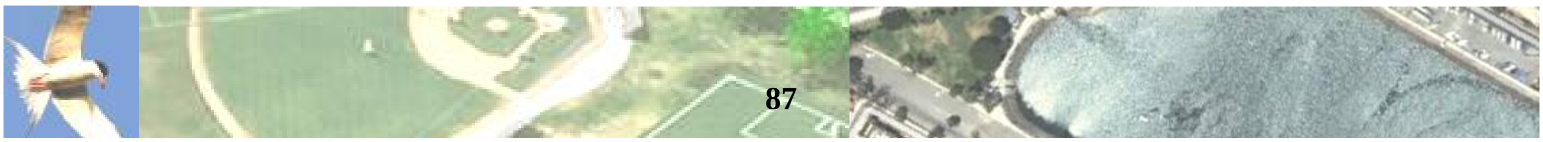
APPENDIX D
Hydrodynamics Report



HYDRODYNAMICS ANALYSIS REPORT
PHASE 2 STUDY
COLORADO LAGOON RESTORATION PROJECT

Prepared for:

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1.0 INTRODUCTION

A tidal hydrodynamic modeling study was performed in support of the Open Channel Conceptive Design as part of Phase II Study of the Colorado Lagoon Restoration Project. The scope of work for this Task 2 study includes: developing numerical models for each alternative, collecting and reviewing existing data, assessing water levels in the lagoon and open channel relative to FEMA requirements, and developing tidal prism, tidal inundation, tidal velocity and storm velocity data. A supplemental analysis was conducted to determine residence time improvement within Colorado Lagoon and one other location within Alamitos Bay.

Four alternatives were developed in Task 1 of this study for the connection between Colorado Lagoon and Marine Stadium, and they are:

Alternative 1 – Parallel / Second Culvert. This alternative proposes to add a second 20 ft wide large culvert and the existing culvert will be cleaned and kept in place for use.

Alternative 2 – EIR-Conforming Open Channel. This alternative has the same basic concept as EIR Proposed Project. The open channel has a top width of about 100 ft, but with different channel alignment (along Eliot St). Bridges are proposed along both Eliot and Colorado Streets, and most of existing culvert left in place for use.

Alternative 3 – Combination Open Channel and Culverts. This alternative has a similar concept as Alternative 2, but bridges along both Eliot and Colorado Streets will be replaced with large culverts, and the existing culvert will be cleaned and left in place for use.

Alternative 4 – Maximum Wetland. This alternative has the optimized channel width for maximum eelgrass / wetland habitat potential. A bridge is proposed along the Eliot Street and a culvert is proposed along the Colorado Street. The existing culvert will be disconnected.

In this modeling study, it is assumed that the lagoon will be dredged and the existing culvert will be cleaned in Phase I of the project. Any modifications to the subtidal dredging footprint should not change tidal muting and prism in the lagoon. Post Phase I lagoon and existing culvert conditions are assumed for the baseline existing condition (or no project condition).

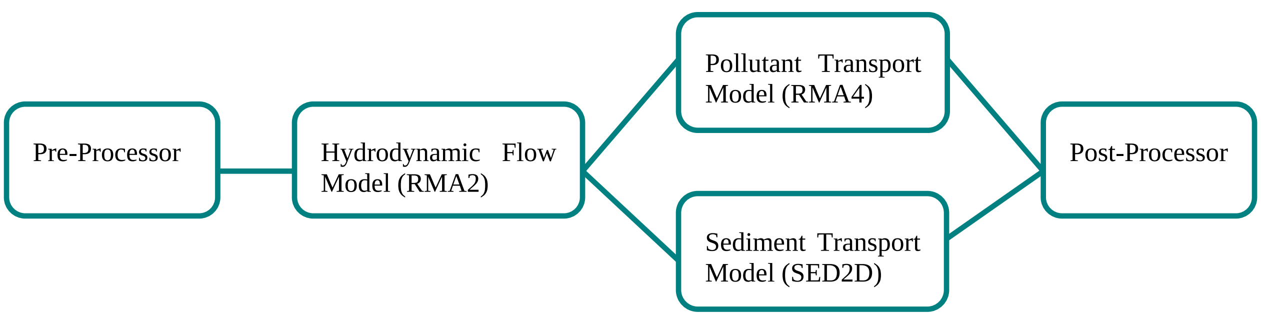
Numerical modeling runs were performed for the baseline condition and four proposed alternatives. This report describes models used and model setup, and summarizes tidal and flood hydrodynamics modeling results as well as residence time analyses results.

2.0 MODEL SELECTION AND DESCRIPTION

The numerical modeling systems used in this study are summarized in the following sections.

The TABS2 (McAnally and Thomas, 1985) 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 below. TABS2 can be used either as a stand-alone solution technique or as a step in the hybrid modeling approach. 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.



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:

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

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

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

For this project study, the RMA2 hydrodynamic model and RMA4 water quality model were applied.

3.0 MODEL SETUP

Setup for the tidal and flood hydrodynamic model for existing condition included determination of the model area, bathymetry, mesh selection, and boundary conditions. The RMA2 model was originally setup for the Colorado Lagoon Feasibility Study (M&N, 2004). The model was updated to reflect the proposed dredged lagoon condition and the proposed tidal connections between the Lagoon and the Marine Stadium for each alternative.

The purpose of this modeling study was primarily focused on comparisons of the proposed project alternatives versus the baseline existing condition. Pumping at two local power plants would affect the tidal conditions in the lagoon; however the pumping effects would be similar on the existing condition, proposed project alternatives, and they are not included in the modeling. Storm flows from a capital storm event (50-year) were input into the model to determine the water level in the lagoon under a joint high tide and storm event condition. The groundwater flow input into the lagoon was not considered in the modeling since the groundwater level in the vicinity is lower than that in the lagoon. The groundwater movement direction should be from the lagoon. Also, the groundwater movement compared to tidal exchange is negligible.

3.1 MODEL AREA

The model area covers Alamitos Bay, Marine Stadium, Colorado Lagoon and nearshore ocean, as shown in Figure 3-1. The model mesh covers a relatively large area. The model's ocean boundary (at an average contour elevation of -45 feet relative to the NGVD29 vertical datum) is approximately one mile from the shoreline. The side boundaries are also approximately one mile northwest and southeast from the project site. Designating the open model boundaries far from the area of interest minimizes boundary effects.

Figure 3-1 Modeling Area

3.2 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). The west arm of the lagoon is based on the post Phase I dredging condition. Design drawings and surveys 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 for the cleaned culvert and proposed culverts were determined analytically.

Figure 3-2 shows the bathymetry of the entire modeling domain. Figure 3-3 shows details of Colorado Lagoon for the proposed project alternatives with bathymetry changes. The study uses the NAD 83 California Zone 6 horizontal coordinate system and the NGVD29 vertical datum. (NGVD29 is approximately 0.18 feet lower than Mean Sea Level of the latest tidal epoch for this area.) English units (feet, feet per second, etc.) are used throughout the model.

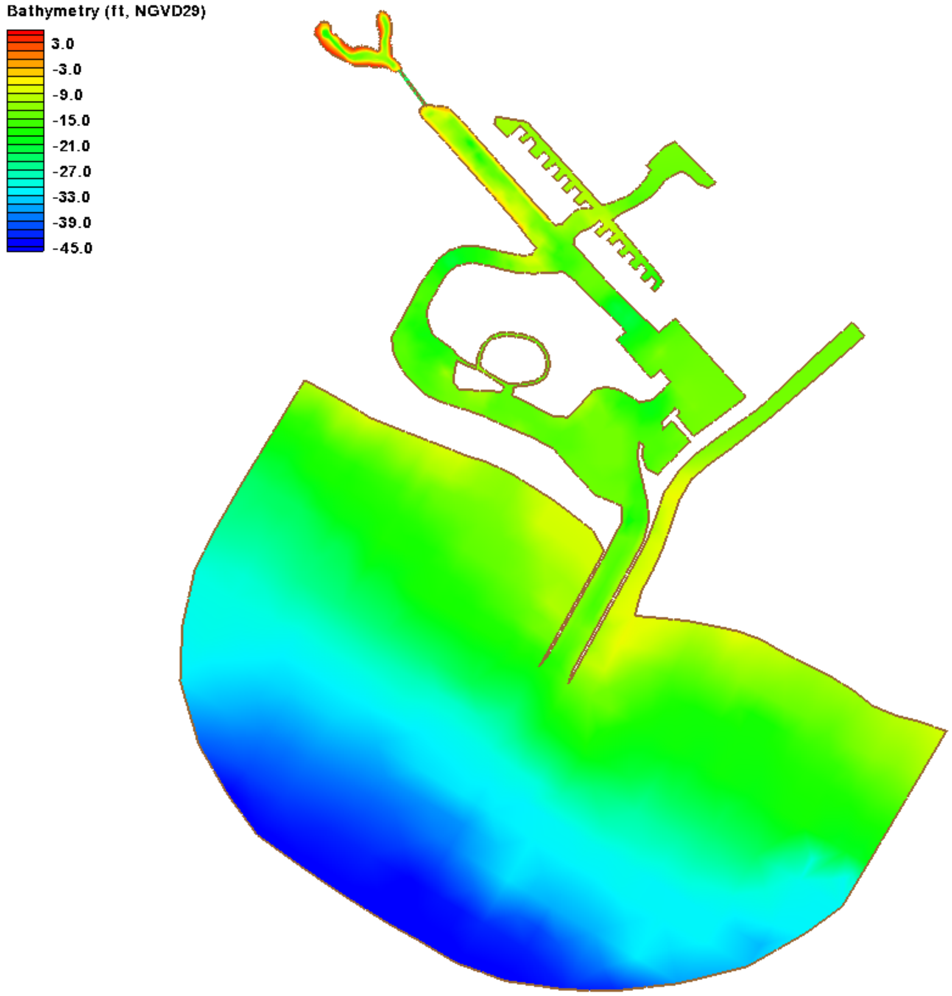


Figure 3-2 Bathymetry of the Entire Modeling Area

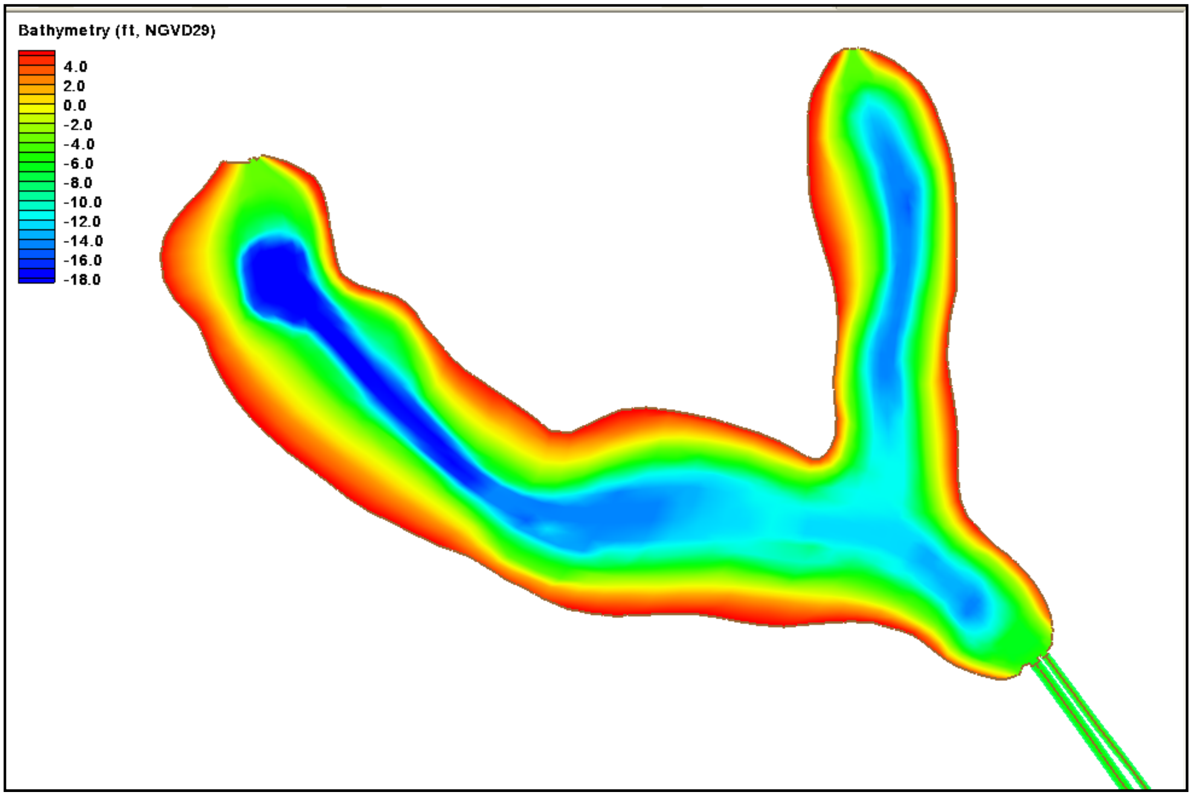


Figure 3-3 Bathymetry of the Colorado Lagoon

3.3 MODEL MESH

The RMA2 model requires the estuarial 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-D 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 estuarial geometry and bathymetry. The results discussed herein correspond to 2-D analyses with the exception of the culverts leading to the Colorado Lagoon which are represented by 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 estuary, 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 lagoon generally dictate the level of detail appropriate for the mesh.

There are several factors used to decide the aerial 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 collected to eliminate the need to interpolate between the boundary conditions from other locations.

The finite element mesh for the existing condition is shown in Figure 3-4. The mesh contains a section of ocean sufficiently large to eliminate potential model boundary effects. The lagoon portion of the mesh is bounded by the +5 foot contour relative to the vertical datum of NGVD29 considered to sufficiently contain the outermost extents of tidal and flood influence. The lagoon area mesh is shown in Figure 3-5.

The entire modeling area, approximately 5 square miles, is represented as a finite element mesh consisting of about 2,800 elements and 8,200 nodes.

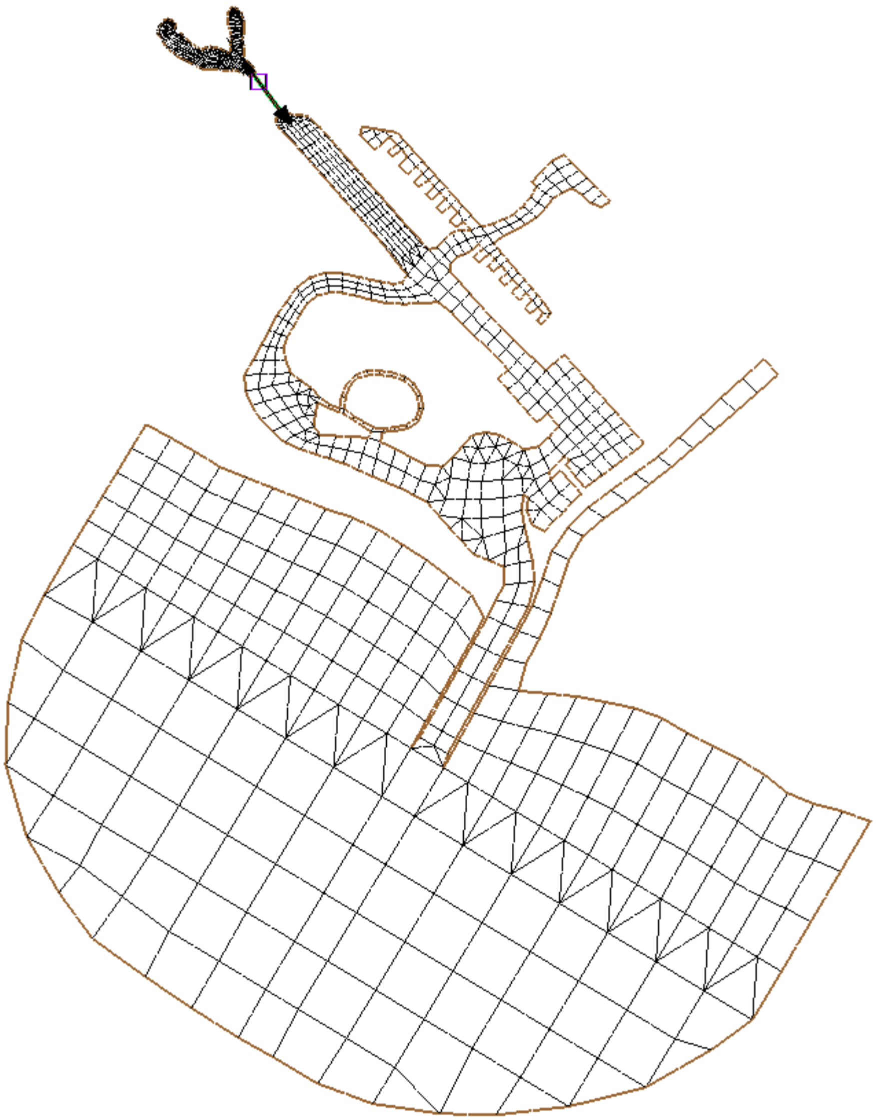


Figure 3-4 Entire Numerical Modeling Mesh

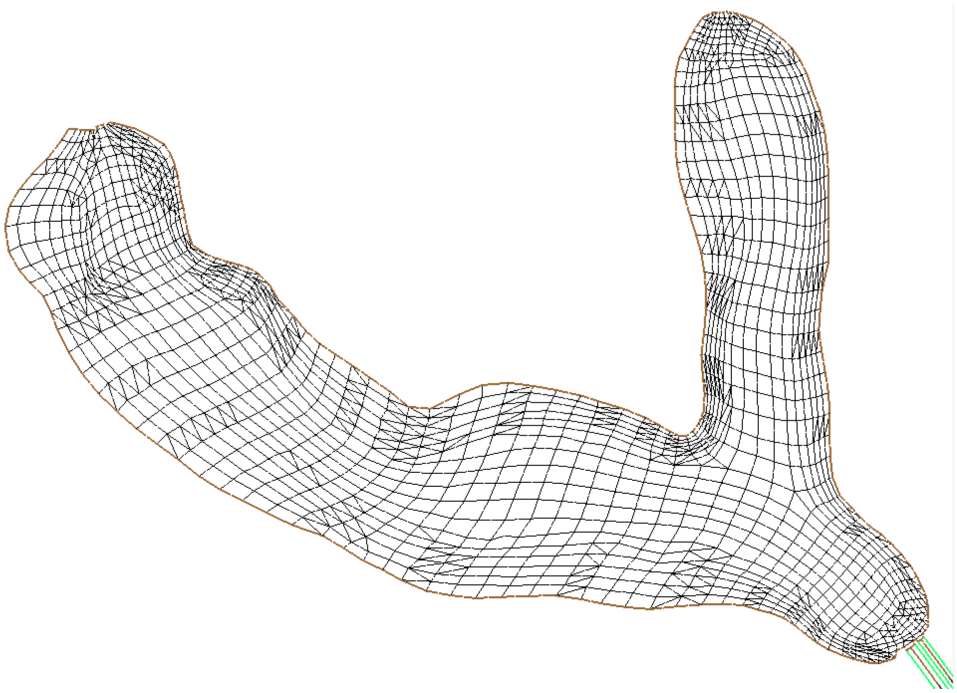


Figure 3-5 Numerical Modeling Mesh of the Colorado Lagoon

3.4 BOUNDARY CONDITIONS

3.4.1 Ocean Tides

Since there are no tide stations in Alamitos Bay, the recorded tides at the Los Angeles Outer Harbor tide gage, which is less than 10 miles away, was used to define the ocean boundary tidal condition. These recorded water levels, relative to both MLLW and NGVD29 datums, are shown in Table 3-1. The diurnal tide range from Mean Lower Low Water (MLLW) to Mean Higher High Water (MHHW) is approximately 5.49 feet. 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 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 3-1 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

3.4.2 Parametric Mean Periodic (PMP) Tidal Series

A synthetic tidal series, referred to as a parametric mean periodic (PMP) tide developed by M&N (1994), is used to simulate long-term average water levels for determining residence times (RMA4 analysis). The series matches the mean water levels (i.e., MHHW, MLLW, etc.) and phase differences of the existing tidal epoch. This provides short duration (days) tidal conditions similar to the 19-year tidal epoch as shown in Figure 3-6 to reduce modeling time while still generating accurate results.

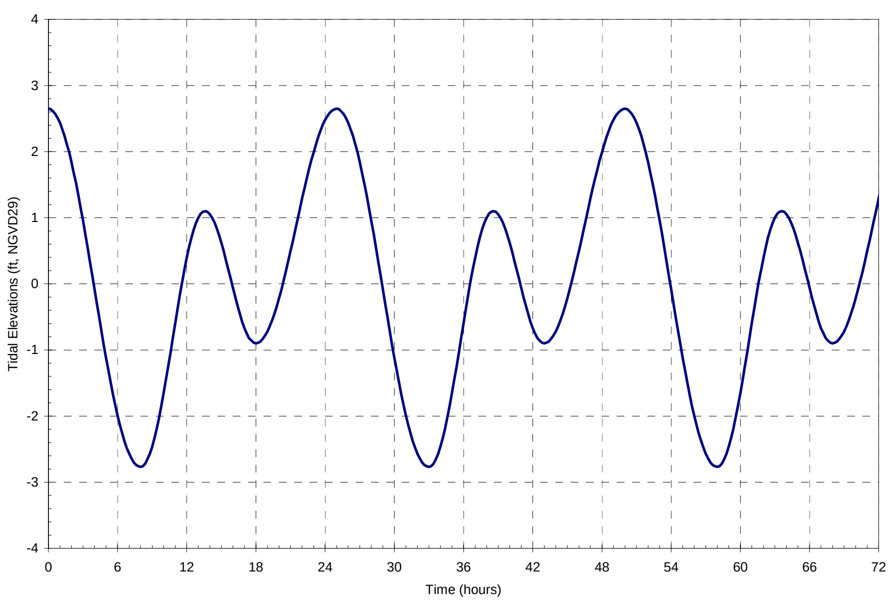


Figure 3-6 Parametric Mean Periodic (PMP) Tidal Series

3.4.3 Tidal Epoch Analysis (TEA) Tidal Series

The TEA tide is a synthetic 14-day tidal series developed statistically to match the cumulative distribution of water levels over a 19-year tidal epoch (1960-1978). The TEA tide includes both spring and neap tidal ranges shown in Figure 3-7. The largest 3-day spring tide period following neap tide inside the red rectangular box in Figure 3-7 was selected to evaluate residence time following THE energetic spring tide. In this area, spring tide ranges in mid-summer (July/August) and mid-winter (December/January) are usually larger than the average spring tidal range.

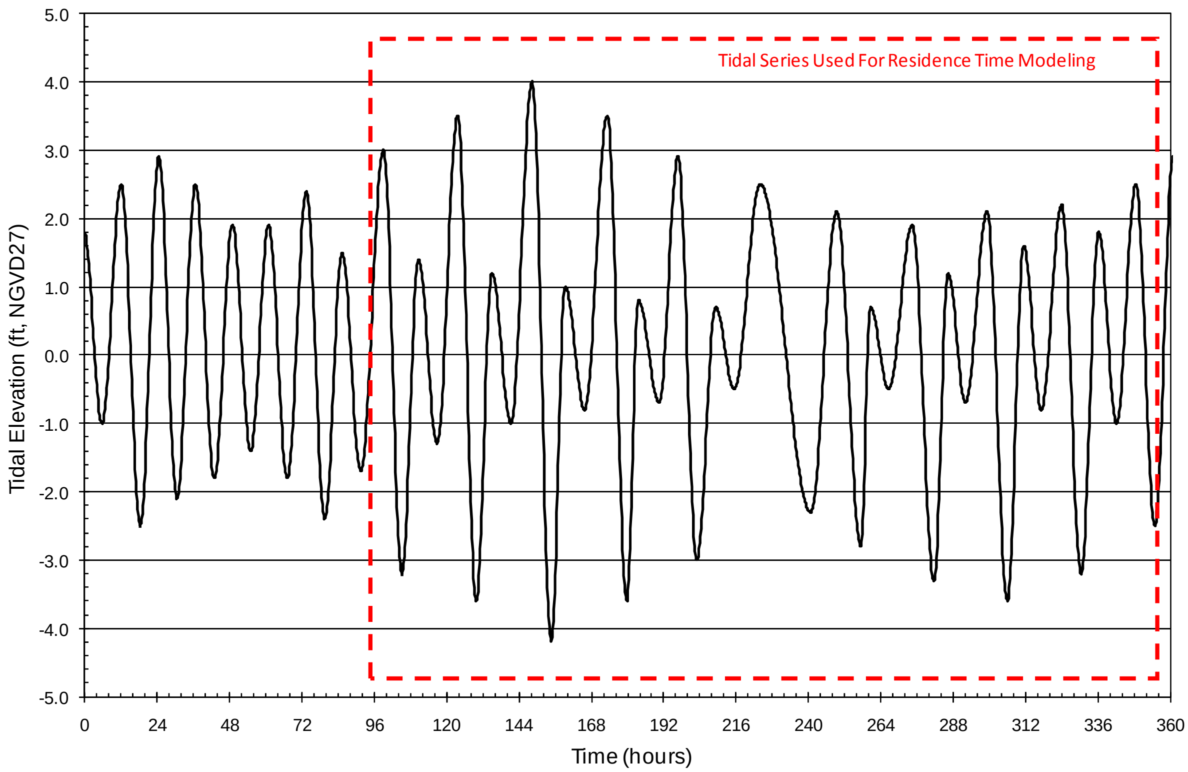


Figure 3-7 Tidal Epoch Analysis (TEA) Tidal Series

3.4.4 Extreme Tidal Series

The estimated extreme water level in the lagoon and Marine Stadium is an important design parameter for determining bridge soft elevation and flood protection elevations in the lagoon area. An extreme tidal series was developed by M&N (1994) by using the water levels measured at Los Angeles Harbor on January 27, 1983. The extreme tidal series was vertical shifted down by 0.2 ft to match the FEMA base flood elevation of 6 ft NGVD (FEMA FIRM Panel No. 0601360025C) in Alamitos bay. The base flood elevation is the anticipated floodwater to rise during the base flood which has a one percent chance of being equaled or exceeded in any given year. Base Flood Elevations (BFEs) are shown on Flood Insurance Rate Maps (FIRMs) and on the flood profiles. The resulting tidal series are shown in Figure 3-8.

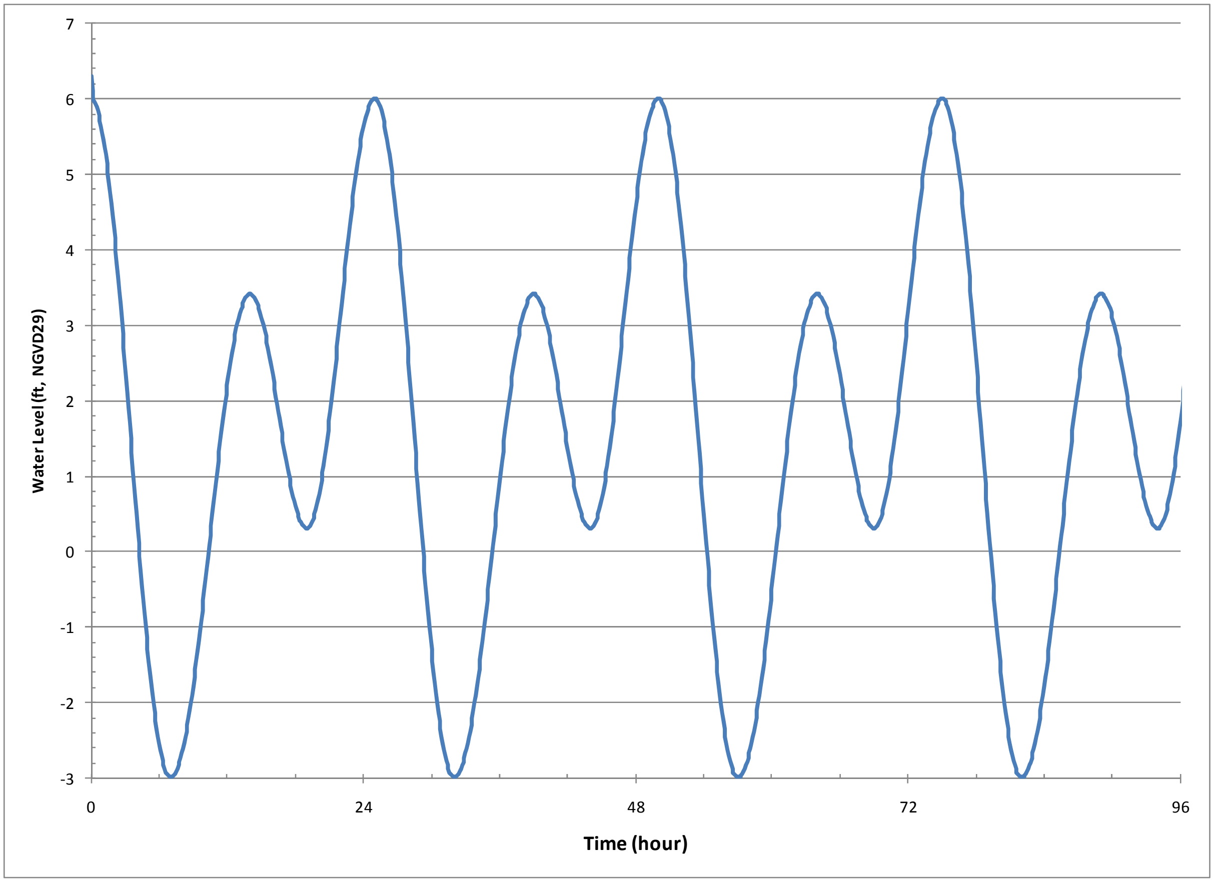


Figure 3-8 Extreme Tide Series

3.4.5 Flood Flow Boundary Conditions

For the flood flow hydrodynamic modeling, it is assumed that the storm runoff into the Lagoon is under the post Termino Avenue Storm Drain project conditions. The west arm of the lagoon receives the storm water input from Line C storm drain of Project Number 452, which is operated by the LACDPW. The 50-yr hydrograph is provided by the County and is shown in Figure 3-9. The east arm of the lagoon receives storm water runoff from three storm drains (Lines I, K, and L) operated by the City of Long Beach. The 50-yr hydrographs are also provided by the County. Line I discharges into the lagoon at the north end of the east arm. Line K discharges into the lagoon about half way to the north end on east shore of the east arm. Line L discharges into the lagoon at the Southern end of the east arm. Their hydrographs are shown in Figure 3-10. The peak flow of Line L is only 2 cfs, and is not very visible in the Figure.

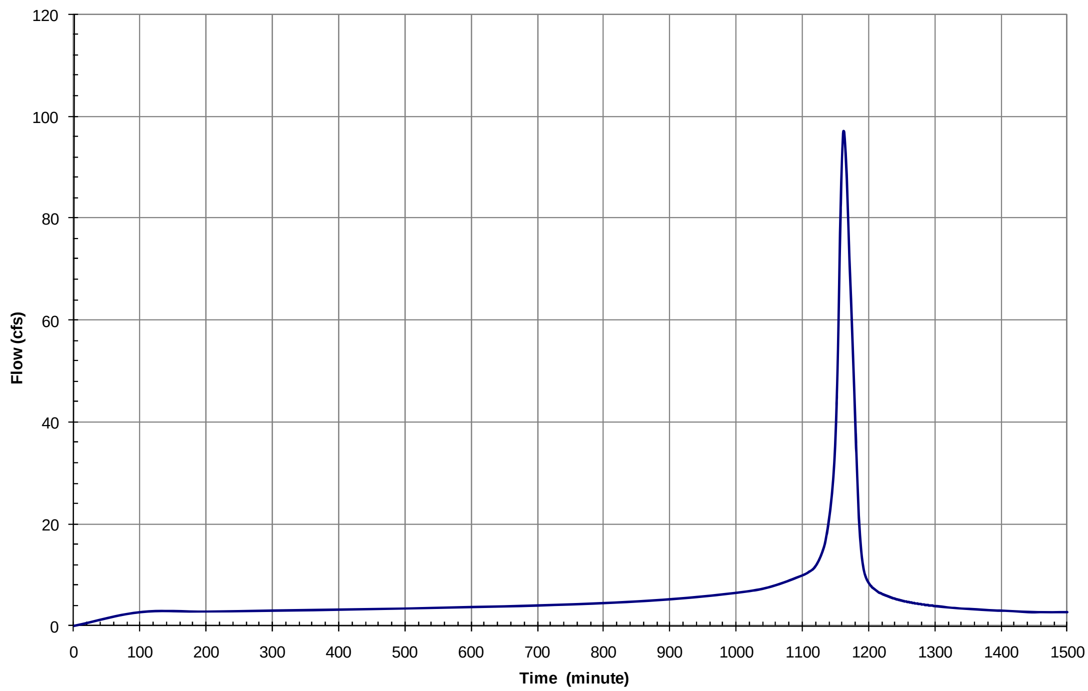


Figure 3-9 50-Year Hydrograph of Project Number 452 Storm Drain

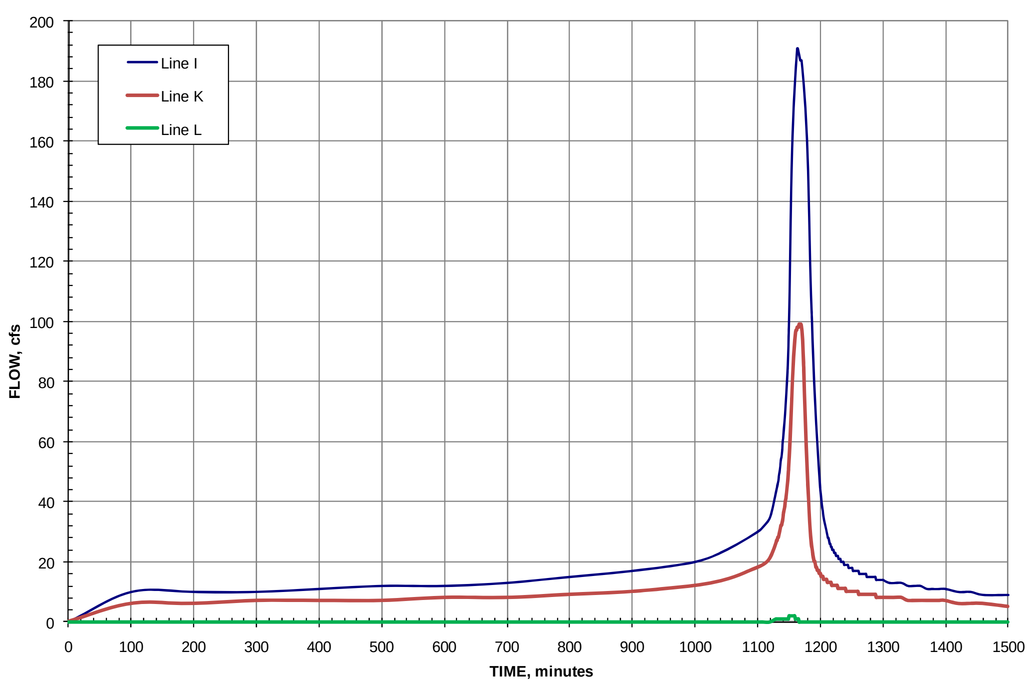


Figure 3-10 Year Hydrograph of Lines I, K, L Storm Drains

3.5 MODEL CALIBRATION

RMA2 calibration involves matching model predictions with measured data by selecting appropriate input variable 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, 2009). 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.

The detailed model calibration was carried out in the feasibility study (M&N 2004). The RMA model is relative robust and is not very sensitive to the roughness and eddy viscosity parameters. The modeling parameters used in this study are presented in Table 3-2.

Table 3-2 Setup Values for Model Calibration

Model Area	Manning's Roughness Coefficient (n)	Eddy Viscosity Coefficient (lb-sec/ft2)
Lagoon Intertidal Areas	0.037	300
Lagoon Subtidal Areas	0.035	150
Marine Stadium Intertidal Areas	0.035	120
Narrow Channels and Marinas	0.025	50
Marine Stadium Subtidal & Alamitos Bay Areas	0.025	150
Nearshore Surf Zone	0.025	250
Offshore from surf Zone	0.03	250

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.

4.0 HYDRODYNAMIC MODELING RESULTS

The calibrated RMA2 numerical model was applied to evaluate tidal hydrodynamics under the dry season, flood hydrodynamics under the Capital Storm (50-year) event and impacts of sea level rises in both the dry and wet seasons.

4.1 TIDAL HYDRODYNAMIC MODELING RESULTS

This section discusses the modeling results under the dry season. The TEA tide series described in Section 3.4.3 is applied in the model to predict the tidal range, tidal inundation frequency and to calculate the tidal prism for each alternative.

The tidal series in the Colorado Lagoon south end, shown in Figure 4-1, under proposed project alternatives are compared with that in the ocean. The gage locations shown in Figure 4-1, where modeling results were extracted, are fixed, although the connection between the lagoon and Marine Stadium varies from alternative to alternative. (Both the Colorado Lagoon South End and the Marine Stadium Northwest End gage locations were used for the residence time analysis).

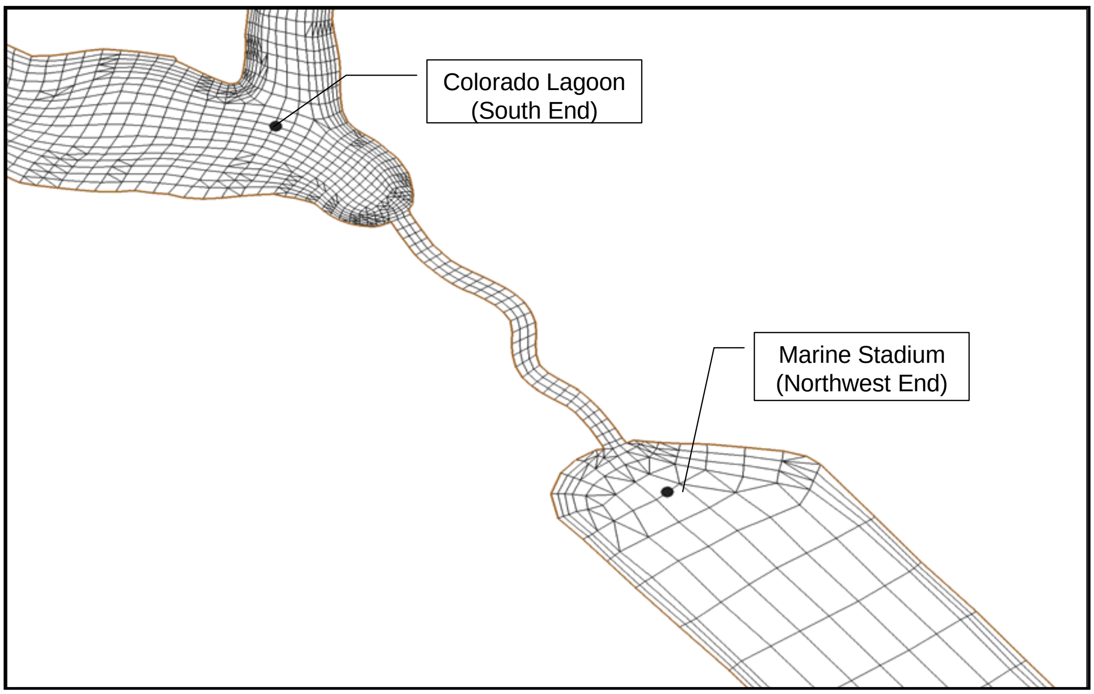


Figure 4-1 Modeling Output Gage Locations

The tidal range and tide muting in the lagoon comparing with those in the ocean are summarized in Table 4-1 and Figure 4-2. The high tide muting is calculated by subtracting the highest ocean tide by the highest lagoon tide, and a positive number indicates the lagoon high tide is muted or lowered. The low tide muting is calculated by subtracting the lowest lagoon tide by the lowest ocean tide, and a positive number indicates the lagoon tide is truncated. The modeling results indicate that there is no muting on the high tide. The minor muting in low tide can be fine tuned and in fact is within the noise of the numerical model. Therefore, it is concluded that the lagoon will experience full spring tide under all proposed alternatives after two modeling iterations were performed. The tidal range and muting under the scenario of post Phase I condition is also presented for comparison purposes. The left most column of Table 4-1 shows the spring tidal prism of the lagoon under four alternatives and post Phase 1 project condition. The lagoon tidal prism is significantly increased under all proposed project alternative conditions over the post Phase 1 project condition. The difference between alternatives is small and a similar prism can be achieved for alternatives with some design refinement. The tidal prism is an indicator of the circulation efficiency. A larger tidal prism often indicates a better tidal circulation.

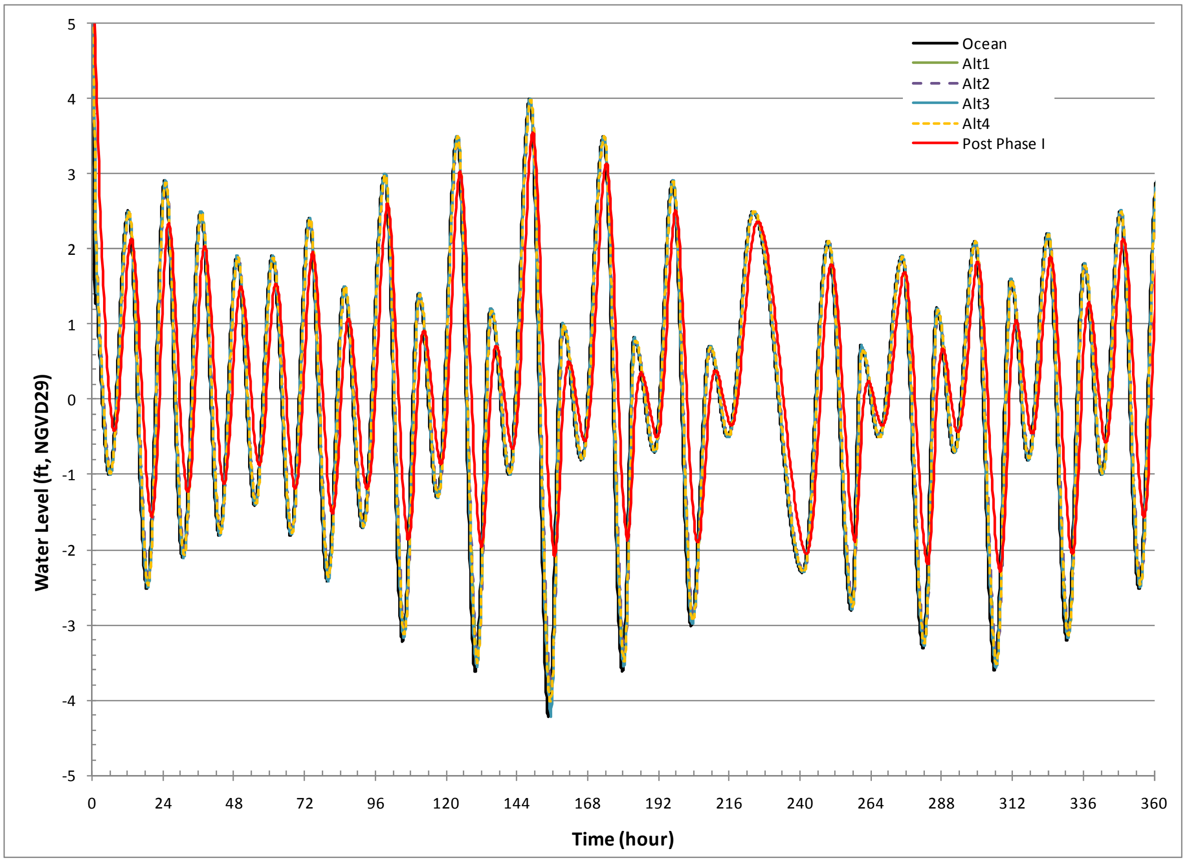


Figure 4-2 Spring Tide Range and Prism Comparisons

Table 4-1 Summaries of Tide Ranges and Prisms - Proposed Project Phase 1

Scenario Tidal	Range (ft)	High Tide Muting (ft)	Low Tide Muting (ft)	Prism (acre-ft)
Ocean	8.2	N/A	N/A	N/A
Alternative 1 - Parallel / Second Culvert	7.9	0	0.3	109.7
Alternative 2 - EIR-Conforming Open Channel	7.8	0	0.4	105.0
Alternative 3-Combination Open Channel & Culverts	8.0	0	0.2	110.7
Alternative 4 - Maximum Wetland	8.0	0	0.2	110.7
Post Phase I (Cleaned Culvert and Dredged Lagoon)	5.8	0.5	1.9	73.4

Figure 4-3 shows the inundation frequency in the lagoon under proposed alternatives, post-Phase 1 project condition, and that in the Ocean. The inundation frequency in the lagoon under all proposed alternatives closely mimics the condition in the ocean. However, the low tide is truncated under the post-Phase 1 project condition without proposed improvement to the connection between lagoon and Marina Stadium.

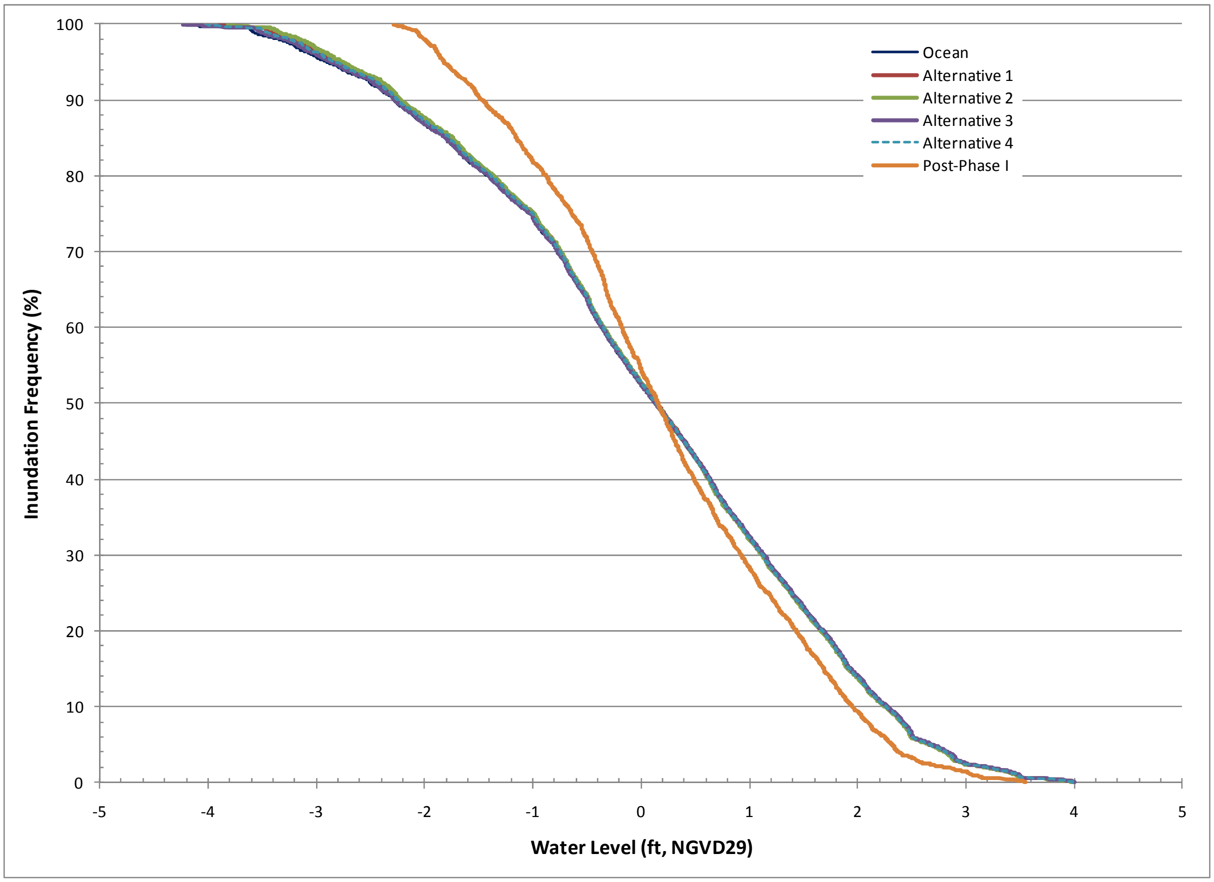


Figure 4-3 Lagoon Inundation Frequency

The velocity in the proposed connection is an important hydraulic parameter for habitat design, fish passage and human safety assessment, channel stability analyses and protection. In the numerical model, the trapezoidal channel section is modeled with a hydraulic equivalent rectangular section to avoid numerical instability. The model predicts the vertical average velocity at each model grid point for each modeling time step. The following table summarizes the peak cross-sectional average velocity under the PMP tide condition and spring tide condition which occurs biweekly. The velocity under the PMP tide condition represents the peak velocity occurring on daily basis.

Table 4-2 Summary of Peak Tidal Velocity

Scenario	Location	Peak PMP Tide Velocity (fps)	Peak Spring Tide Velocity (fps)
Alternative 1 - Parallel / Second Culvert	Existing Culvert	0.7	1.5
	New Culvert	0.9	1.6
Alternative 2 - EIR-Conforming Open Channel	Culvert	1	2.2
	Colorado Bridge	0.7	1.3
	Channel Midway	0.6	1.2
	Eliot St. Bridge	0.9	1.7
Alternative 3-Combination Open Channel & Culverts	Existing Culvert	0.5	1.0
	Colorado Culvert	0.7	1.5
	Channel Midway	0.7	1.8
	Eliot St. Culvert	0.8	1.6
Alternative 4 - Maximum Wetland	Colorado Culvert	0.9	1.7
	Channel Midway	0.5	0.9
	Eliot St. Bridge	0.9	1.6
Post Phase I - Cleaned Culvert & Dredged Lagoon	Existing Culvert	1.8	3.8

4.2 FLOOD HYDRODYNAMIC MODELING RESULTS

For the flood hydrodynamic modeling, the 50-year storm was modeled. The extreme tidal series discussed in Section 3.4.4 was applied in the offshore modeling boundary to drive the numerical model. The input hydrographs are discussed in Section 3.4.5. This section discusses predicted water levels in the lagoon under the extreme tidal condition for both with and without the 50-year storm. The modeling results are summarized in Table 4-3. The water level in the lagoon will reach +6.4 ft under the joint event of a 50-year storm event and an extreme tidal condition. Figure 4-4 shows water level variations under the 50-year storm event in the lagoon. Similar variations occurred for the other three alternatives. All alternatives provide the same efficiency in relieving flood. Table 4-3 also provides water levels under the extreme tidal condition without the 50-year storm event, and the results indicate that there is no tidal muting on high tide in the lagoon. The predicted water levels for the post Phase 1 project condition indicate that the high tide will be muted by 0.2 ft under without flood flow condition; however, the water level in the lagoon will be slightly higher than all proposed alternatives under the 50-yr storm event. Figure 4-5 shows the water level variations in the lagoon under the post Phase 1 project condition. The water level in the lagoon is elevated more and it takes a longer time for the flood water to discharge through the culvert. The proposed connection between the lagoon and Marine Stadium will relief flood flows from lagoon more efficiently.

Table 4-3 Summary of Maximum Water Levels in Lagoon under 50-yr Storm Event

Scenarios Pos	t-Phase 1	Alternative 1	Alternative 2	Alternative 3	Alternative 4
50-Year Storm (ft)	6.5	6.4	6.4	6.4	6.4
No Flood	5.8	6.0	6.0	6.0	6.0

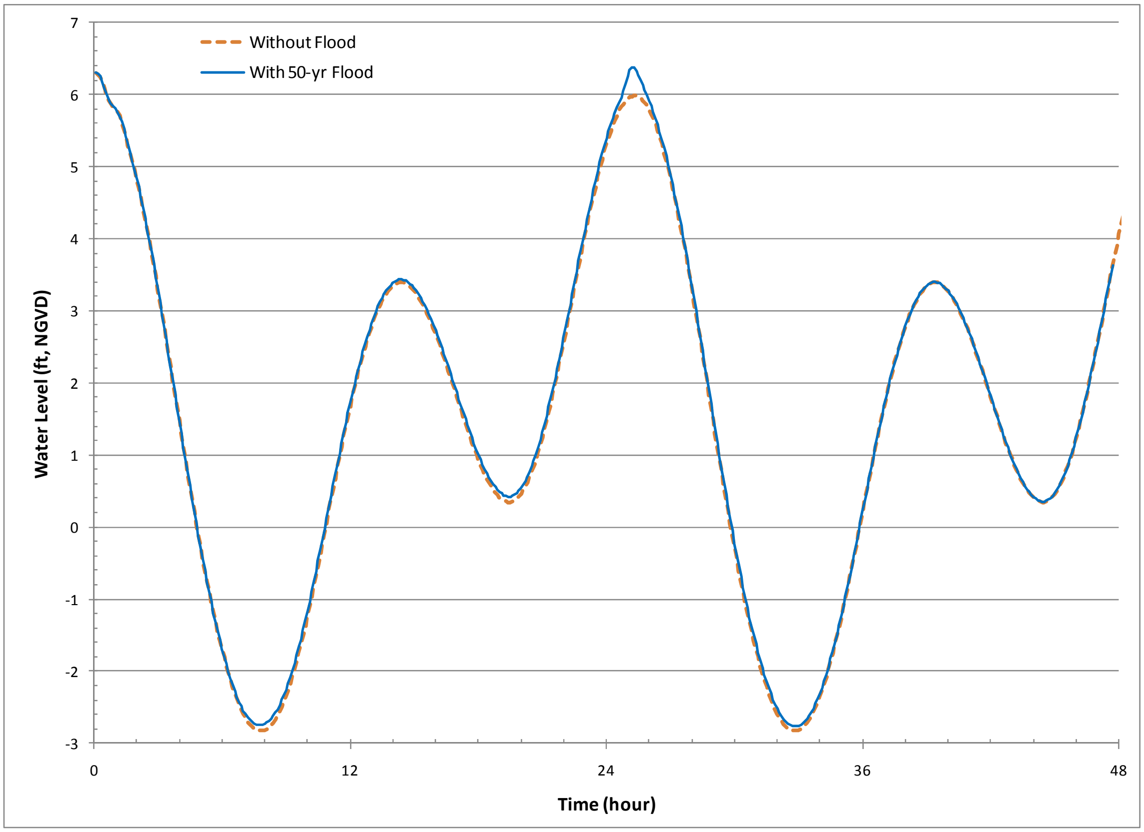


Figure 4-4 Extreme Water Levels for Alternative 2

Modeling runs were also performed to predict potential maximum velocity in the channel under the 50-year storm event. The velocity in the channel will reach the peak value if the peak of the 50-year storm reaches the lagoon at the ebbing tide of the tidal cycle. Table 4-4 summarizes the extreme peak velocity in the channel or culvert under this extreme condition.

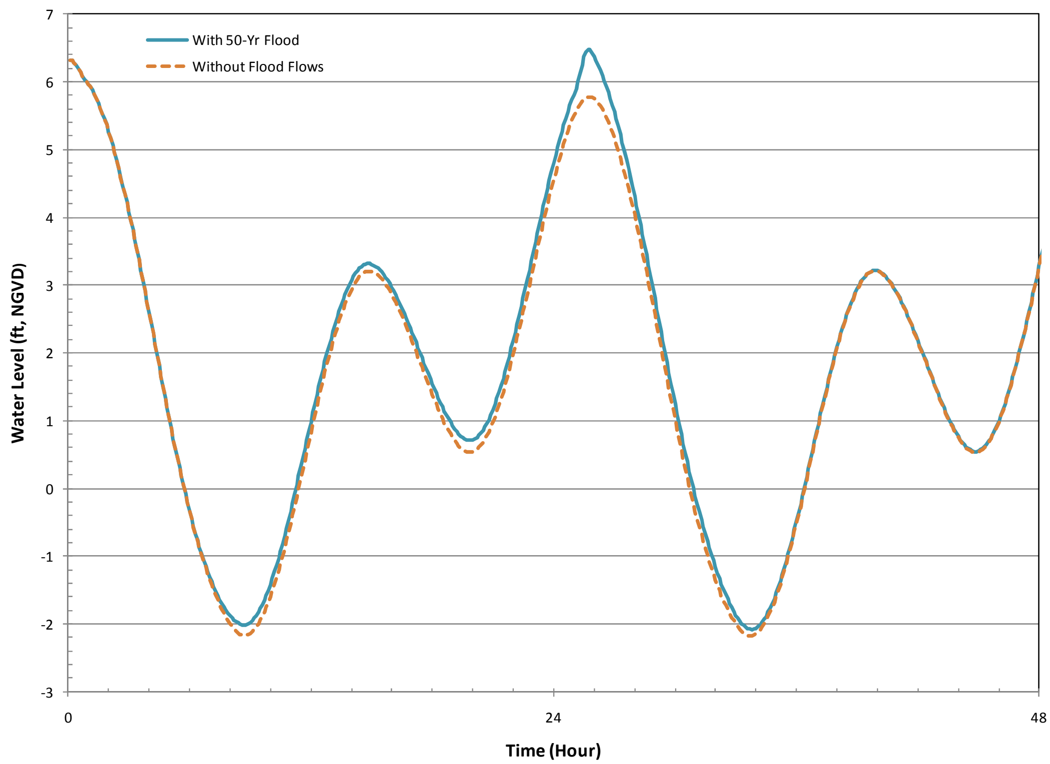


Figure 4-5 Extreme Water Levels for Post Phase 1 Condition

Table 4-4 Summary of Peak Flow Velocity under 50-yr Storm Event

Scenario	Location	Flood Velocity
Alternative 1 - Parallel / Second Culvert	Existing Culvert	2.1
	New Culvert	2.3
Alternative 2 - EIR-Conforming Open Channel	Culvert	2.8
	Colorado Bridge	1.8
	Channel Midway	1.9
	Eliot St. Bridge	2.4
Alternative 3-Combination Open Channel & Culverts	Existing Culvert	1.8
	Colorado Culvert	2.0
	Channel Midway	2.0
	Eliot St. Culvert	2.2
Alternative 4 - Maximum Wetland	Colorado Culvert	2.5
	Channel Midway	1.3
	Eliot St. Bridge	2.3
Post Phase I (Cleaned Culvert and Dredged Lagoon)	Existing Culvert	4.3

4.3 IMPACTS OF SEA LEVEL RISE

As discussed in Section 3 of the main alternative analyses report , the projected sea level rise by 2060 is 1.5 ft. The base flood elevation of + 6.0 ft today will become +7.5 ft by 2060 due to the sea level rise. As discussed in the previous section, the lagoon will receive full ocean tide range under all proposed alternatives; therefore, the extreme high tide in the lagoon will reach +7.5 ft by 2060 with the projected sea level rise. Under a joint event of 50-year storm and extreme high tide, the predicted water level in the lagoon reaches +7.8 ft under the proposed project condition. The storm water level would reach +8.0 ft under the post Phase 1 project condition with Phase 2 project.

Table 4-5 Summary of Water Levels in Lagoon by 2060

Scenarios Pos	t-Phase 1	Alternative 1	Alternative 2	Alternative 3	Alternative 4
50-Year Storm (ft)	8.0	7.8	7.8	7.8	7.8
No Flood	7.3	7.5	7.5	7.5	7.5

5.0 RESIDENCE TIME ANALYSES

5.1 METHDOLOGY DESCRIPTION

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.

5.2 RESIDENCE TIME MODELING RESULTS

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. As there are no data and budget available for RMA4 model calibration, the modeling parameters used were based on literature and past similar project experiences. 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). These affects are not considered in the modeling. The residence times will vary with power plant pumping included. However, the results without pumping are considered sufficient for the purpose of alternative comparisons.

The residence time will also vary under different tide conditions such as spring and neap tide cycles. In this study, a synthetic tidal series representing a long term average tidal condition (PMP tidal series discussed in Section 3.4.2) was used in determining residence times. The residence times are shorter for locations relatively close to the ocean entrance and longer for areas farther upstream such as Colorado Lagoon.

The south end of the Lagoon (near the culvert) and the northwest end of the Marine Stadium, as shown in Figure 4-1, were the locations selected to compare residence times. Residence times at Mother's Beach are also included in the comparison. In general, the northwest end of Marine Stadium represents the best possible condition attainable by the Colorado Lagoon. Table 5-1 summarizes residence times at these locations under the different connection scenarios. The residence time is shortest under the proposed project Phase 2 condition.

Table 5-1 Residence Time Summary under PMP Tide

Modeling Scenarios	Residence Time (days)		
	Colorado Lagoon	Marine Stadium	Mother's Beach
Existing Lagoon and Culvert	8.5	6.9	5.3
Proposed Project Phase 1 - Dredged Lagoon and Cleaned Culvert, No Open Channel	7.7	6.0	4.9
Alternative 1 - Parallel / Second Culvert	7.5	6.0	4.9
Alternative 2 - EIR-Conforming Open Channel	7.2	6.0	4.9
Alternative 3-Combination Open Channel & Culverts	7.4	6.0	4.9
Alternative 4 - Maximum Wetland	7.3	6.0	4.9

The difference between alternatives is small and can be fine tuned to achieve a similar residence time in the lagoon. The residence time differences between Post Phase 1 and Phase 2 projects are relatively small, which is partially contributed to the PMP tidal series used. The PMP tidal series is the average tidal series between the MLLW and MHHW. However, the low tidal muting primarily occurs at the spring low tides for the existing connection. Under the spring tidal condition, the residence time in the lagoon under Post Phase 2 project can be improved more than the existing connection. Table 5-2 presents the residence time predictions following the spring tide series condition. The spring tidal series used are shown in the red box in Figure 3-7.

Table 5-2 Residence Time Summary under TEA Tide

Modeling Scenarios	Residence Time (days)		
	Colorado Lagoon	Marine Stadium	Mother's Beach
Proposed Project Phase 1 - Dredged Lagoon and Cleaned Culvert, No Open Channel	7.1	5.0	3.9
Alternative 2 - EIR-Conforming Open Channel	6.4	5.0	3.9

6.0 SUMMARY

The RMA2 numerical model created and calibrated in the Colorado Lagoon Restoration Feasibility Study (M&N 2004) was modified to reflect the current proposed alternative conditions. The RMA2 and RMA4 models were applied, respectively, to predict: a) tide muting under the average spring tide condition, b) water levels in the lagoon and channels under the 50-yr capital storm event, c) flow velocities in channels/culvert under both tide and storm event conditions, and d) tidal circulation (as measured by residence time) under the average parametric mean periodic tide condition.

Under the existing condition, the model results show that the spring low tides in the Colorado Lagoon are cut off by about 3.1 feet compared to the ocean tide and the spring high tides are muted about 0.7 feet. The existing residence time in the lagoon, for the model conditions, is approximately 1.6 days longer than that at the northwest end of the Marine Stadium. The tidal fluctuations at Marine Stadium are very similar to the ocean, thus indicating the culvert is the restriction on lagoon circulation.

Under the post Phase 1 project condition (Lagoon dredged plus cleaned culvert), the spring low tide is cut off by approximately 1.9 feet compared to the ocean tide, i.e. about one foot less muting than that under the existing condition. The spring high tide elevation in the lagoon is also muted less. The Lagoon residence time for the phase 1 proposed project is approximately 0.8 days shorter than for the existing condition. Residence time in the Marine Stadium and Mother’s Beach is also improved under this scenario.

Under the proposed Phase 2 project condition (Lagoon dredged), both spring high and low tides in the lagoon reach the ocean tide range. All alternatives capable to provide the same full tidal circulation in the lagoon. The tidal prism increases about 50% comparing to the post-Phase 1 project condition. The Lagoon residence time is approximately 1.2 days shorter than that for the existing condition, and about additional 0.4 days shorter than that under post Phase 1 project condition.

Velocities in the existing and proposed culverts are significantly reduced under the Phase 2 project condition, which is beneficial to the fish passage.

7.0 REFERENCES

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