ALAMITOS BAY CIRCULATION STUDY

FINAL REPORT

Prepared for

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August 30, 2007

EXECUTIVE SUMMARY

Alamitos Bay in Long Beach, CA experiences periodic water quality problems with high bacteria readings at popular public beaches such as Mother's Beach. The City commissioned a study of water circulation throughout the Bay to identify any potential causes of stagnation or other conditions that could lead to poor flushing and poor water quality. Two power plants (the AES and Haynes plants) are connected to Alamitos Bay with intake lines that draw water from the Bay for cooling. Pumping by the power plants affects water movement throughout the Bay, but their effects had not previously been clearly defined or quantified. A finite element RMA2 numerical model for hydrodynamics was used to quantify hydraulic circulation conditions and patterns in Alamitos Bay under different power plant pumping conditions. The model was calibrated with data of tides and currents collected in the field during a period in early 2007, and power plant intake pump rates during the same time period. Modeling objectives were to quantify flow conditions and water residence times under the five scenarios of:

1. The annual high rate of pumping by both power plants;
2. The annual low rate of pumping by both power plants;
3. No pumping by the AES plant and the annual low rate of pumping by the Haynes plant;
4. A sustained moderate pump rate by the AES plant to cause a net upstream circulation condition at Mother's Beach, while sustaining the low rate of pumping by the Haynes plant; and
5. A new tidal inlet channel to Alamitos Bay at 54th Street with no pumping by the AES plant and the annual low rate of pumping by the Haynes plant.

Results show that scenarios 1 and 4 are superior to the other scenarios in generating water movement and shortening water residence times. Specifically, water from the upstream areas of Alamitos Bay (at Colorado Lagoon and Spinnaker Bay) tends to be carried downstream toward the ocean past Mother's Beach more frequently during all other scenarios. This process appears to potentially cause high readings of bacteria at Mother's Beach during these periods. Scenarios 1 and 4 cause net flow to move from Mother's Beach to upstream areas of the Bay, thus reducing the frequency and time period of exposure of Mother's Beach to poor-quality water from the upper Bay areas.

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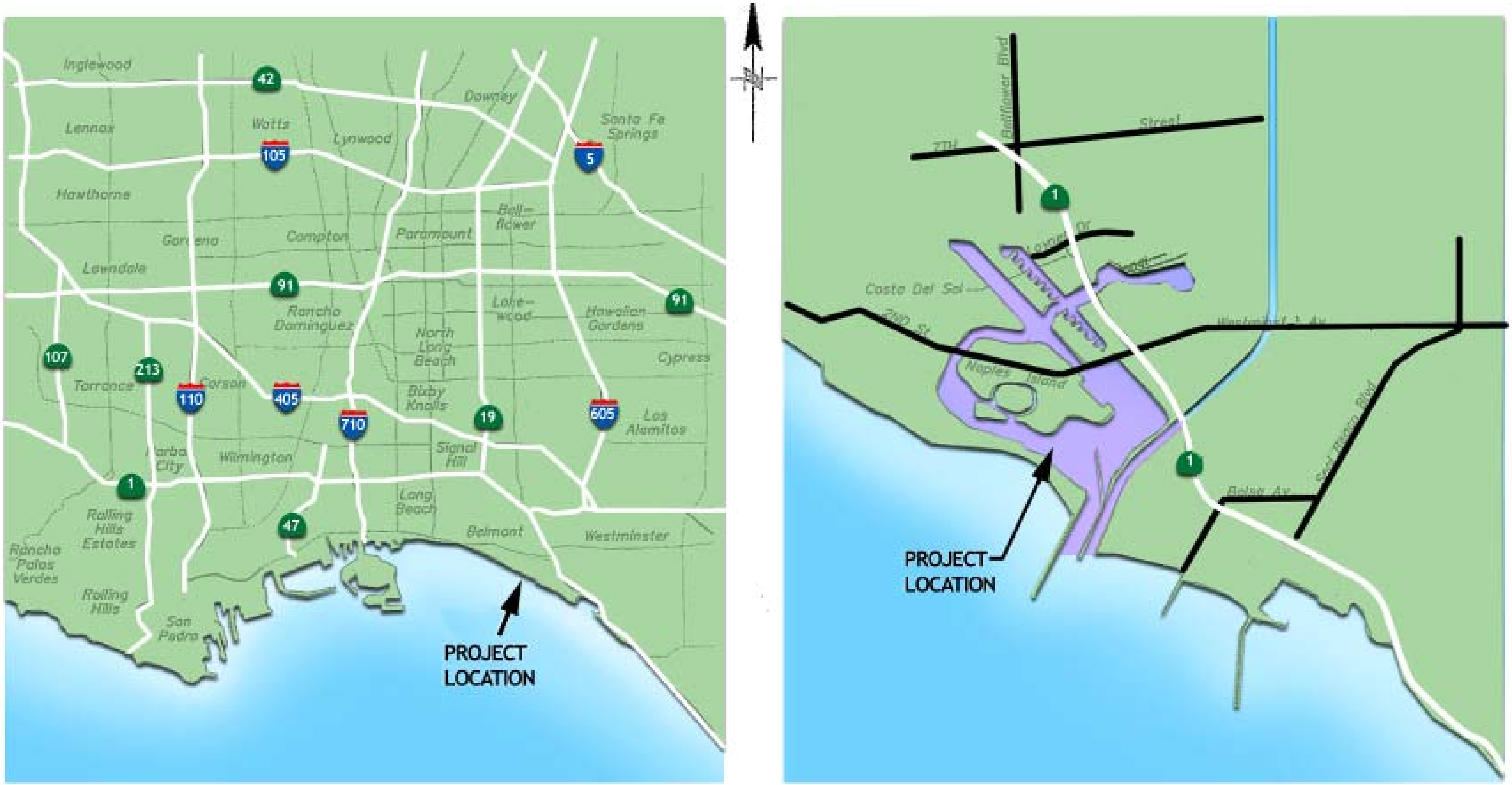
1.0 INTRODUCTION

The City of Long Beach commissioned a study to quantify circulation throughout Alamitos Bay. Certain locations within Alamitos Bay experience relatively poor water quality during various times of the year. For example, a popular public swimming area known as Mother's Beach is periodically plagued with high bacteria counts (Long Beach Health Department, 2006). Other areas of the Bay also receive high readings for bacteria in spring, summer and fall seasons. High bacteria counts at Mother's Beach and other sites are a cause for concern to the City and the staff are endeavoring to solve the problem. Thus the City seeks to understand the water circulation throughout the Alamitos Bay hydraulic system under various conditions to quantify any potential areas of stagnation that could lead to poor water quality. The location of Alamitos Bay and a map of the entire system are shown in Figure 1-1.

This modeling study serves to assist the City in identifying flow patterns that may lead to conditions of high bacterial counts. Results will be a "first-order" attempt to identify potential problem areas due to poor circulation that can be assessed in more detail if appropriate. An important variable in circulation of Alamitos Bay is the operational condition and related pumping intake rates of the two local power plants that draw water from the Bay for use in cooling. This study provides a better understanding of how power plant intake pump rates affect circulation, and offers an opportunity to test the effects on circulation of modified power plant intake rates and a water circulation enhancement approach.

A finite element RMA2 hydrodynamic numerical model simulating Alamitos Bay hydrodynamics was used as part of this study. Numerical modeling of tidal flows and flows from two power plants was performed for the existing conditions at Alamitos Bay. Under dry weather conditions, the local storm drain inputs are not included in the model as the dry weather flow quantity is negligible compared to tidal exchange throughout the Bay. Five different scenarios were simulated with the objective of identifying a potential cause for poor water quality in Alamitos Bay, and possible solutions to any existing problems.



VICINITY MAP
NTS

LOCATION MAP
NTS

Figure 1-1 General Vicinity and Project Location

2.0 SCOPE OF WORK

The scope of work for the study included the following tasks:

1. Gather existing data and new data (using tide and current measurements);
2. Extend the existing model from a previous study to cover all areas;
3. Calibrate the model to previous and new tidal data;
4. Simulate the circulation patterns and water residence times within the Bay for the two documented periods of high power plant inflow rates (July 2006) and low inflow rates (Sept/Oct 2006);
5. Model up to five possible future scenarios of either intake and outflow rates, and one water circulation enhancement approach;
6. Present at two meetings; and
7. Prepare a report of all findings and recommendations.

3.0 MODEL SELECTION AND DESCRIPTION

The technical background of the numerical modeling systems used in this study are summarized in this section.

3.1 MODEL SELECTION

The model selected for use in this study is RMA. This model can perform accurate hydrodynamic calculations for circulation conditions, and can provide estimates of water turn-over time, or residence time, within a system. Both the circulation and residence time information can be used to infer potential causes of poor water quality and to test potential solutions. Specific modeling of water quality for certain pollutants was not included in the scope. That work was deferred to a later time if determined to be necessary. That work is not recommended at this time.

RMA was identified to be appropriate for this work due to successful application of it for similar projects such as the Colorado Lagoon Restoration Project, Bolsa Chica Wetland Restoration, Batiquitos Lagoon restoration, and other projects. RMA is an integrated suite of models for quantifying hydrodynamics and water quality. It includes a user-friendly data illustration component to show model results in color animations. RMA was used for the Colorado Lagoon Restoration Feasibility Study (Moffatt & Nichol, 2005) and was simply expanded in area and modified in grid size to cover all areas of Alamitos Bay for this study in the appropriate level of detail. Finally, RMA is a federally-approved model used by the U.S. Army Corps of Engineers and other agencies for assessing hydrodynamic problems and solutions.

3.2 MODEL DESCRIPTION

The TABS2 (McAnally and Thomas, 1980) modeling system was developed by the U.S. Army Corps of Engineers (USACE), and consists of two-dimensional, vertically averaged finite element hydrodynamics (RMA2), pollutant transport/water quality (RMA4) and sediment transport models (SED2D). TABS2 is a collection of generalized computer programs and pre- and post-processor utility codes integrated into a numerical modeling system for studying two-dimensional (2-D) depth-averaged hydrodynamics, transport and sedimentation problems in rivers, reservoirs, bays, and estuaries. The finite element method provides a means of obtaining an approximate solution to a system of governing equations by dividing the area of interest into smaller sub-areas called elements. Time-varying partial differential equations are transformed into finite element form and then solved in a global matrix system for the modeled area of interest. The solution is smooth across each element and continuous over the computational area. This modeling system is capable of simulating tidal wetting and drying of marsh and intertidal areas of the estuarine system.

A schematic representation of the system is shown in Figure 3-1. TABS2 and its respective RMA models can be used either as a stand-alone solution technique or as a step in the hybrid modeling approach. For instance, RMA2 calculates water surface elevations and current patterns which are input to the pollutant transport (RMA4) and sediment transport (SED2D) models. Existing and proposed geometry can be analyzed to determine the impact of project designs on flow circulation, salinity, water quality and sedimentation in the estuary system. All models utilize the finite element method with Galerkin weighted residuals.

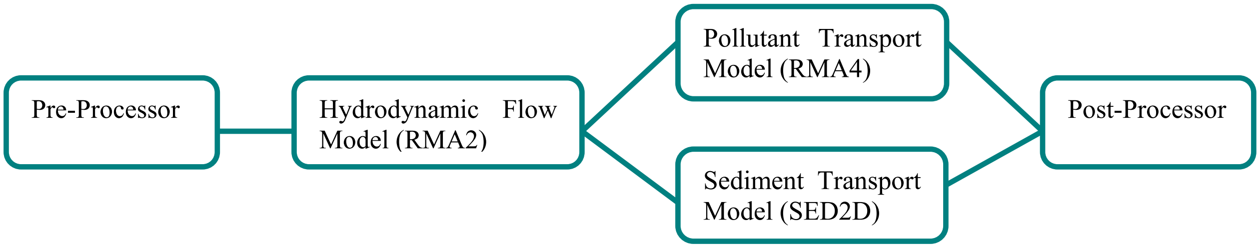


Figure 3-1 TABS2 Schematic

The hydrodynamic model simulates 2-D flow in rivers and estuaries by solving the depth-averaged Navier Stokes equations for flow velocity and water depth. The equations account for friction losses, eddy viscosity, Coriolis forces and surface wind stresses. The general governing equations are:

Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hv)}{\partial y}=0$$

Conservation of momentum equations:

$$h\frac{\partial u}{\partial t}+uh\frac{\partial u}{\partial x}+vh\frac{\partial u}{\partial y}+gh\frac{\partial a}{\partial x}+gh\frac{\partial h}{\partial x}-h\frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2}-h\frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2}+S_{f_x}+\tau_x=0$$

$$h\frac{\partial v}{\partial t}+uh\frac{\partial v}{\partial x}+vh\frac{\partial v}{\partial y}+gh\frac{\partial a}{\partial y}+gh\frac{\partial h}{\partial y}-h\frac{\varepsilon_{yx}}{\rho}\frac{\partial^2 v}{\partial x^2}-h\frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2}+S_{f_y}+\tau_y=0$$

where:

u,v = x and y velocity components

t = time

h = water depth

a = bottom elevation

Sf_x = bottom friction loss term in x-direction

Sf_y = bottom friction loss term in y-direction

τ_x = wind and Coriolis stresses in x-direction

τ_y = wind and Coriolis stresses in y-direction

ε_{xx} = normal eddy viscosity in the x-direction on x-axis plane

ε_{xy} = tangential eddy viscosity in the x-direction on y-axis plane

ε_{yx} = tangential eddy viscosity in the y-direction on x-axis plane

ε_{yy} = normal eddy viscosity in the y-direction on y-axis plane

4.0 MODEL SETUP

Setup of the tidal and power plant pumping flow hydraulic model for existing Alamitos Bay and one of the proposed enhanced circulation scenarios (a second entrance to Alamitos Bay) included determination of the model area, bathymetry, mesh selection, and boundary conditions. Two power plants, namely the AES power plant and Haynes power plant intake cooling water from Alamitos Bay and discharge it into the San Gabriel River (SGR). The Haynes plant is operated and owned by the Los Angeles Department of Water and Power. The AES plant is owned and operated by a private company. Figure 4-1 shows the power plant intake locations. The power plant intakes are modeled as sinks and the power plant discharges are modeled as sources.

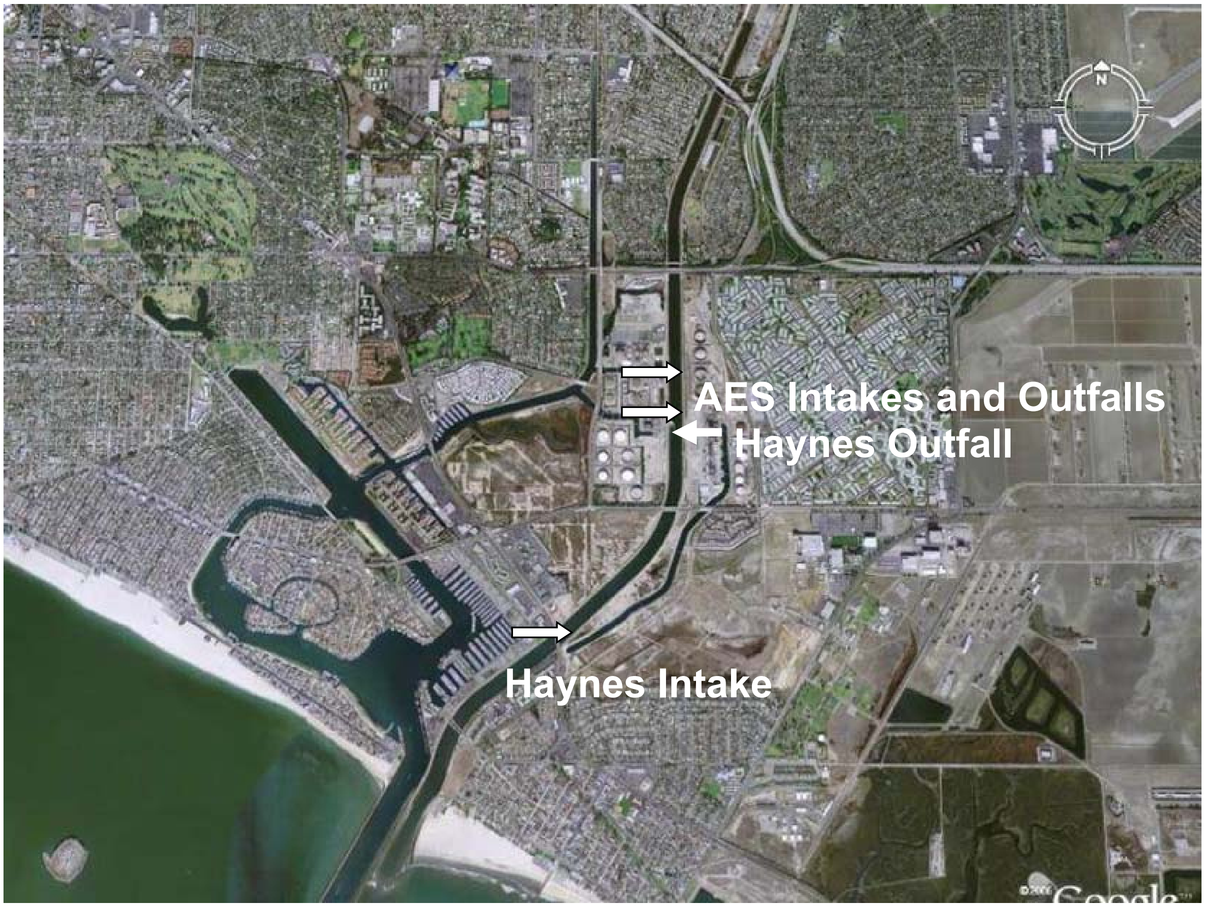


Figure 3-1 Power Plant Cooling Water Intake Locations

4.1 MODEL AREA

The model area, shown by white lines in Figure 4-2, includes all of Alamitos Bay and its components (Marine Stadium, Colorado Lagoon, Los Cerritos channel, and other areas), and the San Gabriel River and the nearshore Pacific Ocean. The model mesh covers a relatively large area. The ocean boundary (at an average contour elevation of -50 feet relative to the NGVD29 vertical datum) is approximately two miles from the shoreline. The side boundaries are approximately one and half miles northwest and southeast from the project site. Designating the open model boundaries far from the area of interest is required to minimize boundary effects.

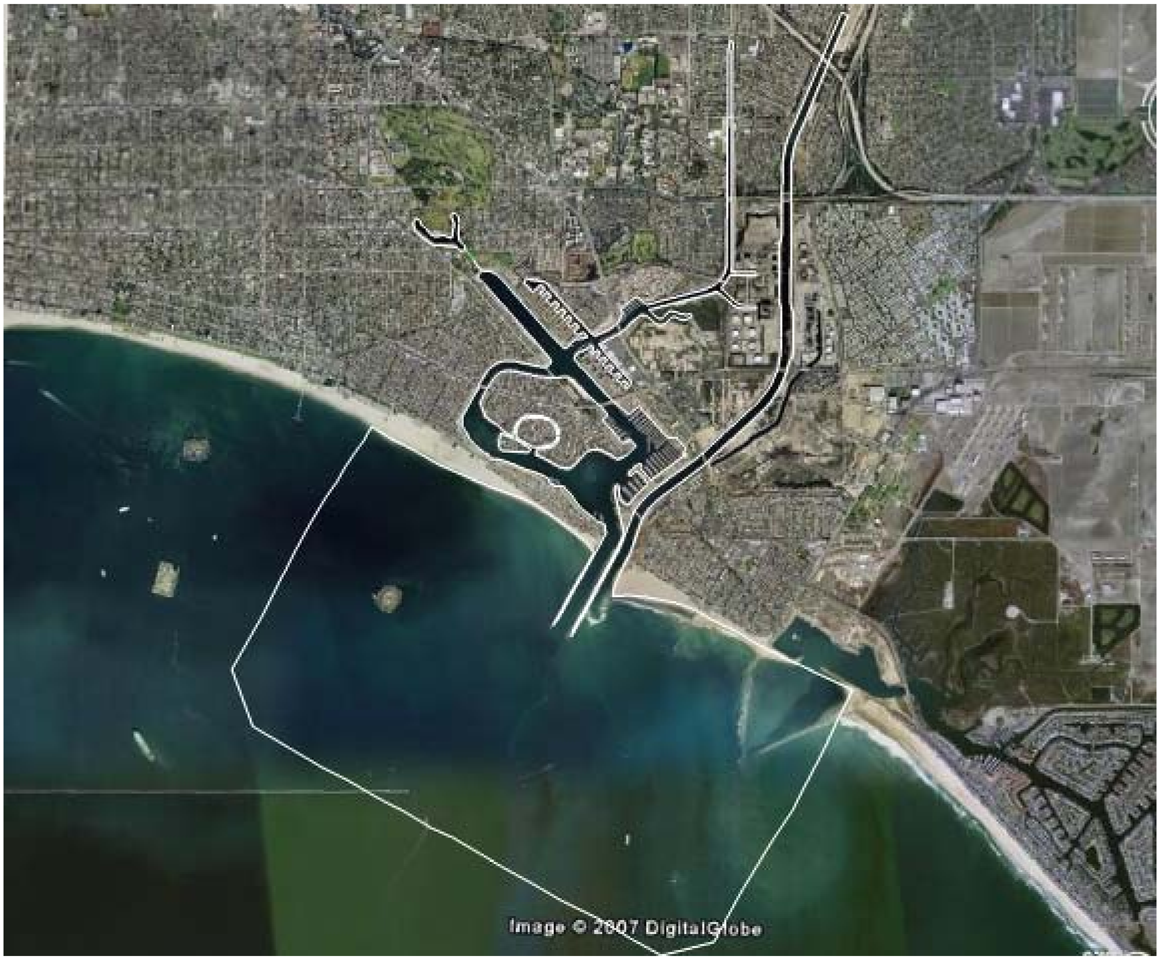


Figure 4-2 RMA2 Modeling Area

4.2 BATHYMETRY

The Alamitos Bay and ocean bathymetry are based on data obtained from the National Oceanic and Atmospheric Administration (NOAA) chart 18749. The bathymetry of Colorado Lagoon and a portion of the Marine Stadium near the culvert connecting the Colorado Lagoon are based on a February 2004 survey by the Los Angeles County Department of Public Works (LACDPW). Design drawings of the culvert connecting Marine Stadium and the Colorado Lagoon were provided by the City of Long Beach. The flow through the culvert is simulated as a rating curve in the RMA2 model. The rating curve was adjusted during the model calibration performed as part of the Colorado Lagoon Restoration Feasibility Study in 2004. The dimensions of the Los Cerritos Channel and San Gabriel River were based on aerial photography provided by the City, and the bathymetry was based on depth readings conducted with a fathometer during the study period along the centerline of the channel and River. The project uses the NAD 83 California Zone 6 horizontal coordinate system and the NGVD29 vertical datum. English units (feet, feet per second, etc.) are used throughout the study.

4.3 MODEL MESH

The RMA2 model requires the hydraulic system to be represented by a network of nodal points defined by coordinates in the horizontal plane and water depth, and elements created by connecting these adjacent points to form areas. Nodes can be connected to form 1- and 2-dimensional elements, having from two to four nodes. The resulting nodal/element network is commonly called a finite element mesh and provides a computerized representation of the basin geometry and bathymetry. The results discussed herein correspond to 2-dimensional (2-D) analyses with the exception of the culverts leading to the Colorado Lagoon which is represented by one-dimensional (1-D) elements.

The two most important aspects to consider when designing a finite element mesh are: (1) determining the level of detail necessary to adequately represent the area of interest, and (2) determining the extent or coverage of the mesh. The model described in this section is numerically robust and capable of simulating tidal elevations, flows, and constituent transport with reasonable resolution. Accordingly, the bathymetric features of the basin generally dictate the level of detail appropriate for the mesh.

There are several factors used to decide the areal extent of a mesh. First, it is desirable to extend mesh open boundaries to areas which are sufficiently distant from the proposed areas of change so as to be unaffected by that change. Additionally, mesh boundaries must be located along sections where conditions can reasonably be measured and described to the model. Finally, mesh boundaries can be extended to an area where conditions have been previously measured to eliminate the need to interpolate conditions from other locations.

The finite element mesh for the existing condition is shown in Figure 4-3. The mesh includes an area of open ocean sufficiently large to eliminate potential model boundary effects, and covers the tidally-influenced portions of the Los Cerritos Channel and the San Gabriel River. The entire modeling area, approximately 7.3 square miles, is represented as a finite element mesh consisting of about 2,500 elements and 7,800 nodes.

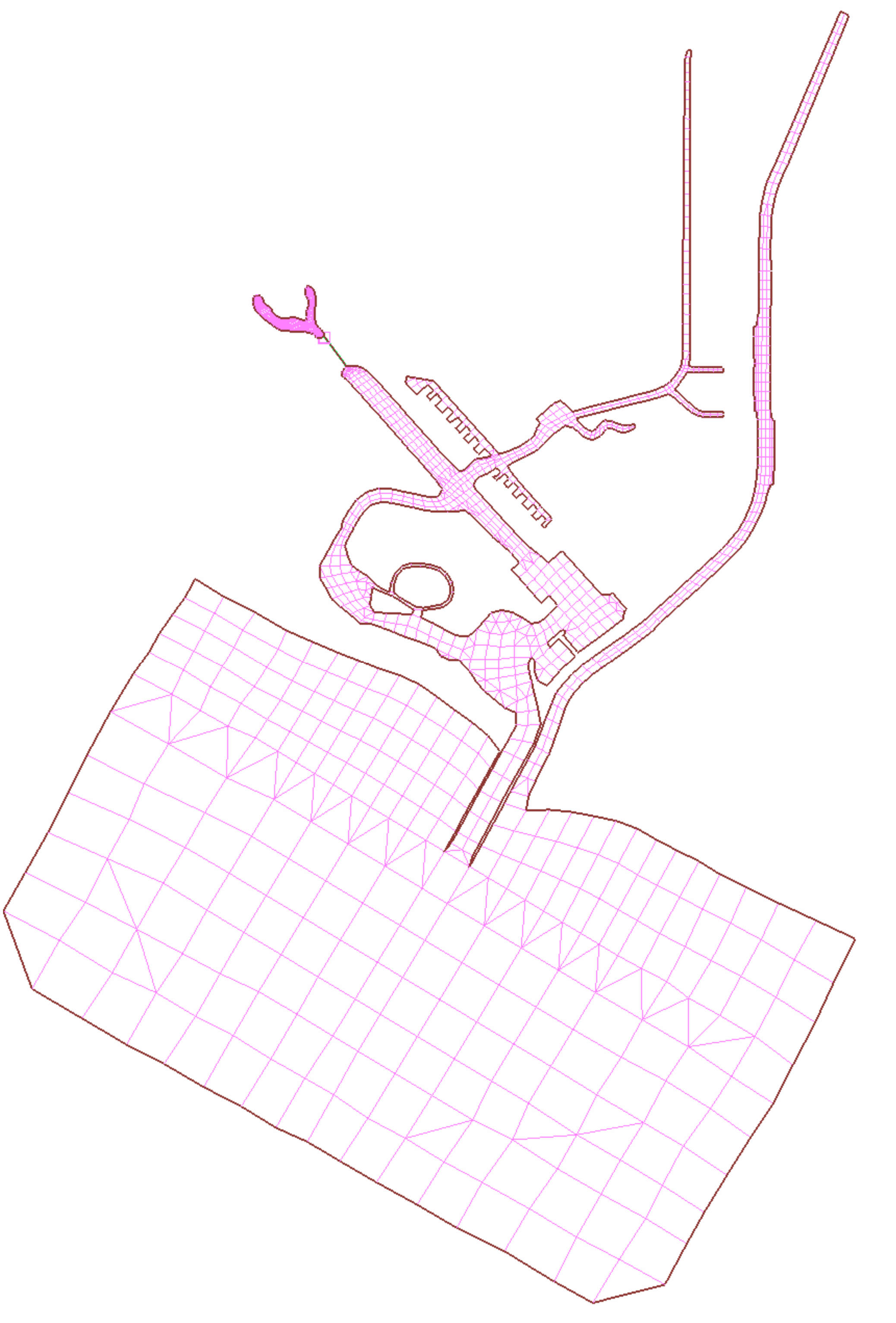


Figure 4-3 RMA2 Finite Element Mesh

4.4 BOUNDARY CONDITIONS

The boundary input for the Alamitos Bay circulation study under dry weather conditions includes the tides and power plant pumping flows. This section describes the general tidal condition within the modeling area. The detailed input data including both pumping flows and tides are described in subsequent sections of this report.

There are no official tide stations within Alamitos Bay. As such, the nearest tide station administered by the National Ocean and Atmosphere Administration (NOAA) at Los Angeles Outer Harbor was assumed to represent the ocean boundary tidal condition as shown in Table 4-1. The diurnal tide range is approximately 5.49 feet from Mean Lower Low Water (MLLW) to Mean Higher High Water (MHHW) and Mean Sea Level (MSL) is at +2.82 feet relative to MLLW.

Water level measurement data provide astronomical tides and other components including barometric pressure tide, wind setup, seiche, and the El Nino Southern Oscillation. Tidal variations can be resolved into a number of sinusoidal components having discrete periods. The longest significant periods, called tidal epochs, are approximately 19 years. In addition, seasonal variations in MSL can reach amplitudes of 0.5 feet in some areas, such as Los Angeles Outer Harbor. Superimposed on this cycle is a 4.4-year variation in the MSL datum elevation that may increase the amplitude by as much as 0.25 feet in San Pedro Bay. Water level measurement data are typically analyzed over a tidal epoch to account for these variations and obtain statistical water level information (e.g., MLLW and MHHW).

Table 4-1 Recorded Water Levels at Los Angeles Outer Harbor (1983-2001 Tidal Epoch)

Description	Elevation (feet, MLLW)	Elevation (feet, NGVD29)
Extreme High Water (1/27/83)	+7.82	+5.18
Mean Higher High Water (MHHW)	+5.49	+2.85
Mean High Water (MHW)	+4.75	+2.11
Mean Tidal Level (MTL)	+2.85	0.21
Mean Sea Level (MSL)	+2.82	0.18
National Geodetic Vertical Datum 1929 (NGVD29)	+2.64	0.00
Mean Low Water (MLW)	+0.94	-1.70
Mean Lower Low Water (MLLW)	0.00	-2.64
Extreme Low Water (12/17/33)	-2.73	-5.37

4.5 RESIDENCE TIME ANALYSIS

Constituent concentrations in a water body reflect a balance between the rate of constituent supply and the rate of constituent removal by tidal flushing. Residence time (i.e., average time a particle resides in a hydraulic system) provides a useful measure of the rate at which water in the hydraulic system is renewed. Accordingly, residence time provides a means for indirectly assessing the water quality of a hydraulic system.

Consider the reduction of a tracer concentration in a tidal embayment due to flushing after being released (Fischer et al., 1979), in which C_0 is initial concentration, K is a reduction coefficient and C(t) is the concentration at time t.

$$C(t) = C_0 e^{-Kt}$$

The residence time of the tracer in the embayment is determined from

$$T_r = \frac{\int_0^\infty t\, C(t)\, dt}{\int_0^\infty C(t)\, dt} = \frac{1}{K}.$$

Since the concentration at $t = T_r$ is

$$C(T_r) = C_0 e^{-1} = \frac{C_0}{e}$$

T_r can be calculated from a regression analysis of the tracer concentration time series computed by the numerical model RMA4.

Based on the above methodology, the general procedure of computing the residence times for different parts of a tidal embayment is as follows:

Assign an initial tracer concentration of one over the entire embayment (entire bay for this study) and a value of zero at the open water boundaries to simulate an instantaneous release of a contaminant in an embayment;

Run the numerical model RMA4 for an adequate number of tidal cycles until substantial reductions of tracer concentrations have occurred due to tidal flushing at the locations of interest;

Analyze the computed concentration results by regression analysis to obtain the tracer reduction distributions at the locations of interest; and

Find the residence times for the locations of interest from the distribution curves.

5.0 RMA2 MODEL CALIBRATION

RMA2 model calibration involves matching model predictions with measured data by selecting appropriate input parameter values to model [e.g., Manning's roughness coefficient (n) and turbulence exchange coefficients (eddy viscosity)].

The RMA2 User's Manual recommends ranges of values for Manning's roughness coefficient (n) and eddy viscosity to be used in the model (USACE WES, 1996). The value of Manning's roughness coefficient (n) is a function of the characteristics of the hydraulic system and represents the roughness of the channel bed. As discussed in Chaudhry (1993), values can range from 0.011 to 0.075 or higher for natural rivers and estuaries. Relatively high values (0.04 to 0.05) are specified for rough surfaces, such as channels with cobbles or large boulders. Mid-range values (0.03) represent clean and straight natural streams. Low values (0.013 to 0.02) are specified for smooth surfaces, such as concrete, cement, wood, or gunite. Values of Manning's roughness coefficient (n) used for this analysis are in the middle range of the recommended values.

Eddy viscosity represents the degree of turbulence in the flow. In this application, the values range from 50 to 300 lb-sec/ft^2. The modeling grid size depends on and is limited by the Peclet number and eddy viscosity. The Peclet number is defined as $\frac{\rho V \Delta X}{E_{ij}}$, in which ρ, V, ΔX, and E_{ij} are the water density, velocity, grid size, and eddy viscosity, respectively. In order for the solution to be stable, the Peclet number has to be less than 50. The Peclet number can be reduced by increasing the mesh density or by increasing the eddy viscosity. However, it is unrealistic and time-consuming to perform the modeling with a very fine grid. Therefore, a relatively high value of eddy viscosity is used in order to preserve numerical stability and to streamline the modeling efforts.

5.1 FIELD DATA COLLECTION FOR MODEL CALIBRATION

Three tide gauges and two current meters were deployed on January 10, 2007 and were retrieved on January 31, 2007. The descriptions of the gauge types and locations are described in Table 5-1 and gauge locations are shown in Figure 5-1. The tide gauges are small cylindrical pressure transducers manufactured by Richard Branckar Research that record water levels. The two current meters are spherically-shaped and self-contained InterOcean S-4DW current measuring sensors. The S-4DW is designed to measure the magnitude and direction of horizontal currents in any water environment. The recorded water levels and current velocities are presented in this section of the report.

Table 5-1 Gauge System and Locations

Data Type	Gauge Location
Currents	Mother’s Beach
	2nd Street Bridge Bayshore
Water Levels (Tides)	Alamitos Bay Entrance
	Los Cerritos Channel @ 7th Street
	San Gabriel River @ 2nd Street

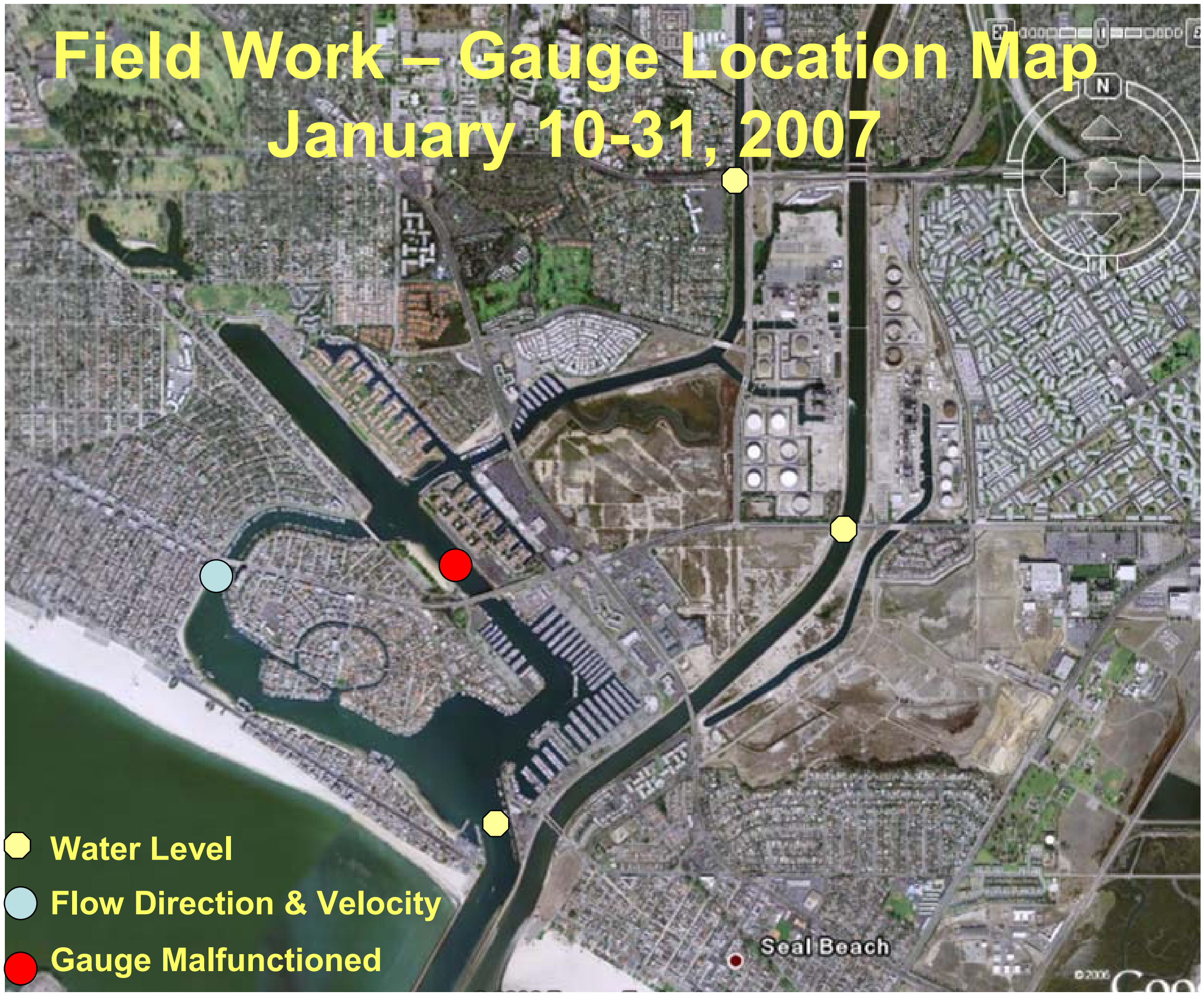


Figure 5-1 Gauge Locations

5.2 BOUNDARY CONDITIONS FOR MODEL CALIBRATION

Boundary inputs for the RMA2 hydrodynamic model include the ocean tides and intake pumping flow rates of the two power plants. Tides measured at Los Angeles Outer Harbor (LAOH) (NOAA, 2004)during the field work period between January 10 and 31 of 2007 were applied in the RMA2 model boundary. The water level time series is shown in Figure 5-2 as a solid black line. The two magenta lines in Figure 5-2 show the intake pumping flow rates by the two power plants. The values of flow rate are shown in the righthand y-axis of the plot. During the field work period, the Haynes plant is pumping approximately 1,150 cubic feet per second (cfs) and the AES is pumping between 150 and 300 cfs.

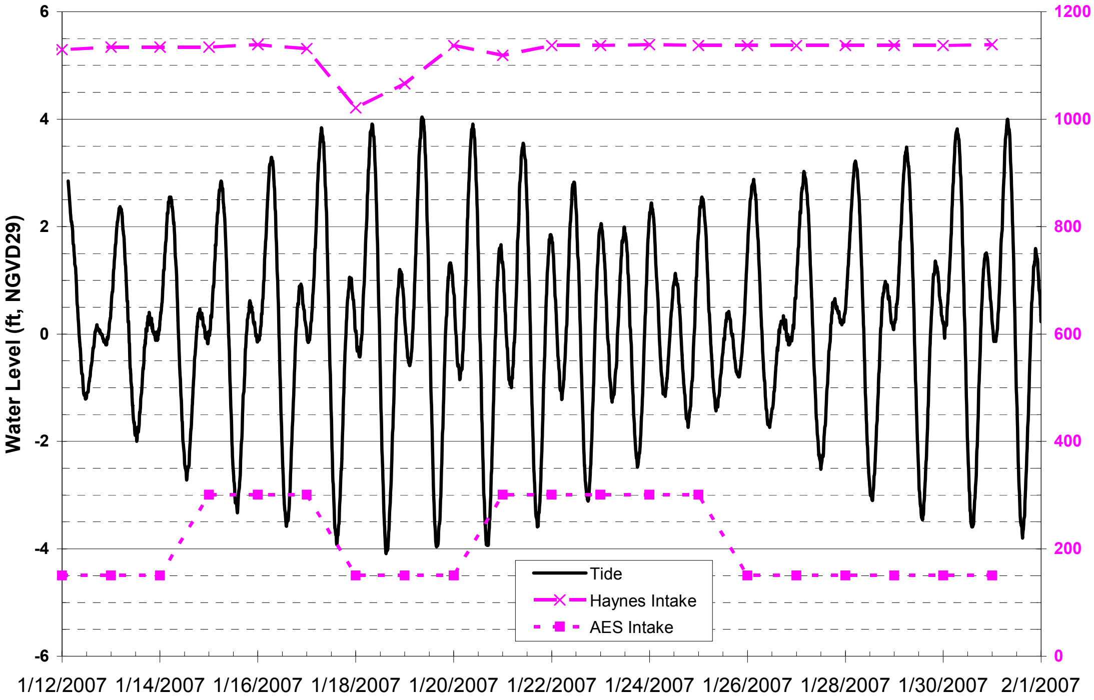


Figure 5-2 Boundary Input Data for Model Calibration

5.3 MODEL CALIBRATION RESULTS

The measured tidal elevations were compared with the model-predicted tidal elevations. Figures 5-3 and 5-4 show the water level comparison at Alamitos Bay entrance and at Los Cerritos Channel under the 7th Street Bridge. Figure 5-5 shows a similar comparison at the San Gabriel River under the Westminster Street Bridge. The measured water levels and their phases matched very well with the model-simulated tides, except for an anomaly in the San Gabriel River gauge, in which the recorded water level shifted upward after 10-days of the record due to gauge malfunction. However, the first 10-days of the record were sufficient for calibrating the model at the River location.

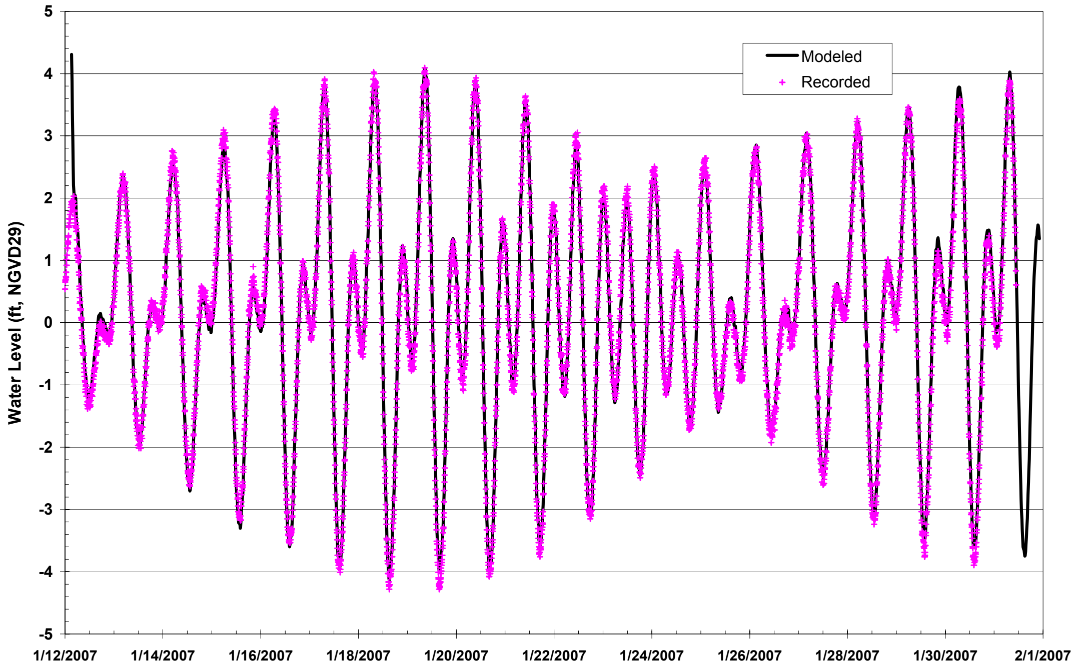


Figure 5-3 Water Level Comparison at Alamitos Bay Entrance

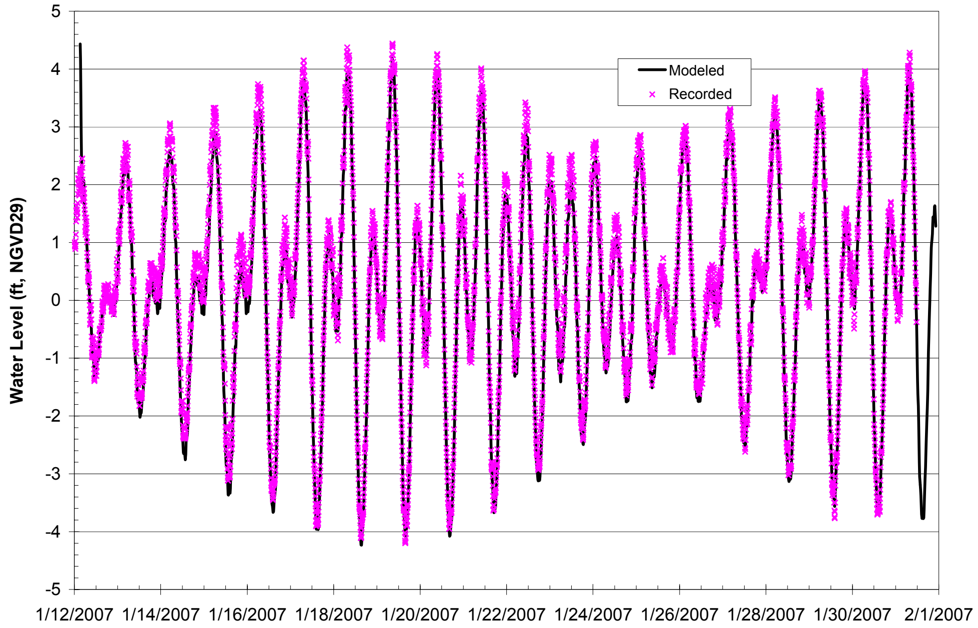


Figure 5-4 Water Level Comparison at Cerritos Channel at the 7th Street Bridge

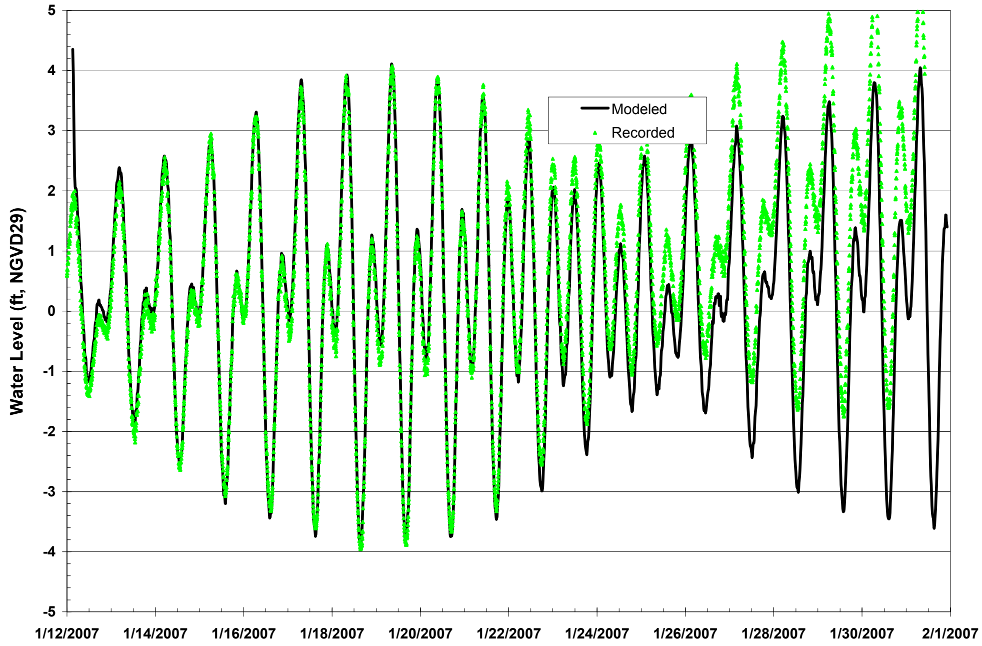


Figure 5-5 Water Level Comparison at San Gabriel River at Westminster Street Bridge

Two S-4ADW current meters were deployed at Mother's Beach and 2nd Street Bayshore as shown in Figure 5-1. The meter at Mother's Beach malfunctioned. The measured currents at 2nd street Bayshore were compared with the model simulated currents and are illustrated in Figure 5-6. The current meter recorded currents in the channel about one foot above the channel bed. The model simulated currents are vertically averaged velocities in the middle of the channel. Current ranges and phases generally matched well. As the measured and predicted tidal conditions and current conditions matched well, it was concluded that the data missing from Mother's Beach were not critical to the study and analyses could be done using model-predicted data.

Modeling parameters including roughness coefficients and turbulence eddy viscosities used in the model calibration are shown in Table 5-2. The turbulence eddy viscosity varies with the flow situations. Under a higher power plant pumping condition the turbulence is stronger than that under a low power plant pumping scenario. These changes were reflected in the scenario model simulations.

The time step is a very important parameter in the modeling. Sensitivity tests were conducted and results showed that the RMA2 model becomes unstable with an increasing time step if the wetting and drying processes are considered. A time step of 0.1 hour was used in order for the solution to be stable and to reflect the dynamic tidal fluctuations.

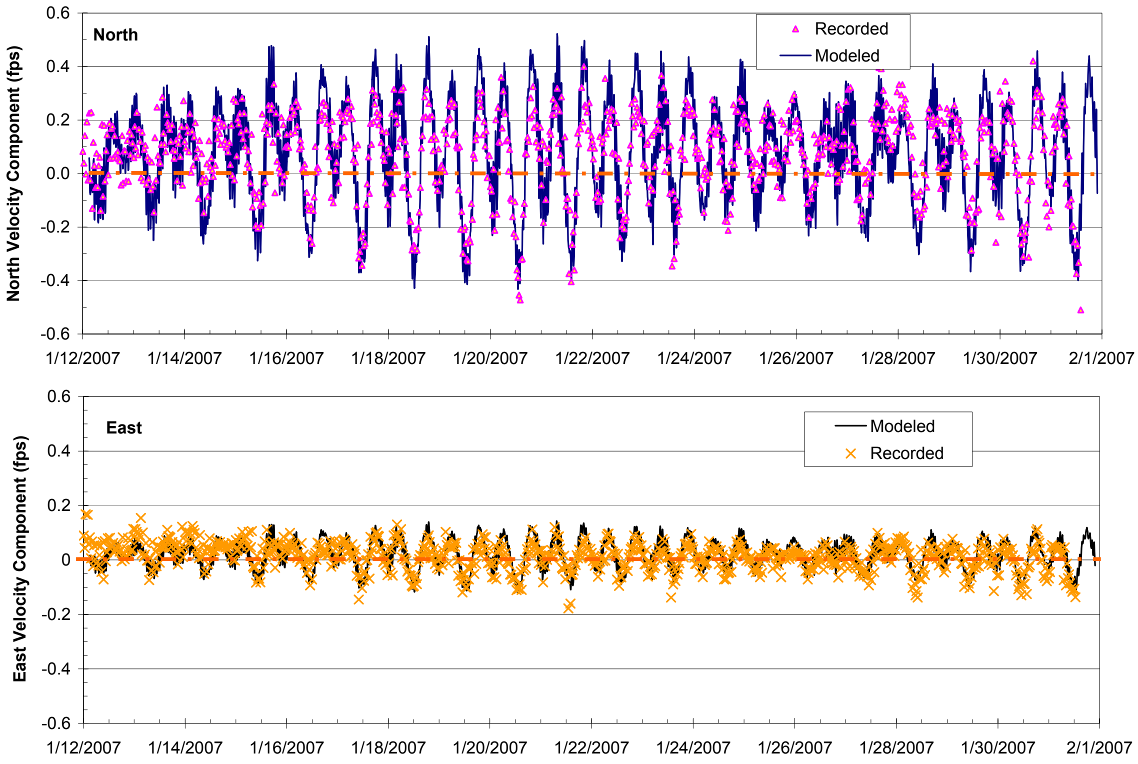


Figure 5-6 Currents Comparison at 2nd Street Bayshore

Table 5-2 Setup Values for Model Calibration

Modeling Area	**Manning's Roughness Coefficient (n)**	**Eddy Viscosity Coefficient (lb-sec/ft^2)**
Lagoon Intertidal Areas	0.037	100
Lagoon Subtidal Areas	0.03	50
Marine Stadium Intertidal Areas	0.035	100
Narrow Channels and Marinas	0.025	75
Marine Stadium Subtidal & Alamitos Bay Areas	0.025	300
Nearshore Surf Zone	0.030	60
Offshore of the Surf Zone	0.02	80

6.0 MODELING RESULTS OF ALTERNATIVE SCENARIOS

The calibrated RMA2 numerical model, together with the RMA4 water quality model, were applied to evaluate the hydrodynamic circulation conditions under five alternative scenarios. The first two scenarios are the highest and lowest power plant pumping rate conditions for 2006, assumed to represent the pattern of annual high and low pumping rates, respectively.

The pumping flow rates in 2006 were provided by both AES and Haynes power plants and are shown in Figure 6-1. The pumping rate of Haynes plant is relatively stable varying from approximately 600 to 1,500 cfs over the year while that of the AES plant varied more from zero to approximately 2,000 cfs over the year. The two periods of high and low pumping identified for modeling to assess flow circulation patterns under these two distinctive conditions are shown in Figure 6-2.

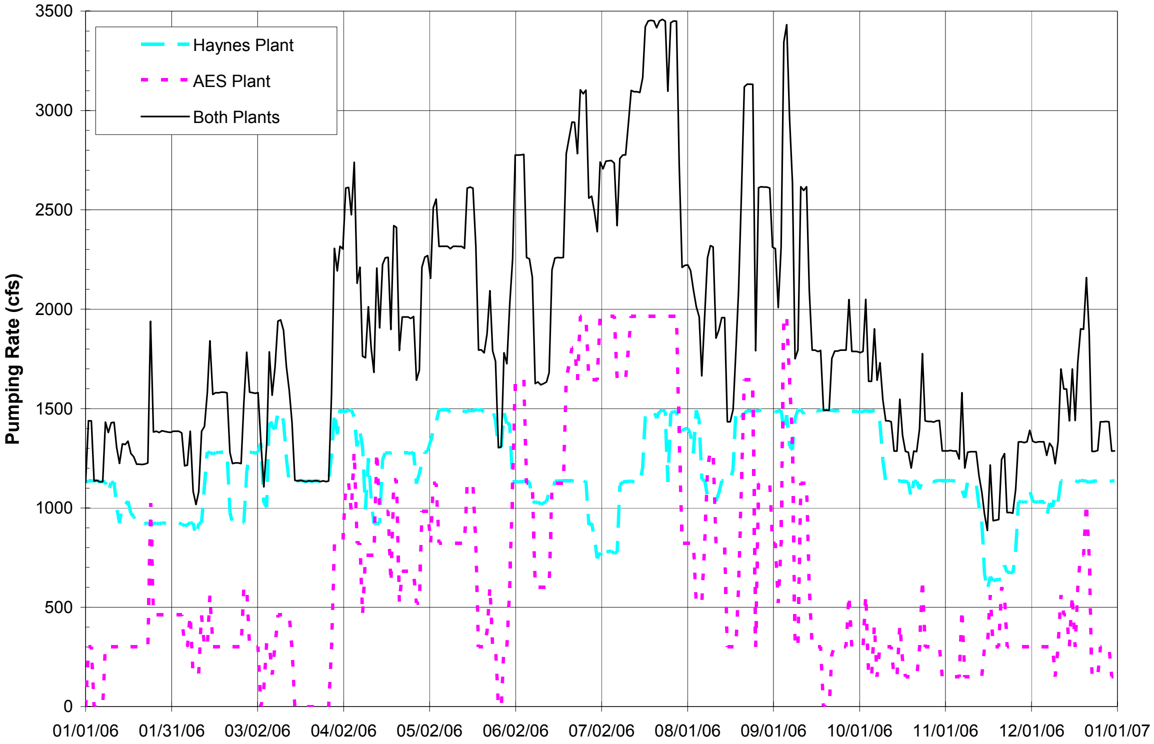


Figure 6-1 2006 Pumping Rates of the Two Power Plants

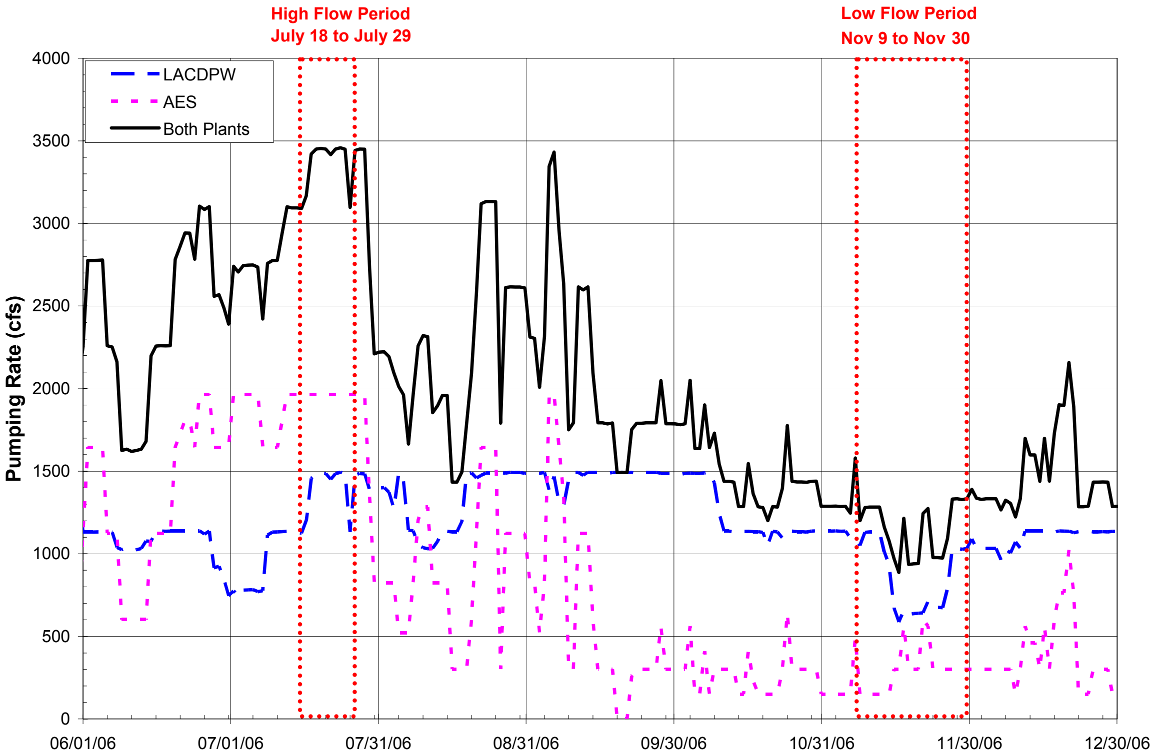


Figure 6-2 High and Low Pumping Rate Periods

6.1 SCENARIO 1 – HIGH PUMPING RATE PERIOD

This scenario of high pumping rates is intended to determine the best hydraulic circulation condition in Alamitos Bay in 2006. The period of high pumping rates measured from July 15 to July 29 was selected for RMA2 hydrodynamic modeling. The modeling for the RMA4 water quality model starts at 2:48 am of July 19 while both power plants were pumping at their highest capacities in 2006 and Alamitos Bay was experiencing an energetic ocean spring tidal cycle as shown in Figure 6-3.

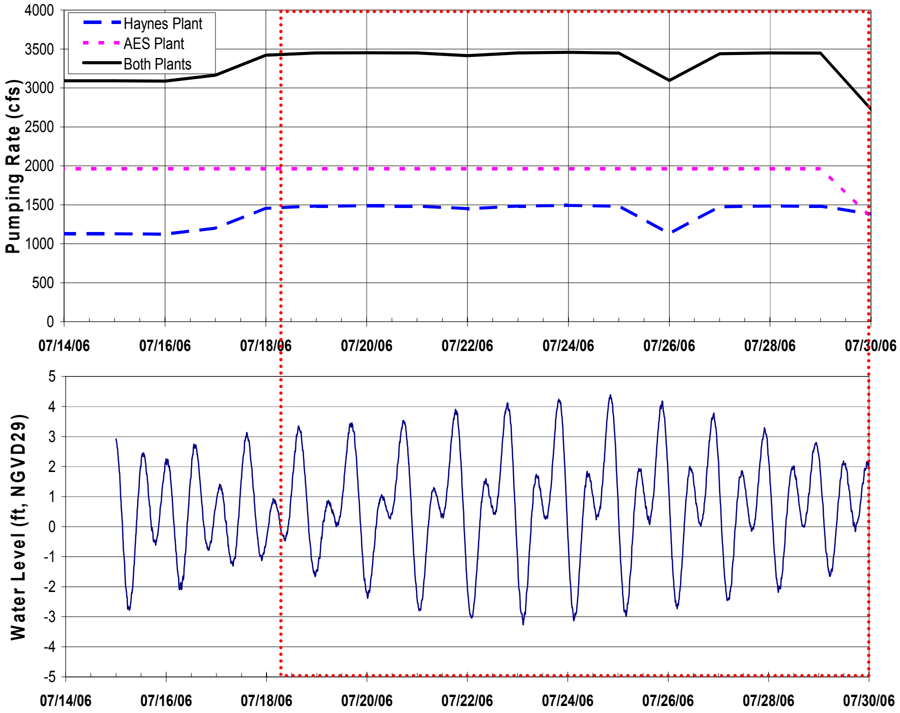


Figure 6-3 Boundary Input for the High Flow Pumping Rate Period

6.1.1 Scenario 1 – Hydrodynamic Modeling Results

The velocity time series at Mother's Beach and 2nd Street Bayshore were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-4 and 6-5. Velocity fluctuations show tidal responses as a result of ocean tidal flooding and ebbing. However, the pumping of the power plants has a dominant effect on net flow directions in the entire bay. At Mother's Beach, the net flow direction is upstream, toward the north at Los Cerritos Channel or the AES plant approximately 80% percent of the time due to the influence of pumping by the AES plant. Similarly, at 2nd Street Bayshore, the net flow direction is also northward toward the AES plant approximately 90% percent of the time under this condition. As a result of the high pumping rate at the AES plant, water at the more distant ends of Alamitos Bay (e.g., at Colorado Lagoon with a much slower circulation, longer residence times and lower flushing rates) is primarily drawn into the AES power plant and then discharged into the San Gabriel River rather than being drawn downstream past Mother's Beach toward the Haynes power plant intake or ocean. Under the high pumping rate condition, the daily pumping rate of the AES plant is approximately 3,900 acre-feet, and that of the Haynes plant is approximately 2,900 acre-feet. Power plant pumping has dramatically increased the flushing within Alamitos Bay. If the Alamitos Bay entrance were to be completed closed off to the ocean, the entire Bay would be pumped dry within one day under this high pumping rate.

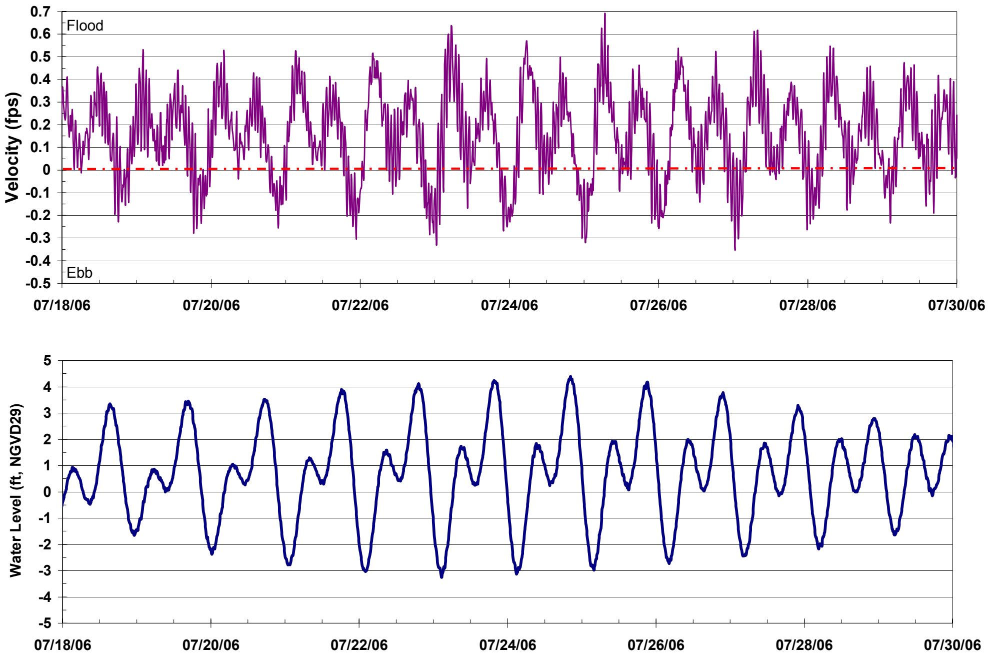


Figure 6-4 Flow Velocities at Mother's Beach Under High Pumping Rates

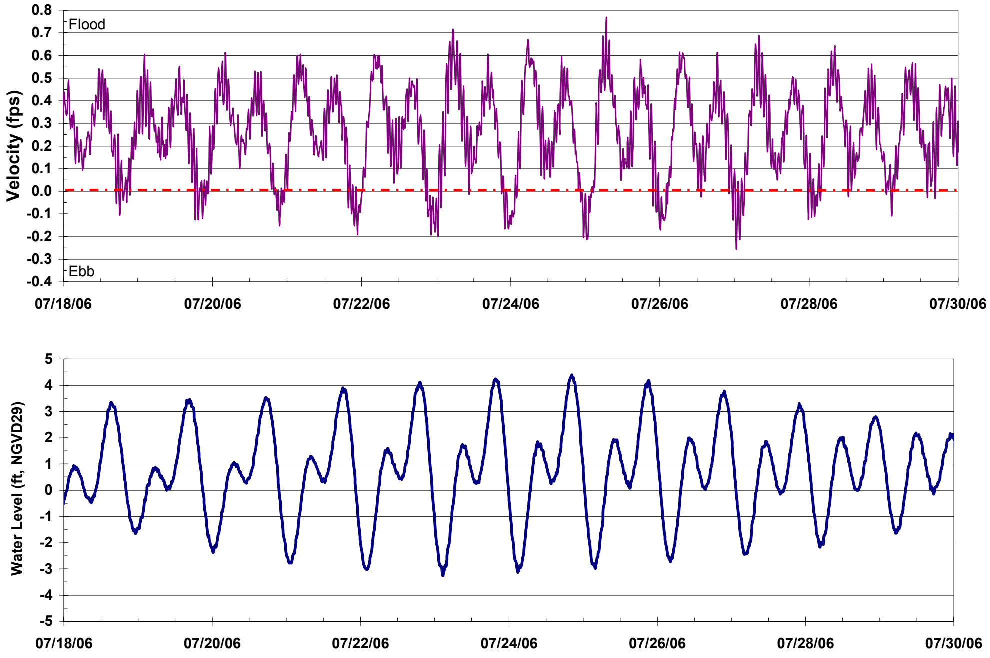


Figure 6-5 Flow Velocities at 2nd Street Bayshore Under High Pumping Rates

6.1.2 Scenario 1 – Residence Time Analysis

Water surface elevations and current patterns simulated by the RMA2 hydrodynamic model were input to the pollutant transport RMA4 model to estimate water residence times throughout Alamitos Bay. The modeling parameters used were based on literature and past similar project experience. The modeling results are shown in Figure 6-6. The residence times are shorter for locations relatively close to the ocean entrance and longer for areas farther upstream and into the Bay such as Colorado Lagoon and Spinnaker Bay. The residence times are relative short under this high pumping rate condition, and are approximately less than 1.0 day at the Mother's Beach area and throughout lower Alamitos Bay.

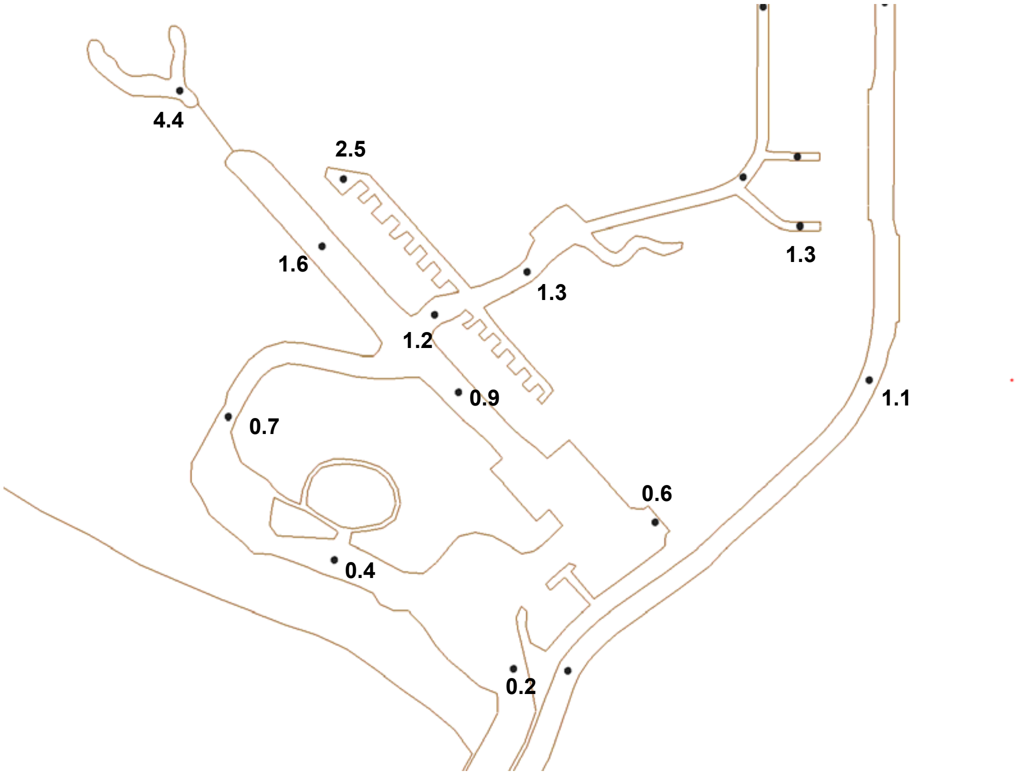


Figure 6-6 Scenario 1 – Residence Time (Days)

6.2 SCENARIO 2 – LOW PUMPING RATE PERIOD

This scenario is intended to determine the relatively poorer hydraulic circulation condition within Alamitos Bay in late summer of 2006. The period selected for hydrodynamic modeling extended from 10:24 am on November 9 to 24:00 pm on November 28, while both power plants were pumping at very low rates and Alamitos Bay was experiencing an ocean neap tidal cycle. This modeling period is shown in Figure 6-7. The RMA4 water quality modeling started at 3:48 am of November 10. The initial time of the RMA2 modeling period serves as the model "warm up." The modeling period required for the low flow rate condition is longer than that for the high flow rate condition because the residence time is longer under the low pumping rate condition.

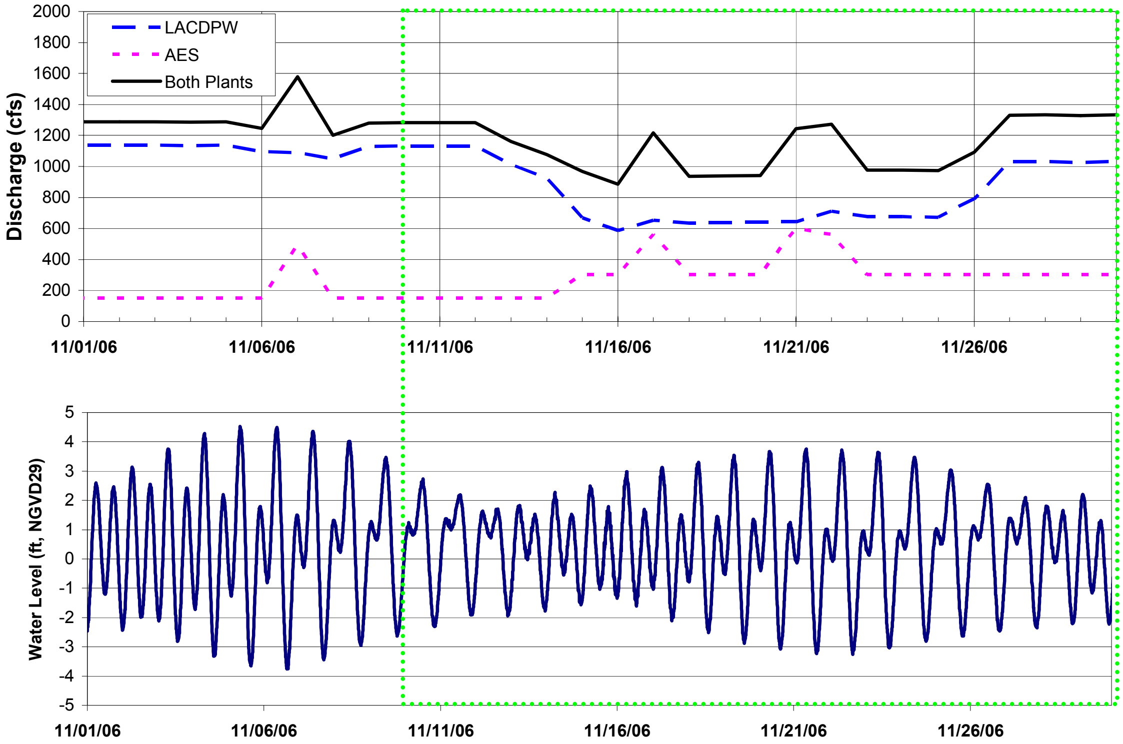


Figure 6-7 Boundary Input for the Low Flow Pumping Rate Period

6.2.1 Scenario 2 – Hydrodynamic Modeling Results

The flow velocity time series at Mother's Beach and 2nd Street Bayshore were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-8 and 6-9. Under this low pumping rate condition, the velocity fluctuations are primarily tidally-driven. There is no discernable net flow direction at Mother's Beach, and is a slight net flow toward the AES plant at 2nd Street Bayshore. Therefore, the sites appear to be nearly entirely influenced by the ocean tides. Thus, aging and relatively poor-quality water passes from distant upstream areas of the Bay downstream past Mother's Beach and either into the Haynes intake or the ocean during tidal ebbing. Relatively poor-quality water being transported past Mother's Beach repeatedly during these conditions could be one of the factors that trigger high bacteria readings during the periods of low pumping rates at the power plants, particularly the AES plant. The low pumping rate at the AES plant is lower than that at the Haynes plant during these conditions, therefore it generates less of a draw on water within Alamitos Bay than the Haynes plant or the ocean tide under these conditions.

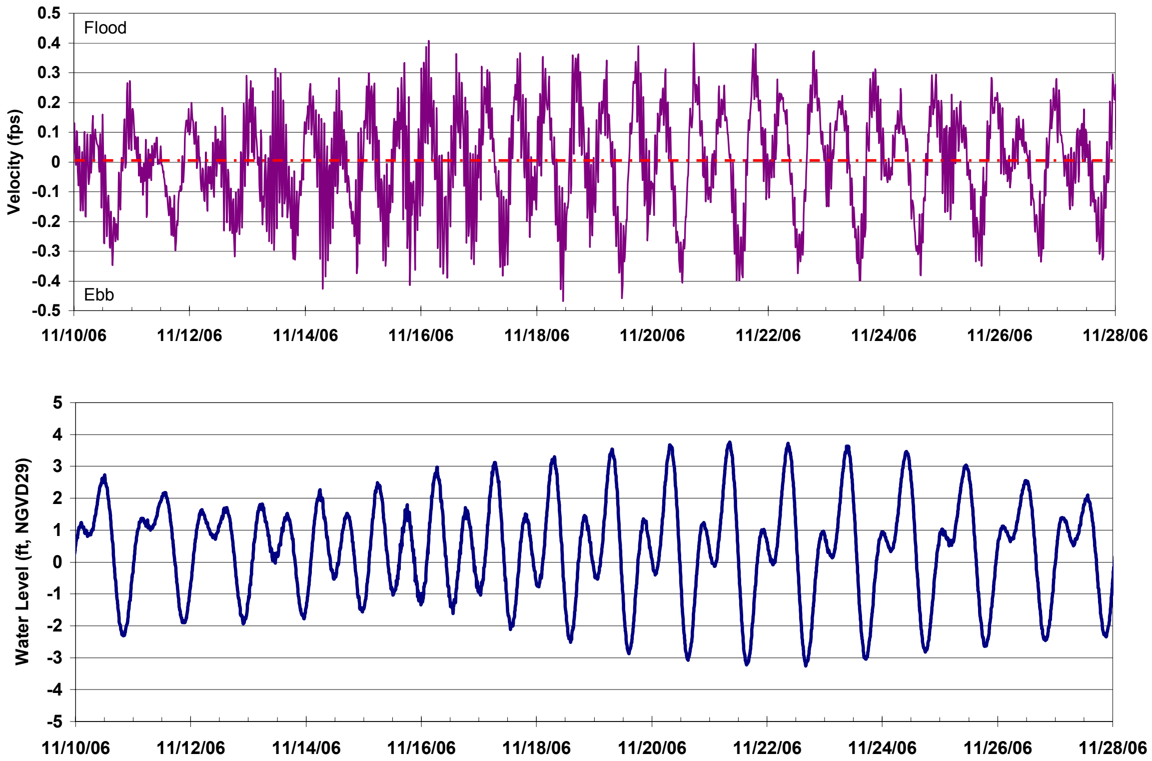


Figure 6-8 Flow Velocities at Mother's Beach Under Low Pumping Rates

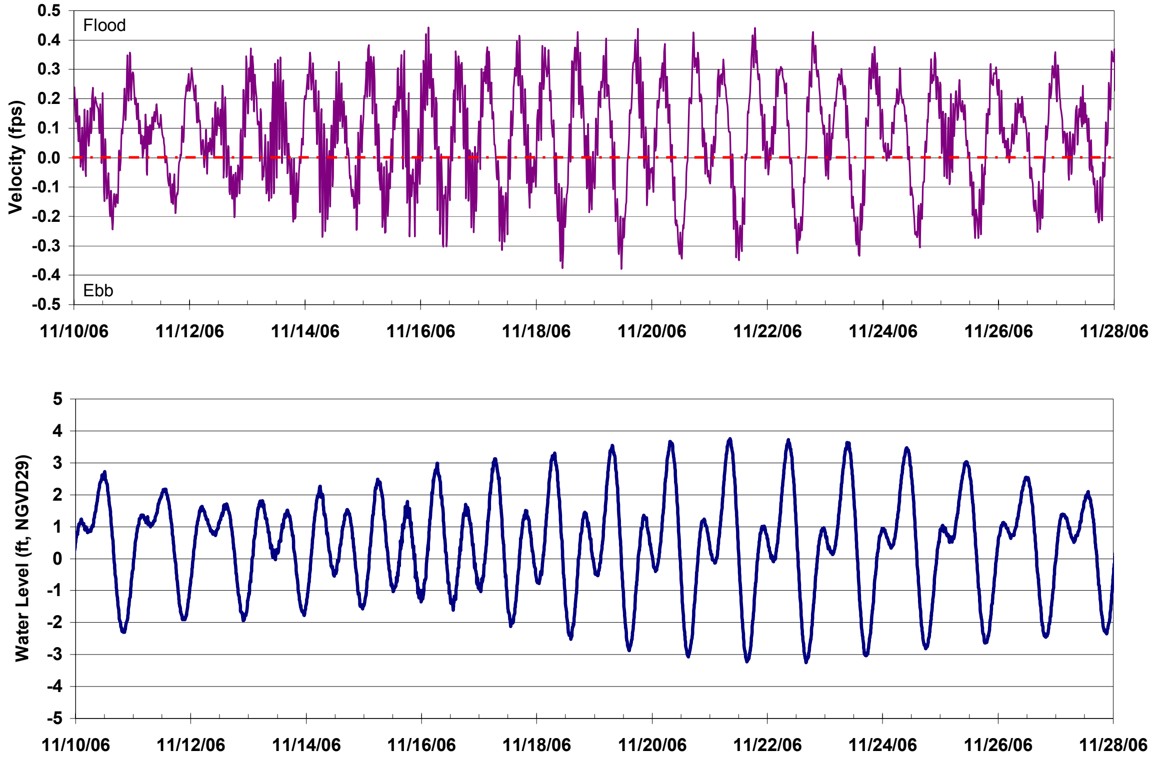


Figure 6-9 Flow Velocities at 2nd Street Bayshore Under Low Pumping Rates

6.2.2 Scenario 2 – Residence Time Analysis

Water surface elevations and current patterns simulated by the RMA2 hydrodynamic model were input to the RMA4 pollutant transport model to estimate water residence times. The modeling results are shown in Figure 6-10. The water residence times are much longer throughout the Bay than those under the high pumping rate scenario, especially for the upper Alamitos Bay area. The residence times are shorter for locations closer to the ocean entrance and longer for areas farther into the Bay such as Colorado Lagoon and Spinnaker Bay. The residence times are approximately 5.0 days under this condition compared to 1.0 day under the high pumping rate scenario. This comparison indicates that power plant pumping, especially at the AES plant, plays a very important role in moving and replacing water within Alamitos Bay. The AES plant pumps water out from the inner/upper Alamitos Bay area and draws new seawater from the ocean into the inner Alamitos Bay area. Most critically, AES plant pumping reduces the amount of volume of aging/poor quality water that travels from the Colorado lagoon area past Mother's Beach, and it reduces the frequency at which Mother's Beach is exposed to poor-quality water from upstream.

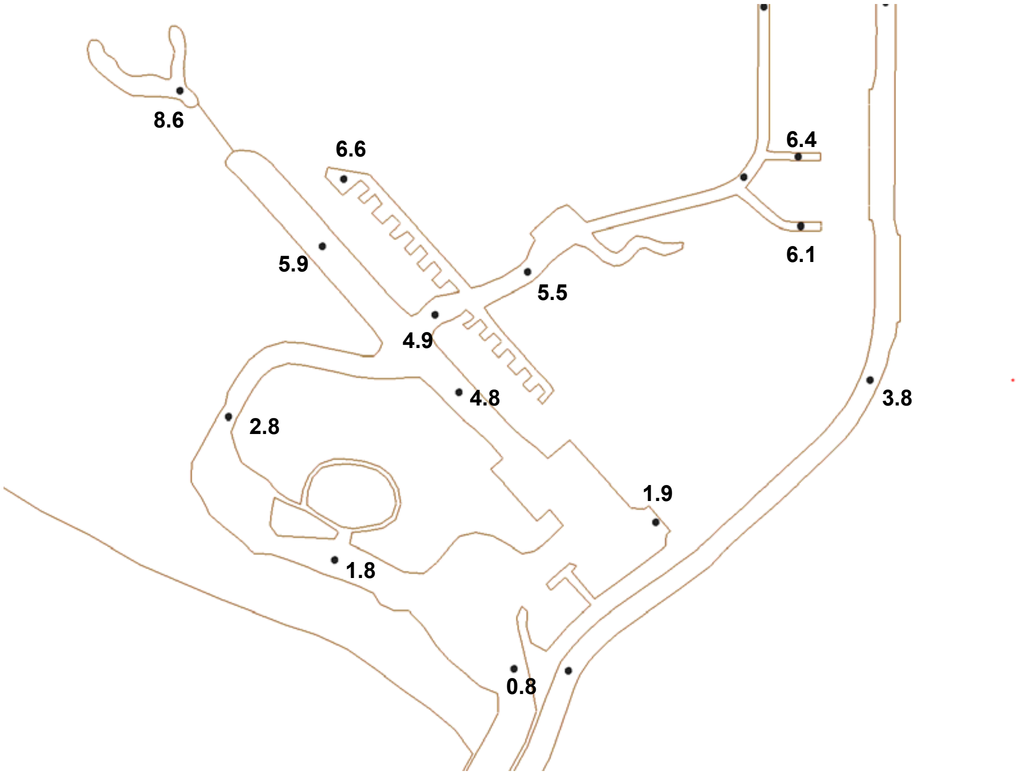


Figure 6-10 Scenario 2 – Residence Time (Days)

6.3 SCENARIO 3 – CONDITION OF NO PUMPING AT THE AES PLANT

The intent of this scenario is to determine the potentially worst-case circulation condition in the future if the AES plant were no longer pumping water from Alamitos Bay and the Haynes plant were pumping at its minimum typical pumping rate. The lowest pumping rate for 2006 of 600 cfs at the Haynes plant was assumed for this scenario. The tidal elevations applied in Scenario 2, which represents a weak neap tidal cycle, were applied in the model offshore boundary as the driving force for this scenario as well. The tidal elevations are shown in the lower part of Figure 6-7.

6.3.1 Hydrodynamic Modeling Results

The velocity time series at Mother's Beach and 2nd Street Bayshore were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-11 and 6-12. Under this condition of a low pumping rate at the Haynes plant and no pumping at the AES plant, the velocity fluctuations are primarily tidally-driven. The net flow at the Mother's Beach is toward the Haynes plant and the downstream ocean. Statistically, approximately 54% of the time, the water flow is moving toward the Haynes plant and downstream ocean; therefore, the aging and poor-quality water from inner Alamitos Bay area would pass by Mother's Beach and go into the Haynes plant or to the downstream ocean during the tidal ebb. At the 2nd Street Bayshore location, the net flow appears to be still slightly toward the upstream area of Alamitos Bay or around the northern shore of Naples Island.

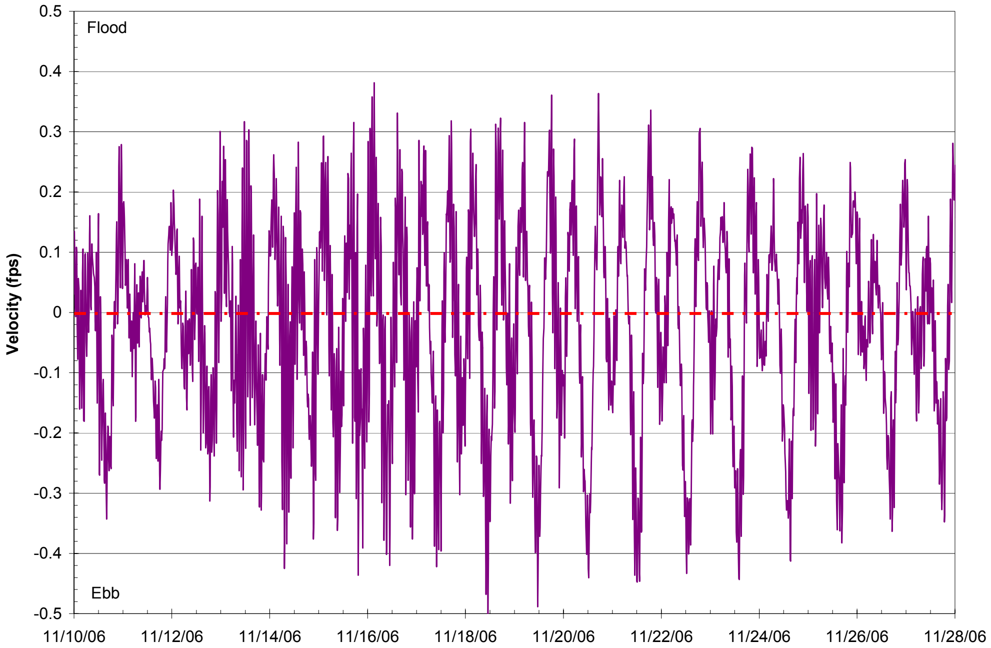


Figure 6-11 Flow Velocities at Mother's Beach Under No Pumping at the AES Plant

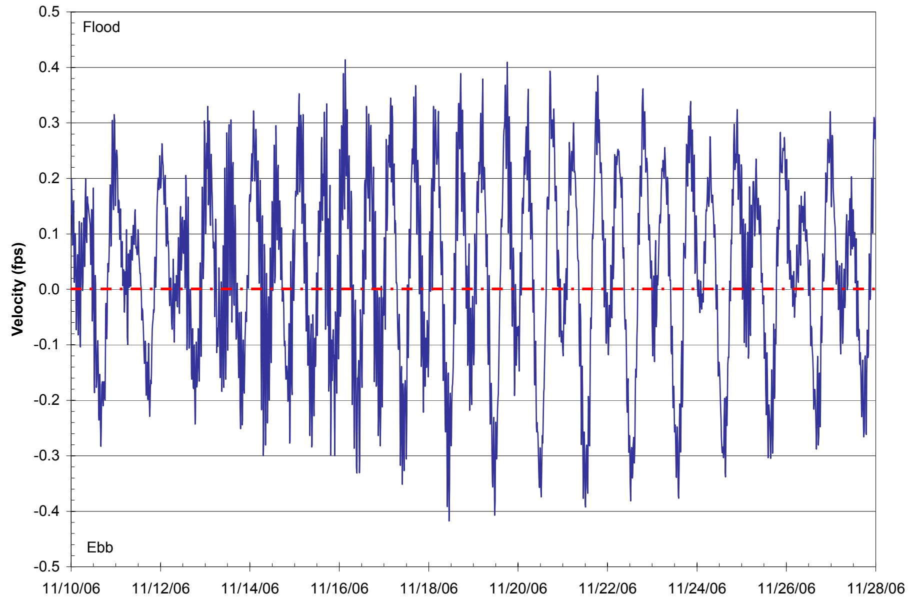


Figure 6-12 Velocity at 2nd Street Bayshore Under No Pumping at the AES Plant

6.3.2 Scenario 3 – Residence Time Analysis

Water surface elevations and current patterns simulated by the RMA2 hydrodynamic model were input into the RMA4 pollutant transport model to estimate water residence times. The modeling results are shown in Figure 6-13. The residence times are longer than those under the low pumping rate period, especially for the inner Alamitos Bay area. The residence times are shorter for locations closer to the ocean entrance and longer for the areas farthest into Alamitos bay such as Colorado Lagoon and Spinnaker Bay. The residence time is about 10.0 days under this condition compared to 5.0 days under Scenario 2 - the low pumping rate condition and 1.0 day under Scenario 2 - the high pumping rate condition. This comparison further indicates that AES power plant pumping plays a key role in moving and replacing water within Alamitos Bay. The AES plant pumps aging water out from the inner/upper Alamitos Bay area and draws renewed seawater from the ocean into the inner Alamitos Bay area.

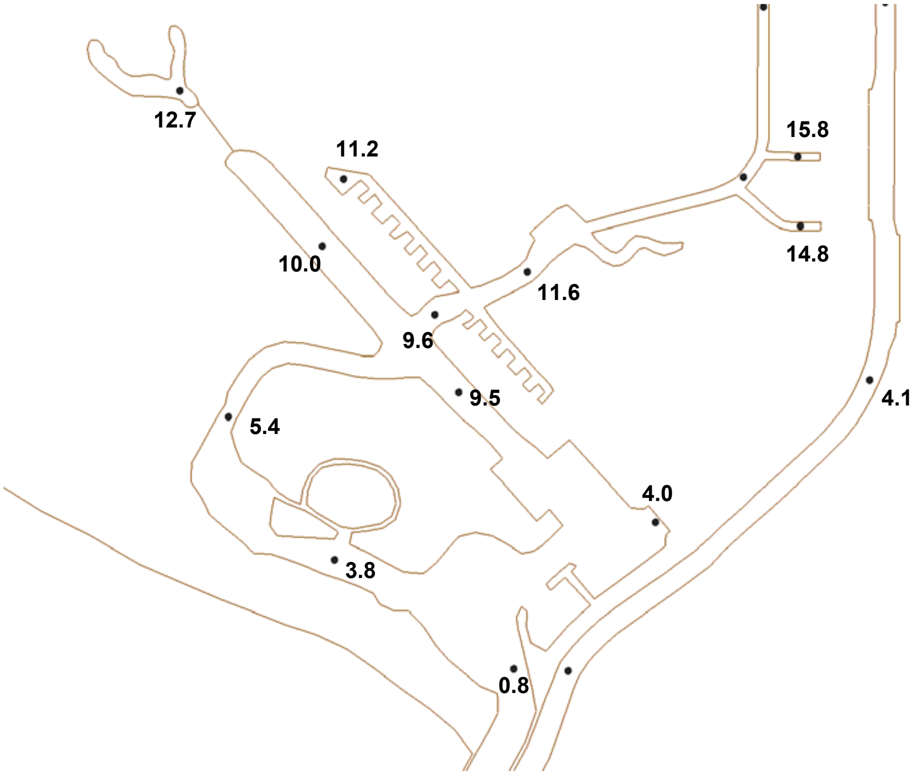


Figure 6-13 Scenario 3 – Residence Time (Days)

6.4 SCENARIO 4 – MINIMUM AES PUMPING RATE REQUIRED TO DRAW BAY WATER UPSTREAM

The intent of Scenario 4 is to determine a reasonable minimum AES pumping rate that the plant would have to maintain to induce a net water movement from Mother's Beach to upstream areas. For the Haynes plant, the lowest pumping rate of 600 cfs in 2006 is applied for this model simulation. In order to assess the impact of the pumping rate at the Haynes power plant on the net water movement direction at Mother's Beach, the modeling assumed that the highest pumping rate at the Haynes plant occurred (1,500 cfs) while the AES plant pumped at a rate of 600 cfs. The tidal elevations used in Scenarios 2 and 3, which represent a weak neap tidal cycle, are applied in the model offshore boundary as the driving force. The tidal elevations are shown in the lower part of Figure 6-7. The modeling results indicate that a pumping flow rate of 600 cfs at the AES power plant would result a residence time of less than 3 days at the Mother's Beach.

6.4.1 Scenario 4 – Hydrodynamic Modeling Results

The velocity time series at the Mother's Beach and 2nd Street Bayshore were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-14 and 6-15. Under a 600 cfs low pumping rate at both the Haynes and AES plants, the net flow direction at Mother's Beach is upstream toward Marine Stadium or the AES plant intakes. Statistically, the flow is flowing toward Marine Stadium approximately 60% of the time. Therefore, less volume of aging and poor-quality water from inner Alamitos Bay will pass by Mother's Beach toward the Haynes plant intake or downstream ocean, although water from upstream will still pass by Mother's Beach under strong ebbing tides. The net flow direction at 2nd Street Bayshore is also upstream toward the AES intakes, and the net circulation pattern around Naples Island is clockwise.

The velocity time series at Mother's Beach and 2nd Street Bayshore under the condition of Haynes pumping at 1,500 cfs while ASE pumps at 600 cfs were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-16 and 6-17. The net flow direction is still toward the Mother's Beach, however, at a lower frequency of 54%, compared to a frequency of 60% if Haynes pumps at a rate 600 cfs. This condition is still superior to the situation under Scenario 3 – Condition of No Pumping at the AES Plant. The net flow direction under Scenario 3 is still toward Haynes Plant, and water flows toward Mother's Beach from upstream only 46% of the time.

At 2nd Street Bayshore, the net flow direction under the condition of Haynes pumping at 1,500 cfs with AES pumping at 600 cfs is toward the AES plant at a frequency of 76% of the time, compared to a frequency of 69% of the time if Haynes pumps at its minimum capacity.

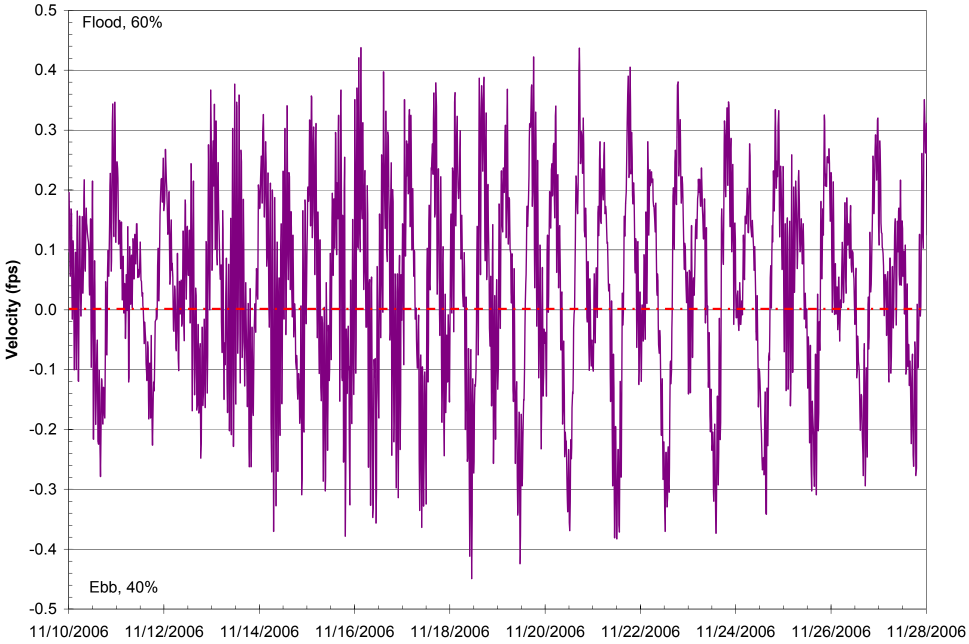


Figure 6-14 Flow Velocities at Mother's Beach Under the Minimum AES Pumping Rate Scenario With Haynes Pumping at 600 cfs

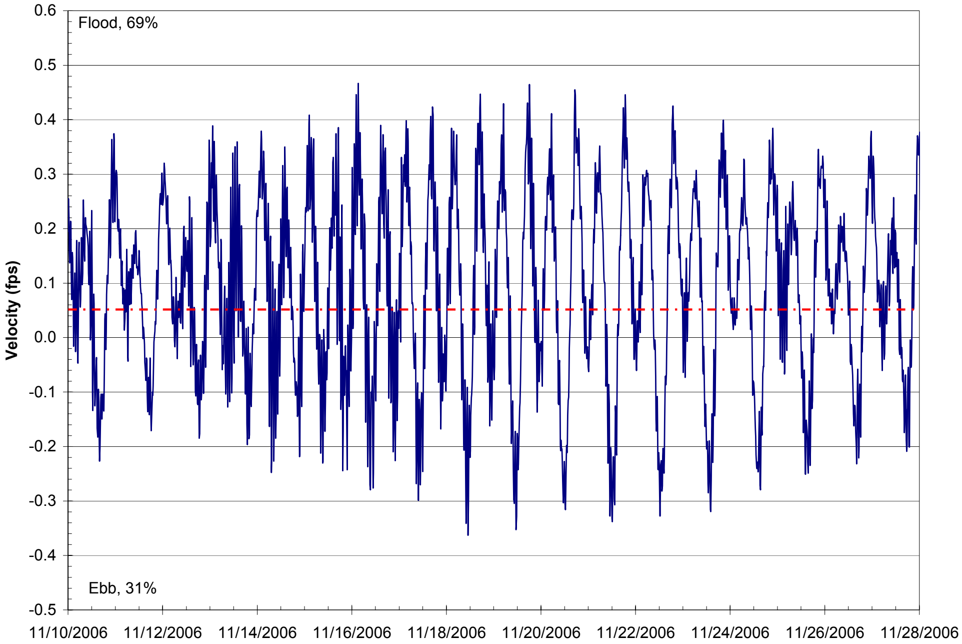


Figure 6-15 Flow Velocities at 2nd Street Bayshore Under the Minimum AES Pumping Rate Scenario With Haynes Pumping at 600 cfs

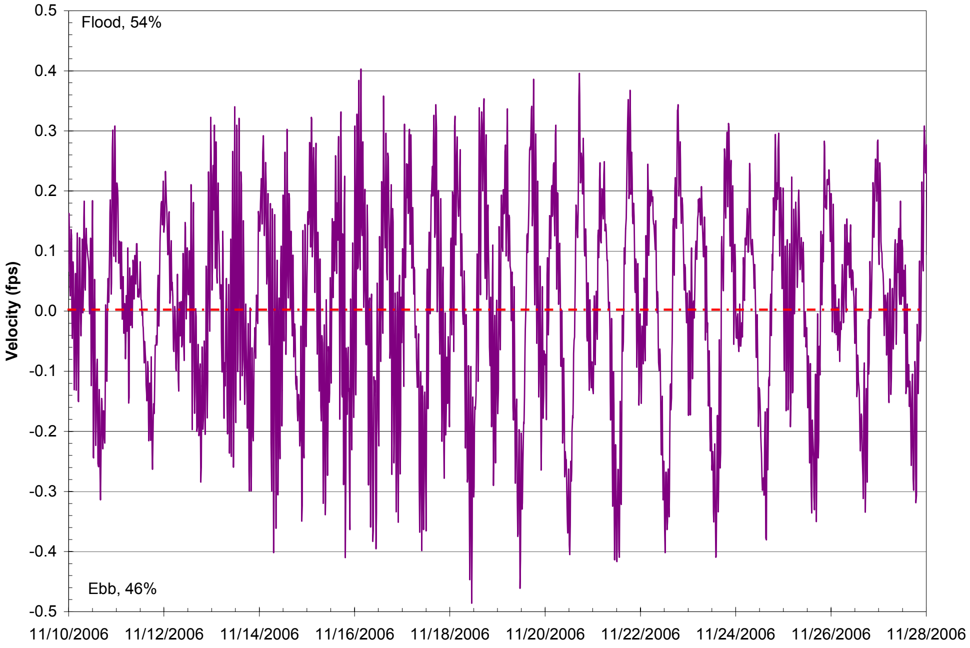


Figure 6-16 Flow Velocities at Mother's Beach Under the Minimum AES Pumping Rate Scenario With Haynes Pumping at 1,500 cfs

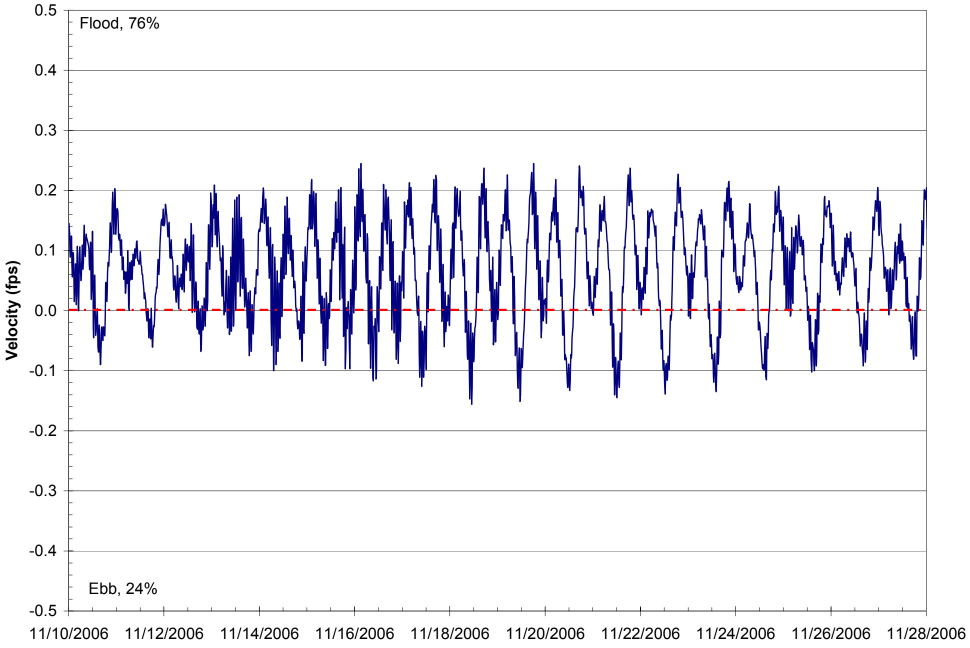


Figure 6-17 Flow Velocities at 2nd Street Bayshore Under the Minimum AES Pumping Rate Scenario With Haynes Pumping at 1,500 cfs

6.4.2 Scenario 4 - Residence Time Analysis

Water surface elevations and current patterns simulated by the RMA2 hydrodynamic model were input into the pollutant transport RMA4 model to estimate water residence times. The model results are shown in Figures 6-18 (Haynes pumping at 600 cfs) and 6-19 (Haynes pumping at 1,500 cfs). In general, the residence times are between those of Scenario 1- the high pumping rate period and Scenario 2 - the low pumping rate period. At Mother's Beach, the residence time is approximately 2.0 to 3.0 days under this condition compared to 5.0 days under Scenario 2 - the low pumping rate condition and 1.0 day under Scenario 1 - the high pumping rate condition. This comparison further indicates that pumping from the AES power plant plays a key role in moving and replacing water within Alamitos Bay. Increasing the pumping rate at the AES plant is the most effective way to enhance circulation and to reduce residences time within the inner Alamitos Bay area.

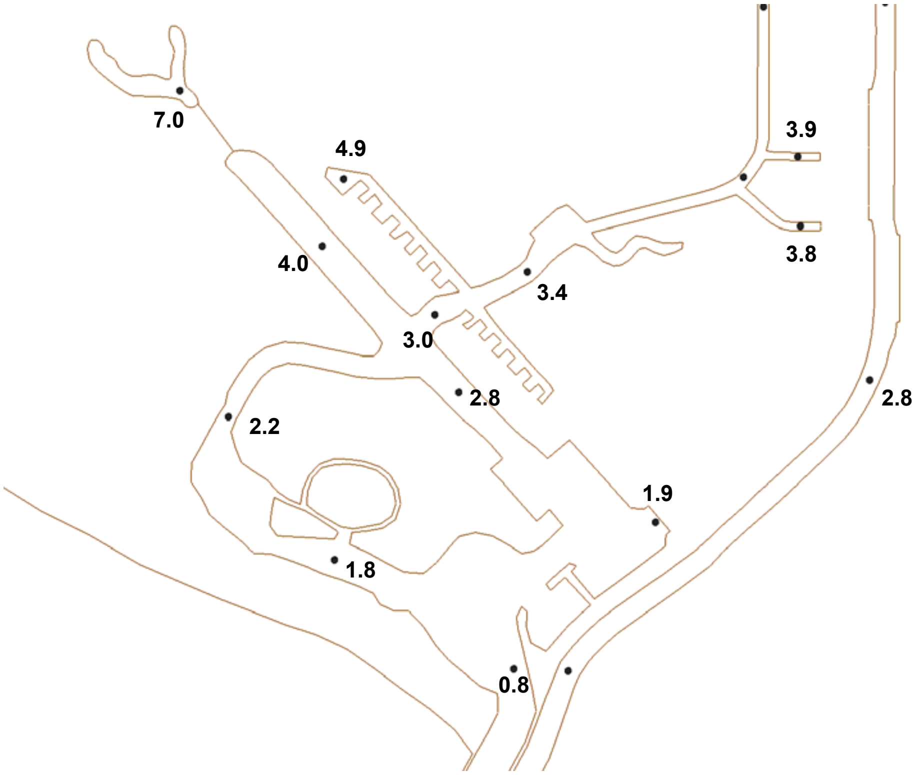


Figure 6-18 Scenario 4 – Residence Time (Days) With Haynes Pumping at 600 cfs

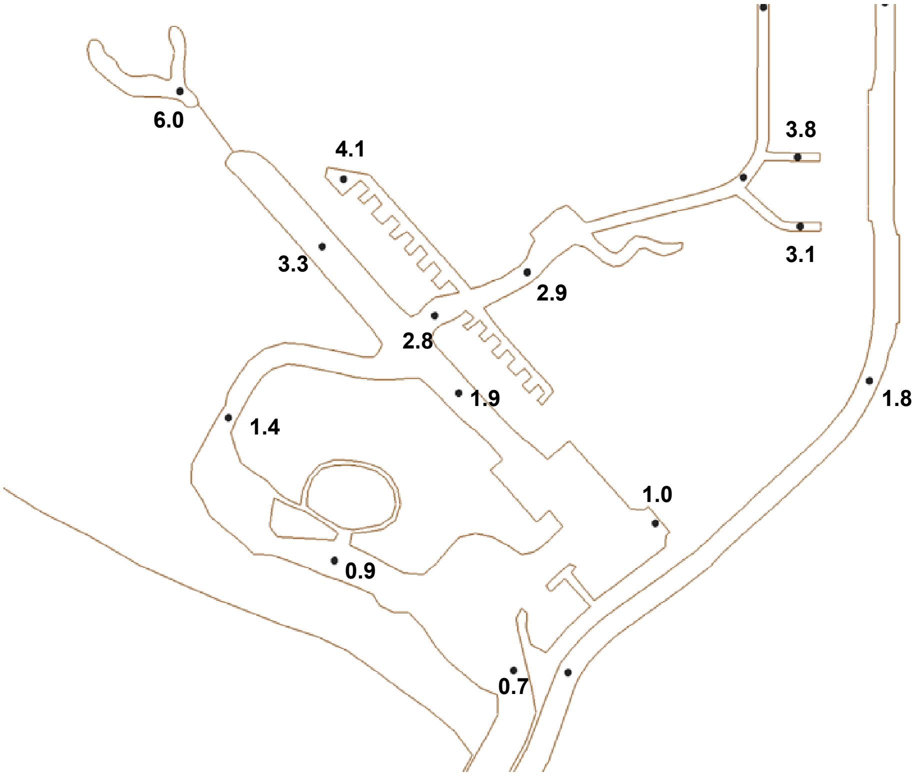


Figure 6-19 Scenario 4 – Residence Time (Days) With Haynes Pumping at 1,500 cfs

6.5 SCENARIO 5 – NEW TIDAL INLET

This scenario is intended to test the efficiency of improving circulation by constructing a new tidal inlet connecting the ocean to Alamitos Bay at the north side of Treasure Island near 54th street. The new inlet dimensions are assumed to be 200 feet wide and 10 feet deep (NGVD29). For this modeling scenario, the lowest pumping rate of 2006 at the Haynes plant intake of 600 cfs is applied. It is also assumed that there is no pumping at the AES power plant. The tidal elevations used in Scenarios 2, 3, and 4, which represent a weak neap tidal cycle, are applied in the model offshore boundary as the driving force. Figure 6-20 shows the nearshore modeling grid for this scenario which was a modified condition to all the previous alternatives by including the new tidal inlet channel.

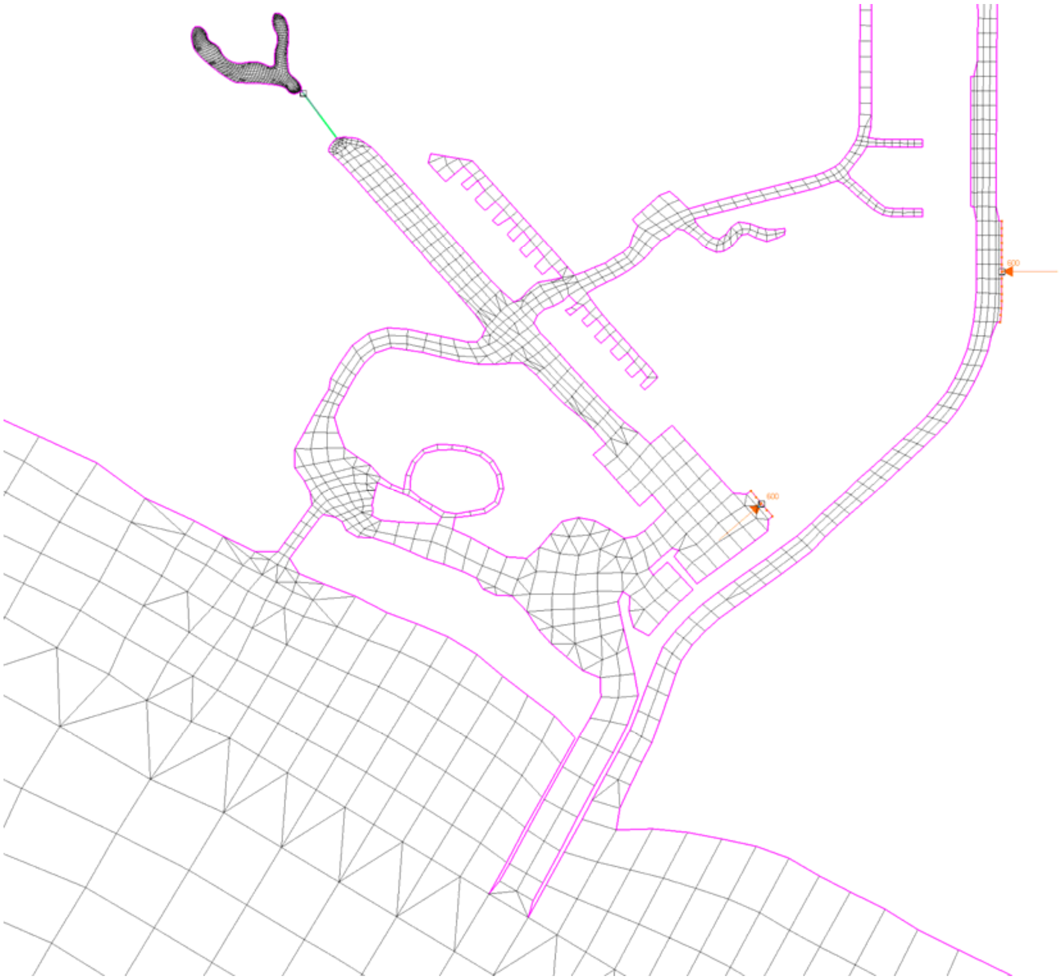


Figure 6-20 Nearshore Modeling Grid for Scenario 5

6.5.1 Scenario 5 – Hydrodynamic Modeling Results

The flow velocity time series at Mother's Beach and 2nd Street Bayshore were extracted from RMA2 hydrodynamic model results and plotted in Figures 6-21 and 6-22, respectively. Under this dual inlet scenario, the net flow direction at Mother's Beach is toward the ocean or the Haynes Power plant intake. Statistically, the flow is flowing toward the ocean approximately 54% of the time. Therefore, more than half of the time the aging and poor-quality water from inner Alamitos Bay area may pass by Mother's Beach toward the Haynes plant intake. At 2nd Street Bayshore, the net flow direction is toward the AES intakes and peak current velocities are approximately 20% higher than those under the other four scenarios.

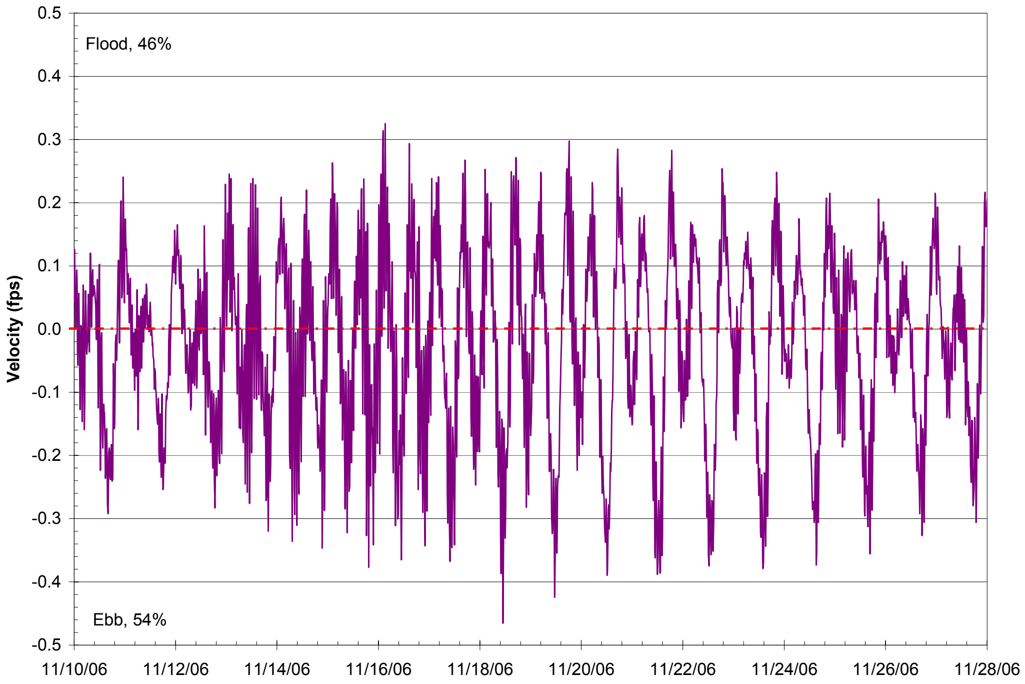


Figure 6-21 Flow Velocities at Mother's Beach Under the New Inlet Scenario

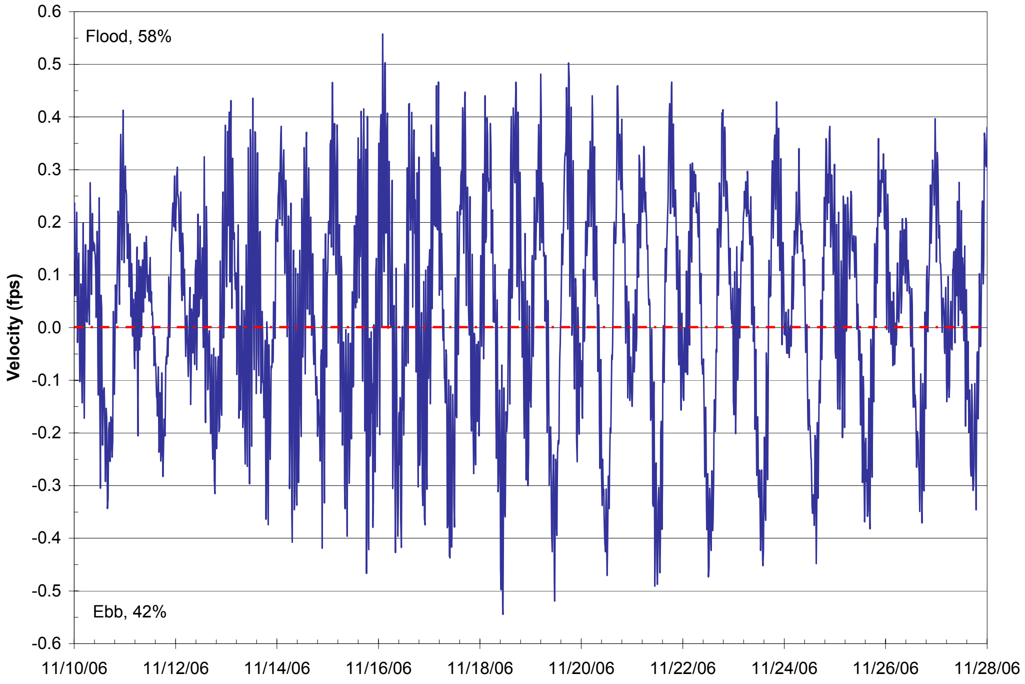


Figure 6-22 Flow Velocities at 2nd St. Bayshore Under the New Inlet Scenario

6.5.2 Scenario 5 – Residence Time Analysis

Water surface elevations and current patterns simulated by the RMA2 hydrodynamic model were input into the pollutant transport RMA4 model to estimate water residence times. The modeling results are shown in Figure 6-23. In general, residence times are shorter than those under Scenario 3 - No AES Pumping and longer than those for Scenario 4 – Minimum AES Pumping. At Mother's Beach, the residence time is approximately 6.5 days under this condition compared to 9.5 days under Scenario 3 and 2.8 days under Scenario 4. At 2nd Street Bayshore, the residence time is 2.9 days compared to 5.4 days under Scenario 3 and 2.2 under Scenario 4. These comparisons further indicate that increasing the pumping rate at the AES plant is the most effective way to enhance circulation and to reduce the residence times in the inner Alamitos Bay area. Constructing a second entrance to Alamitos Bay is not as beneficial to circulation as is increasing the AES pump rate.

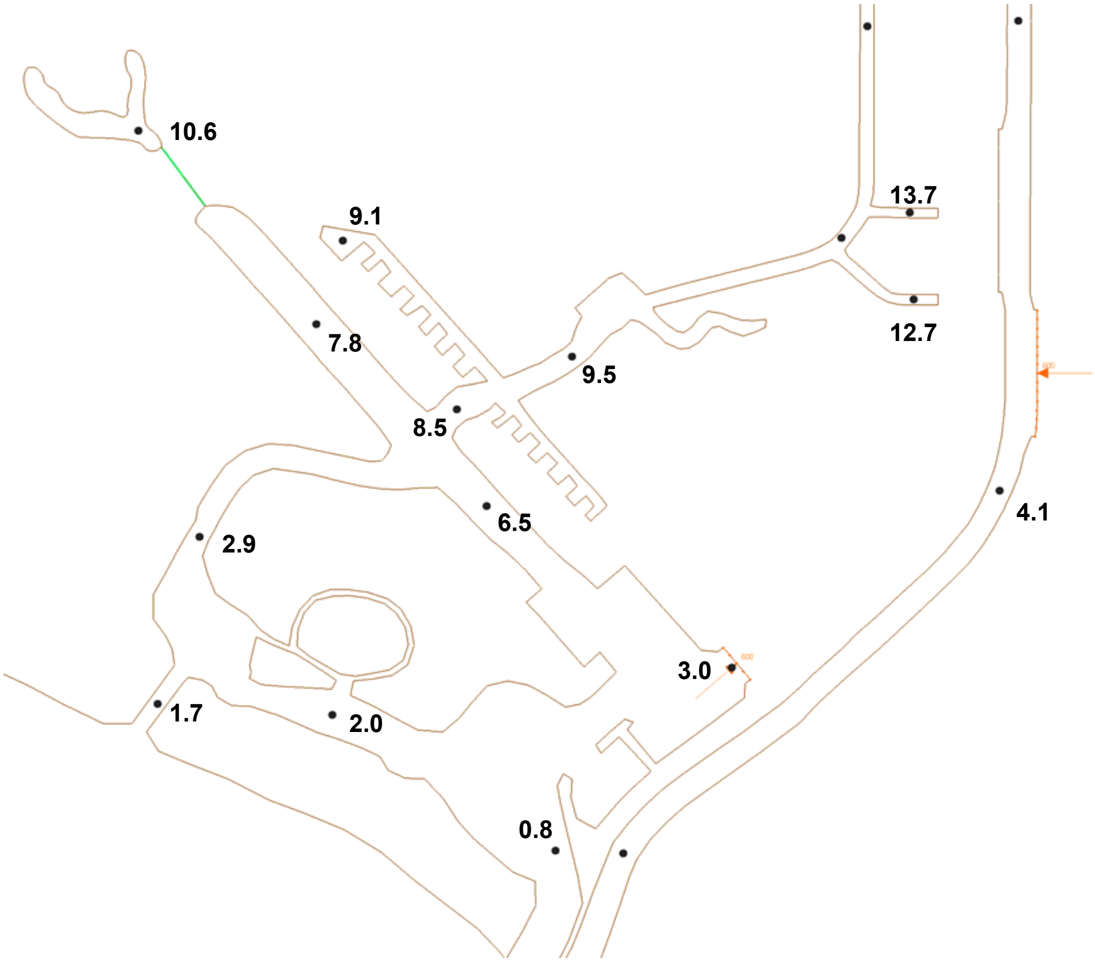


Figure 6-23 Scenario 5 – Residence Time (Days)

7.0 SUMMARY AND CONCLUSIONS

An existing RMA2 numerical model was expanded to include all of Alamitos Bay, the San Gabriel River and AES and Haynes power plant intakes. The RMA2 model was calibrated with measured tide and current data. The calibrated RMA2 model, together with the RMA4 water quality model, were applied in assessing hydraulic circulation efficiency under four different power plant pumping scenarios and one new tidal inlet scenario.

Water residence time is used as a means for assessing the circulation efficiency of the hydraulic system and for indirectly inferring water quality conditions. Table 7-1 summarizes the water residence times under five different modeling scenarios. The results of the study lead to the following findings:

1. The water residence times are shortest and the circulation is the most efficient under Scenario 1 while both power plants are pumping at their capacities.

2. The water residence times are longest under the low or no pump scenarios at the AES power plant, and while the Haynes Plant is pumping at its annual low capacity of 600 cfs. The modeling indicates that aging water from upper Alamitos Bay (Colorado Lagoon and Spinnaker Bay) would frequently move downstream past Mother's Beach toward the Haynes intake and the ocean during ebbing tides.

3. The pumping rate at the AES power plant has the most significant impact on circulation in Alamitos Bay since it removes some of the aging and poor quality water from upstream areas of the Bay and discharges it into the San Gabriel River. Otherwise, the poor-quality water would all circulate downstream past Mother's Beach toward the Haynes intake and the ocean during ebbing tides. This circulation pattern appears to be a possible trigger causing bacteria exceedances at Mother's Beach.

4. A minimum pumping rate of 600 cfs at the AES plant is required to create a net upstream flow direction at Mother's Beach toward the Los Cerritos Channel. This circulation pattern would result in less exposure of Mother's Beach to water movement from upper Alamitos Bay and likely improved water quality.

5. Constructing a second inlet into Alamitos Bay near 54th Street slightly reduces residence times, but is only marginally better than Scenario 3 (no pumping the AES plant), and is therefore is a limited enhancement to circulation within the Bay.

6. Scenarios 1 (maximum pumping) and 4 (maintain pumping of 600 cfs) are the optimum scenarios evaluated in this study for improving circulation at Alamitos Bay and water quality at Mother's Beach.

Table 7-1 Residence Time Summary

Scenarios	Description	Residence Time (Days)	
		Mother's Beach	**2nd Street Bayshore**
Scenario 1	High Flow Pumping Period in 2006	**0.9**	**0.7**
Scenario 2	Low Flow Pumping Period in 2006	**4.8**	**2.8**
Scenario 3	No Pumping at AES and 600 cfs Pumping at Haynes	**9.5**	**5.4**
Scenario 4	600 cfs Pumping @ both AES and Haynes	**2.8**	**2.2**
	600 cfs Pumping @ AES and 1,500 cfs @ Haynes	**1.9**	**1.4**
Scenario 5	A New Inlet, No Pumping at AES and 600 cfs Pumping at Haynes	**6.5**	**2.9**

8.0 REFERENCES

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