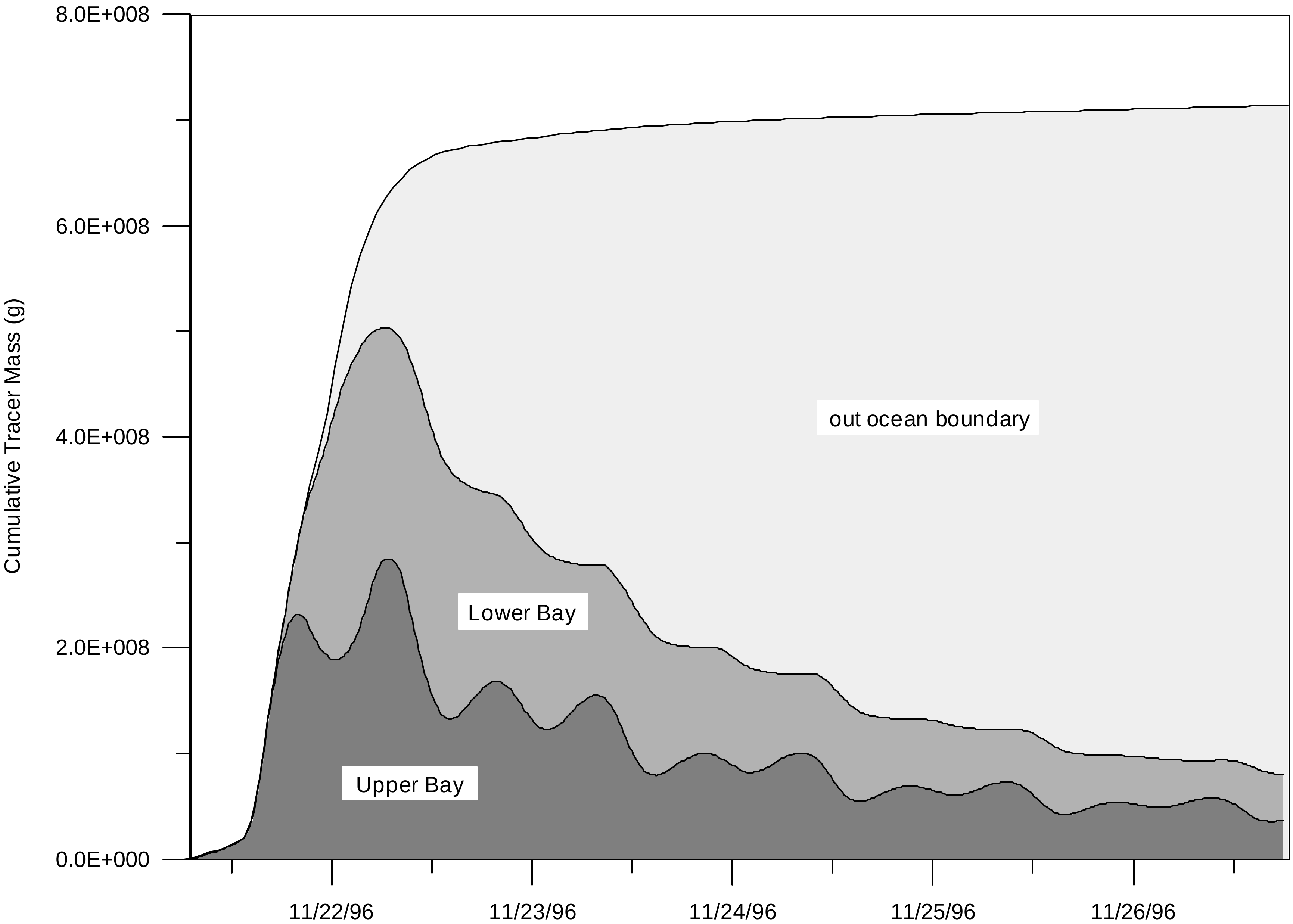

Figure 3.9 Cumulative suspended conservative tracer mass for the 3-D November 1996 large storm simulation (San Diego Creek peak hourly flow 4,500 cfs).

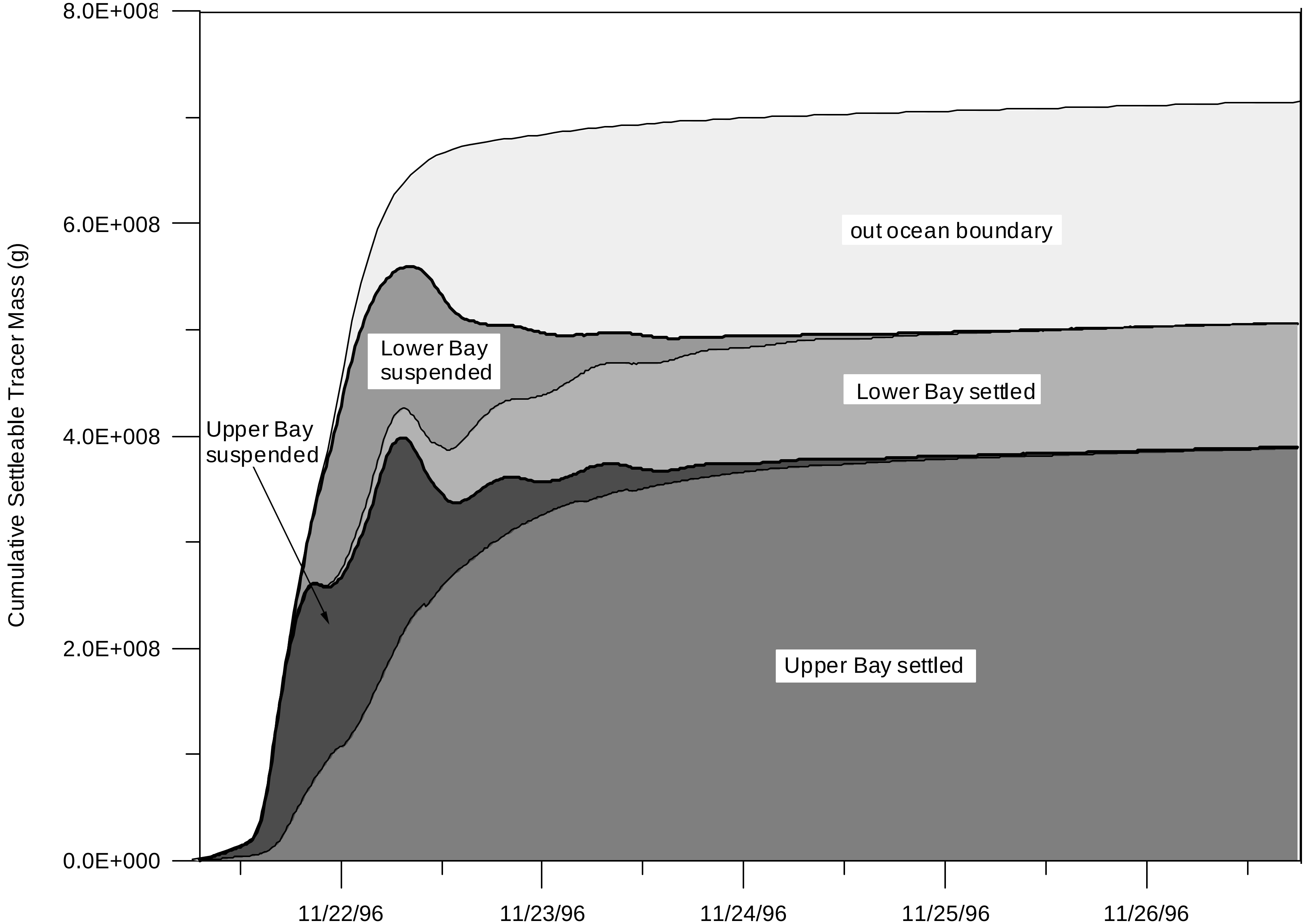

Figure 3.10 Cumulative settleable tracer mass for the 3-D November 1996 large storm simulation (San Diego Creek peak hourly flow 4,500 cfs).

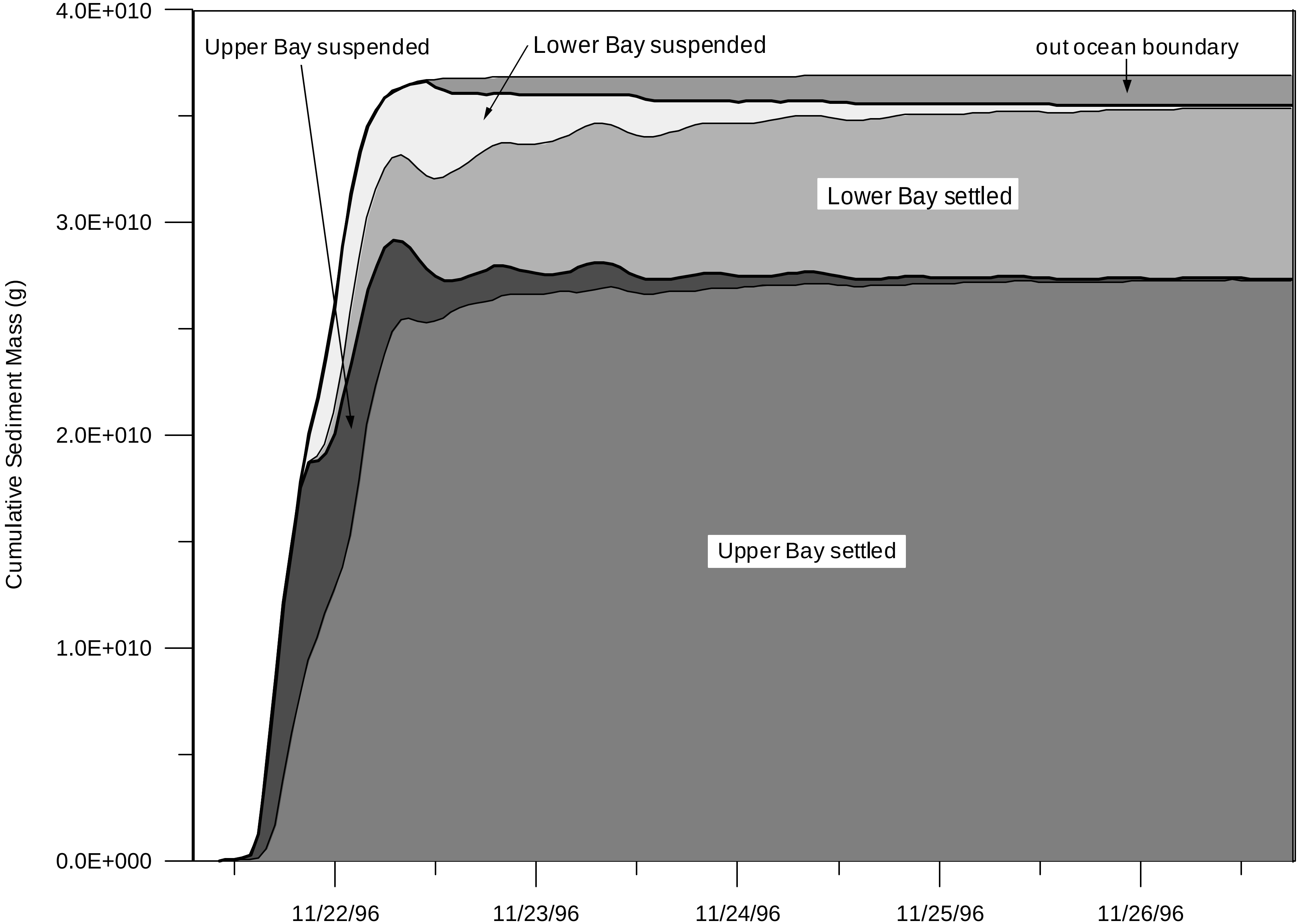

Figure 3.11 Cumulative sediment mass for the 2-D November 1996 large storm simulation (San Diego Creek peak hourly flow 4,500 cfs).

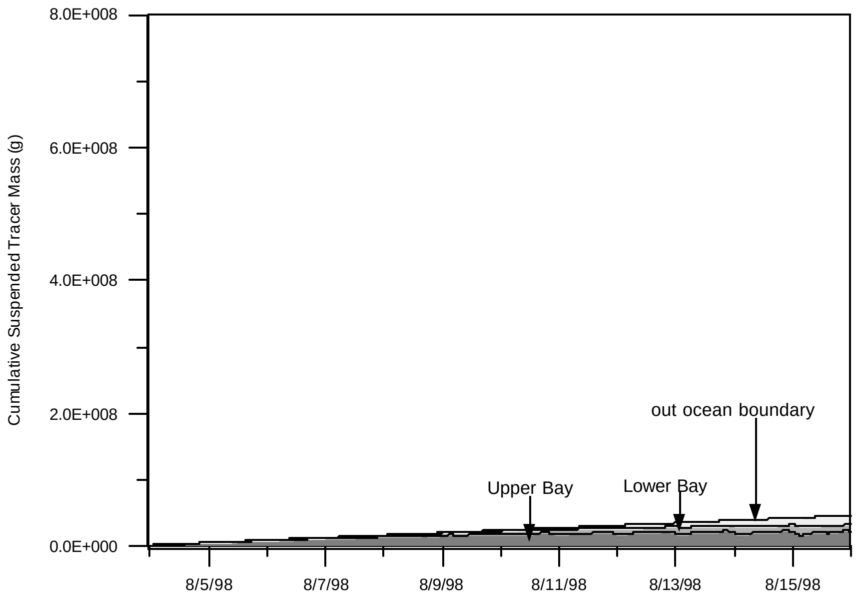

Figure 3.12 Cumulative conservative tracer mass for low flow simulation.

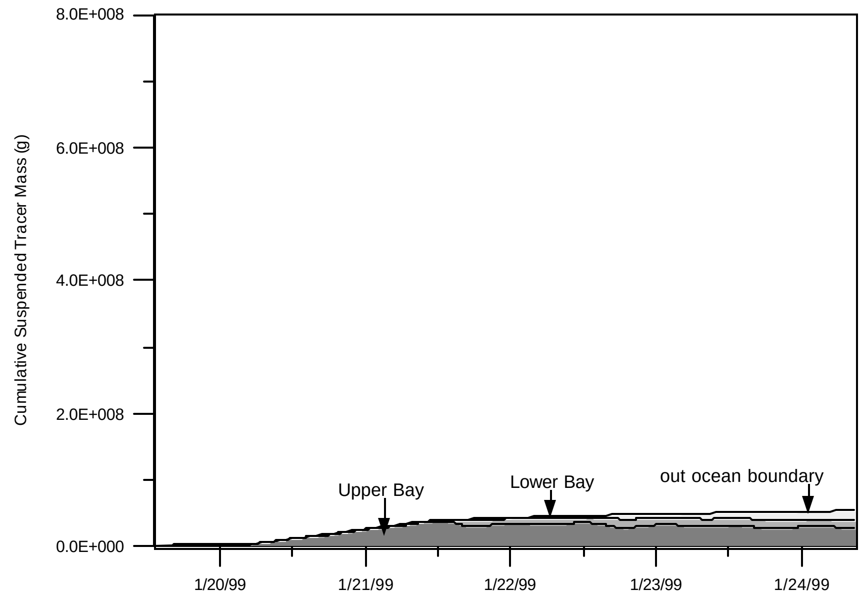

Figure 3.13 Cumulative conservative tracer mass for the small storm simulation.

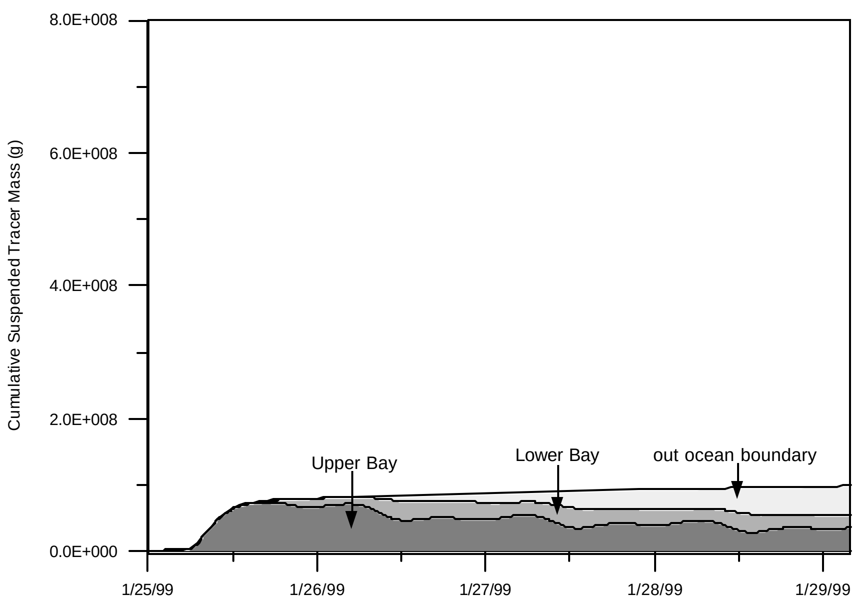

Figure 3.14 Cumulative conservative tracer mass for medium storm simulation.

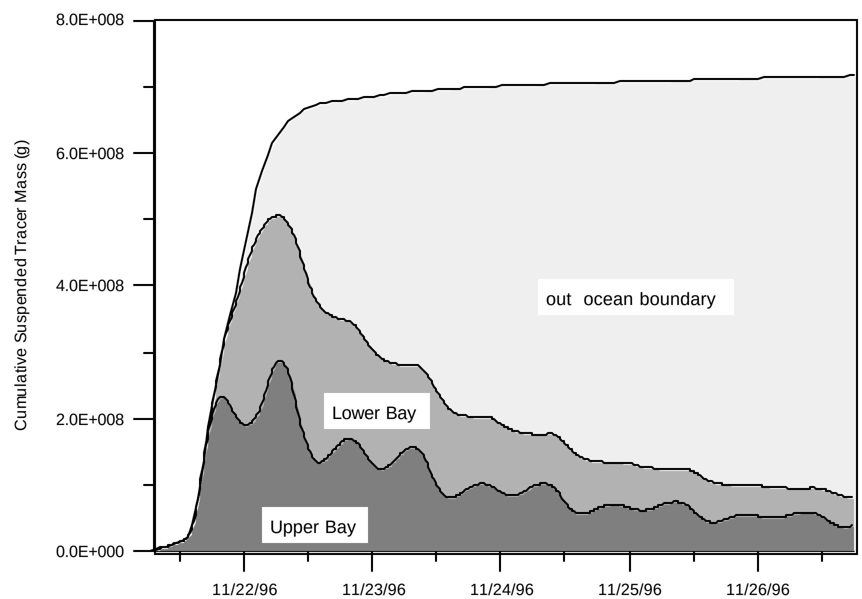

Figure 3.15 Cumulative conservative tracer mass for large storm simulation.

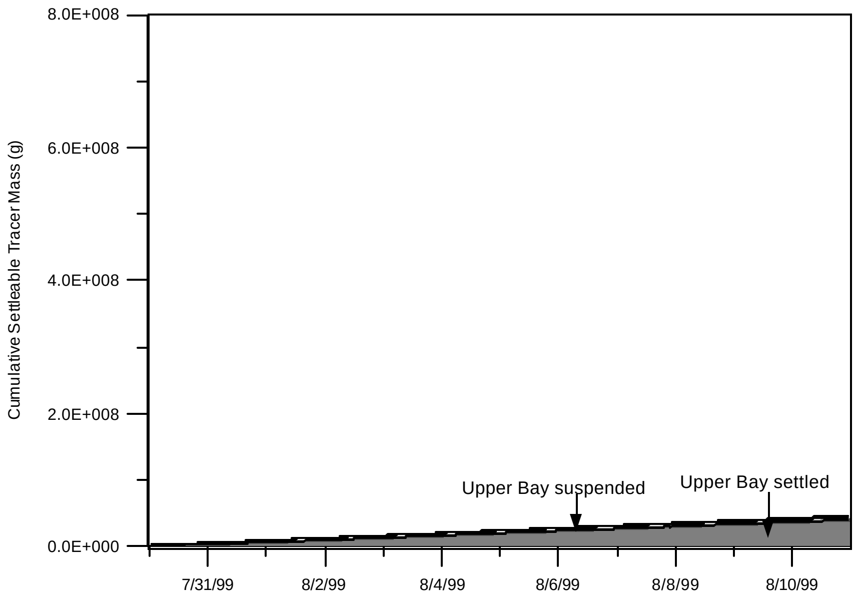

Figure 3.16 Cumulative settleable tracer mass for low flow simulation.

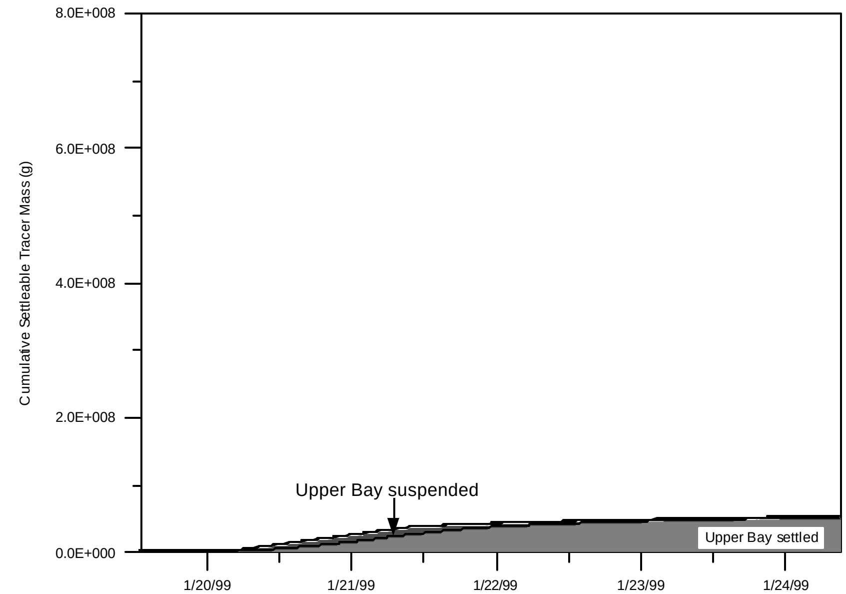

Figure 3.17 Cumulative settleable tracer mass for the small storm simulation.

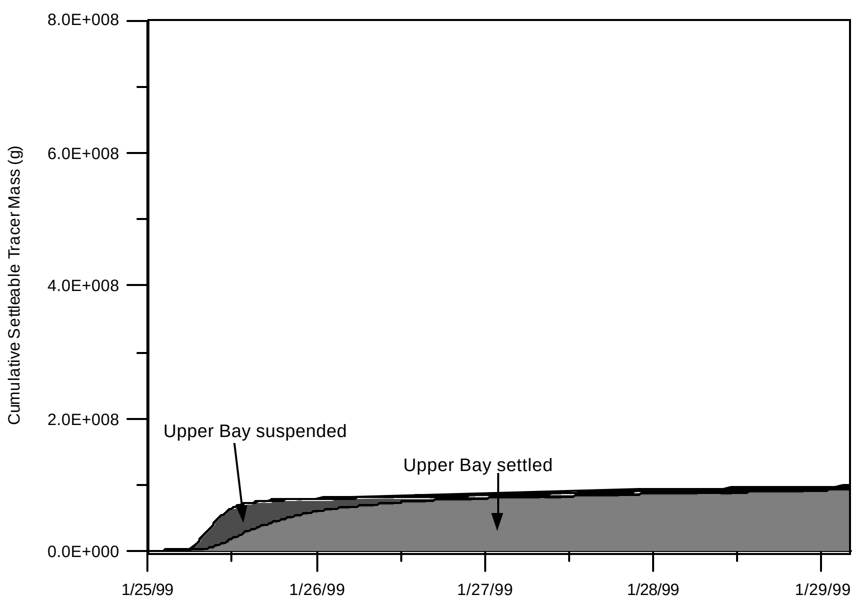

Figure 3.18 Cumulative settleable tracer mass for medium storm simulation.

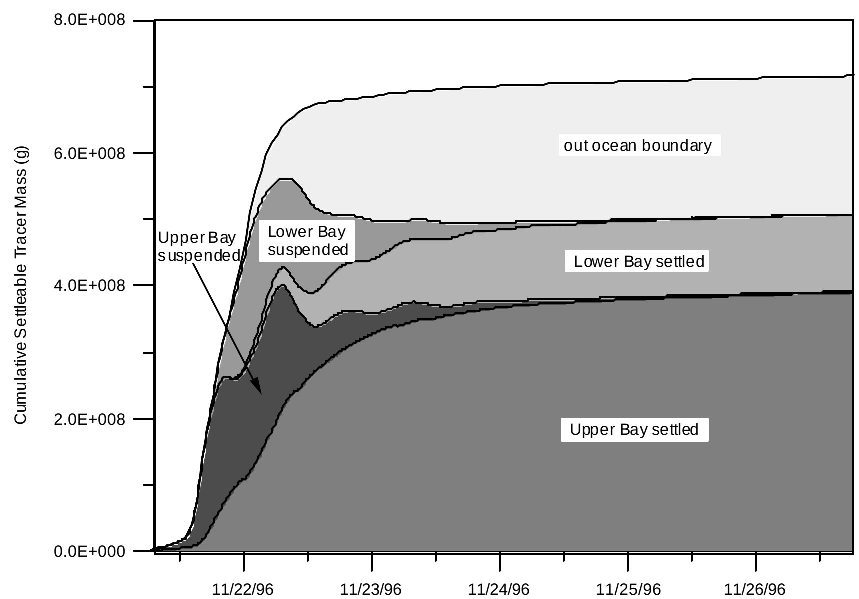

Figure 3.19 Cumulative settleable tracer mass for large storm simulation.

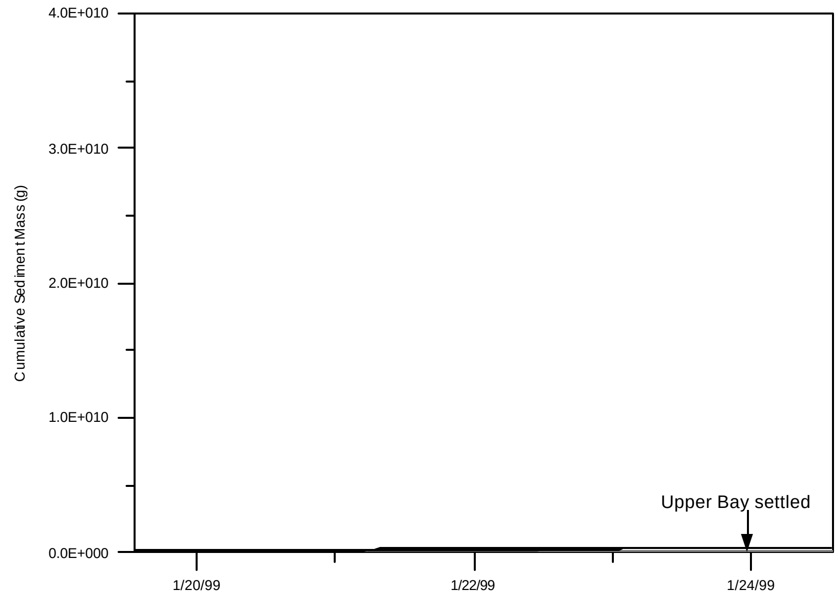

Figure 3.20 Cumulative sediment mass for 2-D small storm simulation.

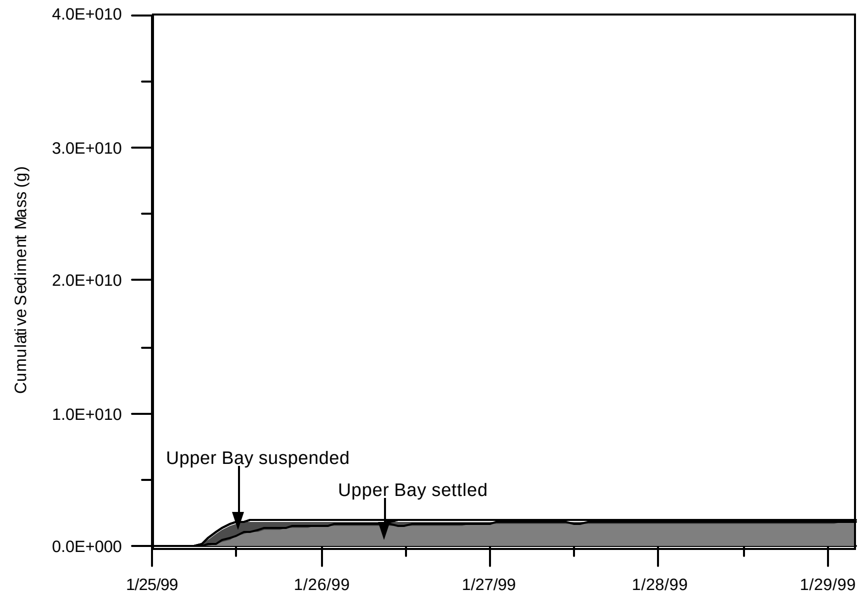

Figure 3.21 Cumulative sediment mass for 2-D medium storm simulation.

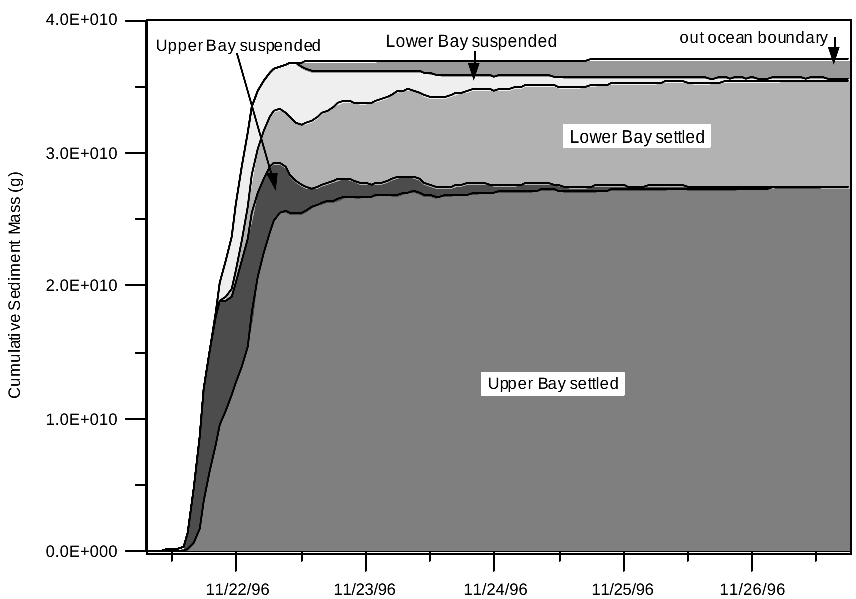

Figure 3.22 Cumulative sediment mass for 2-D large storm simulation.

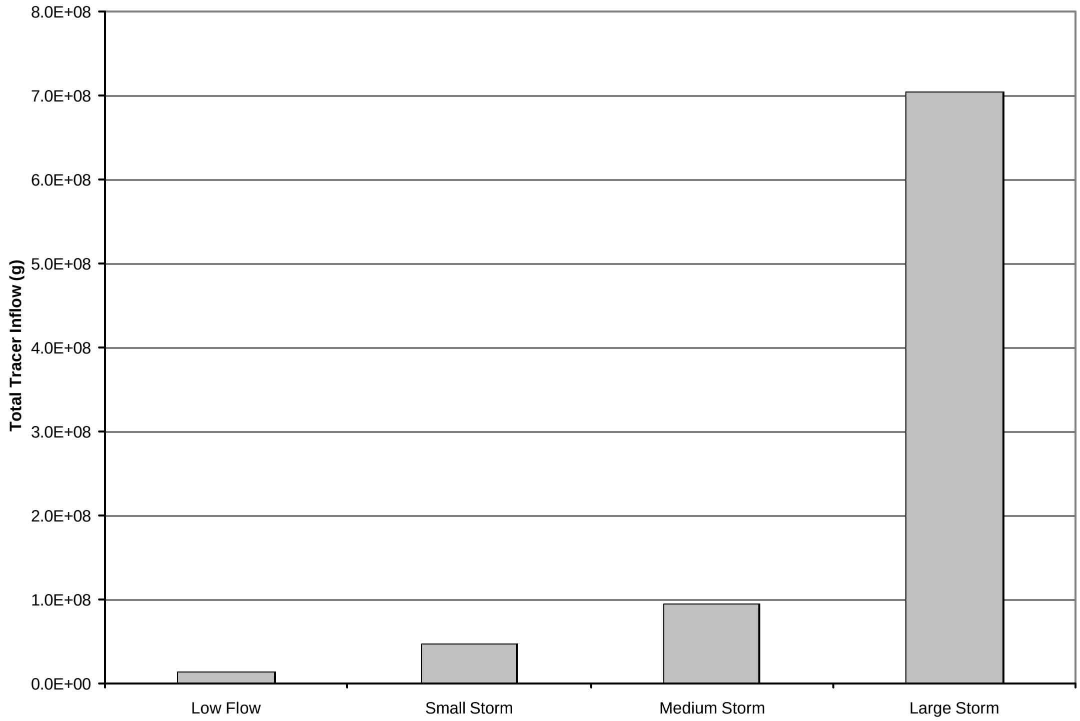

Figure 3.23 Total tracer mass inflow for each of the 3-D simulations.

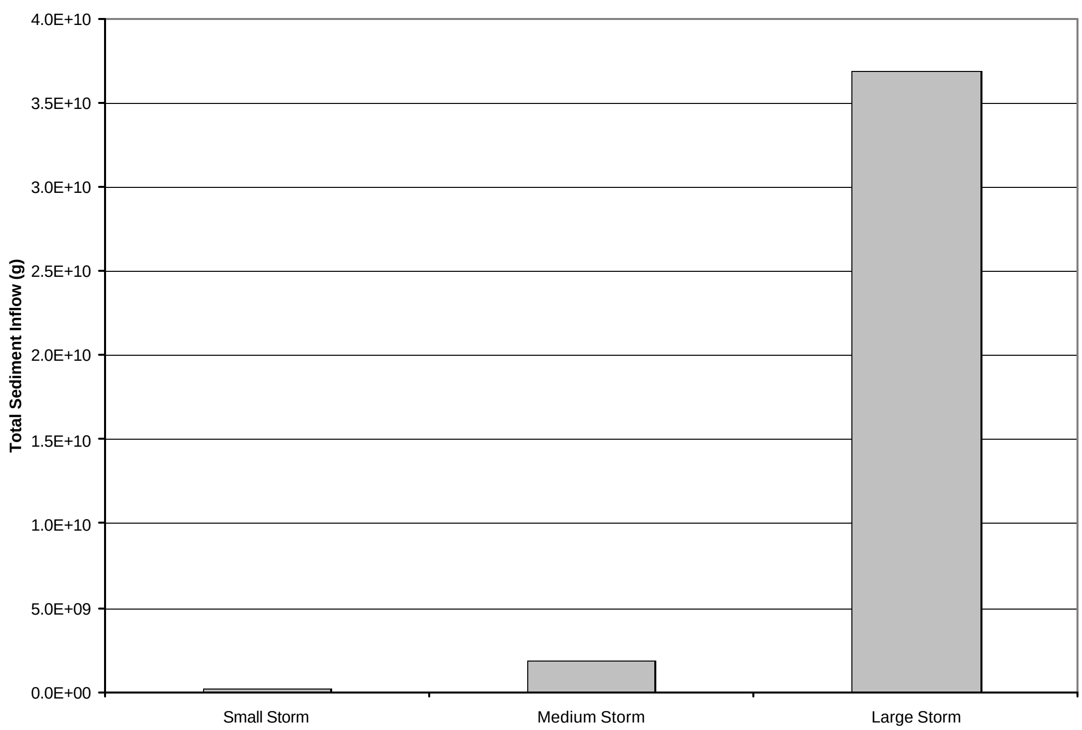

Figure 3.24 Total sediment mass inflow for each of the 2-D simulations.

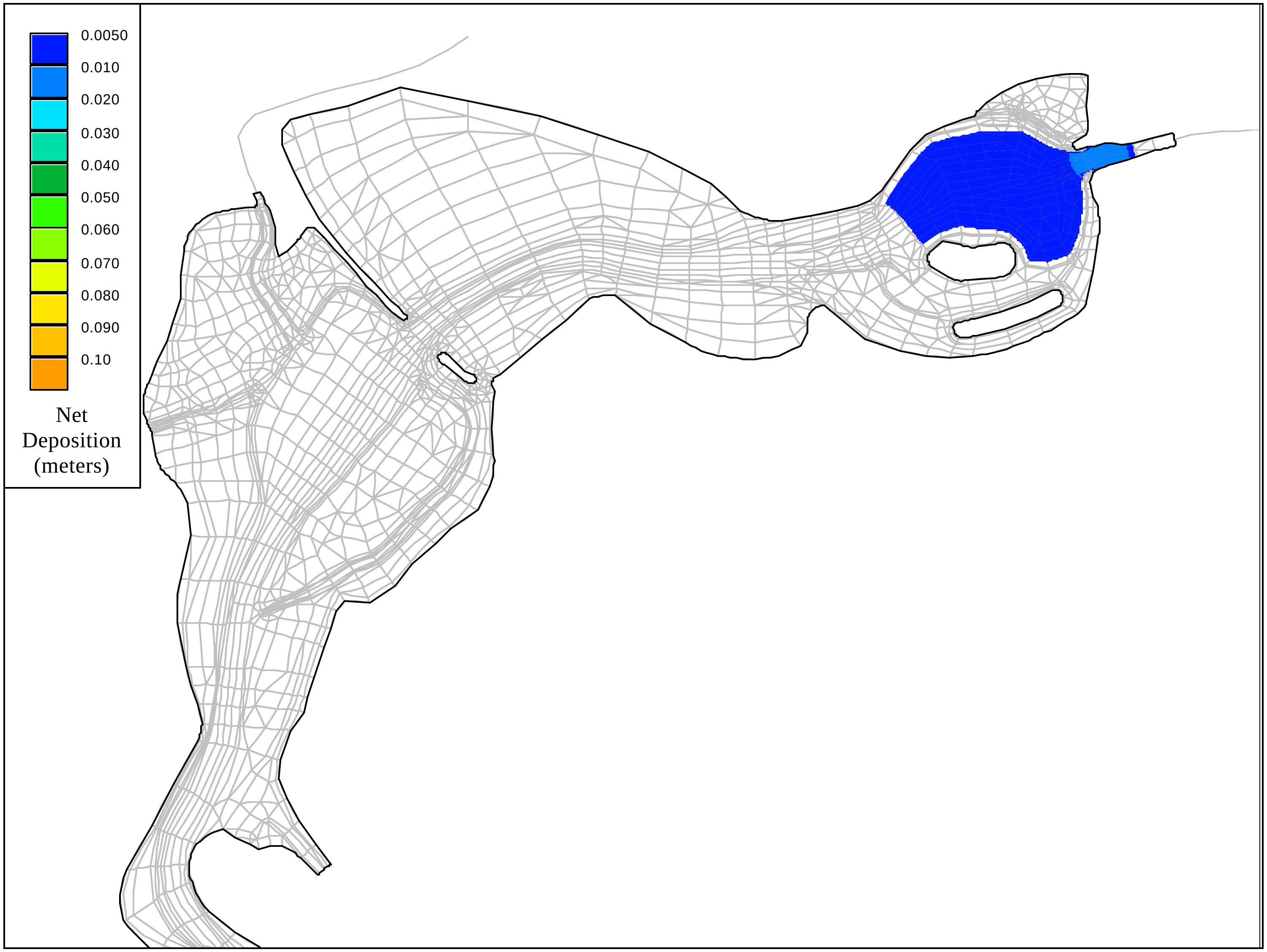

Figure 3.25 Net sediment deposition at the end of the 2-D 100 cfs small storm simulation.

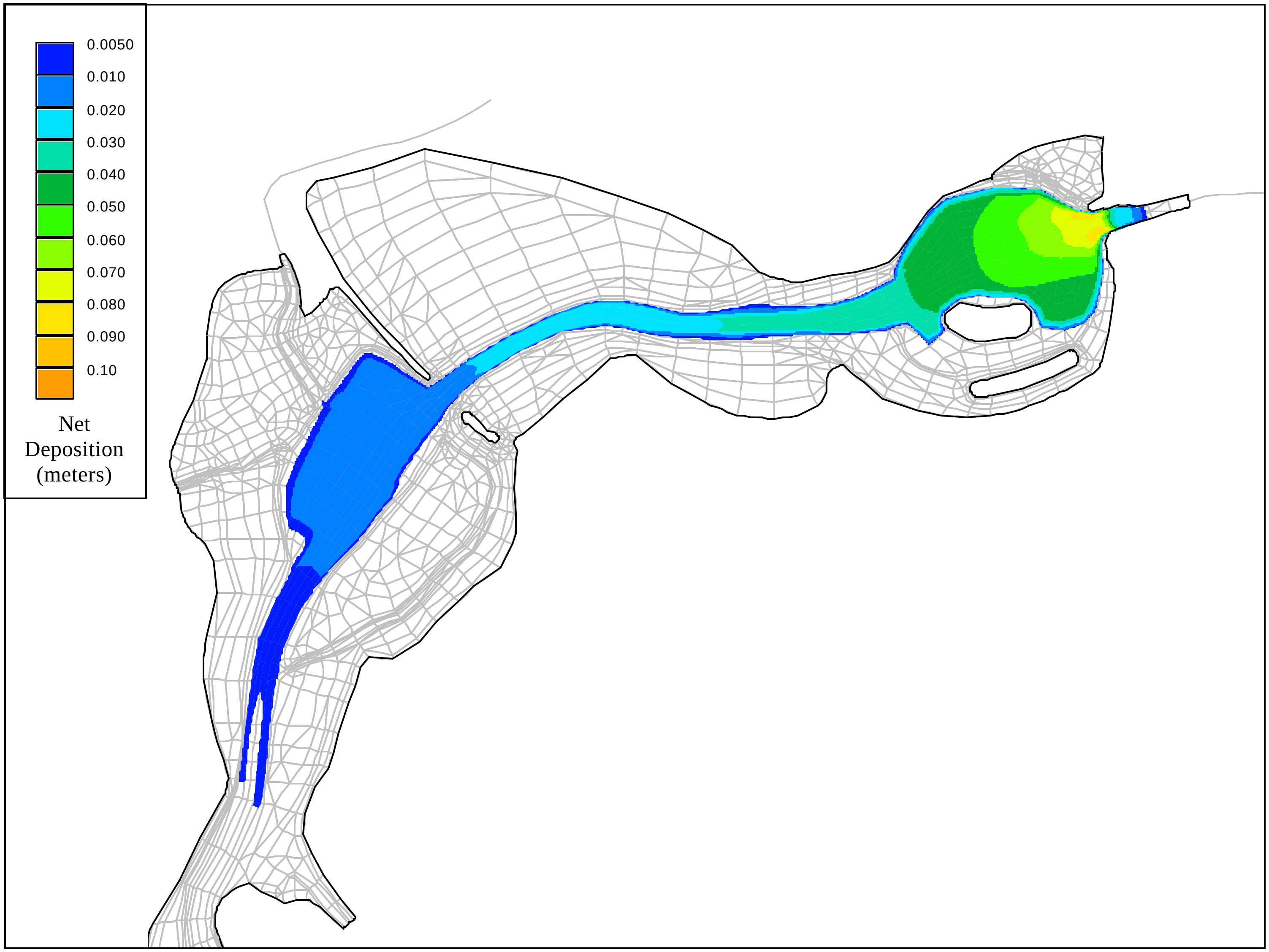

Figure 3.26 Net sediment deposition at the end of the 2-D 1,160 cfs medium storm simulation.

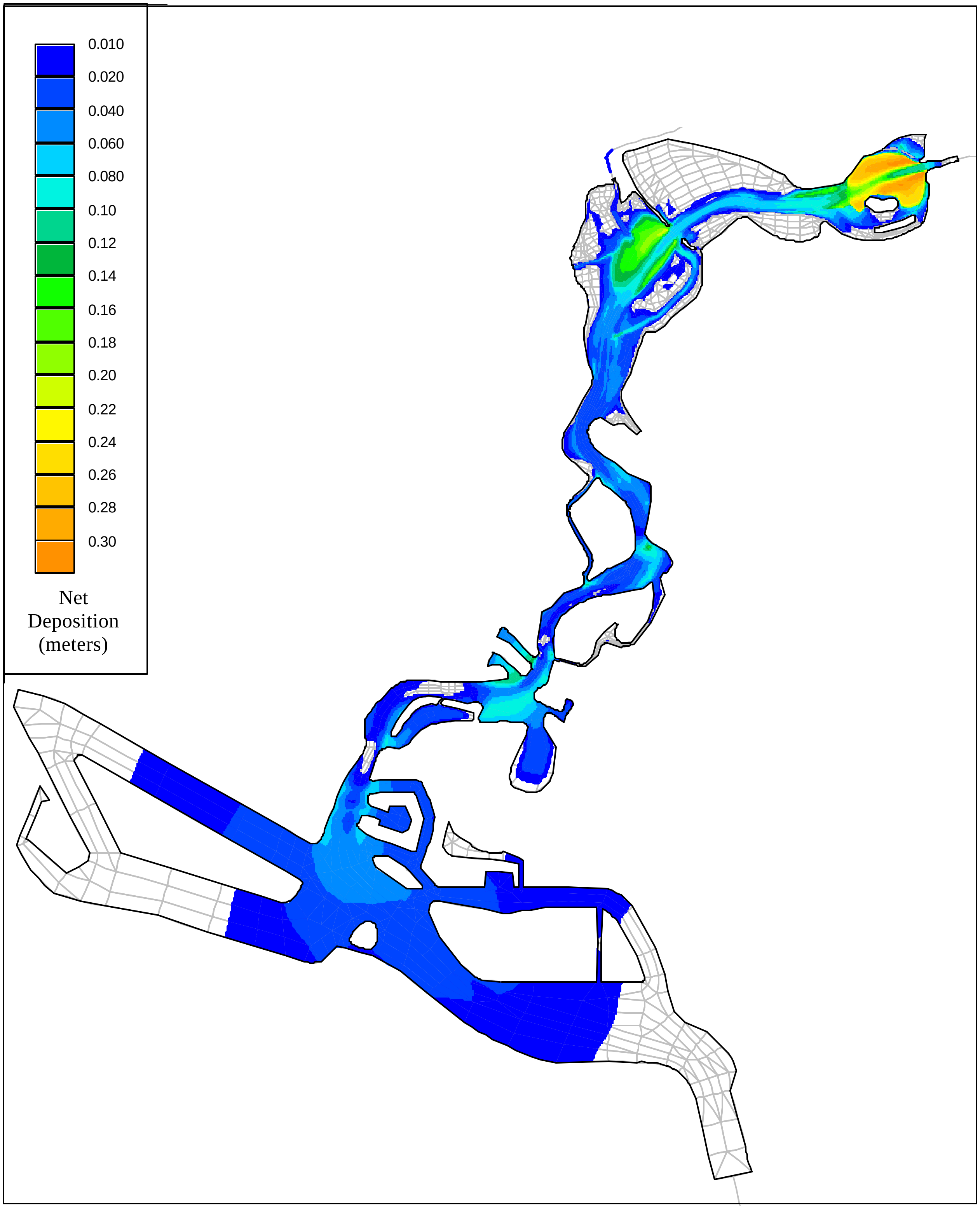

Figure 3.27 Net sediment deposition at the end of the 2-D 4,500 cfs large storm simulation.

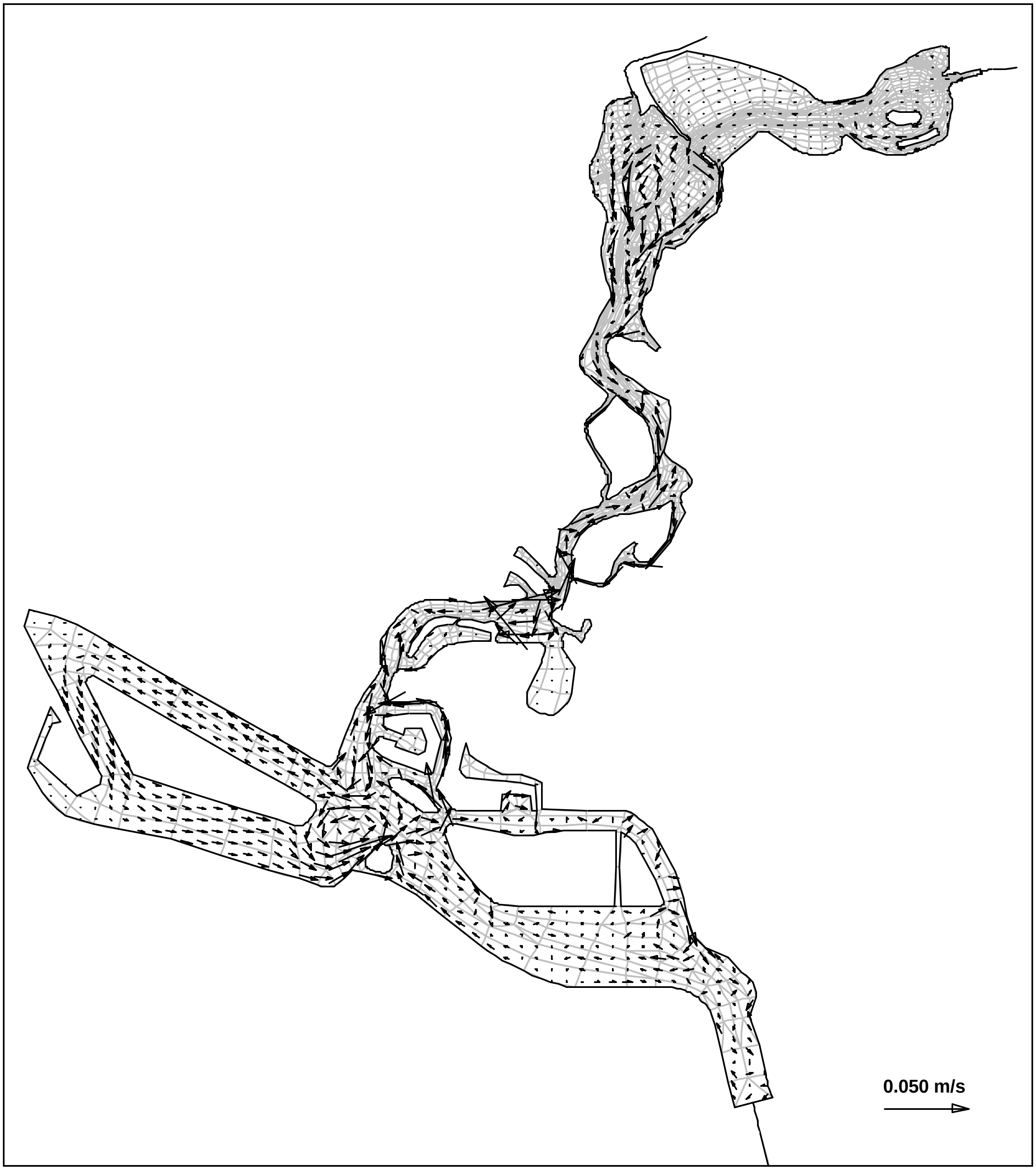

Figure 3.28 Residual velocity vectors in Newport Bay.

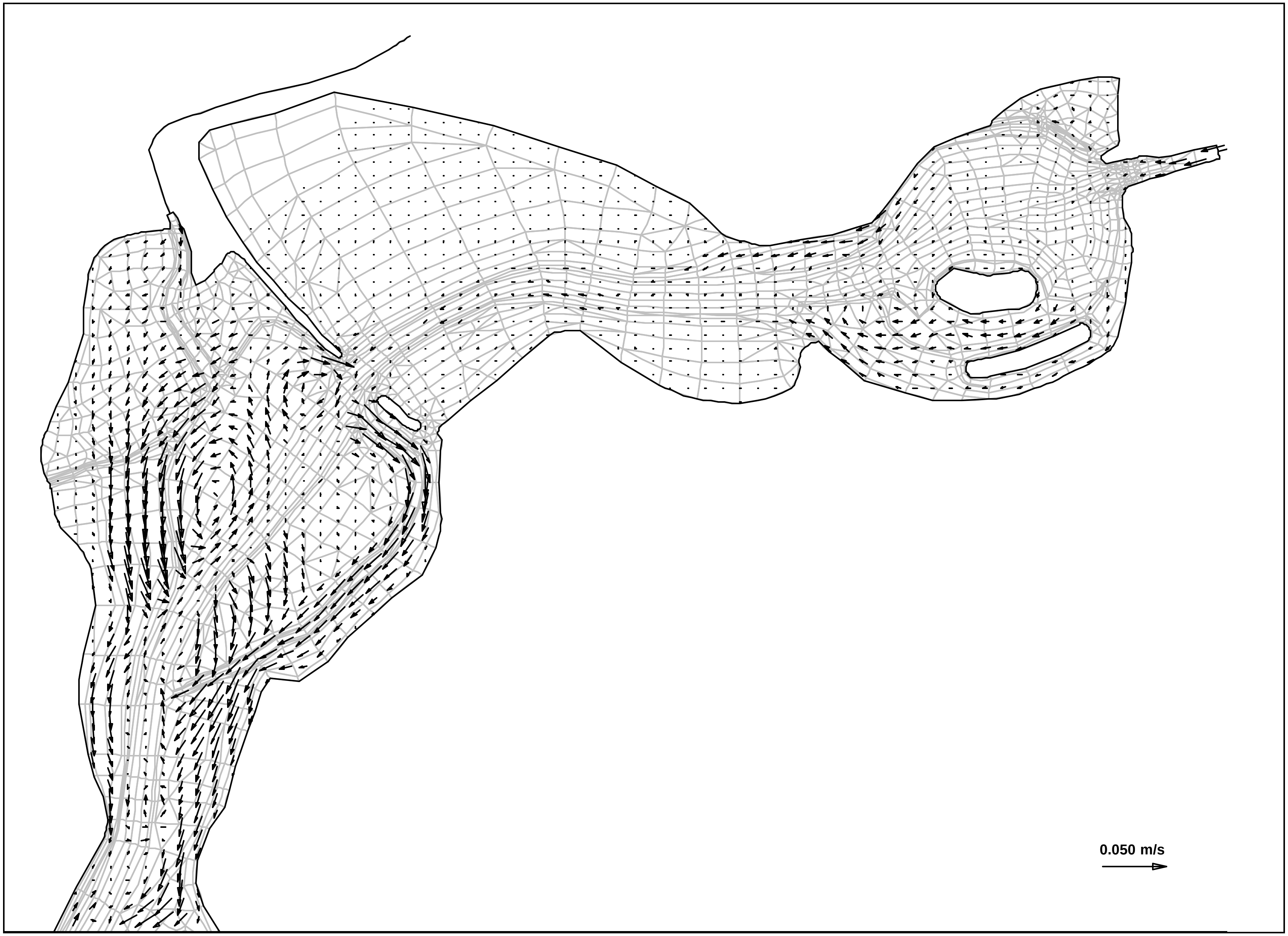

Figure 3.29 Residual velocity vectors in Unit I and Unit II basins.

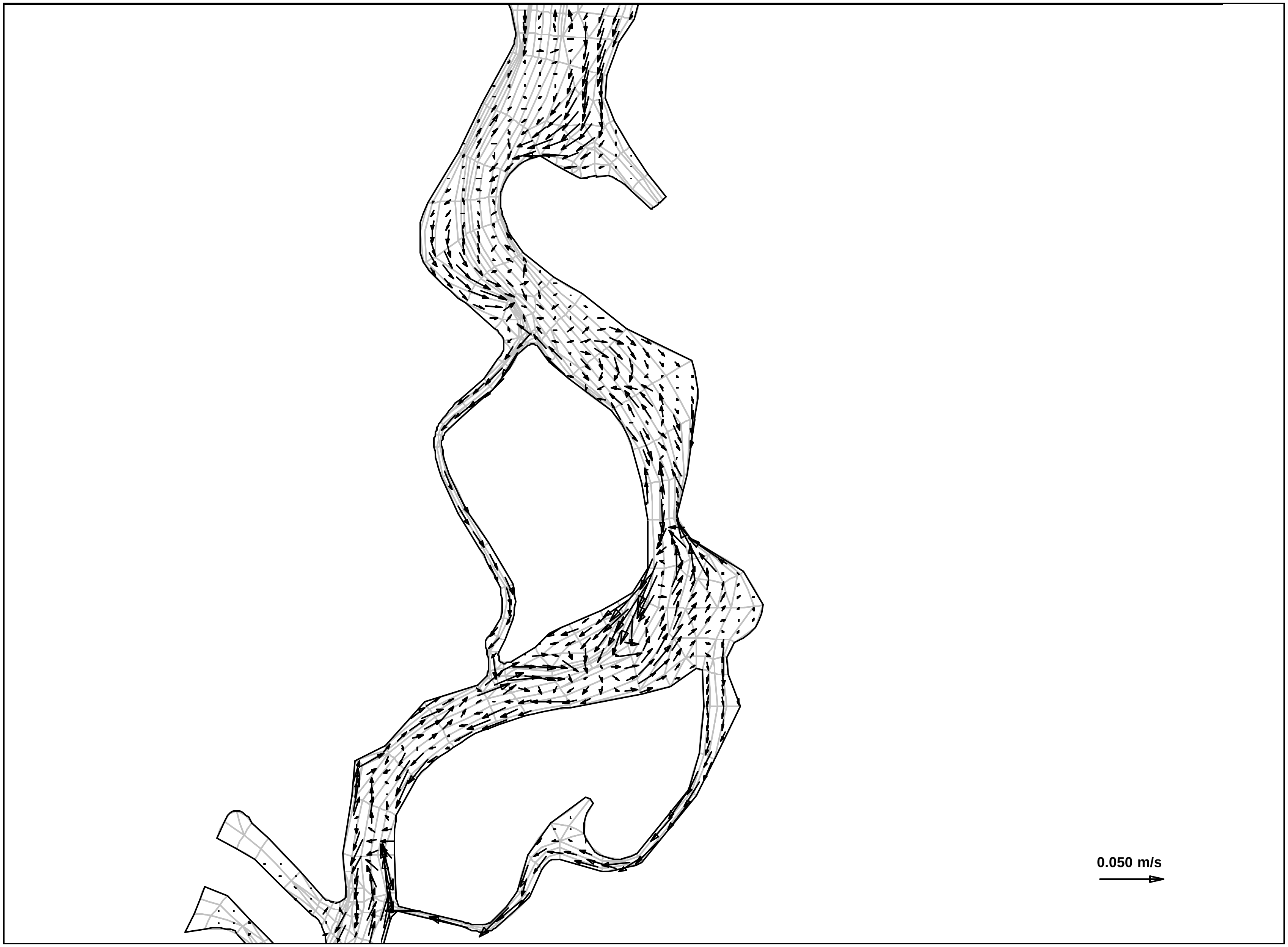

Figure 3.30 Residual velocity vectors in the central portion of Newport Bay.

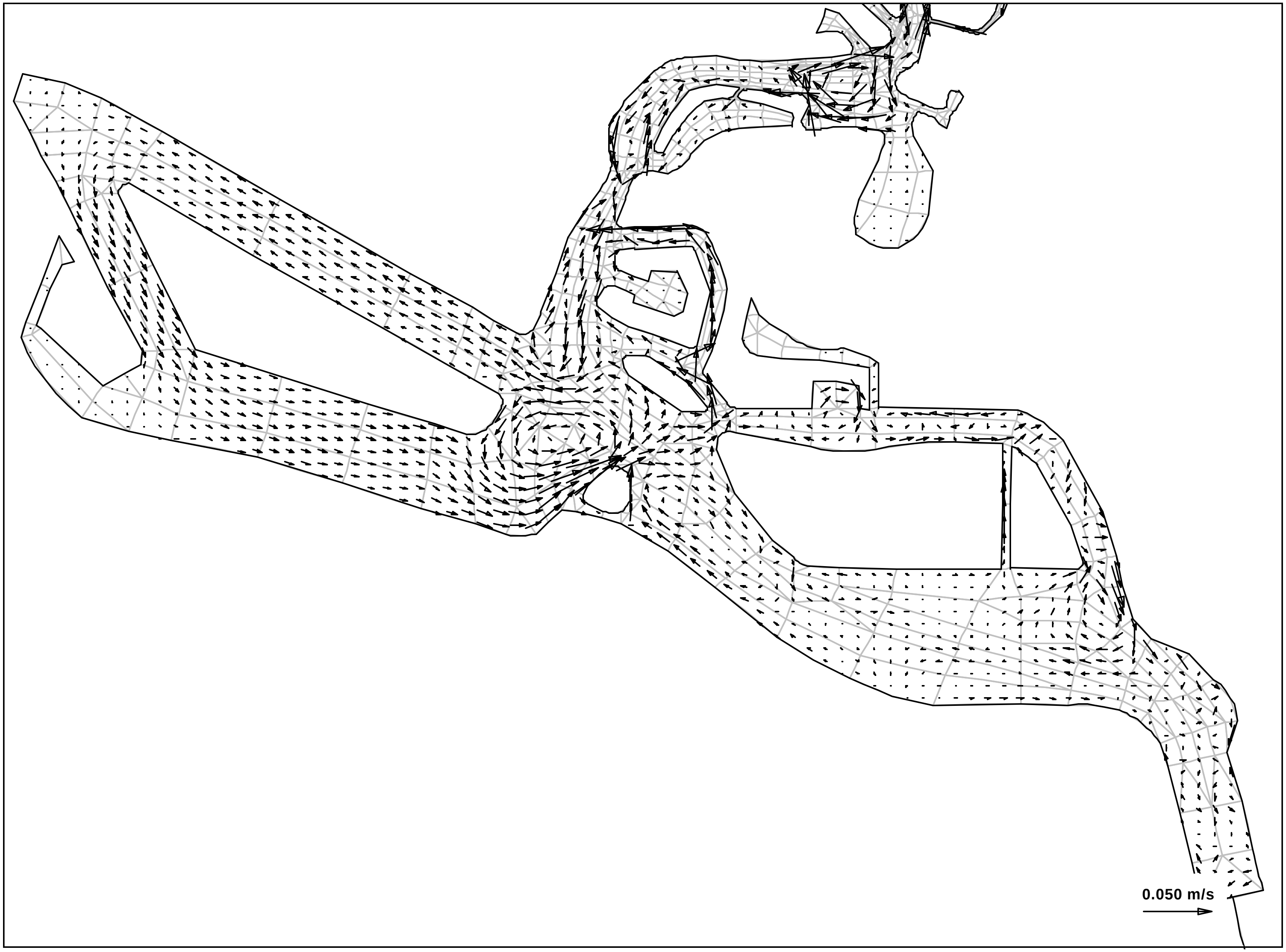

Figure 3.31 Residual velocity vectors in Lower Newport Bay.

4 SUMMARY

The existing 3-D and 2-D water quality transport models of Newport Bay have been used to perform simulations to evaluate transport in Newport Bay and to quantify the mass of contaminants that remains in the Bay relative to the mass supplied to the Bay under a range of inflow conditions. This was accomplished using three different modeling scenarios:

- 3-D simulations using a conservative tracer, with a constant tributary inflow concentration;
- 3-D simulations using a settleable tracer with no resuspension, a constant settling rate, and a constant tributary inflow concentration; and
- 2-D sediment simulations with shear stress dependent deposition and scour, and flow dependent tributary inflow concentrations.

Simulations were performed for low flow and three different storm flow conditions. Storm simulations were four to five days long and the low flow simulations were 12 days long.

4.1 Mass Distribution

Simulation results indicate that by the third day following the storm peaks in the small and medium storm simulation periods, over 90% of the settleable tracer and sediment is settled in the Upper Bay, while only 0 to 1% exits the ocean boundary. For the large storm simulations, more of the settleable tracer and sediment moves into the Lower Bay and settles, but the total amount settled in the Bay is still high with nearly 70% of the settleable tracer settled, and 93% of the sediment settled by the end of the simulation.

With the large storm a significant difference is apparent between the 2-D and 3-D simulations. Stronger density stratification is present with the large storm as the high fresh water flow volumes flow out over the denser salinity wedge at the bottom. The 3-D model is able to simulate this while the 2-D model maintains constant concentrations over depth. Therefore, in the 3-D model, more of the settleable tracer remains near the surface and reaches the ocean boundary before settling out.

By the end of the large storm conservative tracer simulation, most of the tracer mass has passed out of the system following the storm peak. The medium and small storm simulation flows are not large enough to have washed as much tracer out of the system in the three days following the storm.

The low flow conservative tracer simulation has not quite reached equilibrium, however the end result is that at equilibrium, the suspended mass in the Bay is steady, fluctuating only with the tide, and on average the mass exiting the system is equal to the mass entering the system. The low flow settleable tracer simulation has reached equilibrium. The suspended mass is steady, on average, 88% of the mass load is deposited in the Upper Bay, 6% is deposited in the Lower Bay, and 6% exits the ocean boundary.

Regardless of the storm size, the mass concentrations in the Upper and Lower Bay are approaching the same equilibrium values as the tributary inflows return to normal flow conditions. The low flow simulation is building up slowly to that equilibrium concentration, while the storm flow simulations are gradually declining to the equilibrium concentration following the storm peaks. Although the suspended settleable tracer mass and the suspended sediment mass approach the same equilibrium values regardless of the storm size, the settled mass is very much dependent on storm size. In the time frame considered in this study, very little scour and resuspension of the sediment occurs so that the settled mass rapidly increases during the storm events and remains stable. Material may be resuspended later however, during normal tidal action.

4.2 Residual Velocities

Residual velocity analysis indicates that ebb flows dominate the side channels, while no strong ebb or flood patterns are apparent in the main channel of the Bay. There is a counterclockwise flow pattern around Lido Island in the Lower Bay.

5 REFERENCES

Ariathurai, R., and R. B. Krone, "Finite Element Model for Cohesive Sediment Transport," *Journal of the Hydraulics Division*, ASCE, vol. 102, no. hy3, 1976.

Resource Management Associates, Inc. (RMA), "Newport Bay Water Quality Model Development: 3-D Stratified Flow Analysis", prepared for California Regional Water Quality Control Board, Santa Ana Region, February 2001.

Resource Management Associates, Inc. (RMA), "Upper Newport Bay Feasibility Report: Upper Newport Bay Alternative Analysis", prepared for U.S. Army Corps of Engineers Los Angeles District, November 1999.

Resource Management Associates, Inc. (RMA), "Upper Newport Bay Feasibility Report: Upper Newport Bay Salinity Study", prepared for U.S. Army Corps of Engineers Los Angeles District, October 1998.

Resource Management Associates, Inc. (RMA), "Upper Newport Bay Feasibility Report: Upper Newport Bay Numerical Model Development Baseline Conditions Analysis", prepared for U.S. Army Corps of Engineers Los Angeles District, July 1998.

Resource Management Associates, Inc. (RMA), "Upper Newport Bay Feasibility Report: Final Model and GUI Development and Implementation Report", prepared for U.S. Army Corps of Engineers Los Angeles District, October 1997.

U.S. Army Corps of Engineers Los Angeles District, "Upper Newport Bay Reconnaissance Report", p. 34, February 1993.