APPENDIX T

Hydrology Report

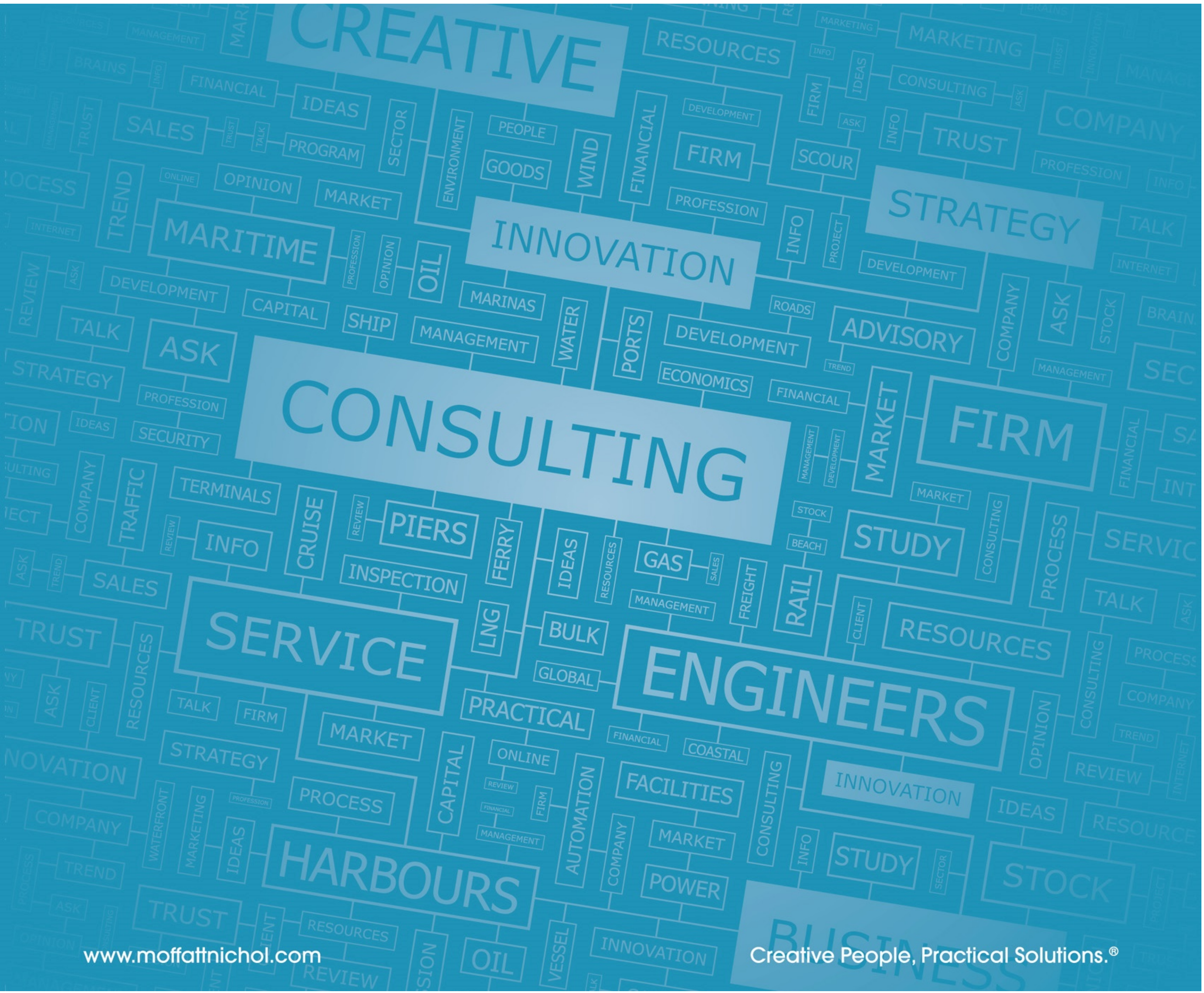
moffatt & nichol

Mission Bay Hydrology Study

Mission Bay PEIR

PRODUCED FOR INTERNAL USE

APRIL 5, 2019



www.moffattnichol.com

Creative People, Practical Solutions.®

Document Verification

Client	City of San Diego and Dudek
Project name	Mission Bay PEIR
Document title	Mission Bay Hydrology Study
Document subtitle	–
Status	Draft Report
Date	5 April 2019
Project number	10278
File reference	

Revision	Description	Issued by	Date	Checked

Produced by:
Moffatt & Nichol
1660 Hotel Circle North, Suite 500
San Diego, CA 92108
T (619) 220-6040
www.moffattnichol.com

Table of Contents

List of Figures

List of Tables

1. Introduction

Moffatt & Nichol (M&N) has been retained by Dudek to perform hydrology and hydrodynamic assessments in Mission Bay (the Bay) that will support preparation of the City of San Diego (City) Mission Bay Park Improvements Program Environmental Impact Report (PEIR). For this purpose, M&N developed a numerical model and conducted simulations of tidal and storm flood hydrodynamics in the Bay. Results from these analyses will serve as a baseline for further evaluation of proposed Mission Bay Park Improvement projects.

1.1. Background

The Mission Bay Park Improvements fund was created in November 2008 to complete a series of capital improvement projects in Mission Bay Park and designated surrounding areas (Improvement Zone). The projects, outlined in the City Charter Section 55.2, include efforts to restore wetlands, wildlife habitat, and other environmental assets; preserve beneficial uses of the Improvement Zone by maintaining navigable water and eliminating navigational hazards; restore embankments and erosion control features; and to improve the conditions of the Improvement Zone for the benefit and enjoyment of residents and visitors.

The City is preparing a Program Environmental Impact Report (PEIR) in accordance with the California Environmental Quality Act (CEQA) for seven prioritized projects (projects) within the Improvement Zone. The environmental document will identify project impacts, determine appropriate mitigation measures, and outline a mitigation and monitoring program that ensures these are effectively implemented.

Preparation of the PEIR warrants hydrology studies of existing conditions in the improvement project areas, and subsequent evaluation of potential impacts to hydrodynamics and water quality of the proposed projects. A component of this effort includes evaluation of feasibility of the projects in terms of habitat creation and coastal resilience.

Four wetland projects and one water quality project are proposed within the prioritized improvement projects. The boundaries of such projects are depicted in Figure 1-1 and a brief description of the projects is provided below.

- Rose Creek Wetland. Enclosed in the dark blue polygon in Figure 1-1, this project encompasses approximately 100 acres of wetland at the mouth of Rose Creek, at the current Campland-by the-Bay location, and adjacent to the existing Kendall-Frost Northern Wildlife Preserve.
- North Fiesta Island Wetland. Proposed as a control habitat area, around 16 acres of new wetland will be created as a buffer to the preserve to the south. Alternatives to improve tidal circulation and water quality in Mission Bay are also proposed for this project. The project footprint for the North Fiesta Island wetland is delimited as a light blue in Figure 1-1.
- Cudahy Creek Wetland. Approximately 5 acres of wetland are proposed at the location of two large storm drain outfalls north of Leisure Lagoon (yellow polygon in Figure 1-1). Design for this wetland will incorporate a bypass system for the storm drain outlets.

- Tecolote Creek Wetland and Fiesta Island Causeway. Approximately 12 acres of wetland (enclosed in the red polygon in Figure 1.1) will be created at the mouth of Tecolote Creek. A water quality project is also proposed at this location. The Mission Bay Master Plan and the Fiesta Island General Development Plan discuss installation of one-way tidal culverts beneath the Fiesta Island causeway. The culverts would theoretically improve circulation in the area by taking advantage of any time lag between tides on either side of the causeway and provide one way "pulses" of clean water from the south side of the causeway to the north side.

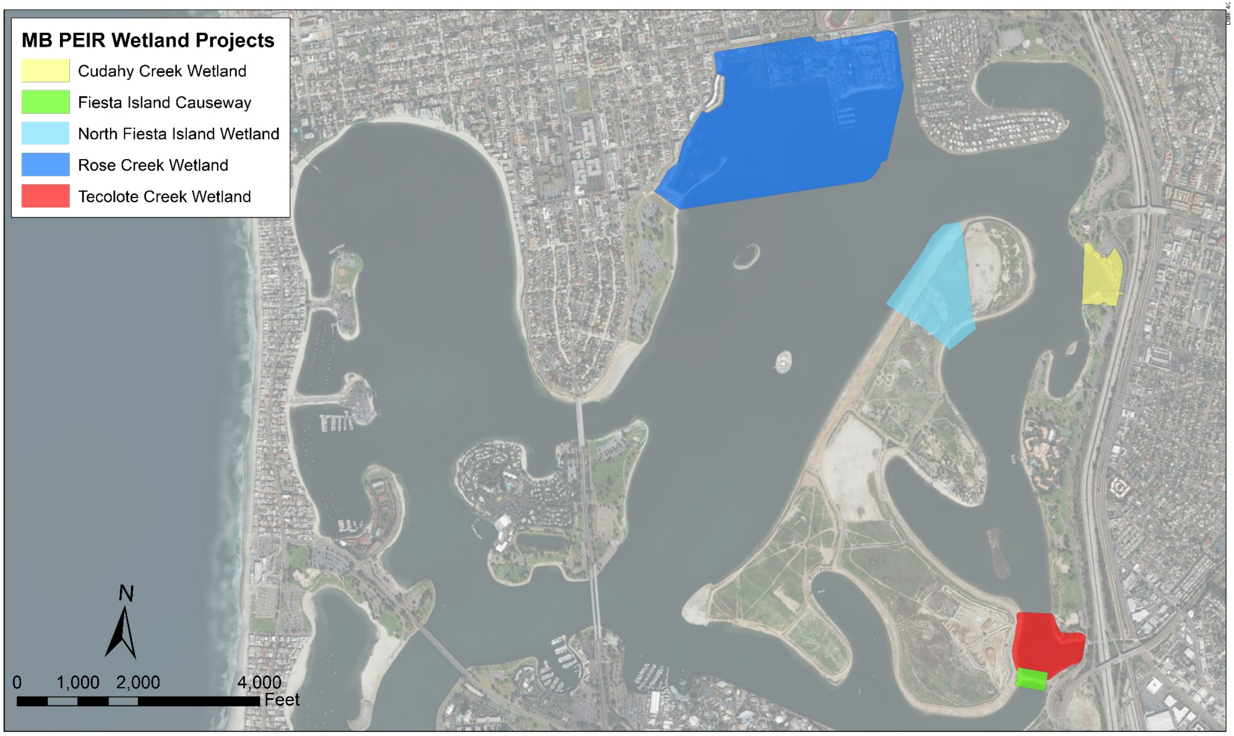


FIGURE 1-1 MISSION BAY PEIR WETLAND AND WATER QUALITY PROJECT BOUNDARIES

1.2. Scope of Work

The purpose of this study is to analyze tidal and storm flood hydrodynamics in Mission Bay, focusing on the proposed wetland and water quality project locations. Formulation of baseline conditions from these analyses will support subsequent studies required for preparation of the PEIR.

The scope of work for the present study includes the following:

1. Numerical model development: A two-dimensional hydrodynamic model of Mission Bay was developed with the use of diverse bathymetric and topographic data sets. Details on model development can be found in Chapter 2.

2. Data collection and Model Calibration: Water levels in Mission Bay are being monitored by means of tide-gauges installed by MN at four strategic locations in Mission Bay. The Mission Bay hydrodynamic model was run iteratively to achieve calibration of the modeled water levels to measured data. Chapters 3 and 4 summarize these efforts.

3. Tidal and storm flood hydrodynamic analysis. The calibrated model was used to evaluate hydrodynamics under typical dry weather conditions (no fresh-water input) and under the 100-year wet weather conditions (fresh-water input from Rose Creek and Tecolote Creek).

2. Model Development

2.1. Model Description

Adaptive Hydrodynamics (AdH) is a state-of-the-art numerical modeling system developed by the Coastal Hydrodynamics Laboratory (CHL) ERDC, USACE[1], that performs simulations of a wide-range of flow conditions, including saturated and unsaturated groundwater flow, overland flow, and shallow water problems. AdH can also simulate the transport of conservative tracers, salinity, water temperature and sediment transport coupled to bed and hydrodynamic changes.

AdH has the capability to be run in three dimensions, however for this study a two-dimensional model which utilizes the two-dimensional shallow water equations under the assumption of hydrostatic pressure, was used to assess tidal and storm flood hydrodynamics in the study area. Numerically, the partial differential equations are solved by finite differences once they are discretized in space with the use of an unstructured computational mesh composed of triangular grid cells, or elements.

The adaptive feature of AdH consists of its ability to dynamically refine and relax both spatial (i.e. the computational mesh) and temporal (i.e. the computational time step) resolutions. This feature allows for optimization of both model accuracy and computational effort.

2.2. Model Domain

The computational domain for the Mission Bay Model (MBM, Figure 2-1) encompasses Mission Bay and San Diego River areas extending inland up to approximately the +15ft (NGVD29) elevation contour, such that both tidal and storm flood flows can be accounted for. To the west, the model encompasses Mission Beach and Ocean Beach, and extends about 2 miles offshore.

The computational mesh is composed of 47,061 triangular grid cell elements, with a resolution that varies throughout the domain, in order to adequately capture important topographic and bathymetric features in Mission Bay (e.g. causeways, channels, jetties), but at the same time ensure computational efficiency. A grid cell resolution of up to around 40 feet was defined for areas requiring a high level of detail to resolve the flow conditions.

The main open boundaries of the model are depicted in Figure 2-1. To force the model, a water level condition is imposed at its 9-mile long offshore boundary. For wet weather simulations, discharge boundaries are defined at the upstream-most locations of Rose Creek and Tecolote Creek, the principal sources of fresh water; as well as at the locations of the main storm drains that contribute flows to Mission Bay.

[1]Engineer Research and Development Center, US Army Corps of Engineers.

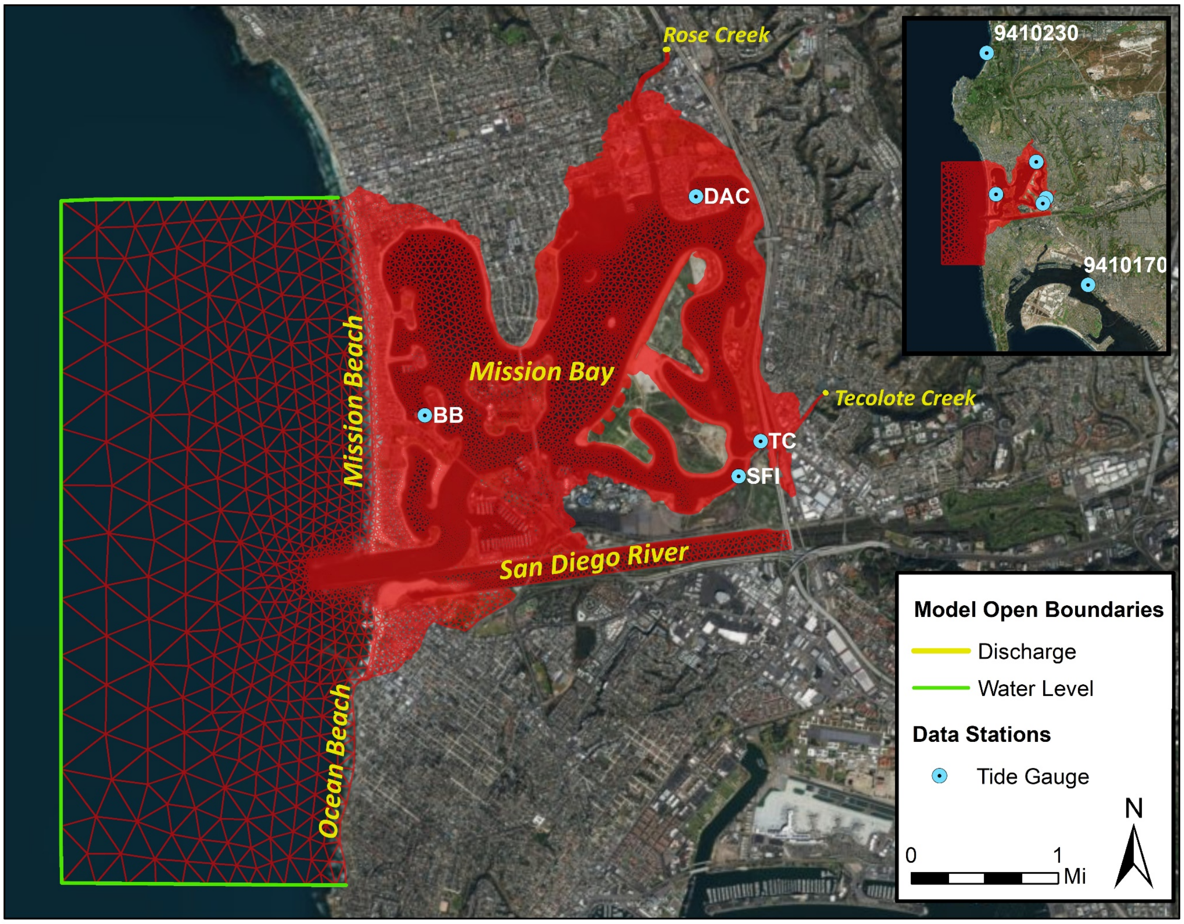


FIGURE 2-1 MODEL DOMAIN AND WATER LEVEL DATA STATIONS FOR THE MISSION BAY MODEL

2.3. Model Bathymetry

Bathymetric and topographic data from different sources were compiled and processed to cover the entire computational domain with adequate resolution. All data sets were adjusted to the NGVD29 vertical datum and projected to NAD83 California State Plane: Zone 6.

A list of the data sets and sources included in the Mission Bay Model are provided in Table 1. Bathymetry within Mission Bay was defined with the use of survey data (Table 1 No. 1) covering the Mission Bay Entrance Channel, subtidal and lower intertidal areas in Mission Bay, and Rose Creek. Bathymetric changes from dredging activities conducted in 2018 as part of the City's Mission Bay Navigational Safety Dredging Project were also incorporated in the model bathymetry (Table 1 No. 2).

The USGS CoSMoS DEM (Table 1 No. 3) was used to define elevations of upland areas, open-coast nearshore and offshore areas, as well as the San Diego River and Tecolote Creek. To fulfil a data coverage gap between data sets, the mouth of Tecolote Creek was surveyed in December 2018 (Table 1 No. 4) as part of this study.

TABLE 2-1 BATHYMETRYC AND TOPOGRAPHIC DATA SOURCES FOR THE MISSION BAY MODEL.

No.	Data Set	Source
1	Coastal Storm Modeling System (CoSMoS) for Southern California, V3.0 Phase 2. Digital Elevation Model (DEM).	USGS, 2018
2	Mission Bay Bathymetric Survey, 2013.	Merkel & Associates, 2015
3	Mission Bay Post-Dredge Bathymetric Survey, 2018.	Merkel & Associates, Oday Consultants, 2018
4	Tecolote Creek Channel Bed Survey, December 20, 2018.	Stuart Engineering, 2018

Figure 2-2 and Figure 2-3 depict the interpolated model bathymetry for the entire modeling domain, and for the Mission Bay Area, respectively. Overall, the seabed in Mission Bay is relatively flat and shallow, with typical water depths ranging from 10 to 12 feet (with respect to the NGVD29 Datum). Due to the dredging operations conducted in recent years, several mid-bay locations exhibit greater depths (up to about 22 feet below NGVD29). The Entrance Channel and the two basins located to its west and east (Quivira Basin, and Mariners Basin, respectively) constitute the deepest areas in the bay, with depths ranging from 18 to 27 feet (NGVD29).

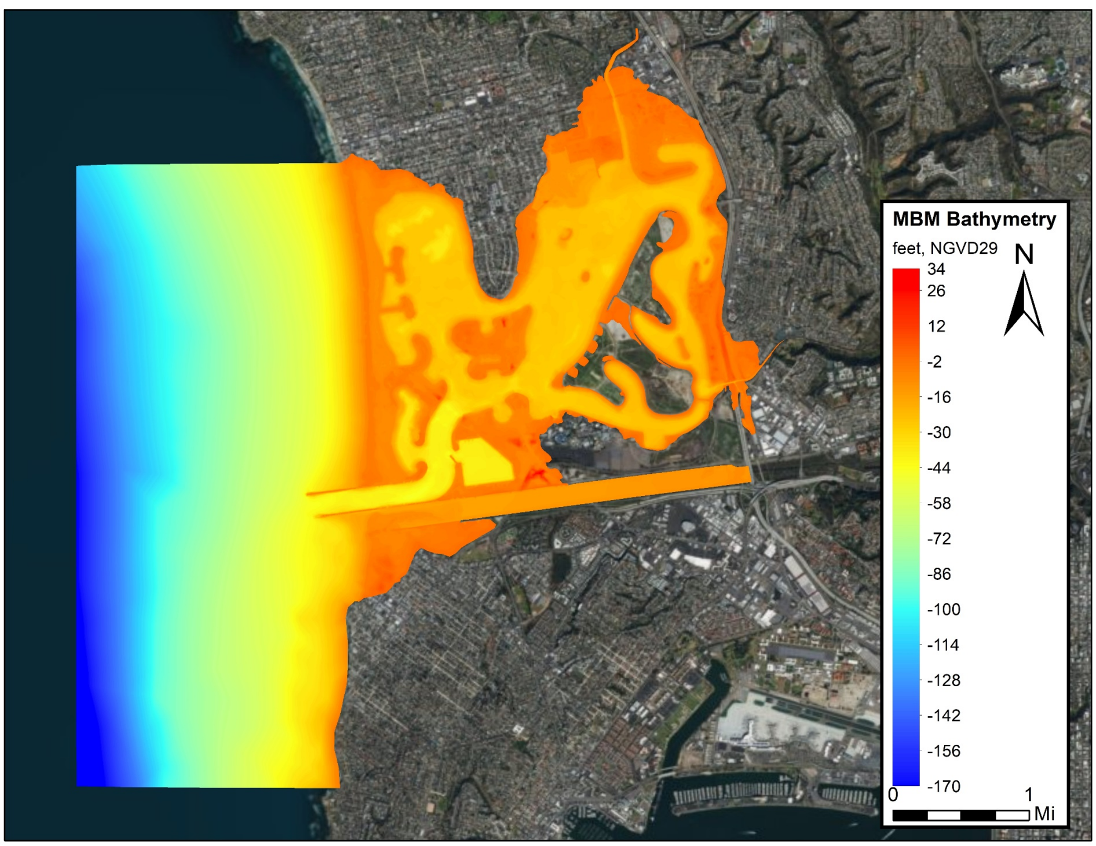


FIGURE 2-2 MISSION BAY MODEL BATHYMETRY

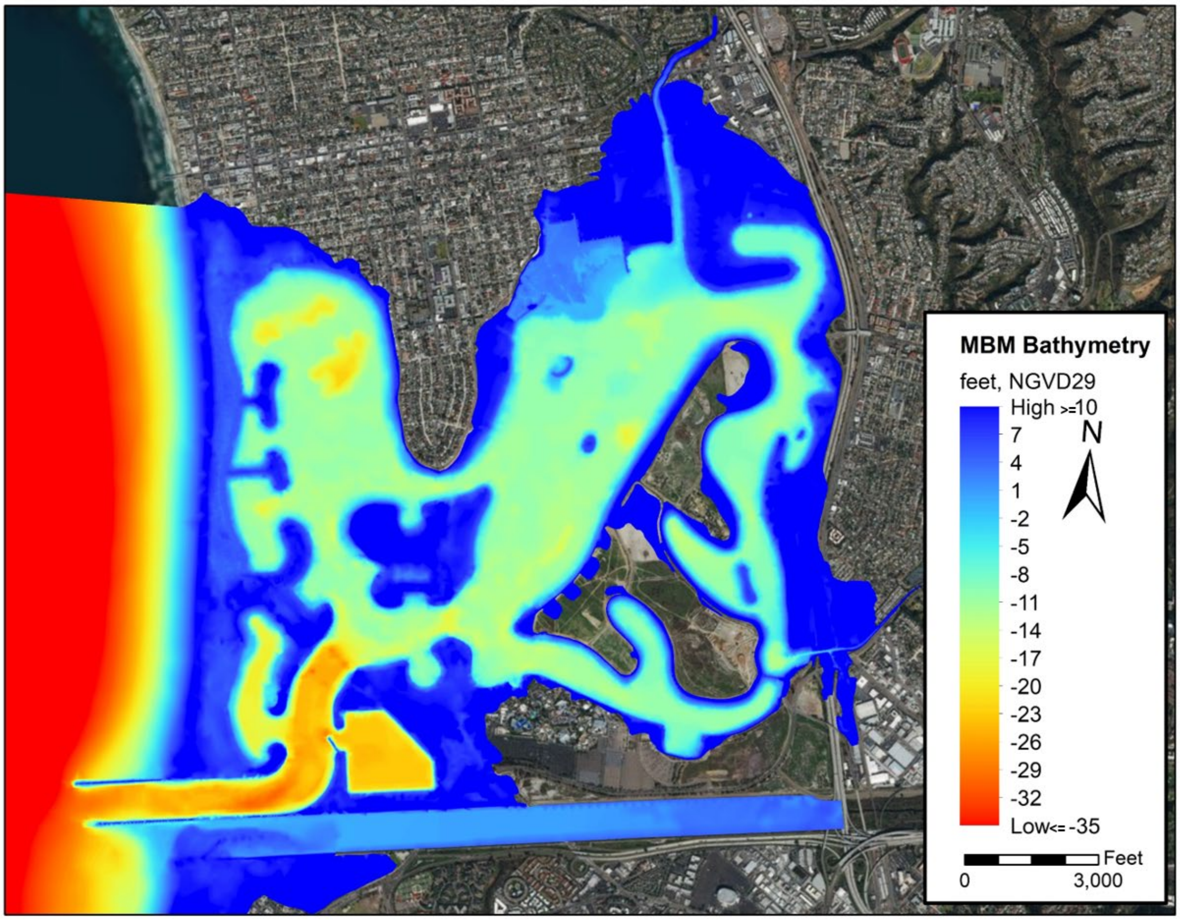


FIGURE 2-3 BATHYMETRY WITHIN MISSION BAY

3. Data Collection

To support hydrology studies required for preparation of the Mission Bay PEIR, M&N has installed tide gauges to record water levels in Mission Bay. A brief discussion on this data collection effort is provided below.

Tide gauges were installed at four locations in Mission Bay between August 29th, 2018 and October 11th, 2018. Table 3-1 and Figure 2-1 provide the locations of the pressure sensors. These locations were selected with the aim of gaining insight on how tides propagate in and out of Mission Bay. Of particular interest were the potential tide-phase differences North and South of the Fiesta Island Causeway, discussed in Section 1.1, which would be reflected as a time lag between High and Low tides at the Tecolote Creek (TC) and South Fiesta Island (SFI) stations.

TABLE 3-1 WATER LEVEL DATA STATIONS

Longitude	Latitude	Station Name	Measurement Type	Installation Date	Source
-117.2471°	32.7729°	Bahia Bay (BB)	Water Level	10/11/2018	M&N
-117.2156°	32.7948	De Anza Cove (DAC)	Water Level	09/28/2015	M&N
-117.2078°	32.7707	Tecolote Creek (TC)	Water Level	08/29/2018	M&N
-117.2104°	32.7672	South Fiesta Island (SFI)	Water Level	08/29/2018	M&N

The pressure sensors built in the tide gauges are set up to record the time-varying water depth at 6-minute intervals. Each tide gauge is secured to a steel post, previously driven into the seabed (see Figure 3-1), this mooring configuration allows for an easy access to remove and re-install the instruments for data-retrieval purposes. Prior to removal of the tide gauges, water levels at each location are surveyed (Figure 3-1) to accurately correct the water depth records into water surface elevation records.

Water level records for all Mission Bay tide gauge stations as of December 22nd, 2018 are provided in Appendix A. detailed discussion of water levels in Mission Bay is provided in Chapter 5.

FIGURE 3-1 STEEL POST AT DE ANZA COVE DURING A SPRING-LOW TIDE (LEFT), WATER LEVEL SURVEY AT SOUTH FIESTA ISLAND (RIGHT).

4. Model Calibration

4.1. Introduction

Prior to conducting tidal and storm-flood hydrodynamic assessments, the Mission Bay Model was calibrated to water level measurements, available from the tide gauge stations discussed in Section 3 (Figure 2-1 and Table 3-1). Model Calibration consisted of performing a series of iterative simulations, where calibration parameters for water levels, namely bed roughness coefficients, were adjusted systematically until the modeled data was found to be in good agreement with measured data. The following sections discuss the assumptions and summarize results of the calibration effort.

4.2. Simulation Boundary Conditions

4.2.1. Water Levels

Water level records from NOAA-NDBC are available from two locations near Mission Bay. The San Diego Bay station (9410170, see Figure 2-1), located approximately 6 miles Southeast of the Mission Bay Entrance Channel, and the La Jolla station (9410230, Figure 2-1), about 8 miles North of the Channel. Table 4-1 provides the tidal datums for each station per NOAA-NDBC (2019). A larger diurnal range (MHHW to MWLL) of 5.72 ft is observed in San Diego Bay, compared to that near La Jolla station which is 5.32 ft.

TABLE 4-1 TIDAL DATUMS IN FEET (NGVD29), PRESENT TIDAL EPOCH (1983-2001)

Datum	San Diego Bay (9410170)	La Jolla (9410230)
Highest Astronomical Tide (HAT)	+5.20	+4.82
Mean Higher High Water (MHHW)	+3.20	+3.00
Mean High Water (MHW)	+2.47	+2.28
Mean Tide Level (MTL)	+0.44	+0.43
Mean Sea Level (MSL)	+0.42	+0.41
National Geodetic Vertical Datum of 1929 (NGVD29)	0.00	0.00
Mean Low Water (MLW)	-1.58	-1.42
North American Vertical Datum of 1988 (NAVD88)	-2.09	-2.13
Mean Lower-Low Water (MLLW)	-2.52	-2.32
Lowest Astronomical Tide (LAT)	-5.61	-4.20

Figure 4-1 compares water levels from La Jolla, and San Diego Bay during spring and neap tides in October 2018. Water levels from the Bahia Bay (closest to the Entrance to Mission Bay) station are also plotted as reference. While neap tide elevations are not considerably different among stations, a more discernable difference is observed between spring high tides at San Diego Bay and La Jolla (up to about 0.3 feet). Additionally, with the exception of the spring low tides, water levels at Bahia Bay resemble more closely those at La Jolla.

Records from La Jolla were selected to be imposed as the forcing condition at the offshore boundaries of the model for calibration, as well as for subsequent simulations, as they are representative of tides in the open ocean, therefore resembling more closely the offshore tidal conditions. The larger tidal amplitudes in San Diego Bay could be the result of tidal constriction, reflection and/or other amplification processes occurring in the Bay. Therefore, assuming these as the tidal boundary conditions would introduce an error in the modeling results.

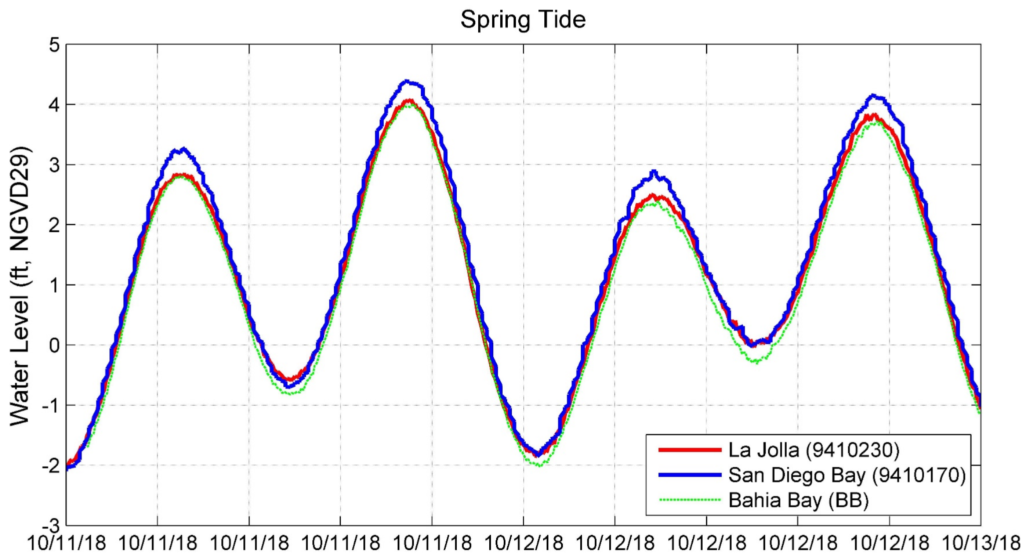


FIGURE 4-1 SPRING TIDES AT A JOLLA, SAN DIEGO BAY AND BAHIA BAY STATIONS

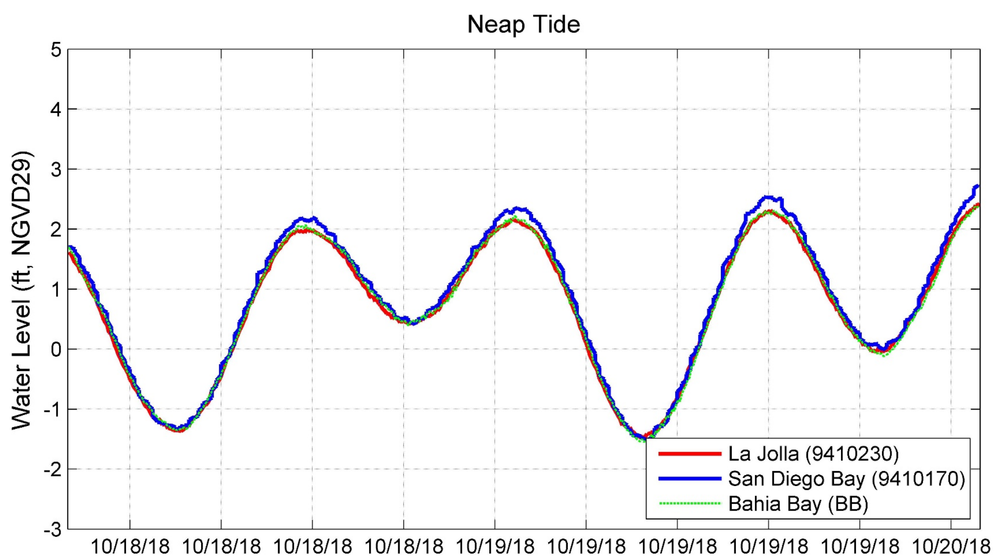


FIGURE 4-2 NEAP TIDES AT LA JOLLA, SAN DIEGO BAY AND BAHIA BAY STATIONS

Based on availability of data for all water level data stations at the time of model calibration, a 17-day simulation period, encompassing a spring-neap tidal cycle, was set for the calibration runs from October 7th, 2018 to October 24th, 2018.

The imposed boundary condition is depicted in Figure 4-3. Non-astronomical components are captured in the record, which result in a mild positive surge (i.e. measured water level above predicted water level) of about 0.7 feet between October 11th and October 12th.

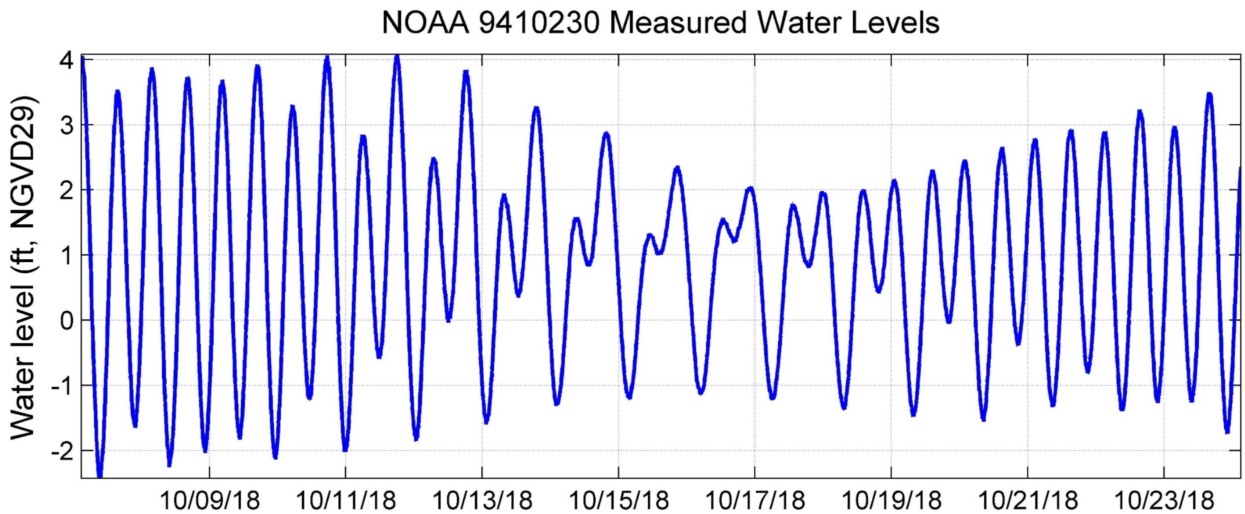


FIGURE 4-3 WATER LEVEL BOUNDARY CONDITION FOR MODEL CALIBRATION

4.3. Fresh Water Inflows

No runoff from Rose Creek and Tecolote Creek was assumed for calibration simulations.

4.4. Water Level Calibration Results

As mentioned above, water level calibration for the Mission Bay Model was achieved by adjusting the values for bed roughness, which is associated with the drag exerted to the flow. Bed roughness was specified by means of the Manning's coefficient (*n*), which ranges from 0.011 to 0.075, or higher for natural rivers or estuaries (Chaudhry, 1993). Relatively high values are specified for rough surfaces, such as channels with cobbles or large boulders, while low values are specified for smooth surfaces, such as concrete, cement or wood channels. A spatially varying bed roughness was specified in the model, in order to more adequately reproduce flow properties through the different environments in the domain. The values for Manning's coefficient *n*, which deemed an adequate calibration to water levels, are listed in Table 2-3.

TABLE 4-2 CALIBRATED BED ROUGHNESS COEFFICIENTS FOR THE MISSION BAY MODEL

Model Environment	Manning's *n*
Offshore Area	0.025
Nearshore Areas (Open coast)	0.025
Entrance Channel (Riprap on banks)	0.037
Intertidal and Subtidal areas (Mission Bay and San Diego River)	0.020
Low to High Marsh (Kendal-Frost Marsh)	0.025
Upland	0.045

A comparison between measured and modeled water levels at the different calibration stations is depicted in Figure 2-5 and Figure 2-6. These figures show that the calibrated model closely reproduce the observed water level variations.

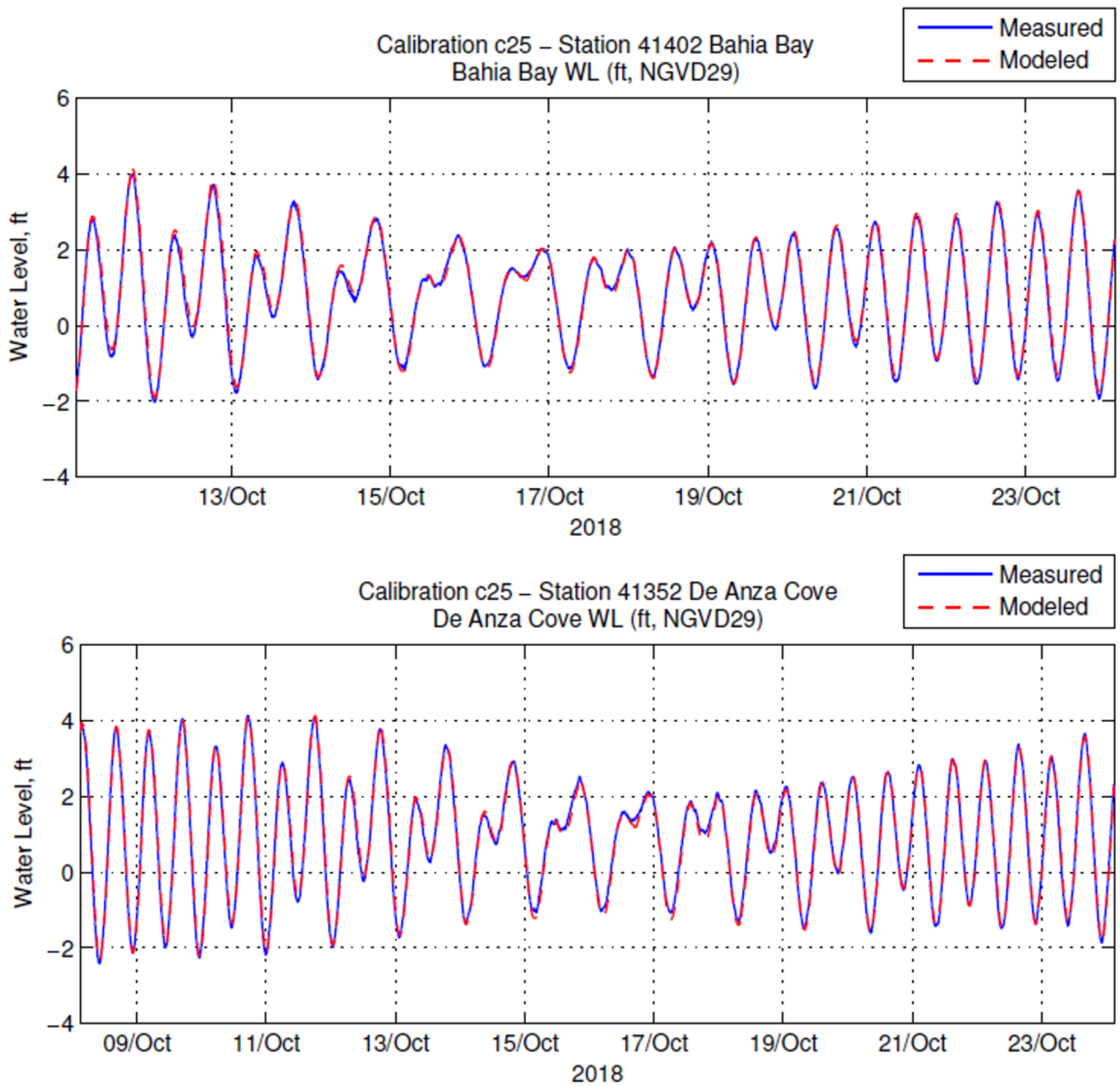


FIGURE 4-4 MEASURED VS MODELED WATER LEVELS IN BAHIA BAY AND DE ANZA COVE

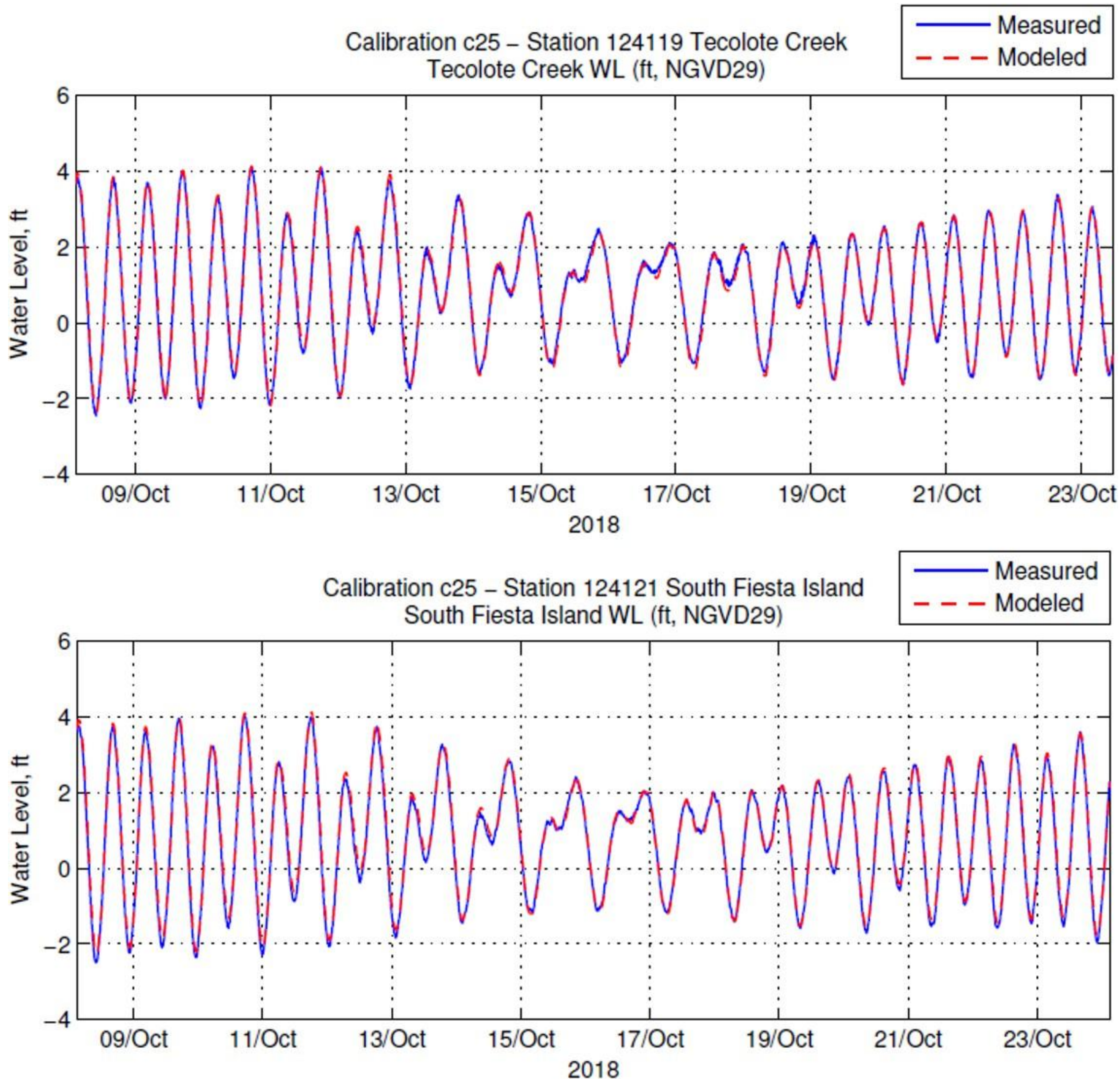


FIGURE 4-5 MEASURED VS MODELED WATER LEVELS IN TECOLOTE CREEK AND SOUTH FIESTA ISLAND

In order to quantify the agreement between measured and modeled data, the following statistical parameters were determined:

- Root Mean Squared Error (RMSE, ft) $\varepsilon_{RMS} = \sqrt{\overline{(x-y)^2}}$
- Mean Absolute Error (MAE,ft) $MAE = \overline{|x-y|}$
- Correlation Coefficient (R) $MAE = \overline{|x-y|}$
- Model Prediction Capability Index (d) $d = 1 - \frac{\overline{(x-y)^2}}{\overline{(|x-\bar{x}|-|y-\bar{x}|)^2}}$

Where x and y represent the measured and modeled water level data, respectively. Results are provided in Table 2-4. Correlation coefficients (R) and prediction capability indices (d) of 1.00 confirm the accuracy of the modeled water levels.

TABLE 4-3 STATISTICAL WATER LEVEL CALIBRATION PARAMETERS

Parameter	Bahia Bay	De Anza Cove	Tecolote Creek	South Fiesta Island
RMSE (ft)	0.14	0.13	0.14	0.15
MAE (ft)	0.11	0.10	0.11	0.12
R (-)	1.00	1.00	1.00	1.00
D (-)	1.00	1.00	1.00	1.00

5. Tidal and Storm Flood Hydrodynamics in Mission Bay

5.1. Introduction

Once calibration of modeled water levels was deemed accurate, tidal and storm flood hydrodynamics in Mission Bay were assessed with two sets of simulations representing typical tide conditions during the dry season (no freshwater inflow) and extreme storm flood conditions (freshwater inflow from Rose Creek and Tecolote Creek).

Simulations of typical tide conditions are intended to provide insight on tidal propagation and circulation in Mission Bay. Assessment of water levels and determination of tidal inundation frequency throughout the Bay is essential to establish potential habitat distribution for the proposed wetlands. Simulation of extreme storm flood conditions are primarily intended to identify peak flow velocities under a 100-year fluvial flood event; determining flow velocity distribution during such an event will support delineation and design of the proposed wetlands.

5.2. Tidal Hydrodynamics Simulations

For a detailed assessment of hydrodynamics, modeled water levels and currents were extracted at six locations throughout Mission Bay, with one in the ocean. As depicted in Figure 5-1, five of these locations are within the footprint of the proposed marsh and water quality projects.

FIGURE 5-1 DATA EXTRACTION LOCATIONS FOR TIDAL HYDRODYNAMIC SIMULATIONS

5.2.1. Simulation Boundary Conditions

5.2.1.1. Water Levels

As discussed in Section 4.2.1, water levels from NOAA-NDBC station 9410230 (La Jolla) were concluded to better represent the offshore tides required to force the hydrodynamic model. The next step for analyzing tidal hydrodynamics in Mission Bay was finding a period in the record in which tides were representative of long-term average conditions. Tidal amplitudes vary throughout the year; as a minimum, a spring-neap tidal cycle, (i.e. about 15 days) is required to assess the range of tidal amplitudes resulting from the shift in alignment of the moon with respect to the earth and sun. Also affecting tidal amplitudes in a longer time scale are annual variations in solar declination, and an18.6-year cycle of lunar nodes. Moreover, superimposed to the astronomical components of the recorded tides are other meteorological components, from short scale barometric pressure tides to interanual processes such as El Niño, and the long-term trend in eustatic Sea Level Rise.

To find a representative tide period, published monthly maximum and minimum tidal elevations at La Jolla from January 2008 to December 2018 representing spring high and low tide elevations were analyzed. A representative spring high tide elevation was found by averaging monthly maximum tide elevations for the 10-year record, while the representative spring-low tide elevation was similarly found by averaging all minimum low tide elevations. The water level records for the La Jolla station were then inspected to identify a period with similar spring-high and low tidal elevations. Spring tides occurring June 14th to June 16th, 2011 reached nearly equivalent elevations. The spring-neap tidal cycle from June 7, 2011 to June 21, 2011 (depicted in Figure 5-1) was then assumed to be representative of long-term average conditions and was used as the tidal boundary condition for the hydrodynamic model.

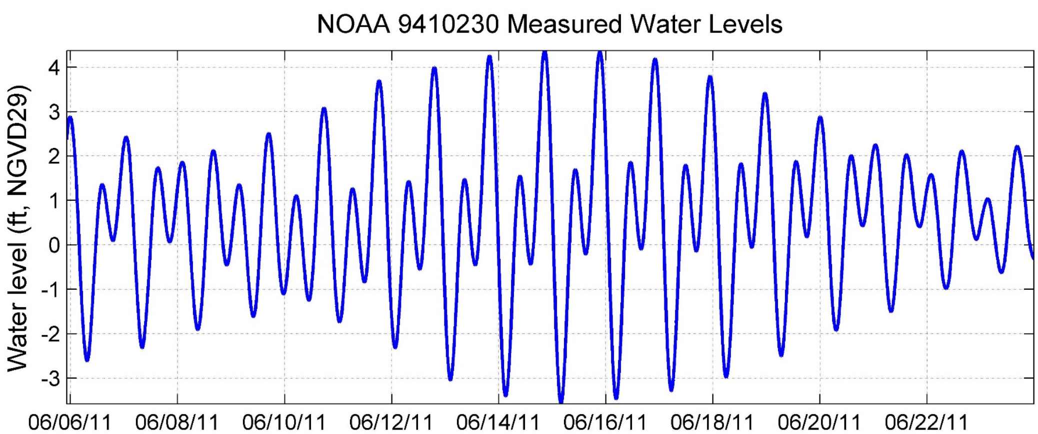


FIGURE 5-2 WATER LEVEL BOUNDARY CONDITION FOR TIDAL HYDRODYNAMICS SIMULATIONS

5.2.2. Fresh Water Inflows

No runoff from Rose Creek or Tecolote Creek was assumed for the tidal hydrodynamics simulations.

5.2.3. Simulation Results.

5.2.3.1. Water Levels.

Similar to the offshore conditions, tides in Mission Bay are mixed semidiurnal with two unequal high and low tides per lunar day. Both mean diurnal high water and low water inequalities, i.e. the average difference between the two high and the two low waters of each tidal day respectively, are about 1.0 foot.

Comparison of modeled water levels indicate that there is no tidal muting in Mission Bay. Table 5-1 lists modeled spring high and spring low tide elevations (i.e. the maximum and minimum water levels through the entire simulation) at each of the data extraction locations. Not only do tides in the Bay reach the same elevations as the open ocean tides, there is a small but consistent amplification of the tidal amplitudes which increase with increasing distance to the Entrance Channel. The spring tidal range for Tecolote Creek, furthest from the entrance, is about 0.2 feet larger than that for the open ocean. Although small in magnitude, and negligible for wetland delineation and other project considerations, this amplification of tidal amplitudes is strongest during spring tides (depicted for the Offshore and Tecolote Creek areas in Figure 5-3) and minimum during neap tides (Figure 5-4), however it is present throughout the 15 day tidal-cycle, as indicated in Table 5-2, which provides the estimated MHHW and MLLW datums, and diurnal ranges (MHHW to MLLW) based on simulation results.

TABLE 5-1 SPRING HIGH AND LOW WATER ELEVATIONS IN MISSION BAY

Station	Spring High Tide (ft, NGVD29)	Spring Low Tide (ft, NGVD29)	Spring Tidal Range (ft)	Spring High Tide (Time, UTC)	Spring Low Tide (Time, UTC)
Offshore (Open Ocean)	4.38	-3.58	7.95	6/14/2011 20:37	6/15/2011 3:54
Entrance Channel	4.42	-3.63	8.05	6/14/2011 20:37	6/15/2011 4:00
Rose Creek/ N. Fiesta Is.	4.47	-3.72	8.19	6/14/2011 20:37	6/15/2011 4:12
Cudahy Creek	4.48	-3.74	8.21	6/14/2011 20:37	6/15/2011 4:12
Tecolote Creek	4.48	-3.74	8.22	6/14/2011 20:37	6/15/2011 4:12
South Fiesta Island	4.46	-3.69	8.15	6/14/2011 20:37	6/15/2011 4:12

TABLE 5-2 MHHW AND MLLW DATUMS ESTIMATED FROM MODEL RESULTS

Station	MHHW (ft, NGVD29)	MLLW (ft, NGVD29)	Diurnal Range (ft)
Offshore	3.36	-2.41	5.77
Entrance Channel	3.40	-2.44	5.83
Rose Creek / N. Fiesta Is.	3.45	-2.46	5.91
Cudahy Creek	3.46	-2.48	5.94
Tecolote Creek	3.46	-2.48	5.94

South Fiesta Island	3.44	-2.46	5.90

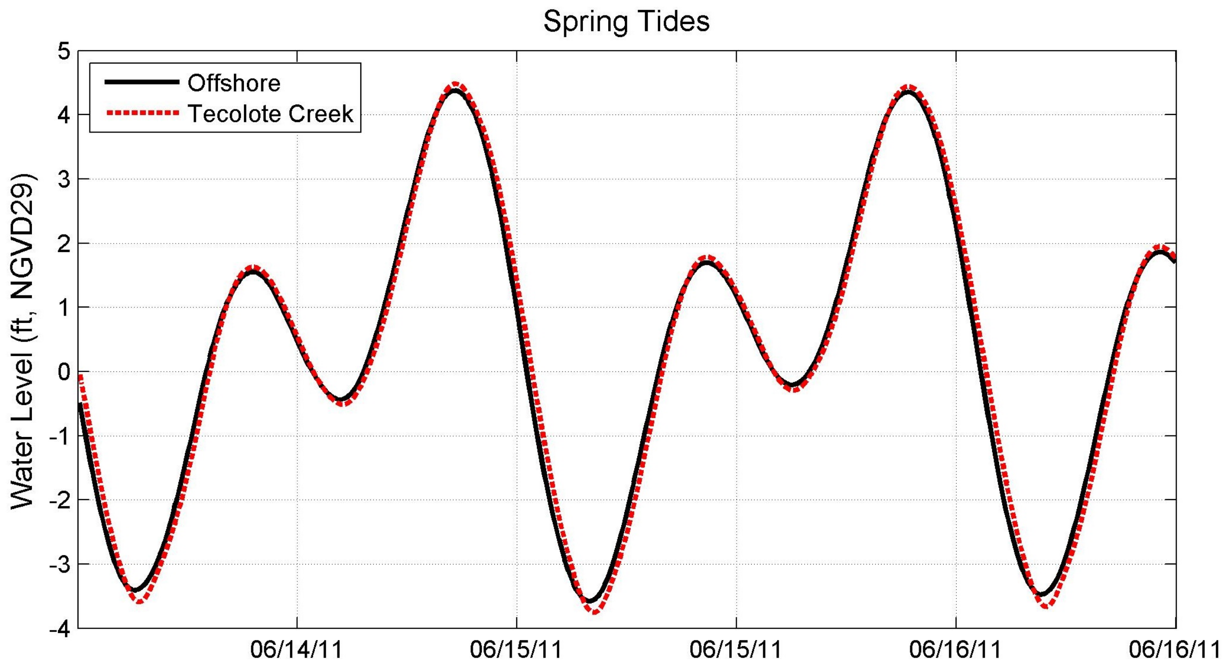


FIGURE 5-5-3 MODELED SPRING TIDES OFFSHORE, AND AT TECOLOTE CREEK.

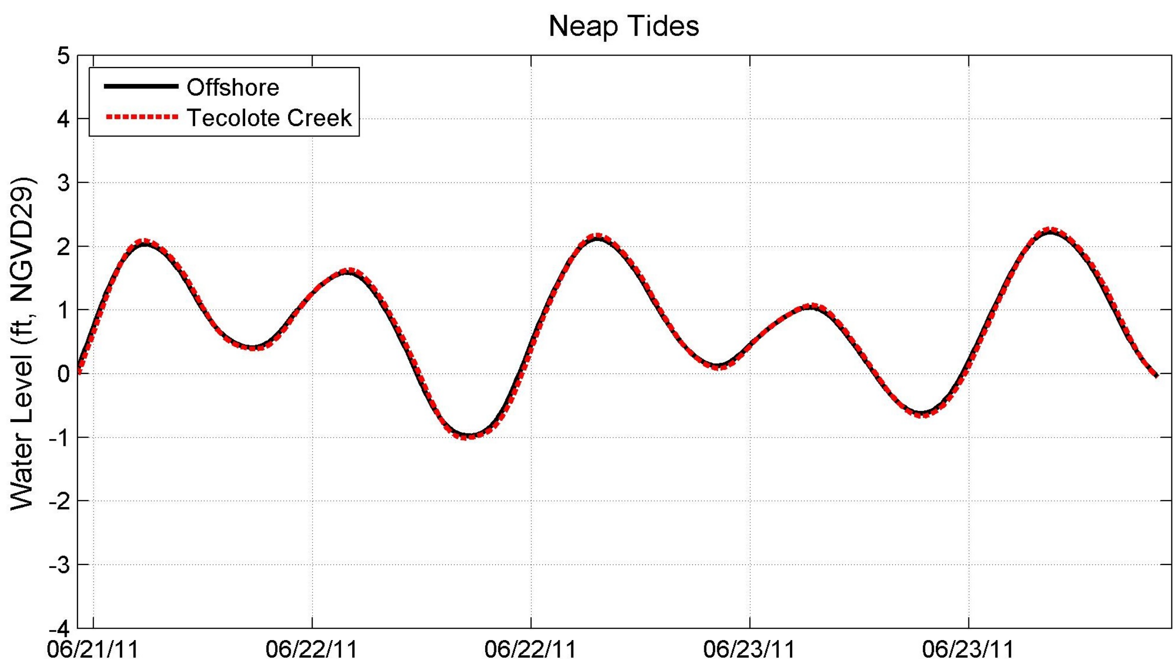


FIGURE 5-4 MODELED NEAP TIDES OFFSHORE, AND AT TECOLOTE CREEK.

Also listed in Table 5-1 are the times of Spring High and Low tides at each data extraction location. Similar to the rest of the daily high tides, spring highs occur simultaneously throughout the Bay. This could be explained by the length-scales of the Bay with respect to that of the tides. Mission Bay constitutes a short and narrow basin, and as the tide passes its entrance, water levels in the Bay immediately follow water levels in the open ocean. Some reflection of the tidal energy occurs at the landward boundaries of the Bay which result in the slight amplification of tidal amplitudes discussed above, and could give rise to secondary effects leading to the observed lag between low tides at East Mission Bay (Rose Creek, Cudahy Creek, Tecolote Creek and South Fiesta Island locations) with respect to the open ocean. Again, the time difference between low tides is largest during spring tides and minimum during neap tides.

No lags were found between high and low tides at either side of the Fiesta Island Causeway, as depicted in Figure 5-4. Furthermore, as indicated in Table 5-1, the difference between tidal amplitudes at these locations is negligible.

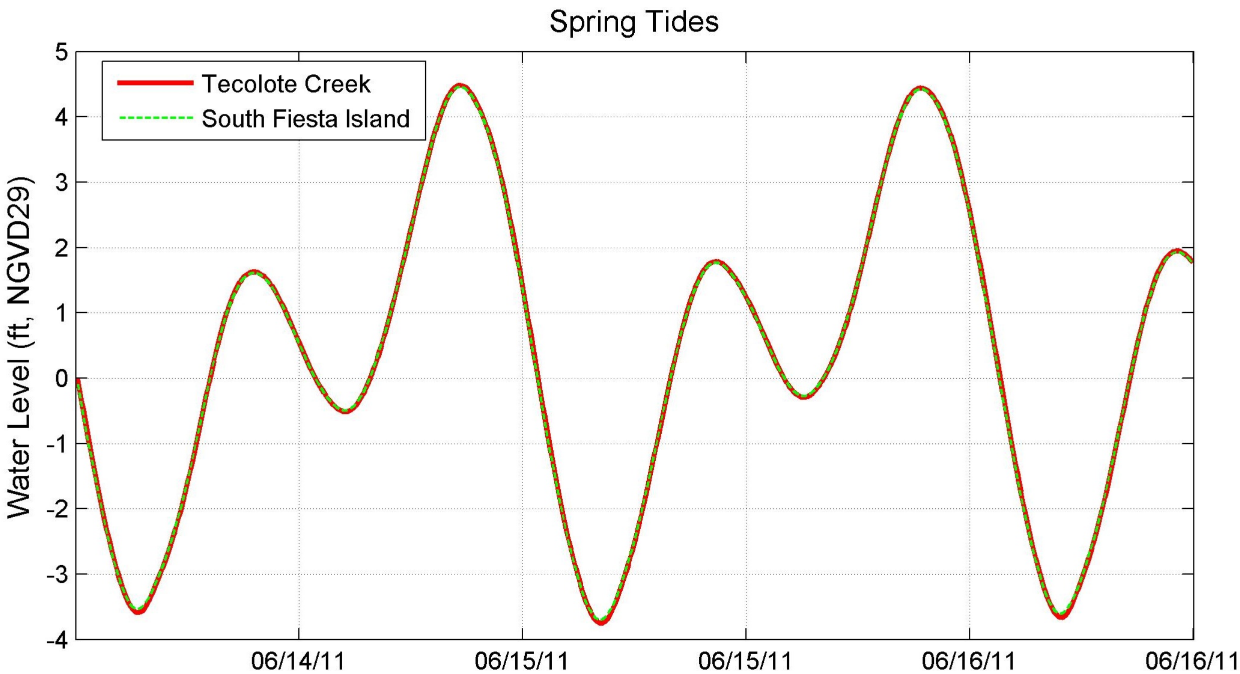


FIGURE 5-5 MODELED SPRING TIDES AT TECOLOTE CREEK AND SOUTH FIESTA ISLAND

5.2.4. Inundation Frequency

Modeled water levels were also used to compare tidal inundation frequency in Mission Bay with respect to the open ocean. Inundation frequency is defined as the percentage of time that the tidal elevation exceeds a certain elevation. It is an important factor for habitat design and distribution because target vegetation species establish at particular inundation frequencies.

Figure 5-6 provides the tidal inundation frequency curve for the open ocean and the proposed project location in Mission Bay. As there is no tidal muting in Mission Bay, inundation frequency is virtually identical inside and outside of the Bay. The full range of marsh habitats could therefore be established in the proposed wetland projects.

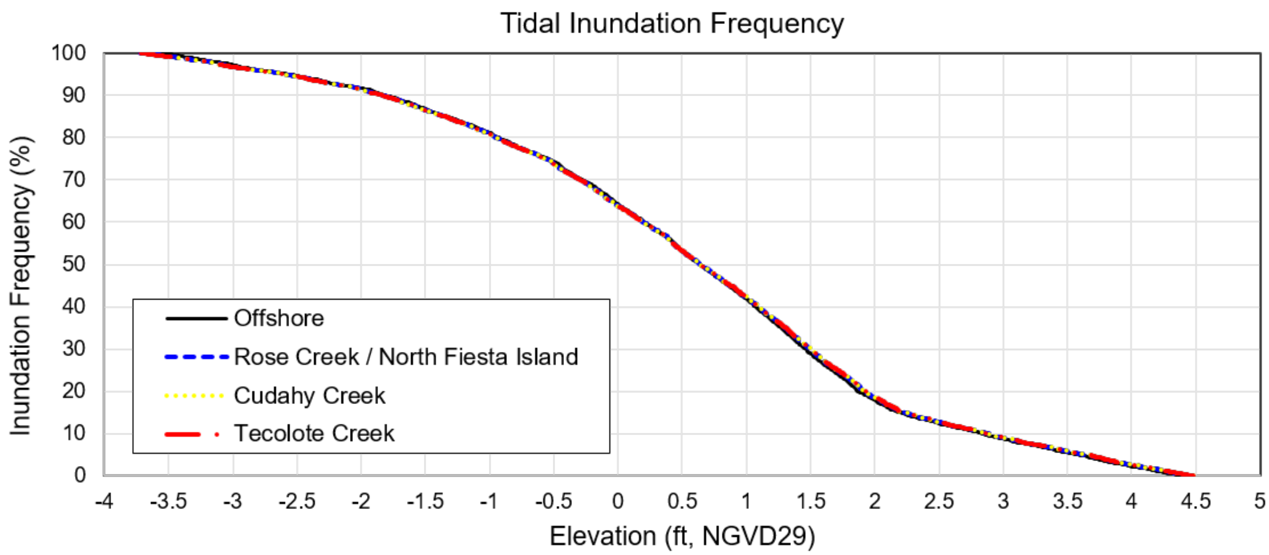


FIGURE 5-6 TIDAL INUNDATION FREQUENCY AT PROPOSED MARSH LOCATIONS

5.2.5. Tidal Current Velocities

Peak flood and ebb tidal velocities, i.e. the maximum current speeds associated with rising and falling tides, respectively, at and around the data stations in Mission Bay are provided in Table 5-3. Peak flood and ebb tidal currents occur during spring tides; however as opposed to water levels which rise and fall nearly uniformly and simultaneously, these peak currents have a variable distribution in space and time.

TABLE 5-3 MODELED PEAK FLOOD AND EBB VELOCITIES IN MISSION BAY

Station	Peak Flood (ft/s)	Peak Ebb (ft/s)	Peak Flood (Time, UTC)	Peak Ebb (Time, UTC)
Offshore	0.10	0.27	6/14/2011 6:43	6/14/2011 1:42
Entrance Channel	1.90	2.51	6/16/2011 8:09	6/15/2011 0:46
Rose Creek	0.14	0.13	6/15/2011 7:03	6/15/2011 1:52
North Fiesta Island.	0.35	0.31	6/16/2011 8:15	6/16/2011 0:44
Cudahy Creek	0.07	0.04	6/15/2011 7:39	6/15/2011 2:04
Tecolote Creek	0.03	0.02	6/15/2011 0:46	6/15/2011 6:45
South Fiesta Island	0.04	0.03	6/15/2011 0:52	6/15/2011 6:33

Spatially, the highest current speeds occur at the Mission Bay Entrance channel. At this location, ebb currents govern over flood currents with peak magnitudes of about 2.5 feet per second (ft/s) and 1.9 ft/s, respectively. As shown in Figure 5-7, outgoing currents increase their velocities as they flow through the constricted channels off the west and south coast of Vacation Island, through the Entrance Channel, and as they exit the Bay. During peak ebb, high currents speeds of up to about 1.8 ft/s occur as far as 3,000 feet offshore. On the contrary, during peak flood (Figure 5-8) offshore current speeds remain low, but the pronounced incoming flow through the narrow entrance channels yields slightly higher current velocities at locations further in the Bay.

Tidal currents are substantially reduced at the northeast region of Mission Bay and have comparable magnitudes during flood and ebb. Although flow constriction between the northern tip of Fiesta Island and the De Anza peninsula also results in some acceleration of the flow (current velocities up to about 0.6 ft/s) calmer flows occur around the Rose Creek area, with peak currents below 0.2 ft/s.

Finally, poor tidal circulation is observed for areas east of Fiesta Island, where tidal currents remain below 0.1 ft/s even during peak flood and ebb.

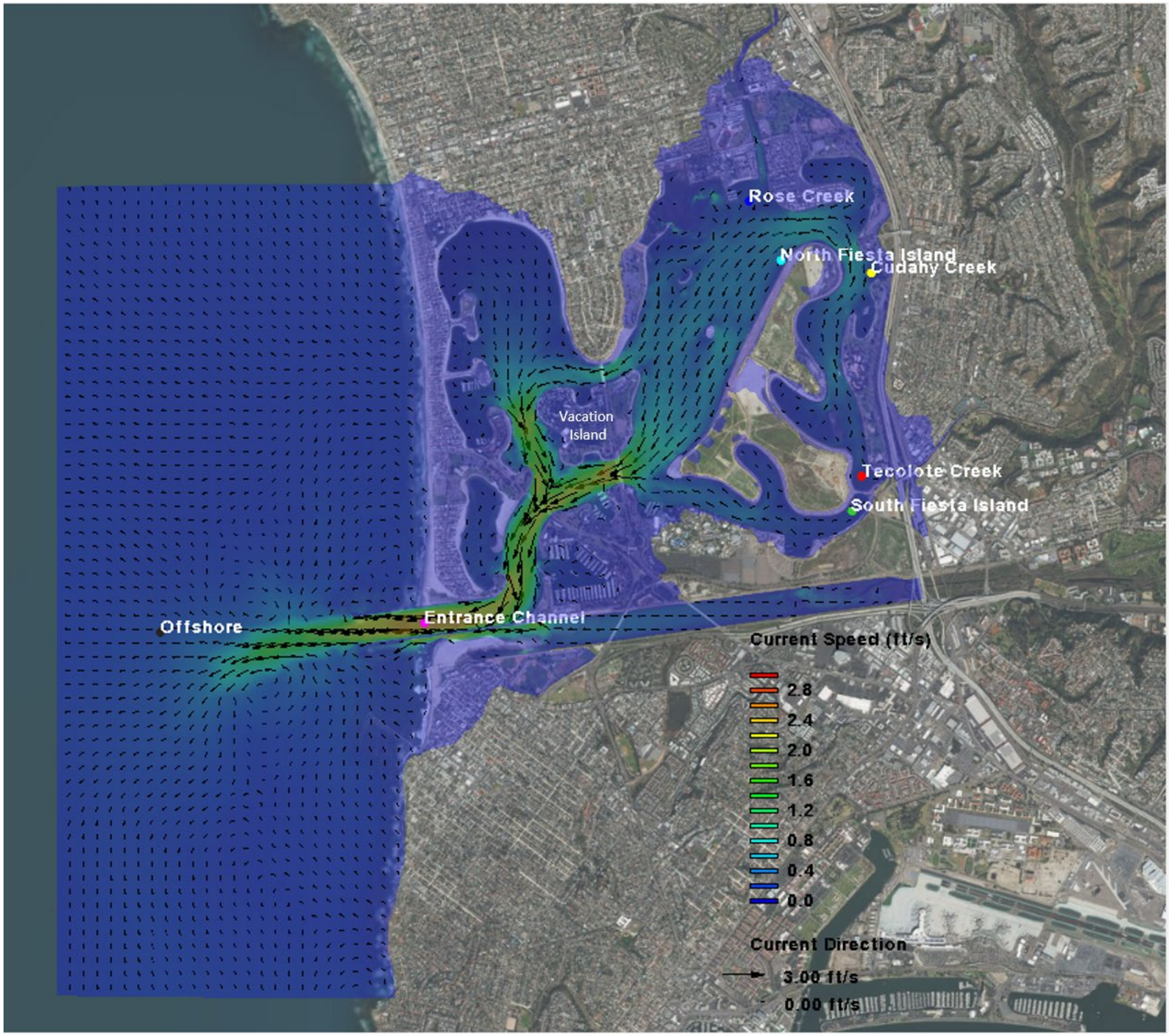


FIGURE 5-7 PEAK EBB CURRENTS AT MISSION BAY ENTRANCE CHANNEL

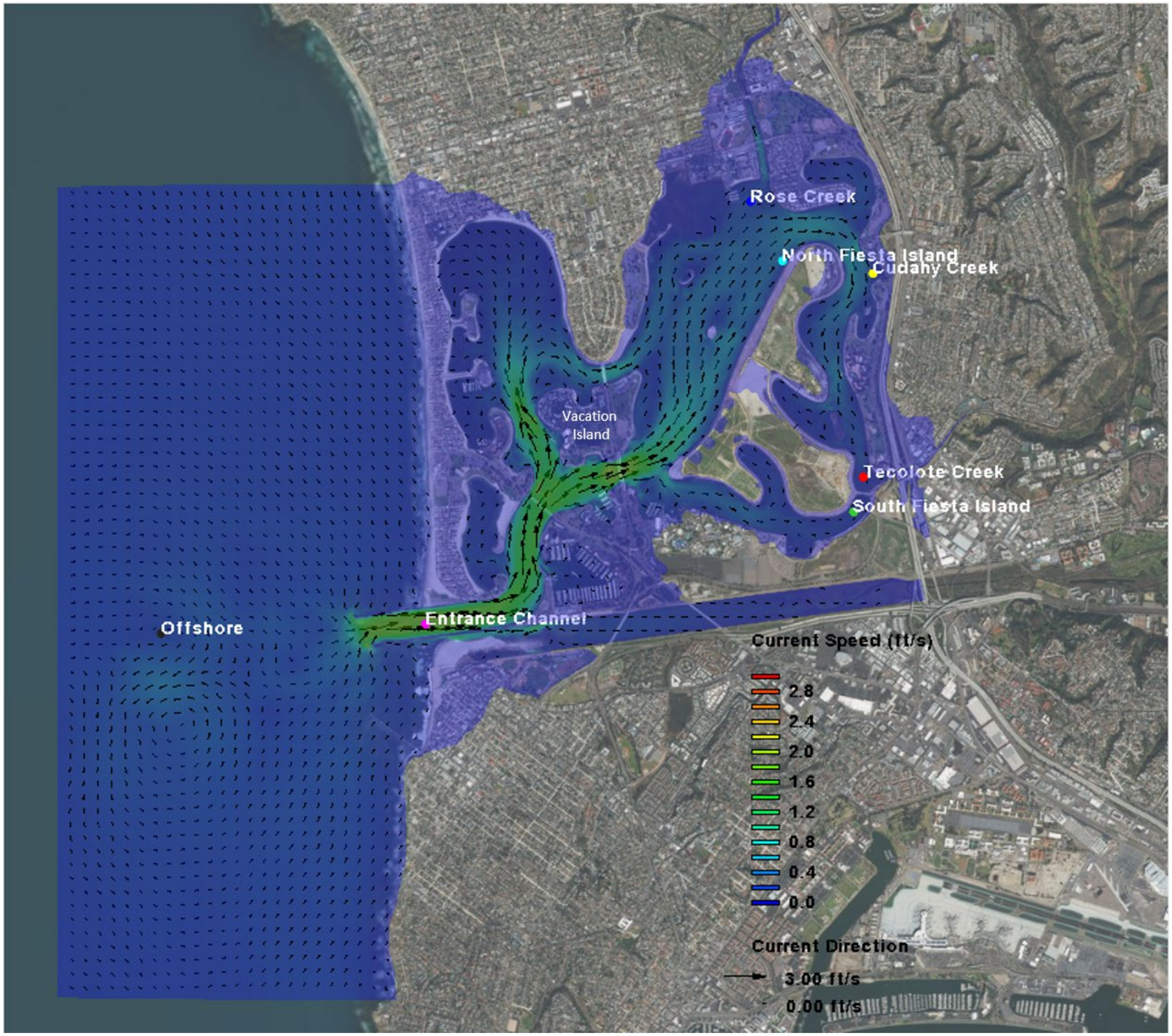


FIGURE 5-8 PEAK FLOOD CURRENT AT MISSION BAY ENTRANCE CHANNEL

5.3. Extreme storm-flood simulations

Evaluation of storm flood hydrodynamics for this study focused on identifying local peak flow velocities associated with an extreme fluvial flood event. Inflows were only considered at Rose Creek and Tecolote Creek, i.e. the two main sources of freshwater into Mission Bay. Therefore, evaluation of current velocities is limited to the mouth of these channels where wetland and water quality projects are proposed. Two hydrodynamic scenarios were evaluated: *1)* Peak inflow discharge coinciding with low tides, and *2)* Peak inflow discharge coinciding with high tides.

Figure 5-9 depicts the data extraction locations used to evaluate current velocities and water levels for the extreme storm-flood simulations. Henceforth these locations will be referred to as Rose Creek Mouth and Tecolote Creek Mouth.

FIGURE 5-9 DATA EXTRACTION LOCATIONS FOR EXTREME STORM FLOOD SIMULATIONS

5.3.1. Simulation Boundary Conditions

5.3.1.1. Water Levels

Average tides from La Jolla were also used as the offshore water level boundary condition for the storm flood simulations. A 24-hr period halfway between spring and neap tides, with a Higher High Tide reaching 3.4 ft, and a consecutive Lower Low tide of -2.5 ft, was selected for simulation of the extreme fluvial flood event.

5.3.1.2. Freshwater Inflows

Flood hydrographs for a 24-hr fluvial storm event with a return period of 100 years were obtained from previous hydrology analysis of the Rose Creek and Tecolote Creek watersheds conducted by Rick Engineering (2019). Rather than attempting to reproduce this event, for which the hydrographs for each watershed peak at a different time, a number of simulations were conducted to achieve concurrent occurrence of high/low tides and peak inflow discharge at Rose Creek and Tecolote Creek independently.

For hydrodynamic scenario 1, several simulations were conducted in order to iteratively identify the highest current velocities at the mouth of Rose Creek and Tecolote Creek. As a starting point, boundary conditions were set up to synchronize peak inflow discharge from both hydrographs (see solid curves in Figure 5-10) with the low tide in the open ocean which, as previously discussed, does not necessarily occur simultaneously with low tides on the east side of Mission Bay. Subsequent simulations were conducted by shifting the hydrograph backward 15, 30, 45 and 60 minutes (see dashed and dotted curves in Figure 5-10).

For hydrodynamic scenario 2, boundary conditions were setup to synchronize peak inflow discharge from both hydrographs with the high tide in the open ocean, which is concurrent with the high tide throughout Mission Bay. No iterative simulations were conducted for this scenario as flow velocities were found to be substantially lower than for hydrodynamic scenario 1.

Figure 5-10 and Figure 5-11 plot the offshore water level and the discharge boundary conditions imposed at the upstream boundaries of Rose Creek and Tecolote Creek for hydrodynamic scenarios 1 and 2.

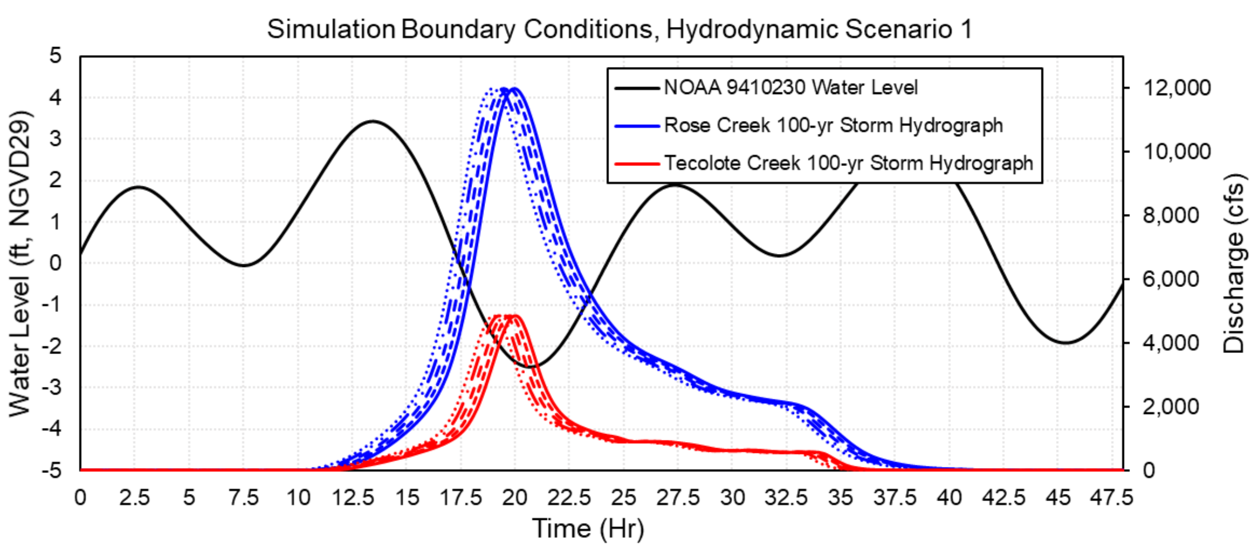


FIGURE 5-10 SIMULATION BOUNDARY CONDITIONS FOR HYDRODYNAMIC SCENARIO 1

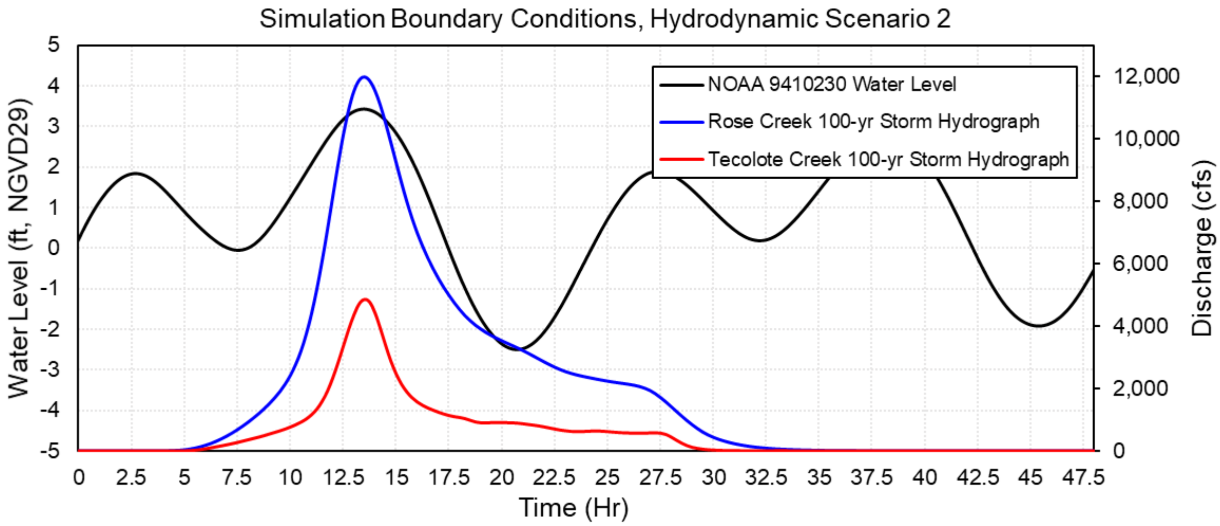


FIGURE 5-11 SIMULATION BOUNDARY CONDITIONDS FOR HYDRODYNAMIC SCENARIO 2

5.3.2. Simulation Results.

Table 5-4 summarizes findings from the extreme storm flood simulation results by providing the peak flow velocities and the amount of time in which flow velocity reached or exceeded 5 ft/s. The hydrodynamic scenario and the time of peak inflow discharge (Q) for each simulation are listed in the table for reference. Overall, higher peak flow velocities result when peak inflow discharge and low tides occur concurrently, however peak inflow discharge during high tide results in prolonged occurrence of high flow velocities.

TABLE 5-4 SUMMARY OF EXTREME STORM FLOOD SIMULATION RESULTS

ID	Hydrodynamic Scenario	Time of Peak Q (hr)	Peak Current velocity (fps)		Current velocity > 5 ft/s (hr)	
			Rose Creek Mouth	Tecolote Creek Mouth	Rose Creek Mouth	Tecolote Creek Mouth
1.1	Peak discharge at low tide	20.00	12.81	20.77	8.29	7.01
1.2	Peak discharge at low tide	19.75	12.61	20.77	8.39	7.29
1.3	Peak discharge at low tide	19.50	12.44	20.77	8.50	7.30
1.4	Peak discharge at low tide	19.25	12.47	20.86	8.54	7.33
1.5	Peak discharge at low tide	19.0	12.56	20.84	8.63	7.43
2.1	Peak discharge at high tide	13.5	8.64	11.05	12.53	9.34

5.3.2.1. Hydrodynamic Scenario 1: Peak inflow discharge coinciding with low tides

Highest peak flow velocities occur for Hydrodynamic Scenario 1 as a result of ebb currents flowing downstream along with freshwater runoff from the Rose Creek and Tecolote Creek watersheds.

Rose Creek

Variation of the depth average peak flow velocities at Rose Creek Mouth is not significant, ranging from 12.8 ft/s to 12.6 ft/s, among the different simulation sub-scenarios. Figure 5-12 plots the modeled water level and depth-averaged current speed at this location for hydrodynamic scenario 1.1. Flows exceeding 5 ft/s occur for about 8.3 hours, while the peak flow exceeding 9 ft/s occurs within a 4.1 hr period.

Figure 5-13 show peak flow velocity contours at Rose Creek for Hydrodynamic Scenario 1.1. Depth averaged flow velocities in the channel reach up to 11 ft/s. Constriction of the channel near the mouth result in depth-averaged current speeds of up to 18 ft/s (depicted in orange shades in Figure 5-13). From this point depth-averaged flow velocities drop below 3 ft/s within a distance of 1,500 feet.

The extreme storm inflow has an effect on water levels at Rose Creek Mouth for lower tide stages. As indicated in Figure 5-12, surface water levels (depicted by the solid blue curve) are above tidal elevations (depicted by the dotted blue curve) during a period of approximately 6.5 hours, in which the water surface rises up to 2.6 ft above tide levels.

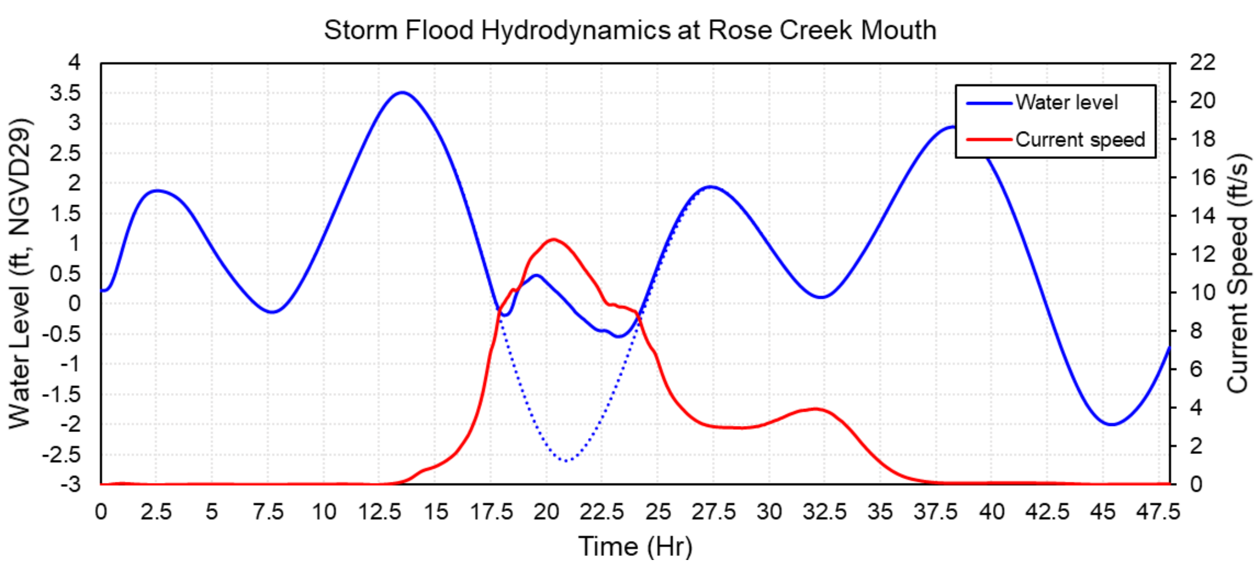


FIGURE 5-12 WATER LEVEL AND DEPTH AVERAGED CURRENT SPEED AT ROSE CREEK MOUTH, HYDRODYNAMIC SCENARIO 1.1

Tecolote Creek

Depth-averaged peak flow velocities are higher at Tecolote Creek mouth and were found to have negligible sensitivity to the tide stage, ranging from 20.8 ft/s to 20.9 ft/s. Figure 5-13 plots modeled water level and depth averaged current speed at this location for hydrodynamic scenario 1.1. For this sub-scenario flows exceeding 5 ft/s occur for 7 hours, while the peak flow exceeding 10 ft/s occurs within a 4.6 hr period. Spatially, flow velocities are considerably larger at the narrower Tecolote Creek, reaching depth-average current speeds of over 20 ft/s (red shades in Figure 5-15) at the downstream end of the channel and around the mouth. Without a larger area to which flows can rapidly disperse, high flow velocities of up to 6 ft/s are observed North of the Fiesta Island Causeway.

As indicated by the blue and dotted curves in Figure 5-13, the extreme fluvial flood event results in a rise of the water levels of up to 1.3 ft with respect to tidal elevations at Tecolote Creek Mouth during a period of about 3.5 hr.

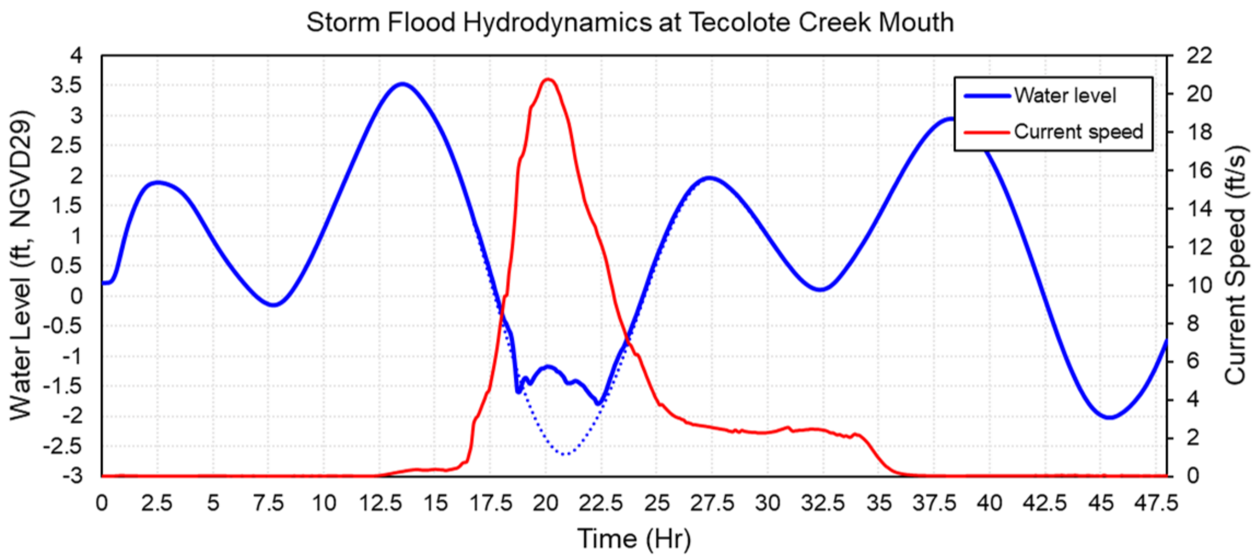


FIGURE 5-13 WATER LEVEL AND DEPTH AVERAGED CURRENT SPEED AT TECOLOTE CREEK MOUTH, HYDRODYNAMIC SCENARIO 1.4

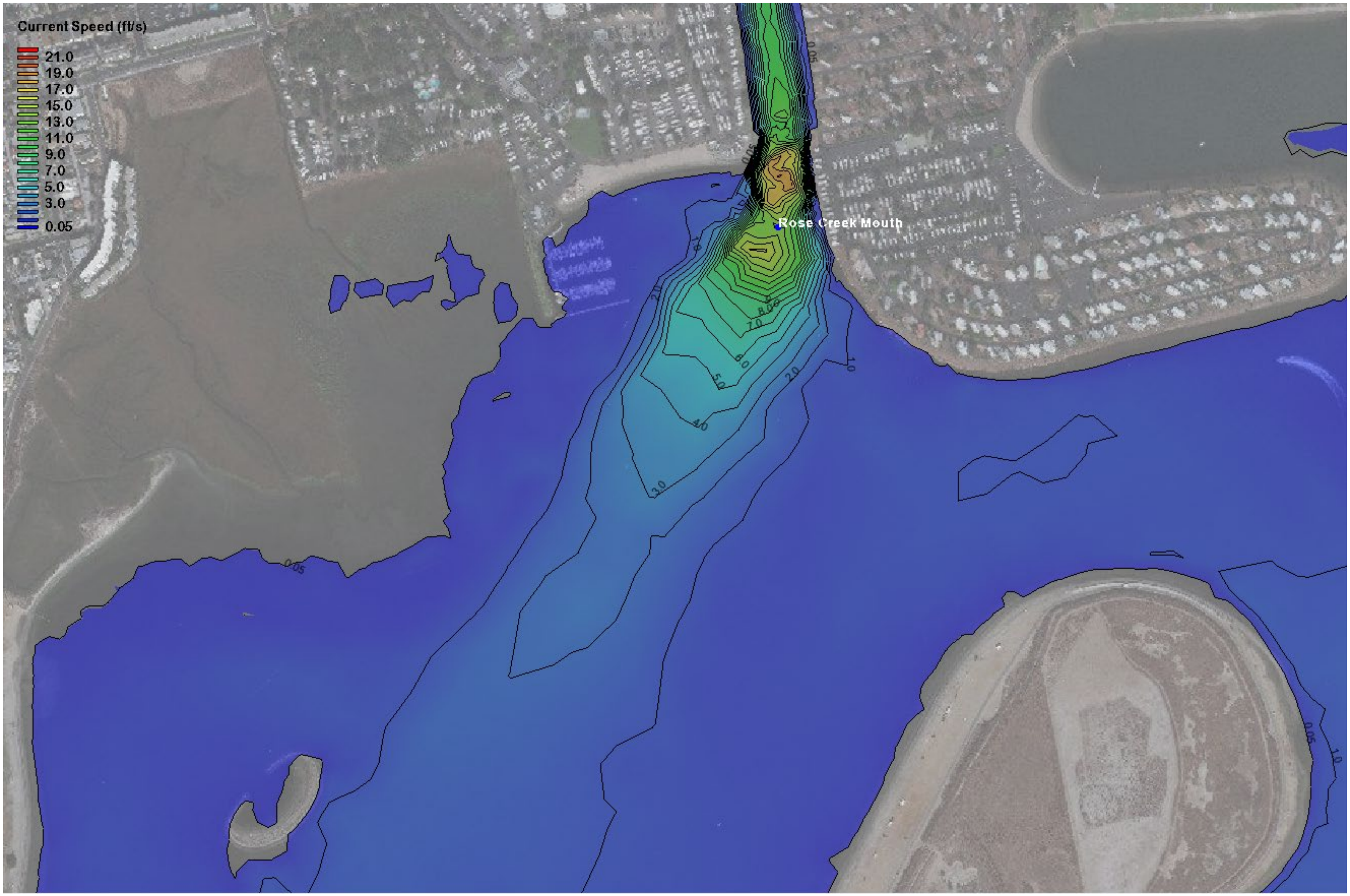


FIGURE 5-14 PEAK FLOW VELOCITY CONTOURS AT ROSE CREEK, HYDRODYNAMIC SCENARIO 1.1

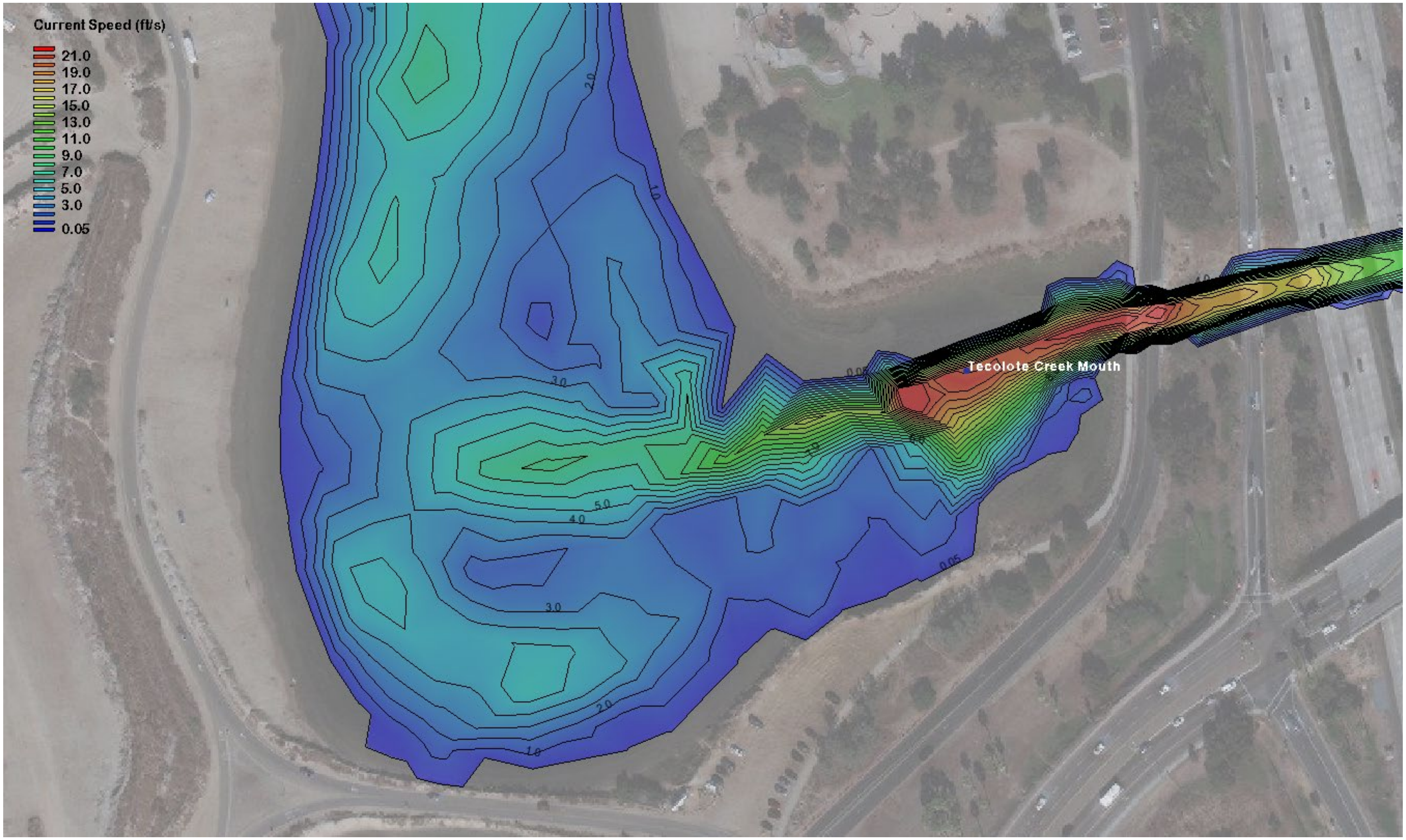


FIGURE 5-15 PEAK FLOW VELOCITY CONTOURS AT TECOLOTE CREEK, HYDRODYNAMIC SCENARIO 1.1

5.3.2.2. Hydrodynamic Scenario 2: Peak inflow discharge coinciding with high tides

Under Hydrodynamic Scenario 2, flood tidal currents in the upstream direction weaken the freshwater inflow currents during high tide, resulting in significantly lower peak flow velocities when compared to Hydrodynamic Scenario 1. However, the occurrence of high flow velocities (i.e. 5 ft/s and higher) is prolonged. As indicated in Figure 5-16 and Figure 5-17 flow velocities peak twice under Hydrodynamic Scenario 2. The first peak, occurring at high tide, is related to the peak discharge from Rose Creek and Tecolote Creek watersheds. As discharge begins to drop, the shift in the direction of tidal circulation occurs, accelerating the flow and giving rise to the second peak in flow velocity, approximately at peak ebb.

Rose Creek

Depth-averaged currents peak at 8.2 ft/s and 8.6 ft/s at Rose Creek Mouth under Hydrodynamic Scenario 2. Current speeds exceeding 5 ft/s occur for about 12.5 hours.

Peak Flow velocity contours at Rose Creek are provided in Figure 5-18. Depth-averaged current speeds now range from 8 ft/s to 9 ft/s in the channel and reach about 14 ft/s at the constricted area near the mouth. From this location, the flow is more rapidly dispersed into Fiesta Bay dropping below 3 ft/s within a distance 1,000 feet.

Surface water levels at Rose Creek Mouth are affected during a period of about 4.5 hours around low tide (Figure 5-16), with a rise of up to 1.2 feet above tide levels.

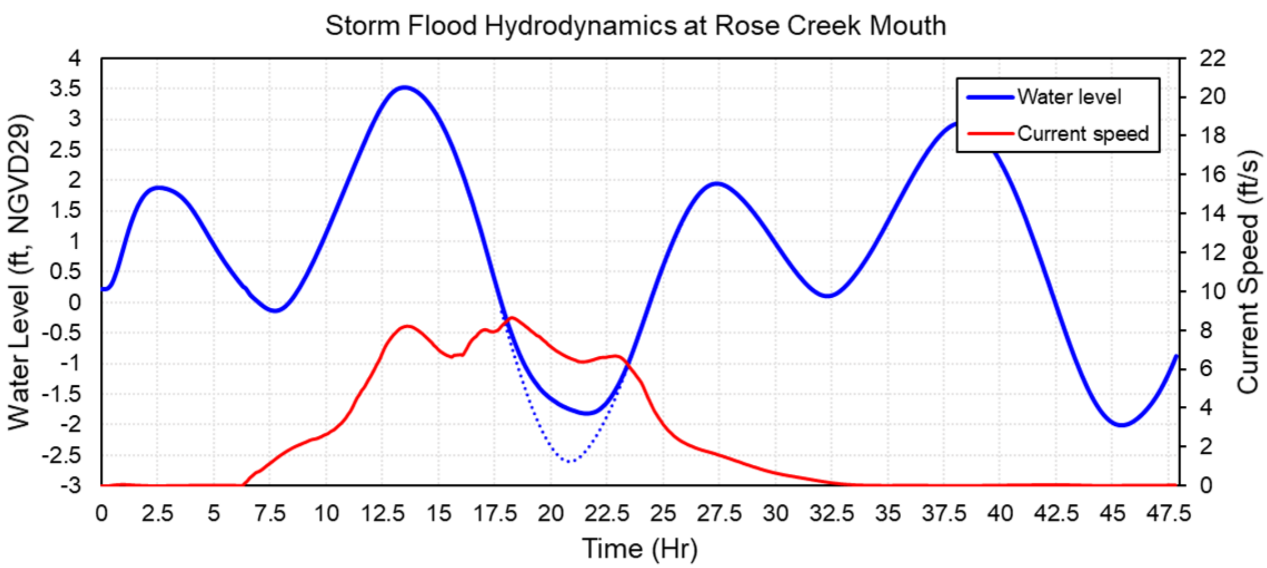


FIGURE 5-16 WATER LEVEL AND DEPTH AVERAGED CURRENT SPEED AT ROSE CREEK MOUTH, HYDRODYNAMIC SCENARIO 2

Tecolote Creek

Flow velocity peaks at 6.9 ft/s and then at 11.0 ft/s at Tecolote Creek Mouth under Hydrodynamic Scenario 2. Current speeds exceeding 5 ft/s occur for about 9.3 hours.

As indicated by the contours in Figure 5-19, peak flow velocities along the downstream end of Tecolote Creek channel reach up to 14 ft/s. Downstream of Tecolote Creek Mouth, flow velocities drop below 3 ft/s within a distance of 250 feet. Current speeds north of the Causeway remain below 1 ft/s.

As illustrated in Figure 5-17, water levels remain below tide elevations throughout the course of the extreme flood event.

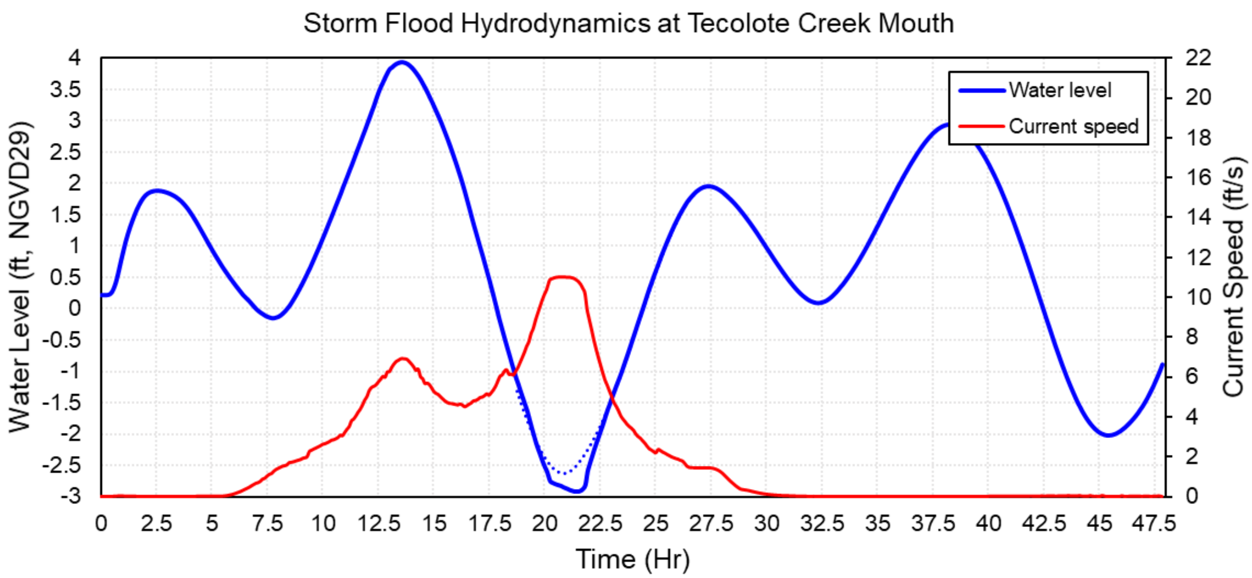


FIGURE 5-17 WATER LEVEL AND DEPTH AVERAGED CURRENT SPEED AT TECOLOTE CREEK MOUTH, HYDRODYNAMIC SCENARIO 2

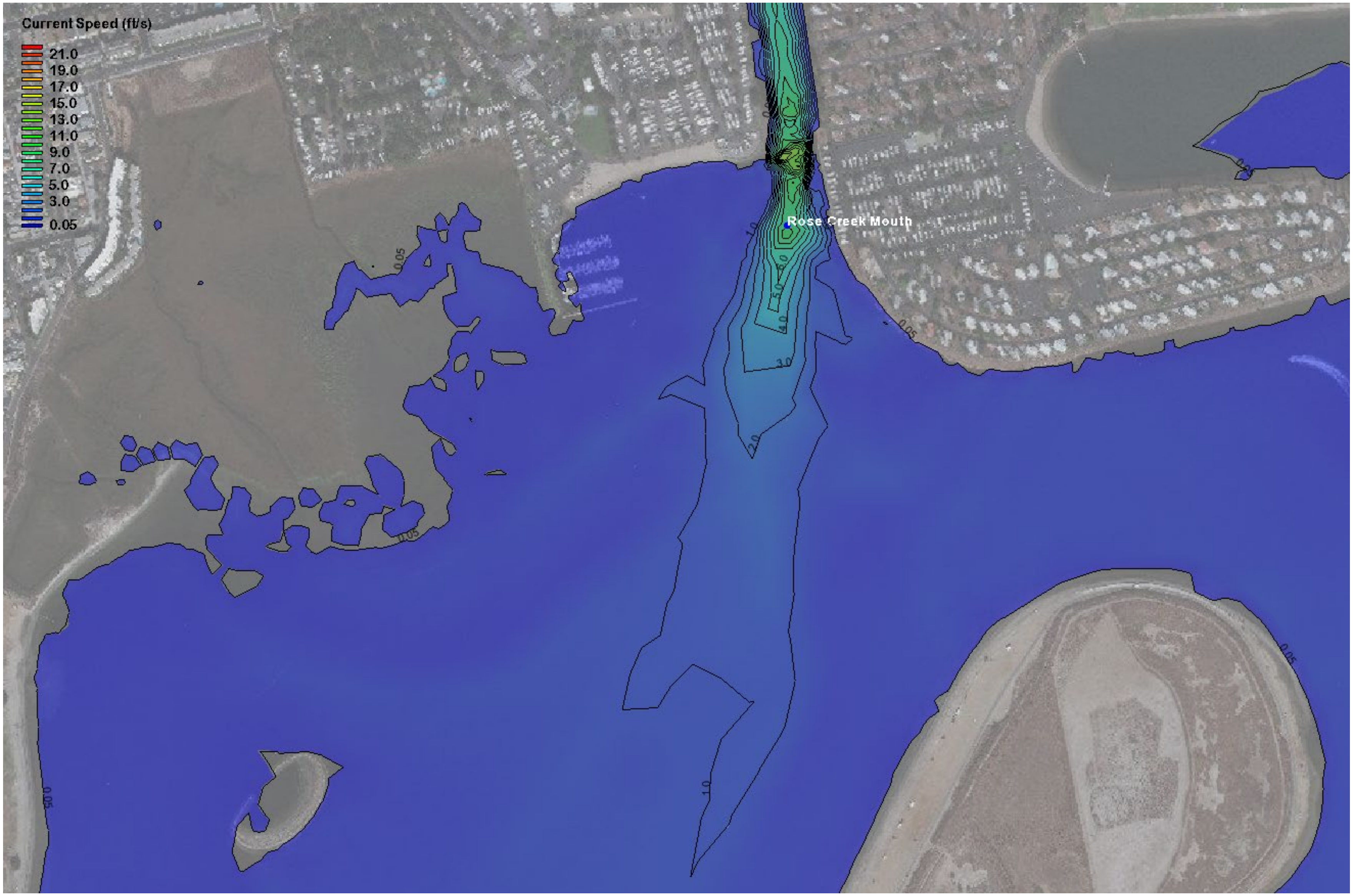


FIGURE 5-18 PEAK FLOW VELOCITY CONTOURS AT ROSE CREEK, HYDRODYNAMIC SCENARIO 2

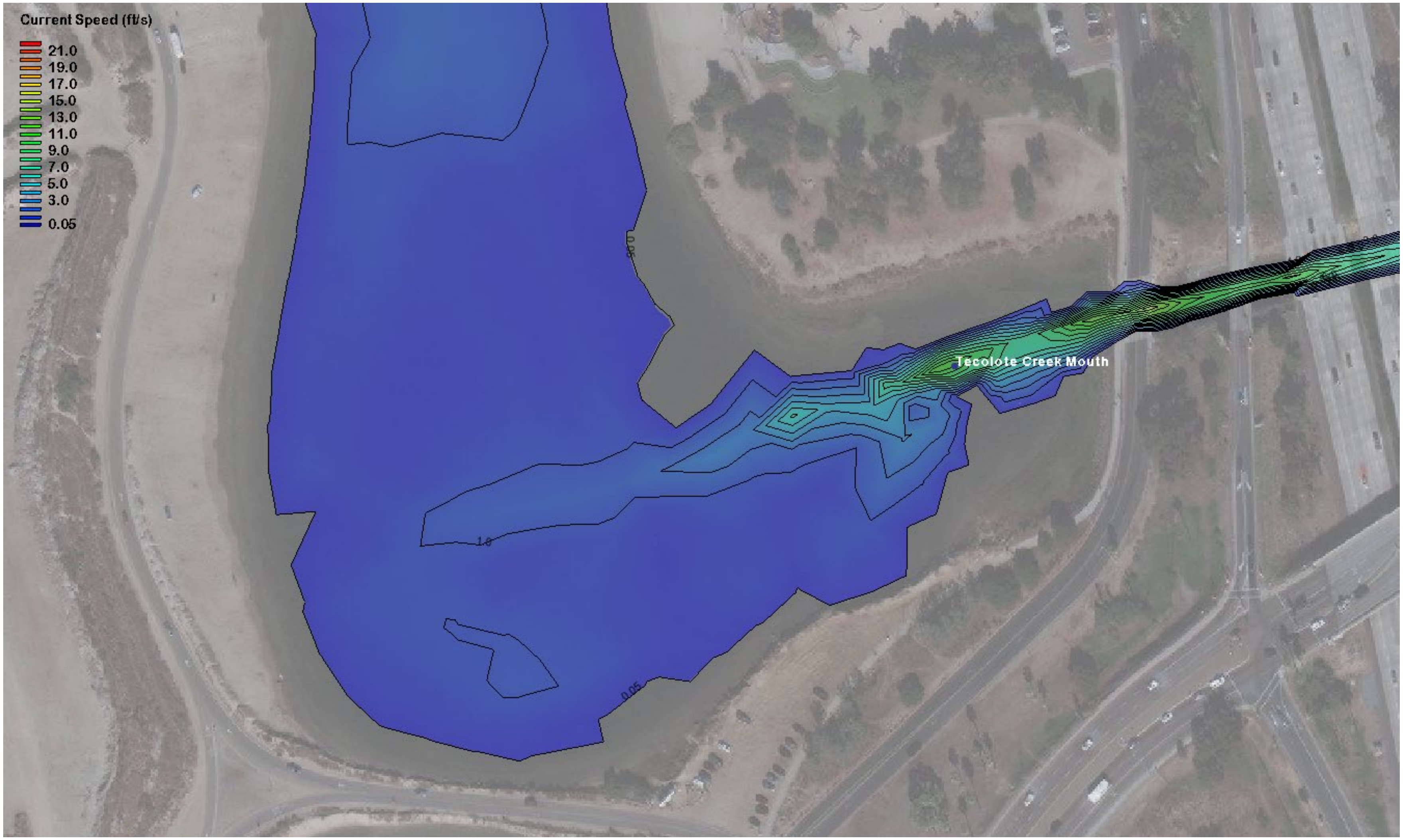


FIGURE 5-19 PEAK FLOW VELOCITY CONTOURS AT TECOLOTE CREEK, HYDRODYNAMIC SCENARIO 2

6. Conclusions

Hydrodynamic modeling of tides and storm flood flows were conducted in this study in support of the proposed wetland restoration and water quality projects in the Mission Bay PEIR, the conclusions are listed below.

6.1. Tidal Hydrodynamics

- There is no tidal muting in Mission Bay. Not only do tides in the Bay reach the same elevations as the open ocean tides, but a slight amplification of the tidal amplitudes occurs, which increase with increasing distance from the Entrance Channel.
- High tides in Mission Bay occur simultaneously with those in the open ocean, while a lag in the low tides occurs for the east area of Mission Bay with respect to the open ocean. This lag is largest during spring tides and minimum during neap tides.
- No lags were found between high and low tides at either side of the Fiesta Island Causeway.
- As there is no tidal muting in Mission Bay so inundation frequency is virtually identical inside and outside of the Bay. The full range of marsh habitats could therefore be established in the proposed wetland projects.
- Largest tidal current speeds in Mission Bay occur at the entrance channel due to flow constriction. At this location, ebb currents govern over flood currents with peak magnitudes of about 2.5 ft/s and 1.9 ft/s, respectively.
- Tidal currents are substantially reduced at the northeast region of Mission Bay and have comparable magnitudes during flood and ebb tides.
- Poor tidal circulation is observed for areas east of Fiesta Island, where tidal currents remain below 0.1 ft/s even during peak flood and ebb tides.

6.2. Extreme Storm Flood Hydrodynamics

- Higher peak flow velocities near the mouths of Rose Creek and Tecolote Creek result under Hydrodynamic Scenario 1, i.e. when peak inflow discharge from each watershed occurs concurrently with low tides.
- Flow velocities have low to negligible sensitivity to the stage of the tide under Hydrodynamic Scenario 1. Variations in the peak flow velocities among the modeled sub-scenarios were below 0.3 ft/s for both Rose Creek mouth and Tecolote Creek mouth.
- Hydrodynamic Scenario 2 results in significantly lower peak flow velocities at the mouth of Rose Creek and Tecolote Creek. However, the occurrence of high flow velocities (i.e. 3 ft/s and higher) is prolonged.
- Extreme storm inflows only affect surface water levels at the mouth of Rose Creek and Tecolote Creek during lower stages of the tide for both Hydrodynamic Scenarios 1 and 2.

7. References

Barnard, P. L., Erikson, L. H., Foxgrover, A. C., Limber, P. W., O'Neil, A. C., & Vitousek, S. (2018, 05 13). *Coastal Storm Modeling System (CoSMoS) for Southern California, v3.0, Phase 2.* Retrieved from USGS, ScienceBase-Catalog: https://doi.org/10.5066/F7T151Q4.

Chaudhry, M. H. (1993). *Open-Channel Flow.* Prentice-Hall: Englewood Cliffs, New Jersey.

CIty of San Diego. (2017). *Request for Proposal for Environmental Services. Program Environmental Impact Report (PEIR) for Mission Bay Park Improvements.* San Diego, CA.: Public Works Department.

Largier, J., Carter, M., Roughnan, M., Sutton, D., Helly, J., Kacena, T., . . . Carrillo, L. (2003). *Mission Bay Contaminant Dispersion Study. Final Report. April 30, 2003.* San Diego: Scripps Institution of Oceanography. University of California.

Merkle & Associates, Oday Consultants. (2018). *Mission Bay Post-Dredge Bathymetric Survey [Bathymetric Survey].* San Diego, CA: Merkle & Associates, Oday Consultants.

Merkle and Associates. (2013). *Mission Bay Park 2013 Bathymetry and Eelgrass Inventory [Bathymetric Survey] .* San Diego, CA: Merkle and Associates, Inc.

Rick Engineering. (2019). *Hydrology Analysis for Rose Creek and Tecolote Creek Water sheeds: 100-yr Flood Hydrographs .* 03/19/2019: Draft.

Stuart Engineering. (2018). *Tecolote Creek. Channel Bed. December 20, 2018 [Channel Bed Elevation Survey].* San Diego: Stuart Engineering.

US Army Corps of Engineers. (2017). *Adaptive Hydraulics 2D Shallow Water (AdH-SW2D) User Manual (Version 4.6).* Vicksburg, MS: USACE. Engineer Research and Development Center. Coastal and Hydraulics Laboratory.

Appendix A
Mission Bay Tide Gauge
Water level records

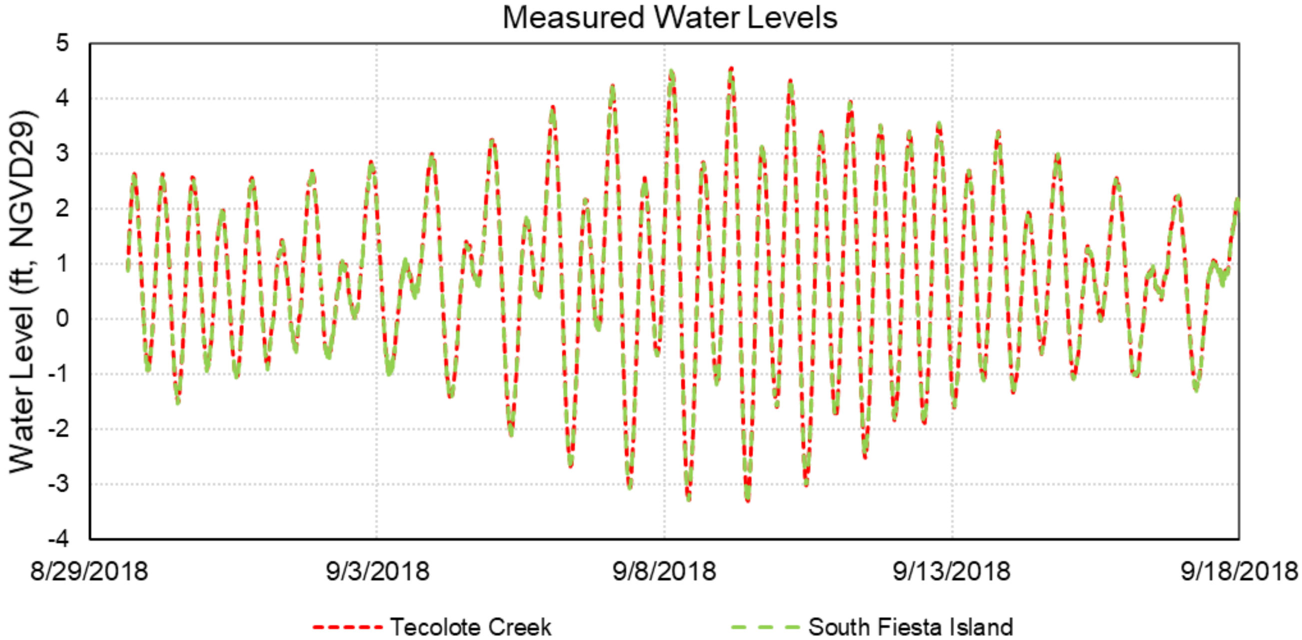


FIGURE A 1 RECORDED WATER LEVELS 08-29-2018 THROUGH 09-18-2018

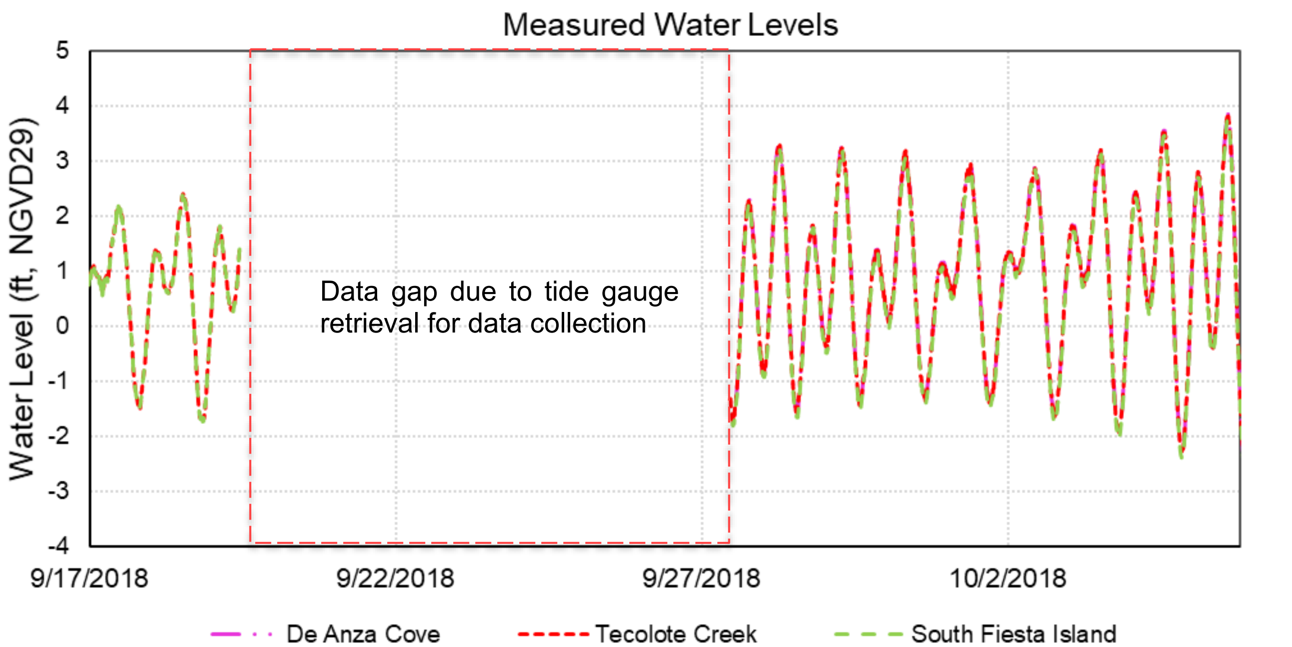


FIGURE A 2 RECORDED WATER LEVELS 09-17-2018 THROUGH 10/08/2018

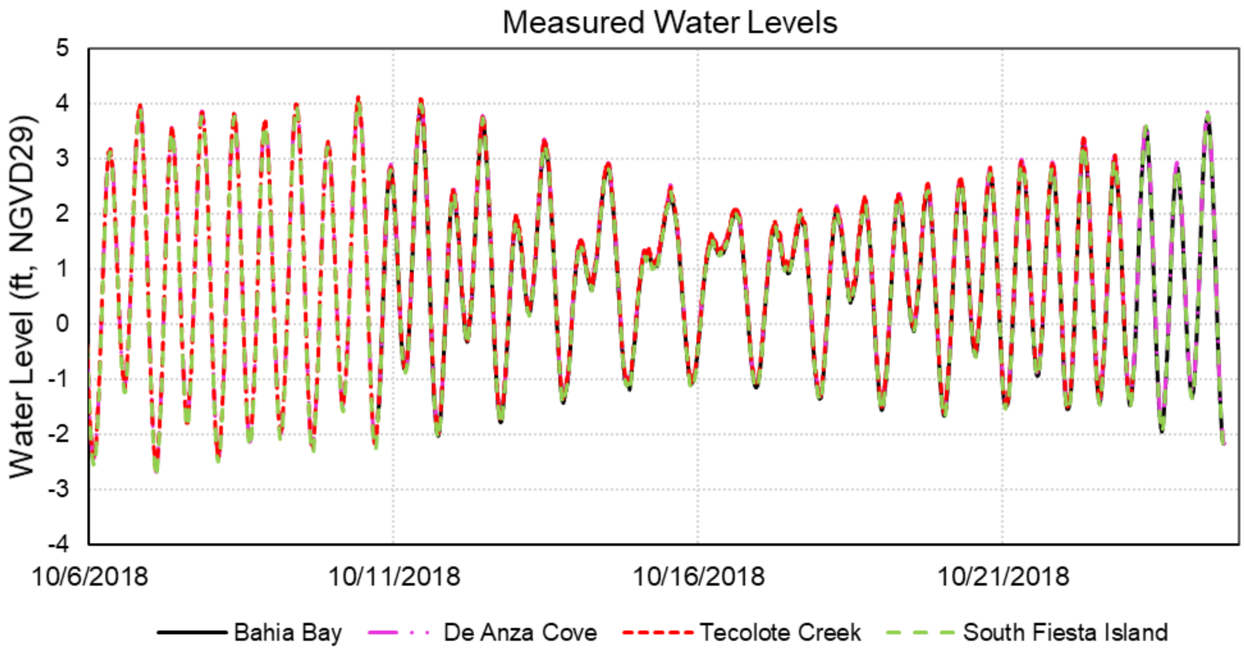


FIGURE A 3 RECORDED WATER LEVELS 10-06-2018 THROUGH 10-24-2018

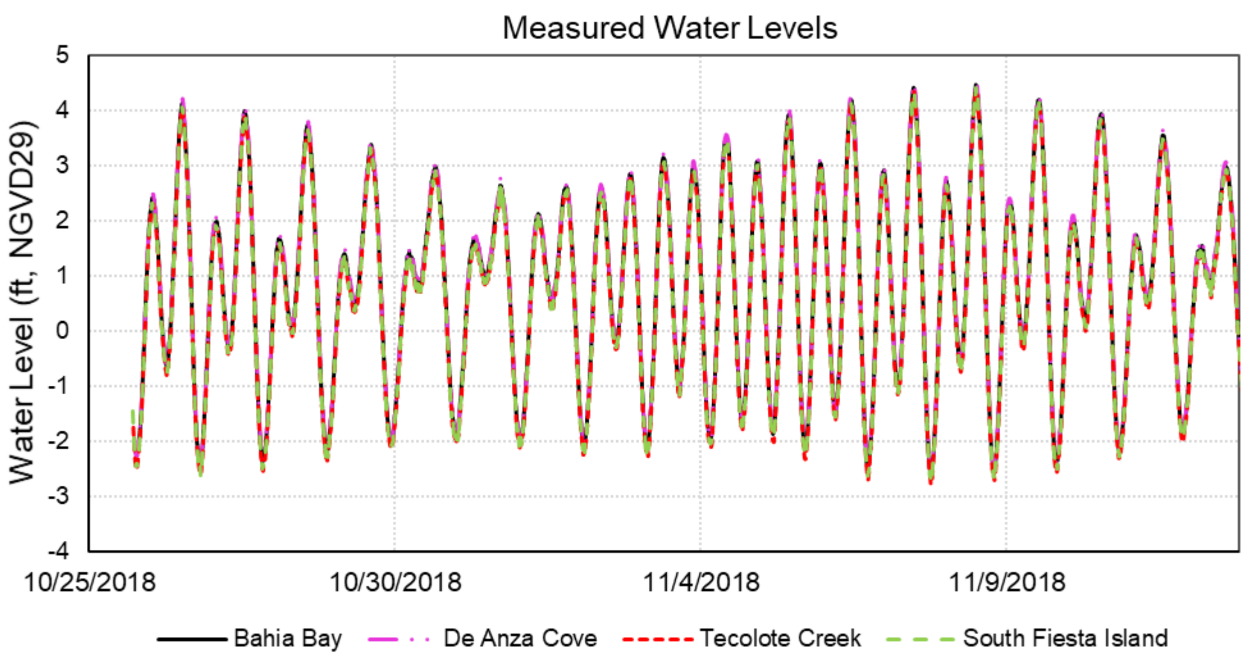


FIGURE A 4 RECORDED WATER LEVELS 10-26-2018 THROUGH 11-12-2018

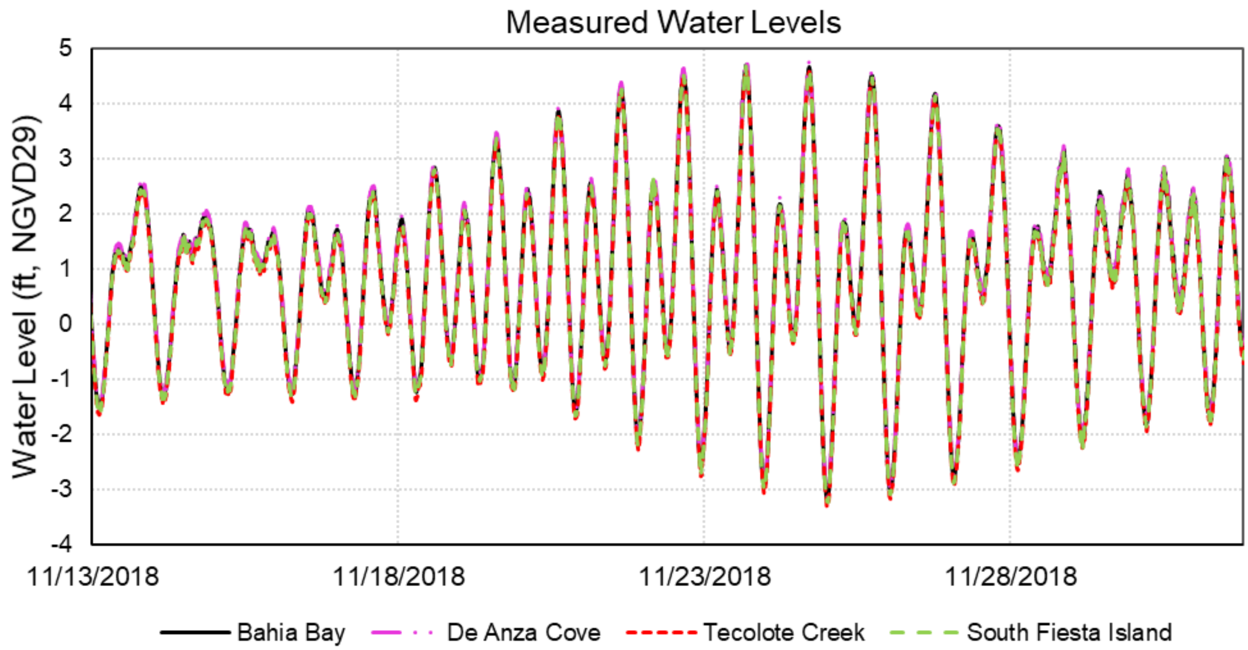


FIGURE A 5 RECORDED WATER LEVELS 11-13-2018 THROUGH 12-01-2018

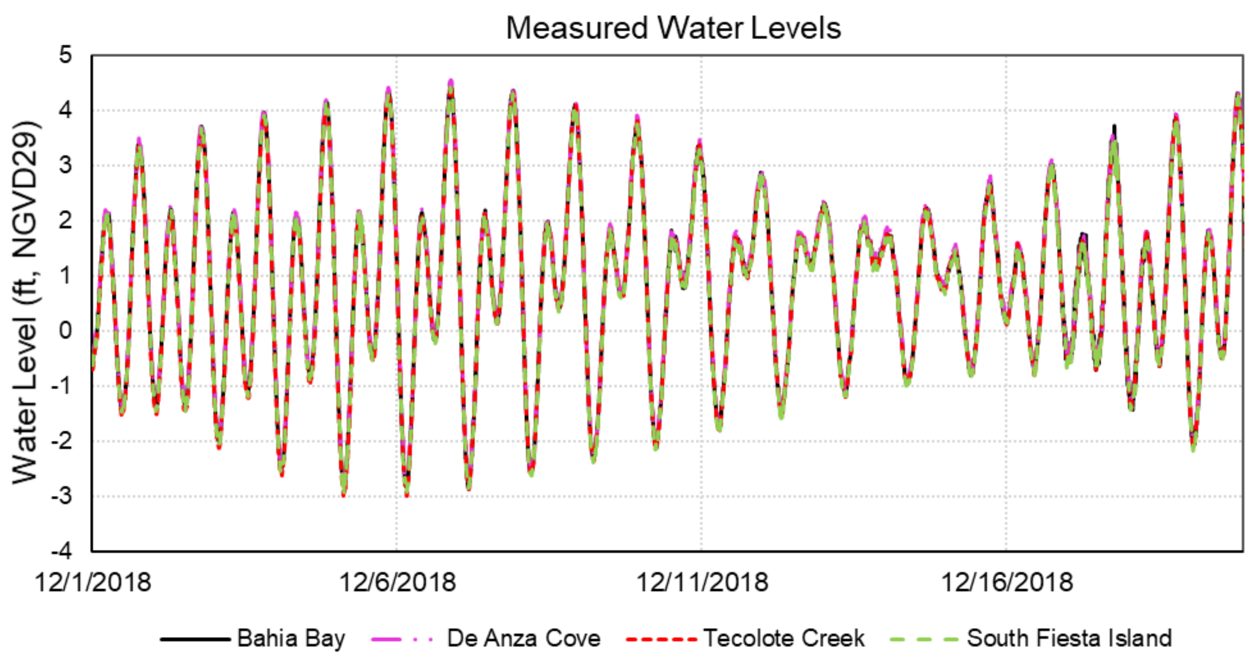


FIGURE A 6 RECORDED WATER LEVELS 12-01-2018 THROUGH 12-22-2018