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MEMORANDUM

DATE: May 5, 2006

TO: Peter Kozelka, USEPA Region 9
L.B. Nye, LARWQCB

CC: David Smith, USEPA Region 9

FROM: John Hamrick, John Craig, and Stephen Carter

SUBJECT: Los Angeles-Long Beach Harbors and San Pedro Bay Hydrodynamic Model Calibration – DRAFT

This memorandum summarizes the current status of development and calibration of the hydrodynamic model component of a coupled hydrodynamic and water quality modeling system under development to support TMDL's in the greater Los Angeles and Long Beach Harbors, including the Los Angeles River estuary and San Pedro Bay. Comments on the memo should also include suggestions for improving this general outline since the final hydrodynamic model calibration report will have a similar format. The memorandum discusses the overall modeling framework to support TMDL development, identifies observational data to support hydrodynamic model configuration and calibration, and presents preliminary calibration results.

Areas of the Los Angeles and Long Beach Harbors and San Pedro Bay, including their tributaries, the Los Angeles and San Gabriel Rivers and Dominguez Channel, are currently on the State of California's 303(d) list of impaired waters. Conventional pollutants on the list include ammonia, fecal coliform, and elevated nutrient levels contributing to algae blooms. A variety of toxic inorganic and organic contaminants contribute benthic effects and sediment toxicity impairments. Specific inorganic metal contaminants on the list include cadmium, chromium, copper, lead, mercury, nickel, and zinc. Organic contaminants listed include chlordane, DDT, dieldrin, PAHs, PCBs, and toxaphene. The fate and transport of metals and organic contaminants in surface water systems is strongly coupled with the fate and transport of organic and inorganic sediments and dissolved organic material due to their affinity to adsorb to sediment particles and bond with dissolve organic carbon to form complexes.

Hydrodynamic and water quality models provide an important tool to evaluate existing conditions, including identifying non-point source load contributions, source controls, and TMDL allocation alternatives. A modeling system which includes hydrodynamic, sediment and contaminant fate, and transport and nutrient-eutrophication simulation is the optimum choice for the greater harbors system in that it allows modeling decision support for the range of listed impairments. This memorandum summarizes the current status of the development of the hydrodynamic component of this modeling system. The remainder of the memorandum is organized as follows:

- *Modeling Framework*. Summarizes the overall modeling framework including model selection and the sequence of steps leading to the decision support modeling system for TMDL development.
- *Observational Data for Model Configuration and Calibration*. Summarizes available observational data for configuration and calibration of the hydrodynamic model component.
- *Model Configuration*. Describes configuration of the model for the greater Los Angeles and Long Beach Harbors system.
- *Hydrodynamic Calibration and Transport Calibration*. Outlines the approach used and presents preliminary results for the hydrodynamic and transport calibration.
- *Summary and Recommendations*. Summarizes the status of the calibration and makes a number of recommendations for configuration and calibration enhancement.

MODELING FRAMEWORK

A modeling system to support TMDL development for a diverse range of impairments in the greater Los Angeles and Long Beach Harbors system requires three primary components: hydrodynamic, sediment and contaminant transport and fate, and eutrophication simulation. The U. S. Army Corps of Engineers (ACOE) has conducted numerous hydrodynamic and eutrophication modeling studies in the greater harbors area (Seabergh and Outlaw, 1984; Seabergh, 1985; CERC, 1990; Hall, 1990; Hall, 1995; Wang et al., 1995; Miller et al., 1998; Bunch, et al., 2000, 2002, 2003) using the proprietary CH3D hydrodynamic and CE-QAUL-IC water quality models. No previous modeling efforts have addressed the fate and transport of sediment adsorbed toxic metals and organic compounds in the greater harbor waters.

The Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992; Hamrick and Wu; 1997; Park et al., 1995) was selected for this study for a number of reasons. The EFDC model includes all required model components (hydrodynamic, sediment and contaminant transport and fate, and eutrophication) and is in the public domain, as well as being supported by the U. S. EPA. The EFDC model has been used for more than 100 surface water modeling applications including nutrient TMDL development (Wool et al., 2003; Zou et al., 2006) and metals and organic contaminant fate and transport at conventional (Ji, et al., 2002; King County, 1999) and superfund sites (U. S. EPA, Region 1, 2006; U. S. EPA Region 10; 2006).

The EFDC modeling framework to support TMDL development in the greater harbors systems is being undertaken in a sequence of steps. The first step is configuration and calibration of the model hydrodynamic component, including salinity and temperature transport. This step will be follow by the configuration and calibration of the sediment-contaminant fate and transport and eutrophication components. This memorandum summarizes the status of the hydrodynamic component configuration and calibration.

OBSERVATIONAL DATA FOR MODEL CONFIGURATION AND CALIBRATION

Observational data for the hydrodynamic model falls within two general classes: data used for model configuration and data used for model calibration. Model configuration data includes the water body shoreline, bathymetry, data used for specifying hydrodynamic and salinity and temperature boundary conditions, atmospheric wind and thermal forcing, and inflows. Calibration data includes observations of hydrodynamic variables predicted by the modeling including water surface elevation, horizontal currents, salinity, temperature, and dye tracer concentration.

Table 1 summarizes the observational data currently used for model configuration and calibration, while Table 2 summarizes additional data sources reviewed and their status with respect to use in model calibration. Data listed in Table 1 and used for the hydrodynamic model configuration and calibration are discussed later in this memo. It is useful to summarize at this point that the available observational data for model configuration are very adequate, while the data for model calibration could be judged as less adequate. The available data being used for calibration are limited to two tide gauges, 4 current meters within the breakwater, six current meters outside the breakwater in San Pedro Bay, and approximately 120 salinity and temperature monitoring stations.

The adequacy of the data for calibration relates to strongly to the hydrodynamic characteristics of the greater harbors system. Previous modeling studies by the ACOE indicated that water surface elevation amplitude and phase vary insignificantly in the system and that the long-term NOAA tide gauge record is representative of the entire system. Recent current meter observations within the breakwater (POLA Prop 13, Table 1, and Alameda Corridor, Table 2) have been confined to the inner regions of Los Angeles Harbor. Current meter observations outside the breakwater (LSCSD Palos Verde Shelf, Table 1) were useful in developing boundary conditions, but are far removed from the primary area of interest within the breakwater. The ACOE deployed a number of current meters in Los Angeles Harbor in the late 1980's (McGehee et al., 1989). These deployments were before the construction of Pier 400, and present current patterns at the deployment locations are likely to differ considerably. Use of these current meter observations would require reconfiguration of the model grid and digitization of the data from the hard copy report.

Table 1 lists a number of discrete salinity and temperature monitoring studies, representing approximately 120 stations. With respect to temperature, these data are very adequate. However because temperature variability is primarily temporal, model temperature prediction is more of a measure of correctness of atmospheric thermal forcing rather than hydrodynamic transport. The adequacy of the salinity observations in these monitoring data sets is very limited. This is due to the climate and hydrology of the area that results in significant salinity variability being associated with episodic freshwater inflow events. Of the 120 monitoring stations, only 20 have observations corresponding to times when the salinity is significantly less than the 32 to 33 ppt level characteristic of the greater harbors system. Further at these 20 stations, there are only 3 observations per station showing depressed salinity. Salinity monitoring data from the Bight 03 study (Table 2), which includes inflow event sampling, has been requested. To supplement the limited salinity observations, which provide a measure of hydrodynamic transport response, dye tracer simulations will also be conducted and will be included in the final hydrodynamic model calibration report. Two field tracer studies have been conducted (POLA Prop 13, Table 1, and Alameda Corridor, Table 2) in Los Angeles Harbor. Observational data from the POLA study has been received and data from the Alameda Corridor study, which also includes three current meter observation records, has been reviewed and requested in digital format.

Table 1. Data Used for Model Configuration and Calibration

Data Type	Use	Source
Shoreline, Breakwaters and Fairways	Model Grid Generation	NOAA Electronic Navigation Charts
Bathymetry	Primary Model Bathymetry Configuration	NOAA High Resolution Coastal Relief Bathymetric Data Set
Bathymetry	Local Model Bathymetry Configuration	NOAA Electronic Navigation Charts
Bathymetry	Local Model Bathymetry Configuration	Port of Los Angeles
Tide Gauge Record at	Development of Tidal	NOAA Center for Operational

Data Type	Use	Source
Port of Los Angeles	Boundary Conditions and Tidal Elevation Calibration	Oceanographic Products and Services
Port of Los Angeles Prop 13 Current Meter Record	Tidal Elevation Calibration	Electronic Data Provided to US EPA by Study Contractor
LSCSD Palo Verde Shelf Study Current Meter and CTD Records	Development of Tidal and Temperature Boundary Conditions and Tidal Current Calibration	Electronic Data Provided to US EPA by Study Contractor (SAIC, 2004)
Port of Los Angeles Prop 13 Current Meter Record	Tidal Current Calibration	Electronic Data Provided to US EPA by Study Contractor
Stream Flow Records	Dominguez Channel Los Angeles and San Gabriel River Inflows	County of Los Angeles, Department of Public Works
WWTP Discharge Record	Terminal Island Treatment Plant Discharge	City of Los Angeles
Wind Speed and Direction Records	Wind Forcing	NOAA National Climate Data Center Records for LAX and LB Airport
Atmospheric Temperature, Relative Humidity, Solar Radiation and Cloud Cover Records	Atmospheric Thermal Forcing	NOAA National Climate Data Center Records for LAX and LB Airport
Atmospheric Temperature, Relative Humidity, Solar Radiation and Cloud Cover Records	Atmospheric Thermal Forcing	California Irrigation Management System Long Beach Station
Salinity and Temperature Monitoring Data	Transport Calibration and Temperature Calibration	City of Los Angeles
Salinity and Temperature Monitoring Data	Transport Calibration and Temperature Calibration	Harbor Generating Station
Salinity and Temperature Monitoring Data	Transport Calibration and Temperature Calibration	Port of Los Angeles
Salinity and Temperature Monitoring Data	Transport Calibration and Temperature Calibration	Port of Los Angeles & Port of Long Beach Biological Baseline Study
Port of Los Angeles Prop 13 Salinity, Temperature and Dye Data	Transport Calibration	Electronic Data Provided to US EPA by Study Contractor

Table 2. Data Reviewed for Potential Use in Calibration

Data Type	Use	Status
US Army Corp of Engineers Current Meter and Related Data	Tidal Current and Transport Calibration	Reviewed Reports. Data Collected in Late 1980's, Predating Construction of Pier 400 and Is Likely Not Readily Available in Electronic Form
Alameda Corridor Currents and Tracer Study Data	Tidal Current and Transport Calibration	Reviewed Report (Moffatt & Nichol Engineers & Reed International, 2001) and Requested Electronic Data
Salinity and Temperature Monitoring Data (Bight 03 data on stormwater runoff and dispersion)	Transport Calibration and Temperature Calibration	Data Requested by EPA
Port of Long Beach Tide Gauge and Current Meter Data	Tidal Elevation and Current Calibration	Data Have Been Requested by EPA, But Have Not Been Received

MODEL CONFIGURATION

The following subsections outline the steps conducted to configure the EFDC hydrodynamic model.

Model Grid System

A multi-resolution, curvilinear spatial grid of the greater harbors and San Pedro Bay was constructed using the using the Visual Orthogonal Grid Generation (VOGG) grid generation system (Tetra Tech, 2002). Shoreline boundaries for the grid were based on the NOAA/NOS electronic navigation charts in GIS format. The grid and shoreline are shown in Figure 1. The grid system uses a multi-domain mapping, unique to the EFDC model, which allow a course resolution outside the breakwater in San Pedro Bay and a finer resolution in the harbors system. The grid has 2568 horizontal cells. In the vertical, the number of sigma layers is readily changed to allow for use of an optimum number of layers to represent hydrodynamic and transport processes. The final number of vertical layers is anticipated to be four or five.

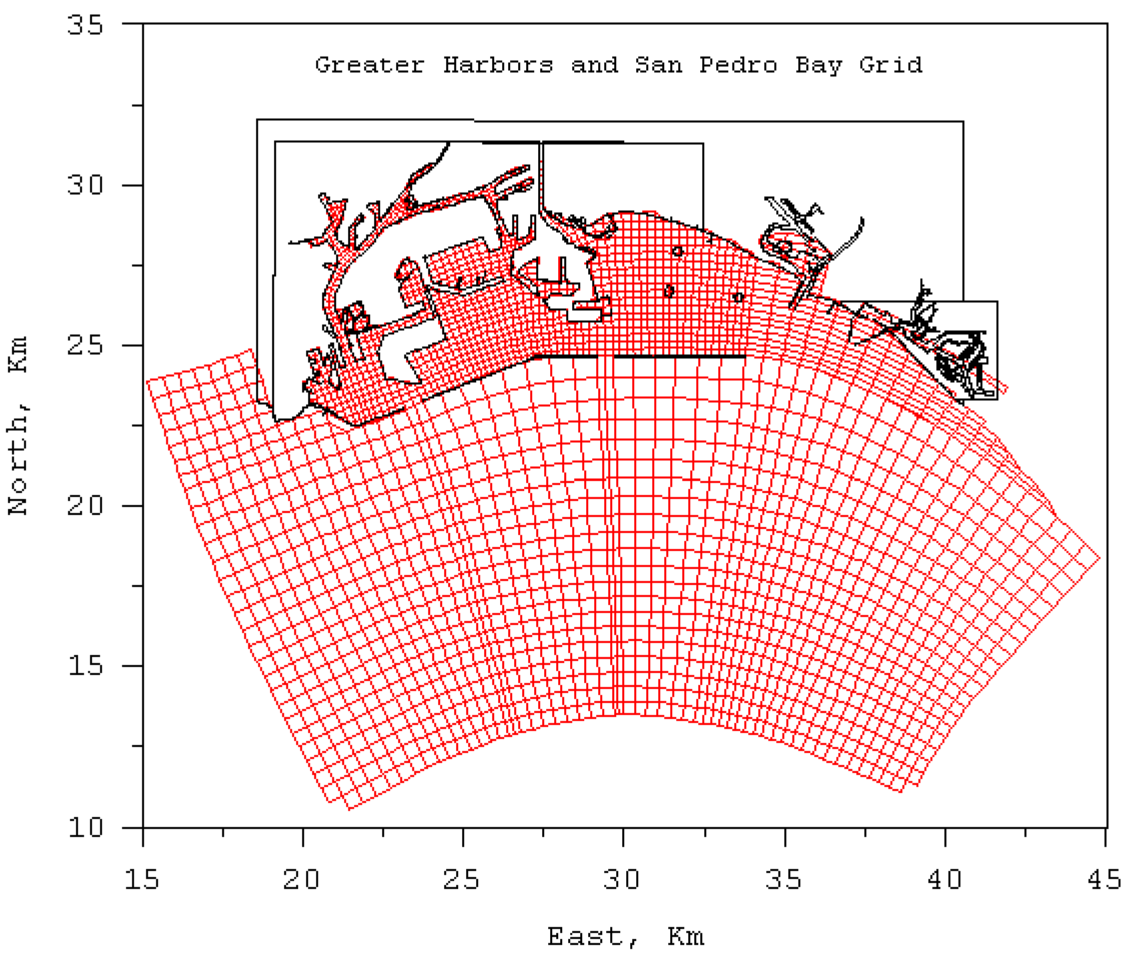


Figure 1. Greater Harbors and San Pedro Bay Grid

Bathymetry and Topography

Bathymetric data were interpolated on to the model grid using an average of the bathymetric data points falling within a cell. The primary bathymetric data set used was the NOAA High Resolution Coastal Relief Data, which has a horizontal resolution of approximately 90 meters. This data set was supplemented by recent bathymetric survey data provided by the Port of Los Angeles. Additional bathymetry adjustments were made by visual comparison of gridded bathymetry with NOAA/NOS electronic navigation charts. Model bathymetry is shown in Figure 2.

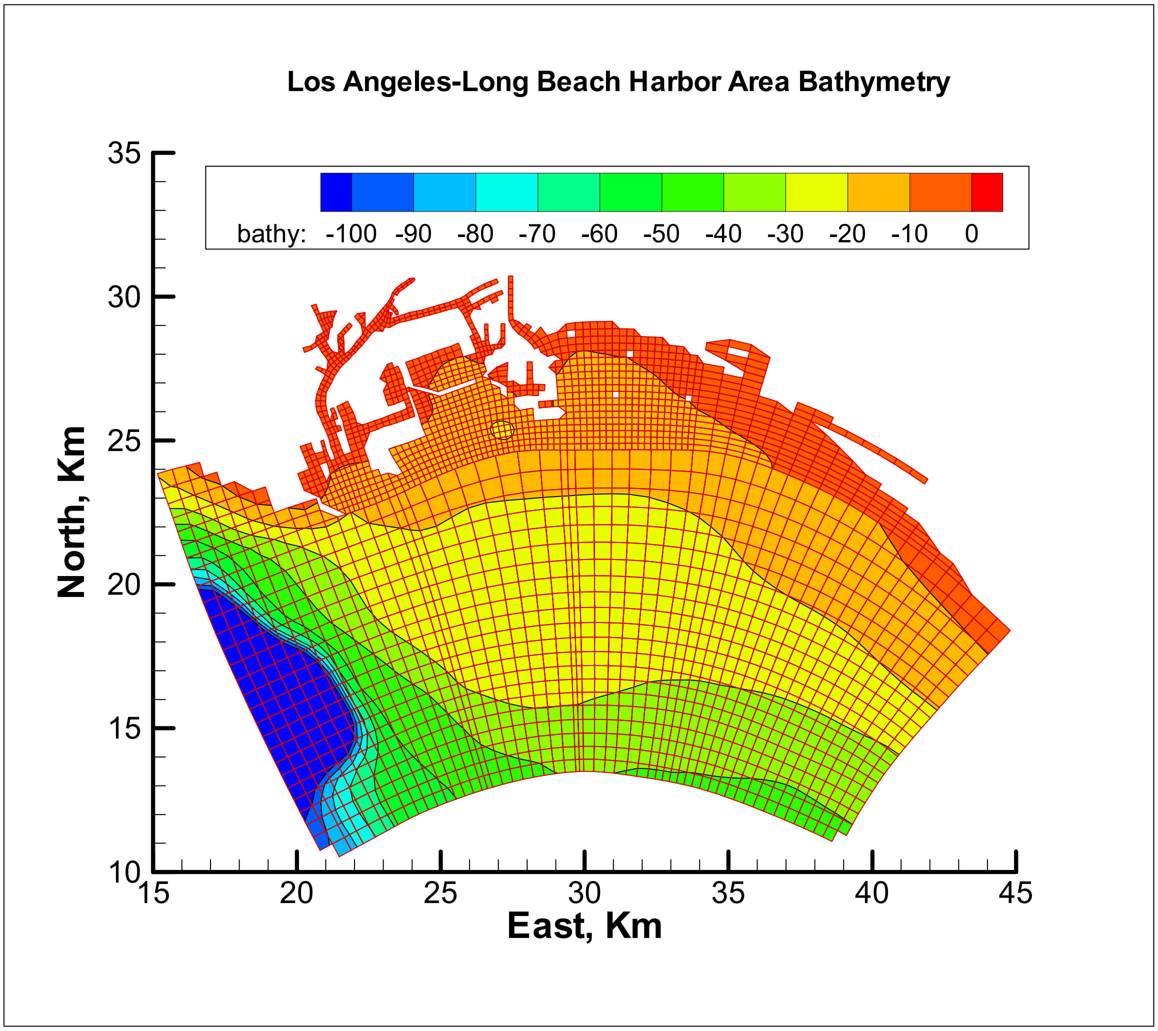


Figure 2. Los Angeles-Long Beach Harbor Area Bathymetry

Selection of Temporal Simulation Period

The hydrodynamic and transport model was initially configured for a three-year historical simulation period spanning October 2002 through September 2005. This period encompasses the greatest density of observational data for model calibration. The simulation period is being extended to span 2000 through

2005 to allow use of the Biological Baseline monitoring data (Table 1) and, if available, the Alameda Corridor data (Table 2).

Open Boundary Hydrodynamic Forcing

Circulation in the greater harbor system is forced by water surface elevation and transport along the grid boundaries in San Pedro Bay. The hydrodynamic boundary condition used along the three open boundaries is a radiation separation condition of the form

$$\zeta - \frac{\mathbf{n} \bullet \mathbf{u}H}{\sqrt{gH}} = 2\zeta_R \qquad (1)$$

where ζ is the water surface elevation relative to a sea-level data, n is the outward normal vector to the boundary, u is the horizontal barotropic velocity vector, H is the water depth, and ζ_R is the equivalent progressive wave amplitude. Along the open boundaries, the water surface elevation is composed of periodic tidal components and a transient or low frequency component in the sub-tidal frequency spectrum. The equivalent incoming wave boundary condition (1) was specified as the sum of a low frequency component and harmonic components, described by equation (2):

$$\zeta_R = \zeta_{LF} + \sum_{m=1}^{M} \left(\zeta_{RCm} \cos\left(\omega_m t\right) + \zeta_{RSm} \sin\left(\omega_m t\right) \right) \qquad (2)$$

where M is the number of tidal constituents, ζ_{RCm} and ζ_{RSm} are cosine and sine amplitudes at frequency ω_m. Six harmonics constituents (M2, S2, N2, K1, O1, and P1) were used. Since observational data were not available along the open boundaries, the tidal frequency components of the incoming wave open boundary condition were estimated by an optimization based inverse procedure to obtain a best-fit prediction of water surface elevation and current meter observations within the model domain shown in Figure 3.

Salinity and Temperature Open Boundary Conditions

Salinity and temperature open boundary conditions were specified as spatially constant and temporally varying along the open boundary. The salinity boundary condition was based on fitting monitoring data to a seasonally varying function with an adjustment factor to account for higher salinities in San Pedro Bay. The adjustment factor was calibrated. The temperature boundary condition was based on fitting the Palos Verde Shelf station A8 CTD record (SAIC, 2004) to a seasonally varying function.

Wind and Atmospheric Forcing

Wind speed and direction and atmospheric thermal conditions including air temperature, relative humidity, rainfall, solar short wave radiation, and cloud cover data were obtained from the NOAA National Climate Data Center for Los Angeles and Long Beach Airport. These data were supplemented by California Irrigation Management System observational data for Long Beach and Santa Monica. The resulting model wind forcing is a spatially variable weighted average taking into account regional topographic conditions, while the atmospheric thermal forcing is spatially uniform and based on a composite of the various data sets.

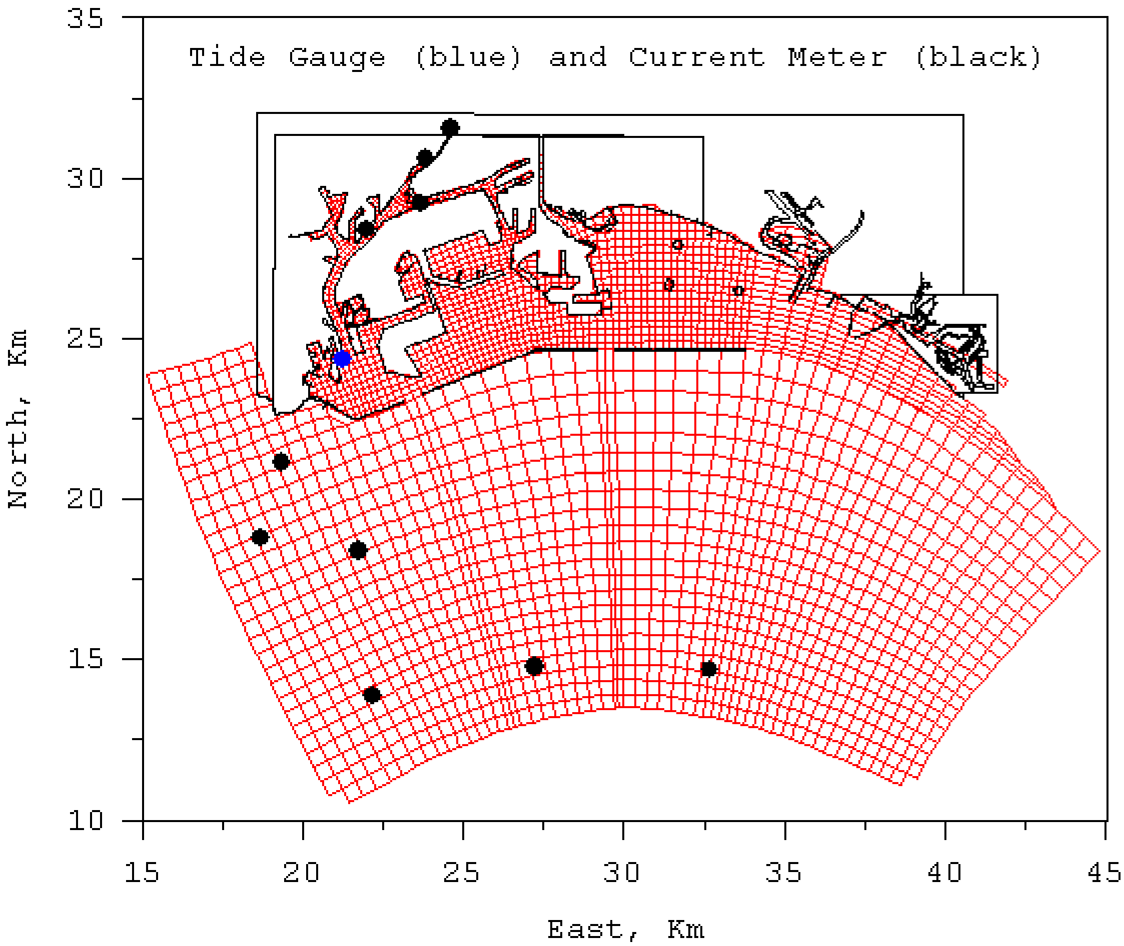


Figure 3. Location of Tide Gauge (blue) and Current Meters (black)

Fresh Water Inflow

Fresh water inflow along the boundaries of the model domain is introduced for Dominguez Channel and the Los Angeles and San Gabriel Rivers. Inflow data were provided by the Los Angeles County Department of Public Works. Terminal Island Treatment Plant Discharges, provided by the City of Los Angeles, were introduced into the interior model grid cell at the corresponding diffuser location.

HYDRODYNAMIC CALIBRATION

Hydrodynamic model calibration involved the adjustment of open boundary forcing, bottom roughness, and bottom elevations to obtain a best agreement between model predictions and observations of water surface elevation and horizontal currents. Quantitative evaluation of the hydrodynamic calibration is based on comparison of observed and model predicted harmonic amplitudes and phases of tidal water surface elevation and currents and time series error analysis of observed and low frequency water surface elevation. The following subsections summarize the steps followed in the calibration process.

Tidal Frequency Water Surface Elevation

Tidal frequency water surface elevation calibration is based on a comparison of observed and model predicted tidal constituent amplitudes and phases at the NOAA Los Angeles Harbor tide gauge shown in Figure 3. Table 3 summarized the comparison, which shows that for five of the six constituents, normalized amplitude errors are less than 1 percent (0.01). The normalized amplitude error for the N2 constituent is approximately 10 percent, but is judged acceptable since the N2 constituent is of secondary importance. Absolute phase errors for all constituents are less than 13 minutes, with the error for the dominant M2 constituent being only 2 minutes. Model predicted tidal water surface amplitudes and phases indicated little variability throughout the system, which is consistent with previous model study findings.

Table 3. Water Surface Elevation Tidal Constituents Comparison at NOAA Gauge in Los Angeles Harbor

Tidal Constituent	Observed Amplitude (meters)	Modeled Amplitude (meters)	Amplitude Error (|Observed-Modeled|/Observed)	Observed Phase (seconds)	Modeled Phase (seconds)	Phase Error (Seconds)
M2	0.503	0.500	0.006	27434	27554	120
S2	0.203	0.203	0	31335	31457	122
N2	0.119	0.106	0.109	31824	32293	469
K1	0.371	0.374	0.008	19854	20624	770
O1	0.246	0.247	0.004	7829	8253	424
P1	0.107	0.106	0.009	22894	22868	16

Low Frequency Water Surface Elevation

Low frequency or sub-tidal water surface elevation in the greater harbors responds to low-frequency sea level variability in San Pedro Bay with negligible amplitude and phase variation. Time series error analysis to support this will be included in the final hydrodynamic model calibration report.

Tidal Frequency Currents

Table 4 summarizes the comparison of M2 horizontal tidal current major axis amplitudes, phases and orientation angles at six Palos Verde Shelf current meter locations. The locations correspond to the six current meter locations outside the breakwater shown in Figure 3. Although absolute quantitative agreement between the observations and model predictions is poor, the qualitative agreement is reasonable in that current magnitudes are similar and phases are consistent. Predicted major axis orientations are generally good having angular errors of less than 20 degrees. The final hydrodynamic calibration report will include results for additional constituents and comparisons for the four current meter stations inside the breakwater shown in Figure 3.

Table 4. Horizontal Current M2 Major Axis Amplitude, Orientation and Phase Comparison at Palo Verde Shelf Current Meter Stations

Station	Observed Major Amplitude (m/s)	Modeled Major Amplitude (m/s)	Observed Phase (seconds)	Modeled Phase (seconds)	Observed Angle (degrees CCW from East)	Modeled Angle (degrees CCW from East)
PV A6	0.053	0.023	37926	39960	-20	-39
PV A7	0.096	0.035	39639	42420	-1	-13
PV A8	0.047	0.060	33884	43990	-35	-28
PV A9	0.069	0.040	36643	42050	-9	12
PV AB	0.053	0.085	31530	38210	-39	-23
PV AD	0.052	0.070	5873	-7414	-54	-51

Low Frequency Currents

Comparison of low frequency or sub-tidal current meter observations and predictions at the 10 current meter locations (Figure 3) is in progress and will be included in the final hydrodynamic model calibration report.

TRANSPORT CALIBRATION

Transport calibration involves the quantitative comparison of model predicted and observed concentrations of dissolved and suspended material in the water column. For freshwater influenced estuarine and coastal waterbodies, salinity transport calibration provides an additional level of confidence in model predictive ability, particularly in the absence of extensive current meter observations. Model prediction of temperature is generally more sensitivity to wind and atmospheric thermal forcing rather than hydrodynamic transport, the exception being situations that have large thermal loads from power plants. In the absence of significant salinity variability, simulation of other tracers, including dye, is also an important means of transport calibration.

Salinity Calibration

Salinity calibration involves the adjustment of salinity open boundary conditions and possibly freshwater inflows if there is significant uncertainty associated with the inflows. Although there are approximately 120 salinity monitoring stations, only 20 of these stations exhibit significant salinity variability (when the salinity is significantly less than the 32 to 33 ppt level characteristic of the greater harbors system) (Figure 4). Figure 5 shows scatter plots comparing predicted and observed data, corresponding to averages over the upper and lower halves of the water column. The data comparison points correspond to 7 sampling times (Julian Days 16, 44, and 72 of 2003, Julian Day 351 of 2004, and Julian Days 13, 55, and 68 of 2005), three of which (44 of 2003 and 13 and 55 of 2005) correspond to depressed observed salinity. Predicted salinities over the lower half of the water column (Figure 5, bottom graph) agree reasonable well with observations and have a lumped relative error of –0.3 ppt (sum of observed minus predicted), indicating the model is slightly over predicting salinity over the lower half of the water column. Predicted salinities over the upper half of the water column (Figure 5, upper graph) agree poorly with observations and have a lumped relative error of –1.5 ppt, indicating the model is significantly over predicting surface salinity over the upper half of the water column. The relative errors would, of course, have been much lower had all sampling times for these monitoring stations been considered.

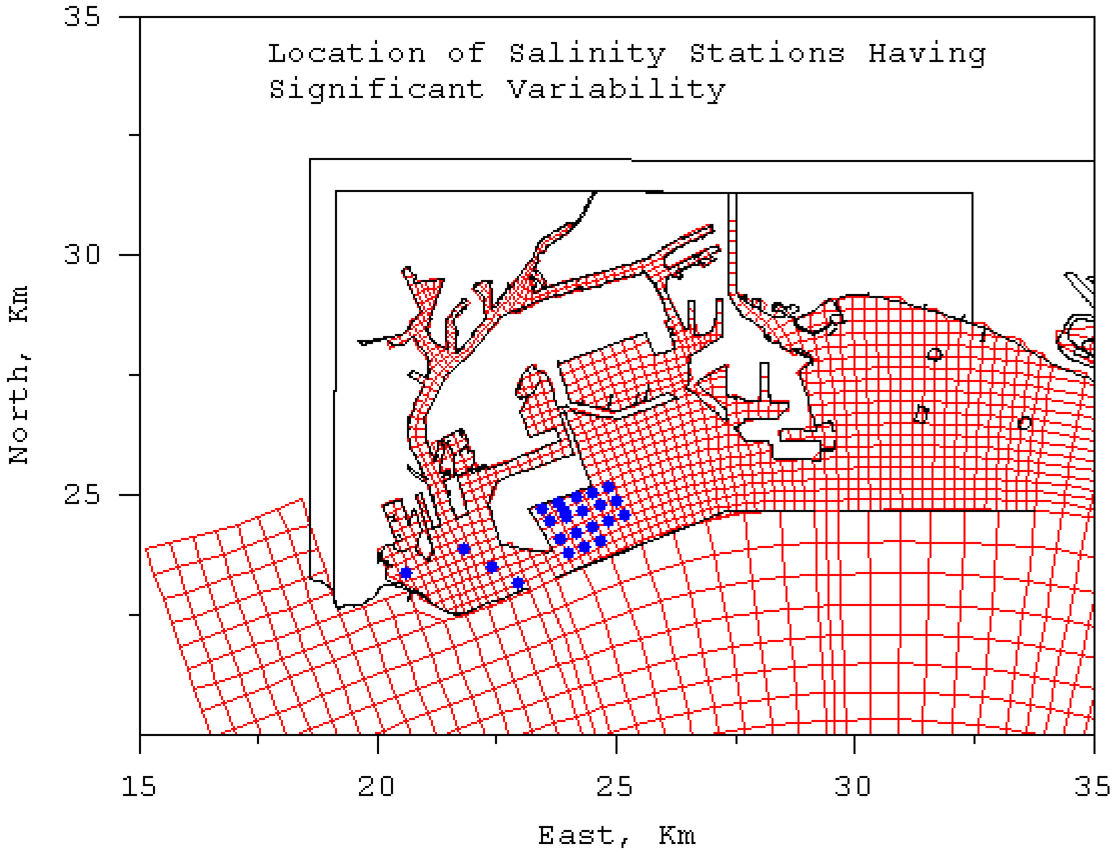
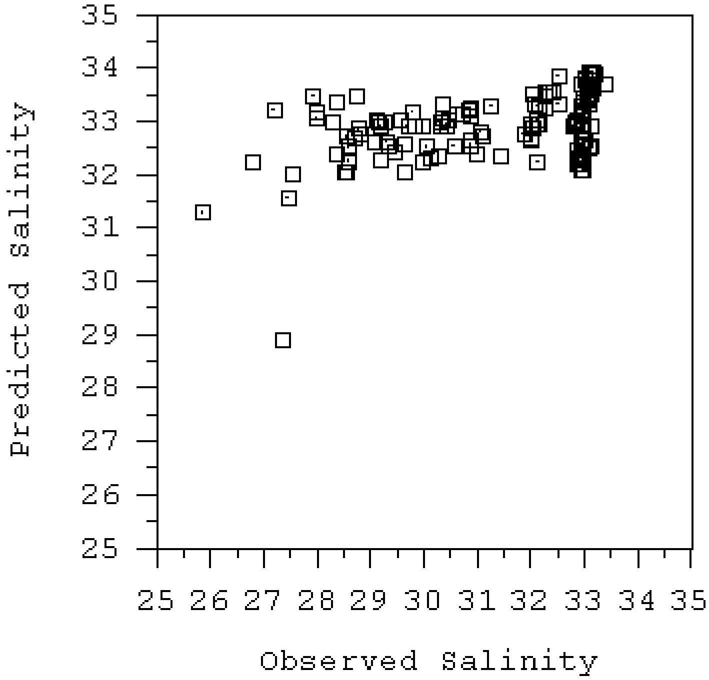


Figure 4. Location of Salinity Stations Having Significant Variability

There are a number of possible causes for the salinity over prediction. These include the absence of nonpoint source runoff freshwater inflow in the present model configuration and direct water surface rainfall. Nonpoint source runoff will be incorporated into the model configuration using output from the LSPC watershed model currently under development as part of the TMDL support effort. Direct water surface rainfall has been omitted from the present model configuration primarily because temperature simulations and associated evaporation predictions are not fully configured. Direct rainfall and evaporation predictions will be active for the final hydrodynamic model calibration simulations. The final hydrodynamic calibration report will include detailed error analysis of model predictions at all current salinity monitoring stations and POLA Proposition 13 stations. Salinity data form the Alameda Corridor and Bight 03 studies (Table 2) will also be utilized, if available.



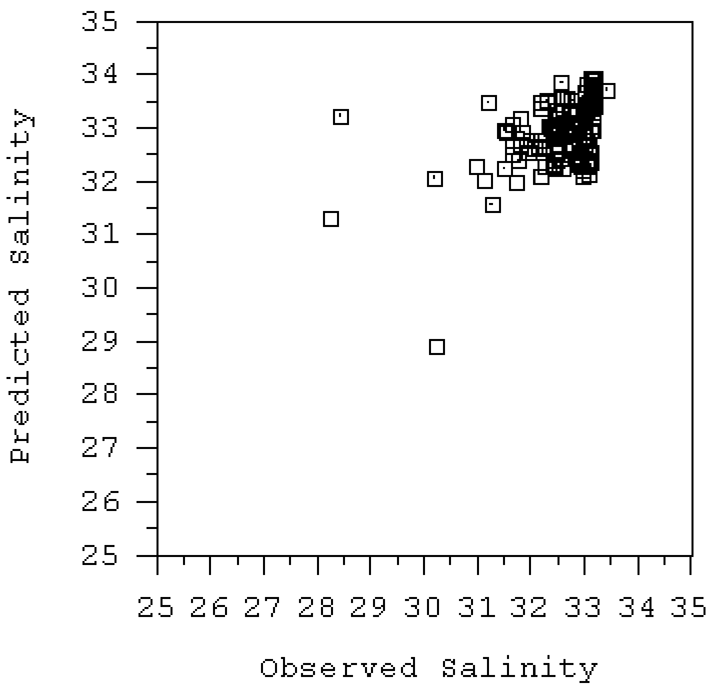


Figure 5. Comparison of Model Predicted and Observed Salinity at 20 Stations at 7 Monitoring Times (Top -Upper Water Column, Bottom -Lower Water Column)

Temperature Calibration

Temperature calibration generally only involves the adjustment of incoming solar short wave radiation and its attenuation over the depth of the water column. Temperature prediction is currently being implemented in the model and error analysis of model predictions at selected temperature monitoring stations will be presented in the final hydrodynamic model calibration report.

Tracer Calibration

The POLA Proposition 13 field study (Table 1) dye tracer data has been obtained and is currently being processed to allow simulation of the dye transport by the model.

SUMMARY AND RECOMMENDATIONS

This memorandum summarized the current status of the calibration of the hydrodynamic component of the EFDC model. Observational data to support model configuration and calibration were reviewed and the data were judged very adequate for model configuration. Limitations of the observational data for calibration were discussed and it is recommended that data from two identified recent studies, the Bight 03 study on stormwater runoff and dispersion and the Alameda Corridor study, be obtained in digital format to enhance the model calibration. In addition, the currently available data are biased toward the Los Angeles side of the greater harbor systems. Therefore, efforts are continuing to identify and obtain digital bathymetry, current meter, temperature, and salinity data for the Long Beach side of the harbor.

The model calibration approach was outlined and some preliminary calibration results presented. Enhancements to the model configuration, including nonpoint source fresh water runoff, direct water surface rainfall, and full temperature simulations with evaporation predictions, are underway and will be included in the final hydrodynamic model calibration. Additional calibration results and analyses to be included in the hydrodynamic model calibration report have also been defined.

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