APPENDIX A

TIDAL WATER LEVEL AND VELOCITY MONITORING 2021 ANNUAL REPORT; WATER QUALITY ANALYSIS FOR SAN ELIJO LAGOON RESTORATION PROJECT MEMORANDUM

SAN ELIJO LAGOON RESTORATION PROJECT

Tidal Water Level and Velocity Monitoring 2021 Annual Report

Prepared for:
The Nature Collective

San Elijo Lagoon
RESTORATION
Reviving Your Wetlands

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1. INTRODUCTION

This report documents the methods and results of a tidal water level monitoring campaign in San Elijo Lagoon from January through December 2021. The campaign was conducted by Moffatt & Nichol (M&N) for The Nature Collective in support of the San Elijo Lagoon Restoration Project (SELRP).

1.1 Project Background

San Elijo Lagoon (SEL) is a 960-acre coastal wetland located between the cities of Solana Beach and Encinitas. Due to its significant biological and ecological resources, SEL has been designated as a State Marine Conservation Area by the California Department of Fish and Wildlife.

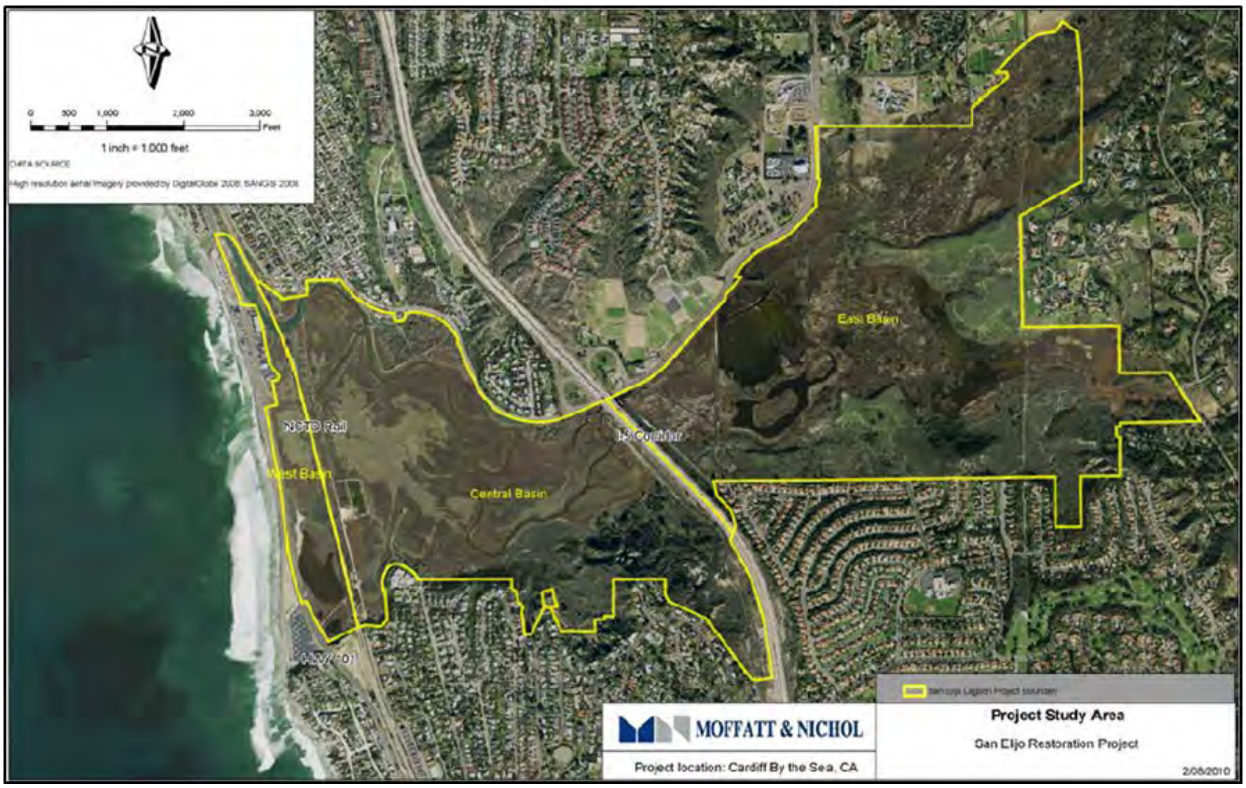

Figure 1-1: Location of San Elijo Lagoon.

The SELRP aims to protect, restore, and maintain the saltwater, brackish, and freshwater marsh resources and adjacent uplands within the SEL ecosystem by pursuing the following:

1) Physical restoration of estuarine hydrologic functions of the lagoon;
2) Biological restoration of habitat and species within the lagoon; and
3) Management and maintenance of the lagoon to ensure the long-term viability of restoration efforts.

With respect to the physical restoration of SEL, the SELRP aims to enhance tidal conveyance and the tidal prism of the lagoon by modifying the lagoon's geometry; particularly in channels, at the I-5 bridge crossing, and in the east basin. The I-5 freeway generates a "choke point" that restricts the hydraulic capacity of SEL. Increasing the width of the lagoon at this "choke point" will enable the tide to flow more freely throughout the lagoon; this is expected to increase the overall tidal prism of SEL.

The construction phase of the SELRP was initiated in December 2017 and largely concluded in June 2020. Additional dredging events took place during the summer and winter of 2021 to remove sand bars that had developed during a significant storm in April of 2020. The construction phase of the I-5 bridge expansion is expected to conclude in April of 2022.

1.2 Tidal Water Level Monitoring Campaign

A water level monitoring campaign in SEL was initiated in September 2016 with the long-term objective of documenting tidal water level conditions throughout the lagoon prior to, during, and following the construction phase of the SELRP. Water level data collected in 2016 and 2017 serve as baseline conditions for the hydraulic restoration of SEL. These baseline conditions are used in combination with data taken during and following the construction phase to evaluate the progress of hydraulic restoration efforts with respect to the established project goals. They can also be used in the design of adaptive management strategies to improve lagoon functionality if certain conditions are observed that represent relatively poor or declining function.

Monitoring of water levels during project construction began with the initiation of construction efforts in SEL in December 2017. Construction and post-construction water level records reported herein span from December 2017 through December 2021; however, as discussed in the following sections, water level monitoring efforts were periodically interrupted by construction operations to avoid impeding construction and potential damage to monitoring equipment.

1.3 Tidal Velocity Monitoring Campaign

A water velocity monitoring campaign was added to the monitoring effort in February 2020, after the initiation of the tidal monitoring work, with the long-term objective of documenting post-construction changes in tidal prism, or the volume of water that is exchanged between the lagoon and ocean over the course of a tidal cycle. Observed water velocities within SEL will be used to calibrate a numerical model of the lagoon, which will then be able to accurately estimate the SEL tidal prism and visualize post-construction tidal circulation patterns.

2. DATA COLLECTION

2.1 Data Stations

During 2021, water levels in SEL were monitored at five locations. Two monitoring stations each were located within the West Basin and East Basin, and one monitoring station was located within the Central Basin. Water velocities were monitored at two locations along the main channel: one in the West Basin and one in the Central Basin. The locations of water velocity measurements roughly correspond to water level monitoring stations at the Tidal Inlet Channel and the Nature Center[1]. The geographic locations of water level monitoring stations are listed in Table 2-1 and shown in Figure 2-1.

Measured water levels in SEL were compared with water level records from NOAA CO-OPS station 9410230 (La Jolla, CA) to determine the relationship of tidal amplitude and range within the lagoon relative to tides on the open coast. The NOAA reference station (shown in Figure 2-1 as a light blue triangle) is located approximately 10 miles south of the mouth of SEL at Scripps Pier.

Table 2-1: Reference station and water level monitoring stations during 2021.

Longitude (East)	Latitude (North)	Station Name	Source	Installation Date
-117° 16' 43.61"	33° 0' 46.19"	Tidal Inlet Channel*	M&N	12/01/2017
-117° 16' 40.05"	33° 0' 37.25"	Las Olas	M&N	12/01/2017
-117° 16' 29.04"	33° 0' 46.95"	Nature Center*	M&N	02/01/2018
-117° 15' 35.88"	33° 0' 46.49"	East Basin North Branch	M&N	07/19/2019
-117° 15' 18.57"	33° 0' 39.86"	East Basin South Branch	M&N	11/06/2019
-117° 15' 24.00"	32° 52' 00.00"	La Jolla, CA (9410230)	NOAA / CO-OPS	N/A

*Water velocities were also monitored at the Tidal Inlet Channel (installed 07/10/2020 roughly at -117° 16' 43.29" E, 33° 0' 46.88" N) and the Nature Center station (installed 02/19/2020 roughly at -117° 16' 29.27" E, 33° 0' 46.94" N).

[1] The Nature Center monitoring station referenced in this report was referred to as the Nature Center Downstream monitoring station in previous reports; it has been renamed here as Nature Center because the upstream station at the Nature Center is no longer occupied.

Figure 2-1: Water level monitoring stations during the 2021 deployment. Stations shown in red were first deployed in 2017, those shown in orange were first deployed in 2018, and those shown in yellow were first deployed in 2019.

2.2 Instrumentation

RBR pressure gauges (RBR model: *RBRsolo D*) were used at all monitoring stations during the 2021 deployment to measure water levels in intervals of six minutes or less. These gauges, referred to as tide gauges, use built-in pressure sensors to measure the time-varying height of the water column above them (i.e., the distance from the water surface to the pressure sensor within the tide gauge). During the deployment, tide gauges were fixed to six-foot-long steel fence posts with zip-ties (see Figure 2-2). The posts were driven two to three feet into the lagoon bed and the gage was positioned one foot above the bed. This configuration simplified the periodic retrieval and reinstallation of the instruments, which was required for cleaning and data downloading.

Acoustic Doppler Current Profilers (Aquadopps) were used to measure water velocities at the Nature Center and Tidal Inlet Channel stations throughout 2021. These instruments use acoustic signals to measure horizontal water velocities at pre-defined depths. All instruments deployed in 2021 were programmed to measure velocities every 10 minutes in 0.25-meter depth-bins. Water velocities were measured by a side-looking Nortek *Aquadopp Profiler* (Figure 2-3), which was mounted close to the bottom of the lagoon bed at each sampling station. There are gaps in the water velocity record at the Tidal Inlet Channel from mid-May to mid-July, and from mid-November through December, as the instrument was removed to avoid interference with dredging of a sand bar near the rail bridge.

Figure 2-2: RBR *Solo D* tide gauge and an example of the mounting system; the photograph on the right was taken during the 2017 deployment.

Figure 2-3: Nortek *Aquadopp Profiler*. The transducers, which emit and receive acoustic signals, are the black spots on the right end of the Aquadopp Profiler.

2.3 Data Processing

Data processing is a common practice when dealing with in-situ measurements. Standard measurement errors (including instrumentation, user, and environmental) are identified in the raw data and removed from the final data set. Any odd or unexpected variations in the data are investigated further and an attempt is made to explain their appearance. For both tide gauges and Aquadopps, anomalies in SEL were associated with events that corresponded both temporally and geographically. As one of the monitoring goals is to determine meaningful changes in tidal elevations and velocities over time, this section includes descriptions of all significant modifications to the observed tidal records.

Water depths (measured by the tide gauges) were converted to water surface elevations by surveying the water surface relative to the North American Vertical Datum of 1988 (NAVD88). During the 2021 deployment, water surface elevation surveys were conducted by KDM Meridian at each monitoring station prior to each removal of the tide gauge for maintenance (Figure 2-4).

Figure 2-4: Water surface elevation survey near the tidal inlet channel station.

Small (≤0.25 ft) gradual shifts in water level measurements were periodically detected at various sites in 2021, including the Tidal Inlet Channel, Nature Center, and East Basin North. These occurred during repeated deployments and were attributed to systematic drifting of the trend in the data being recorded by the instrument because they were out of calibration. The instruments in question have since been recalibrated, and the gradual shifts in water level measurements have been removed with linear corrections based on multiple water level surveys, when present. This was possible due to an increase in the frequency of water level surveys in 2021, as similar gradual shifts were detected in 2020 and attributed to instrument error and/or changes to the mounting system by contact with construction equipment or other disturbances (e.g., leaning fence posts under the weight of kelp that accumulated over time). During most 2021 deployments, water levels were surveyed twice: one shortly after the tide gauge was deployed and one shortly before it was retrieved. In some cases, both surveys produced varying water levels; these water level records were corrected using the most appropriate survey available based on water levels measured during prior deployments. Surveyed water level variation can occur from simple human-induced variations on how the person holds the survey rod.

Despite these corrections, the corrected low water levels at the Nature Center[2] are 0.1-0.2 ft higher than low water levels measured both downstream and upstream of the monitoring station during portions of 2020 and 2021 (See Table A-4 and Table A-5). As the difference is consistent relative to both upstream and downstream stations, the discrepancies are likely due to the instrument being out of calibration. Consequently, the surveyed water levels at the Nature Center are possibly high by 1-2 inches, though the tidal *ranges* at the Nature Center station (given in Table 3-1, Table A-4, and Table A-5) are accurate as they are not referenced to a vertical datum.

During 2019, the Nature Center station showed an anomaly in water level measurements that was determined to be a result of the instrument being out of calibration. Consequently, the 2019 surveyed water levels at the Nature Center station are shown in Figure 3-9 and Table A-3 for illustration purposes only. However, the tidal ranges at the Nature Center station (given in Table 3-1 and Table A-3) are accurate as they are not referenced to a vertical datum.

During 2018, an upward trend was identified in the water level record at the Tidal Inlet Channel station from March to mid-July due to the mooring being struck by a dredge discharge line. The impact to the mooring introduced an error into the vertical datum of the water level measurements, and the surveyed water levels described in Table A-2 and plotted in Figure 3-7 show that error. However, the tide ranges provided in Table 3-1 and Table A-2 are accurate as these values are not referenced to a vertical datum.

Water levels are also measured by ADCPs to identify data points located above the water surface. A gradual upward trend in water level was detected in the relic Workhorse ADCP measurements between mid-February and mid-April 2020 that did not match any changes measured at the adjacent tide gauge. To reconstruct the water surface at the ADCP (relative to the top of the ADCP), water levels at the tide gauge were vertically shifted by using a linear best-fit between the tide gauge water level and ADCP record in late February. Note that the Workhorse ADCP was retired in April 2020 due to instrument age and condition and was replaced with a newer Aquadopp instrument.

Velocity data were also checked for erratic measurements, which reflect interference in the acoustic signals used to estimate velocity. These erratic measurements are observed as unusually high water velocities that do not match trends before or after the velocity spike; in many cases, the directions associated with erratic measurements do not match general directional trends at the observation site. Velocity measurements that fit these characteristics were removed from the dataset.

2.4 Data Inventory

Table 2-2 provides an inventory of surveyed water level and velocity records within SEL during 2021. Gaps in water velocity data coverage during May-July and November-December are due to Aquadopps being removed during dredging activities. The period of incomplete water level data coverage at Las Olas from September onward is due to an instrument malfunction that was identified in November; no tide gages were available to replace the instrument during the November 2021-January 2022 deployment.

Tide gauges remained deployed during June earthwork operations. These construction activities often require the partial or complete closure (with temporary dams or dikes) of specific regions of the lagoon. During periods of closure, tidal water level fluctuations can be reduced or absent at stations upstream of the relevant dam/dike. This phenomenon is shown in Figure 2-5 as a reduction in water level fluctuations at all water level measurement stations. A reduction in tidal water velocity and variability during June construction operations can also be seen at the Nature

[2] Nature Center Downstream during deployments prior to 2021.

Center station in Figure 2-5. Water levels and tidal velocities return to previous amplitudes following the June earthwork operations.

Table 2-2: Monthly percentages of data coverage in SEL from January through December 2021.

Month	Tidal Inlet Channel		Las Olas	Nature Center		East Basin North Branch	East Basin South Branch
	wl	vel*		wl	vel		
Jan	100%	99%**	100%	100%	100%	100%	100%
Feb	100%	91%	100%	100%	100%	100%	100%
Mar	100%	99%	100%	100%	100%	100%	100%
Apr	100%	100%	100%	100%	100%	100%	100%
May	100%	57%	100%	100%	100%	100%	100%
Jun	100%	-	100%	100%	100%	100%	100%
Jul	100%	42%	100%	100%	100%	100%	100%
Aug	100%	82%	100%	100%	100%	100%	100%
Sep	100%	79%	56%	100%	100%	100%	100%
Oct	100%	87%	-	100%	100%	100%	100%
Nov	40%	36%	-	100%	40%	100%	100%
Dec	-	-	-	100%	-	100%	100%

wl = water level data coverage
vel = water velocity data coverage
**The Aquadopp at the Tidal Inlet Channel was moved closer to the bank in late January to avoid burial.*
***Velocity data coverage of >75% indicates that the instrument was actively deployed, but data loss occurred due to extraneous velocity measurements (environmental error) and/or the instrument was deployed too shallow to collect meaningful water velocity measurements.*

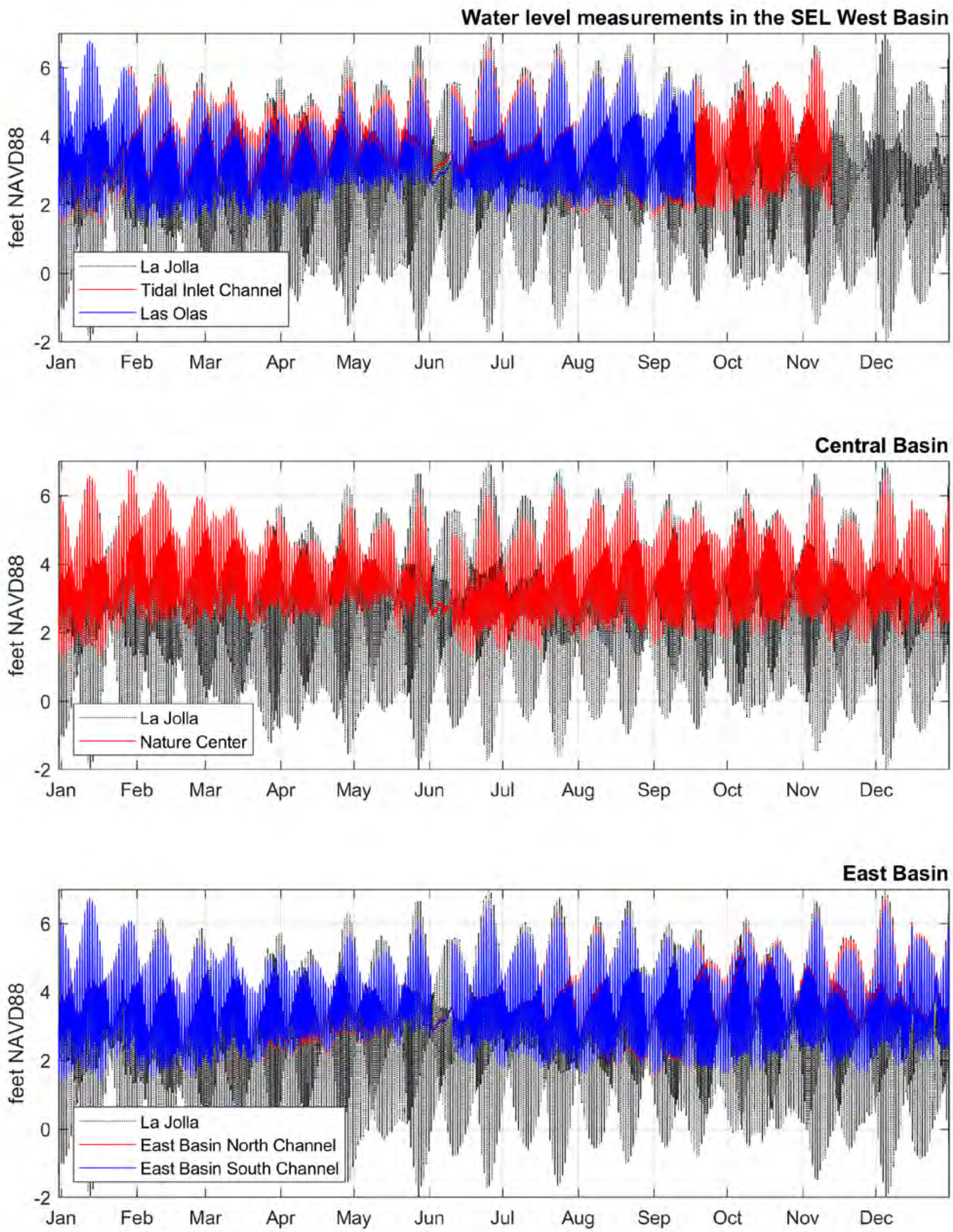

Figure 2-5: Water level measurements within SEL from January through December 2021.

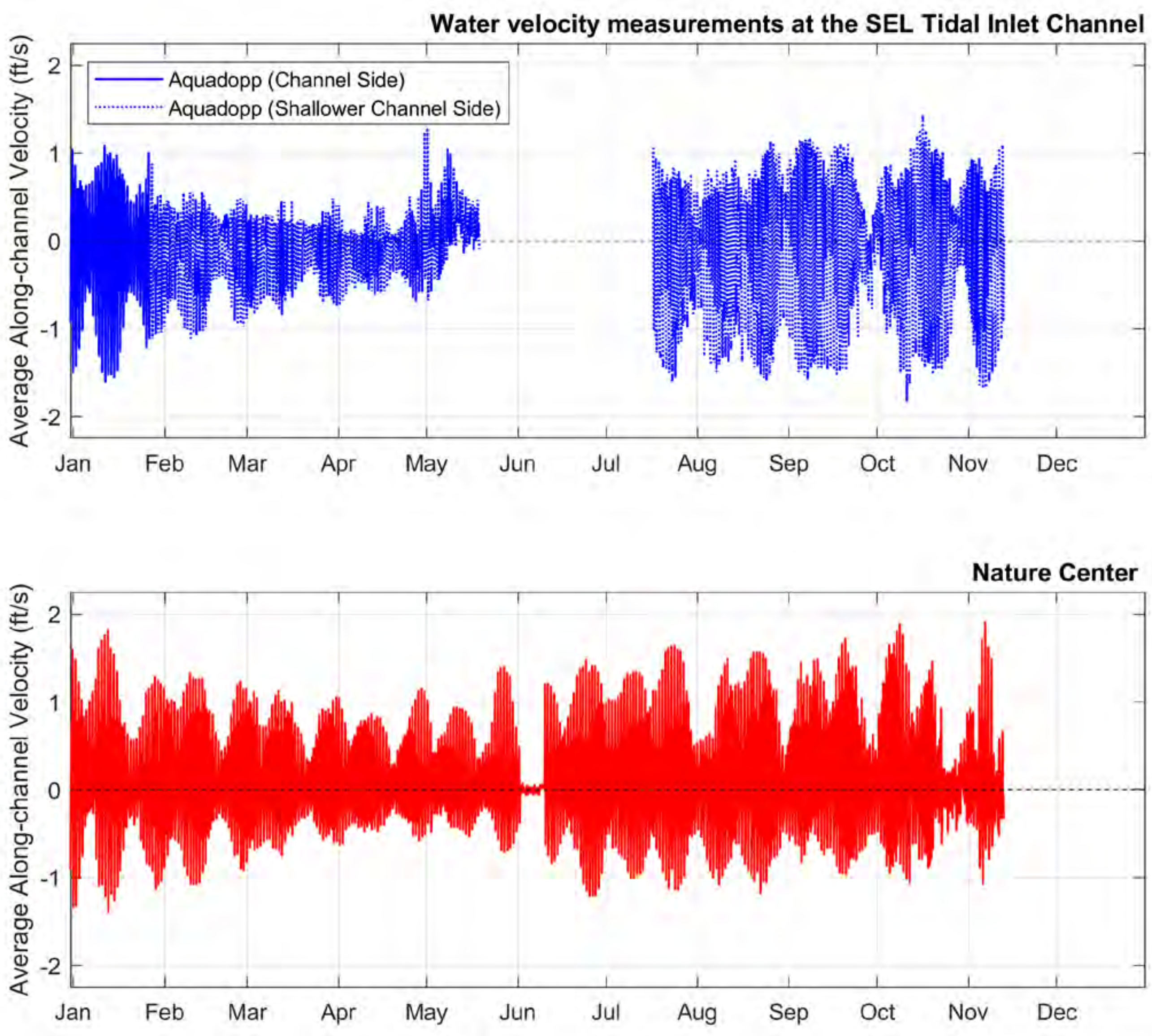

Figure 2-6: Water velocity measurements within SEL during 2021; positive velocities are directed landward, negative velocities are directed seaward.

3. RESULTS

Water level and velocity measurements during 2021 revealed temporal variability associated with construction activities and also provided an indication of the long-term construction effects on tidal amplitudes within the lagoon.

Post-construction measurements during both 2020 and 2021 (see Figure 2-5) have shown that tidal conditions are similar throughout SEL. This indicates that the SELRP has increased tidal exchange in the lagoon relative to conditions near the tidal inlet. During 2020, low tides were muted throughout the lagoon, while high tides showed little to no muting compared to open ocean conditions (i.e. at the La Jolla gage). Although all monitoring stations in SEL showed similar tidal ranges during 2021, the overall tidal range during 2021 was smaller than the range during 2020 due to increased muting of high tides. This may have been caused by changes near the mouth of the lagoon, such as increased shoaling at the rail bridge.

Maximum depth-averaged tidal velocities at the Tidal Inlet Channel station during 2021 were roughly 1.5 ft/s during spring tides and 0.5 ft/s during neap tides (Figure 2-6). Peak depth-averaged velocities were similar in magnitude at the Tidal Inlet and Nature Center stations, though depth-averaged velocities in 2021 at the Tidal Inlet Channel station are generally higher during ebb tides while depth-averaged velocities at the Nature Center were generally higher during flood tides (Figure 3-1).

At the Tidal Inlet Channel station, the Aquadopp was deployed near the western bank of the channel to avoid periodic burial by sand. During ebb tide, peak velocities exit the central basin beneath the rail bridge and are directed toward the western side of the channel (i.e., the location of the Aquadopp). This pattern of strong ebb velocities and weak flood velocities was exaggerated after the Aquadopp was moved further from the center of the channel to a shallower channel side in late January. During May, however, the pattern was reversed; this was likely due to changes in the shape of the channel caused by sand deposited upstream and downstream of the monitoring station. Following June dredging, both flood and ebb tidal velocities significantly increased at the Tidal Inlet Channel station. This suggests that dredging was effective in widening the channel and increasing tidal exchange between the lagoon and the open ocean.

At the Nature Center station, depth-averaged tidal velocities are higher during flood tides due to a higher-velocity landward flow over a relatively short flood tide that is balanced by a lower-velocity seaward flow over a relatively long ebb tide. Both flood and ebb velocities generally decreased from mid-January through late May. After dredging, both flood and ebb velocities increased substantially, reflecting values similar to those measured in early January. This suggests that dredging was effective in increasing tidal flow throughout SEL.

A brief summary of changes in tidal variability due to dredging near the mouth of SEL during June 2021 is provided in Section 3.1 . These relatively-rapid changes are placed in context with an examination of the ongoing effects of the restoration project on tidal water levels in Section 3.1 . The overarching conclusions from the project to-date are provided in Section 4.

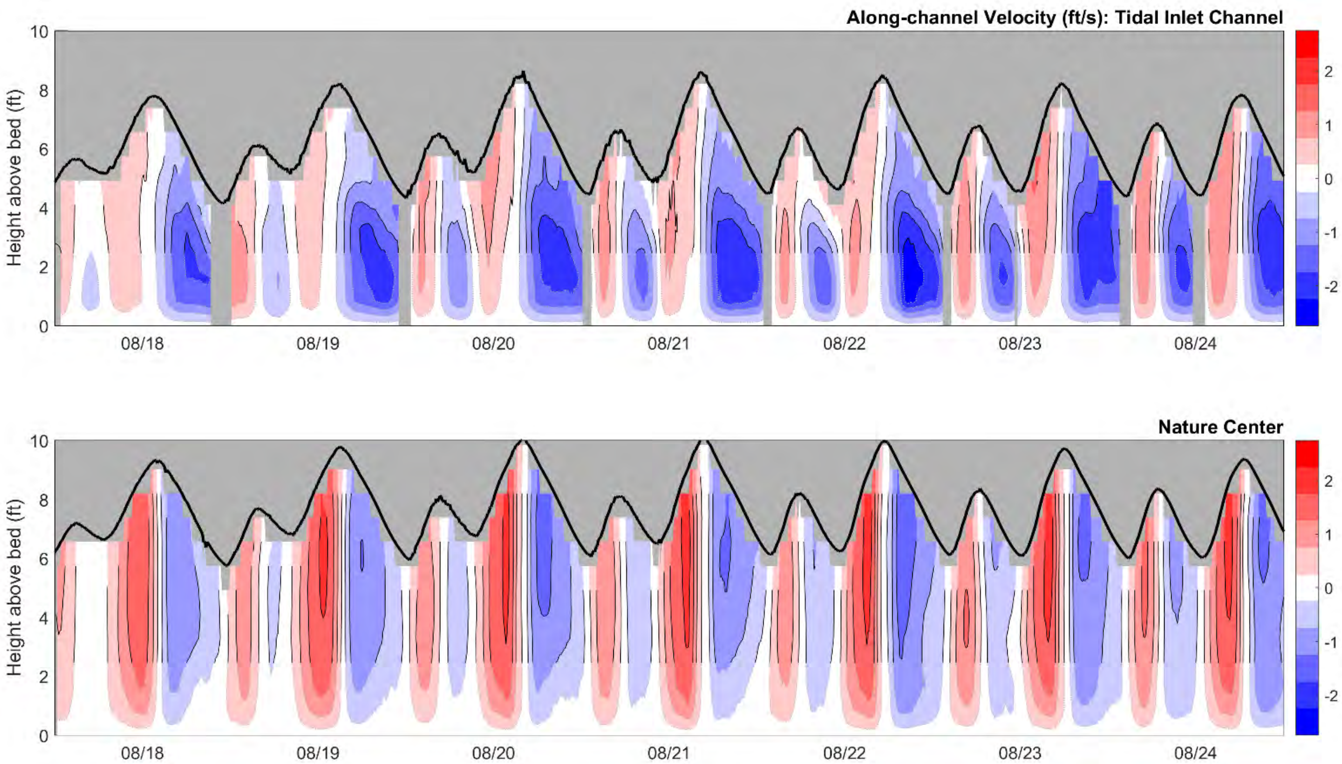

Figure 3-1: Vignette of along-channel velocities at the Tidal Inlet Channel and Nature Center stations.

3.1 Water Level/Velocity Variability Due to Dredging

The June 2021 dredging event that took place along the channel leading to the mouth of SEL (seaward of the Tidal Inlet Channel monitoring station) substantially increased tidal water level variability throughout the lagoon. Water level measurements for the SEL West Basin, Central Basin, and East Basin both before and after the dredging event are shown in Figure 3-2, Figure 3-3, Figure 3-4, respectively. Along-channel velocities at the Nature Center (Central Basin) are shown in Figure 3-12.

Consistent changes in tidal variability were observed within all three basins. Earthwork involved in the dredging operation caused a lack of tidal variability for approximately 10 days in early June. Following dredging completion and the removal of tidal exchange barriers, an increase in tidal variability was observed across all basins. Higher high tide elevations and lower low tide elevations were measured within each basin, indicating that dredge operations were successful in increasing tidal exchange throughout SEL and reducing muting during both flood and ebb tides. Reduced tidal muting during ebb tides is especially apparent in the tidal velocities observed at the Nature Center. Along-channel velocities substantially increased after dredging, and the reduction of tidal muting during ebb tides is evident in the shorter ebb tides with higher along-channel velocities observed after the dredging event. This suggests that dredging was effective at increasing the efficiency of tidal transport out of the lagoon.

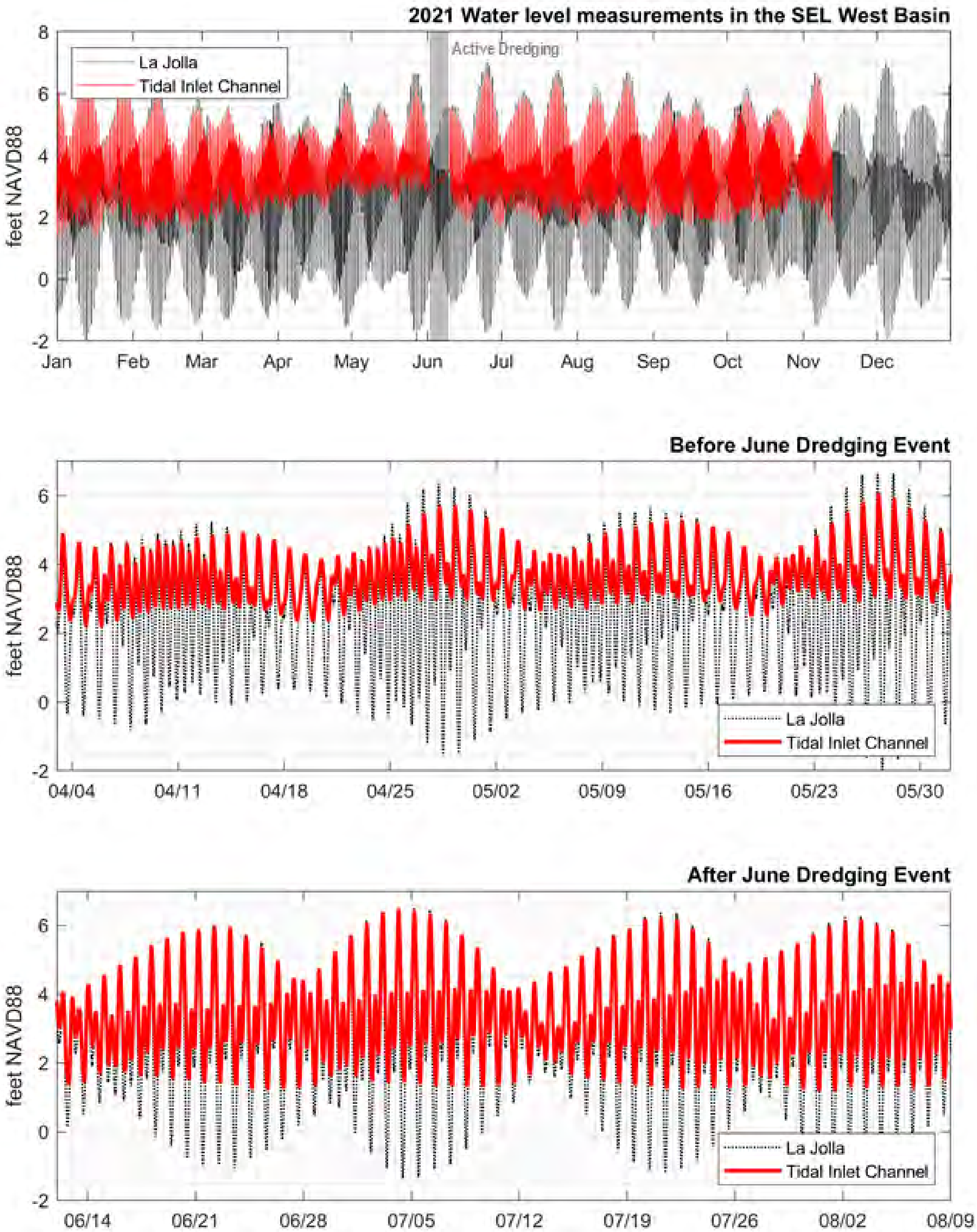

Figure 3-2: Measured water levels at the SEL West Basin before and after the June 2021 dredging event.

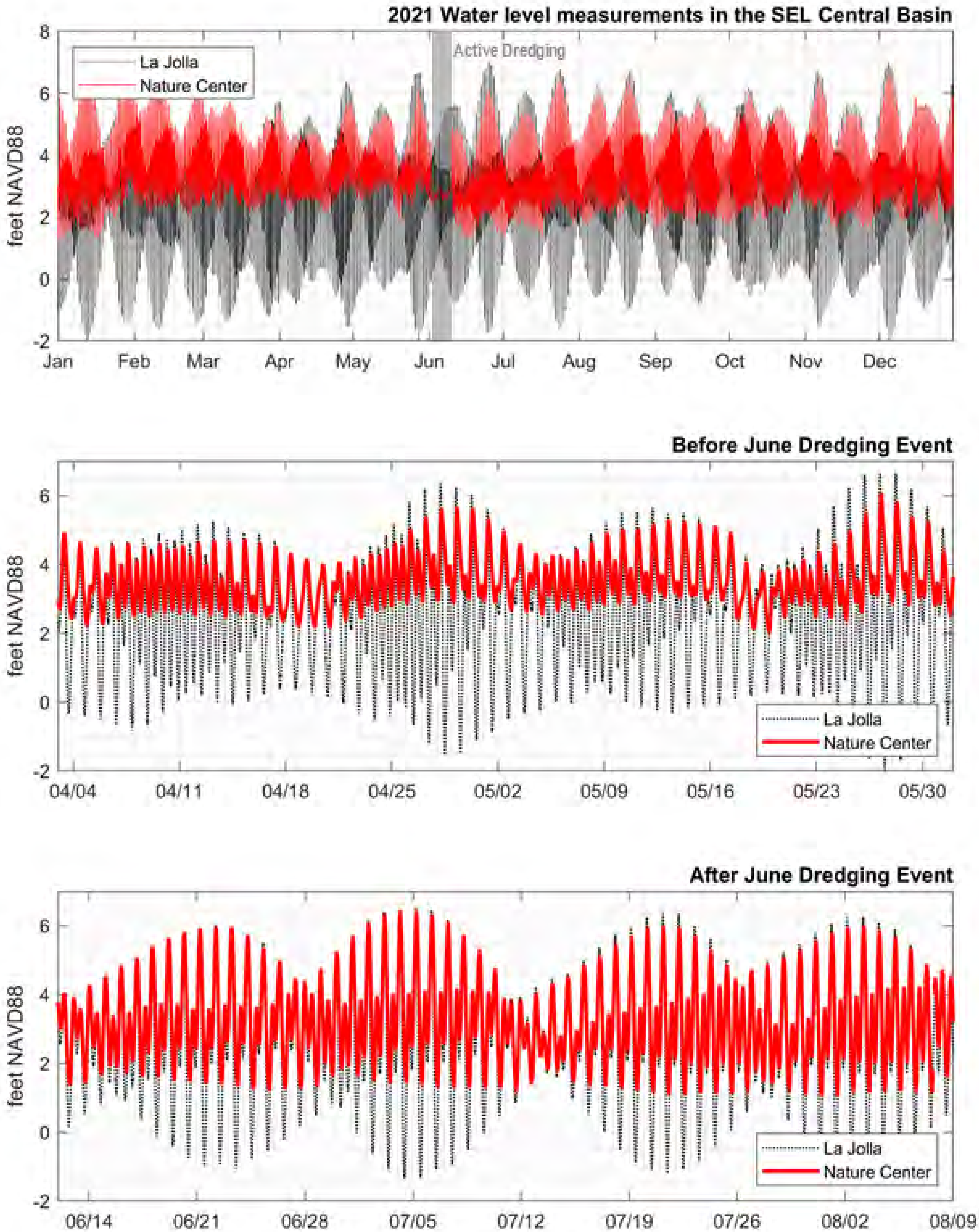

Figure 3-3: Measured water levels at the Central Basin before and after the June 2021 dredging event.

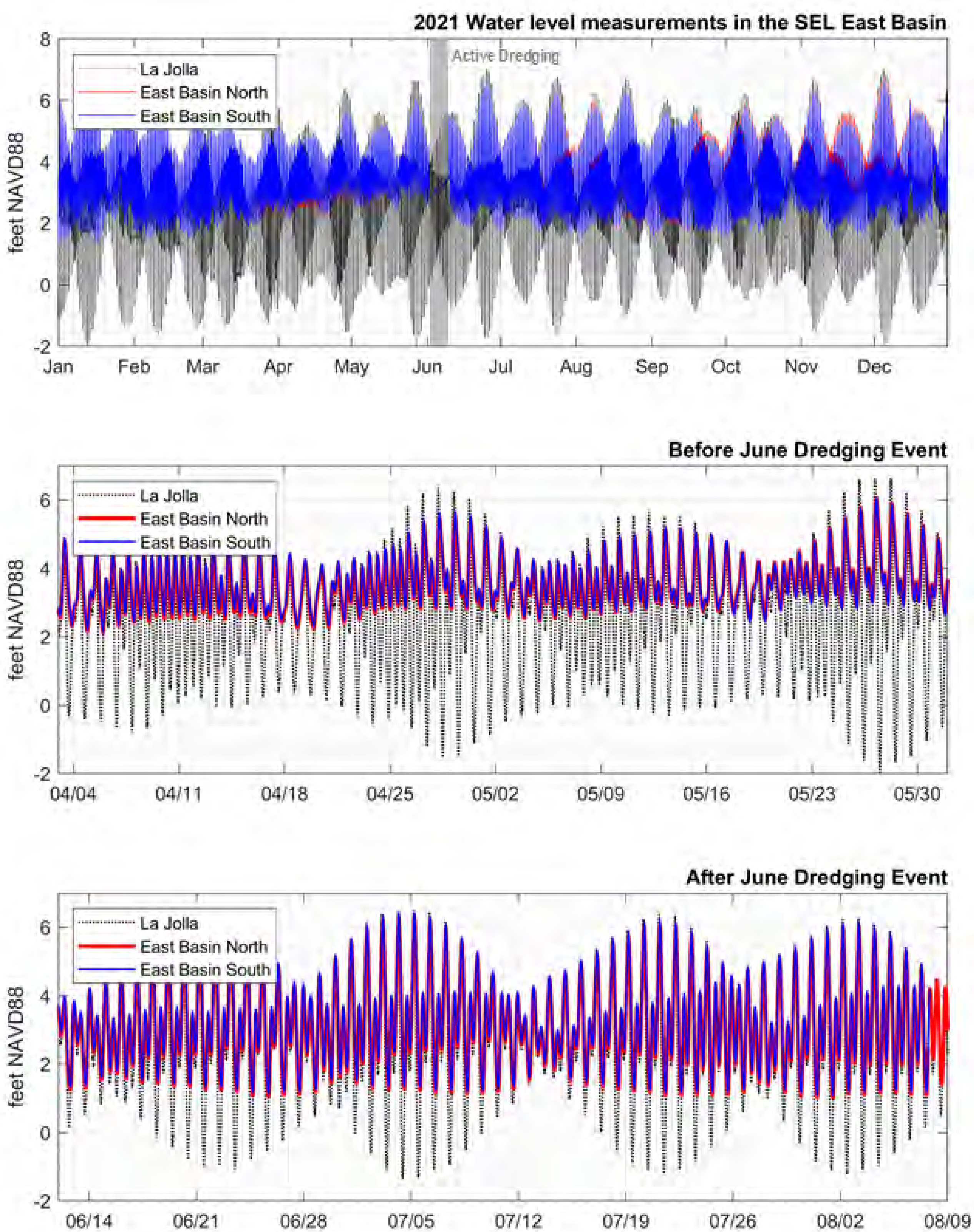

Figure 3-4: Measured water levels at the SEL East Basin before and after the June 2021 dredging event.

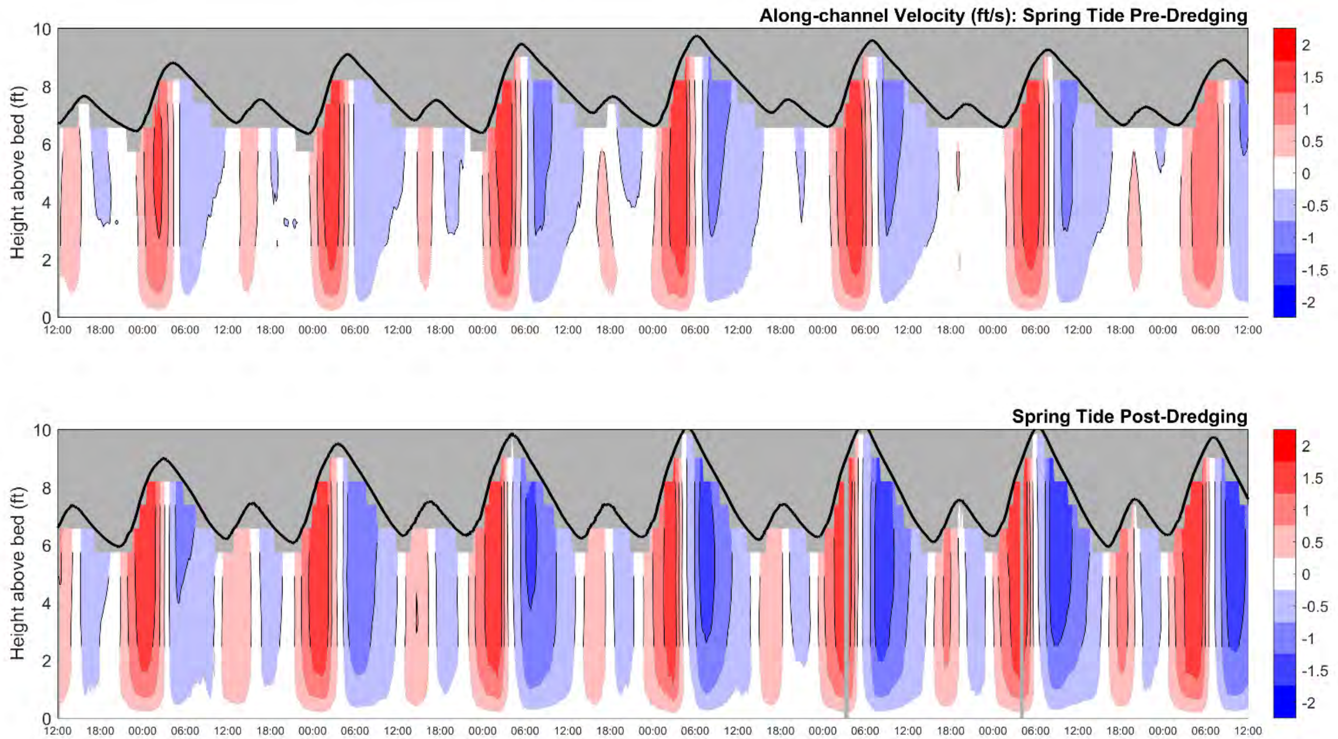

Figure 3-5: Vignette of along-channel velocities at the Nature Center station shortly before and after the June 2021 dredging event.

3.2 Water Level Variability Due to SELRP Construction

One of the goals of the SELRP has been to increase tidal exchange between the lagoon and the ocean, as observed through changes in tidal amplitude and range. To document changes associated with the construction of the SELRP, water level measurements during the 2021 deployment were compared with similar measurements from the 2017, 2018, 2019, and 2020 deployments. For this purpose, we identified a 30-day period within each yearly deployment in which all stations have continuous and undisturbed water level records. These 30-day records were selected to include two fortnightly spring/neap tidal cycles; consequently, these periods are referred to as "tidal months." Conditions during 2017 represent pre-construction water level variability, conditions during 2018 and 2019 represent water level variability during construction, and conditions during 2020 and 2021 represent post-construction water level variability.

It should be noted that some of the differences between the tidal months (for a given station) are related to processes that fluctuate on annual and/or longer time scales and *not* to modifications in SEL as part of the SELRP. Figure 3-6 illustrates this by showing recorded water levels at La Jolla during each of the tidal months. Overall, tidal water levels in the open ocean are highest in 2017 and are lowest during 2018. During the spring tide in late July 2017, water levels at high tide reach roughly 7.0 feet NAVD88; to compare, maximum high tide water levels during 2018 reach roughly 6.0 feet NAVD88, and those in 2019-2021 reach roughly 6.5 feet NAVD88. Tidal datums at each monitoring station for each tidal month are provided in Appendix A.

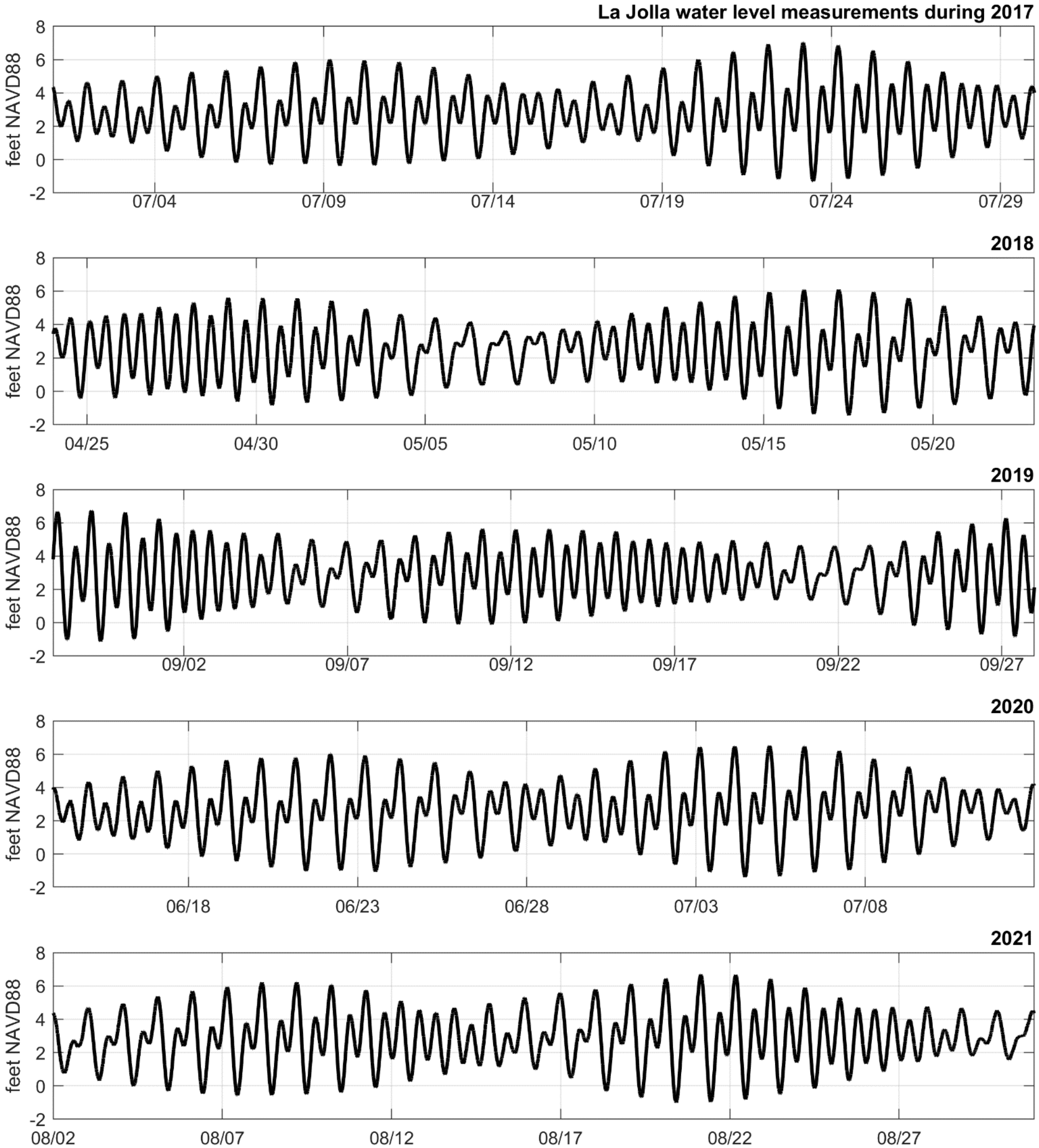

Figure 3-6: Measured water levels at La Jolla during 2017-2020 tidal months.

To examine changes in SEL tidal water levels from 2017- 2021 that are due to construction activities rather than changes in the open ocean tide, tidal ranges within SEL were normalized to the tidal range in the open ocean (i.e., at La Jolla). The normalized tide range for a given station is defined as follows:

$$\text{Normalized Tidal Range} = \frac{\text{Tidal Range at station}}{\text{Tidal Range at La Jolla}}$$

Therefore, the normalized tidal range in La Jolla always has a value of 1. Values for all stations are given in Table 3-1. The Great Diurnal Range is estimated as the average difference between the daily higher-high and lower-low tides over the course of the selected tidal month, and the Spring Tide Range is estimated as the difference between the highest high and lowest low tide of the selected tidal month; see Appendix A for more details.

Table 3-1: Normalized great diurnal ranges and spring tide ranges for 2017- 2021 tidal months.

Station	Great Diurnal Range					Spring Tide Range				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
La Jolla	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tidal Inlet Channel	0.73	0.54	0.63	0.60	0.56	0.54	0.45	0.61	0.64	0.51
Las Olas	0.53	0.45	0.41	0.60	0.56	0.49	0.41	0.36	0.65	0.51
Nature Center	-	0.50	0.63	0.60	0.55	-	0.42	0.60	0.64	0.50
East Basin North Channel	-	-	0.60	0.61	0.55	-	-	0.55	0.65	0.51
East Basin South Channel	-	-	-	0.61	0.55	-	-	-	0.65	0.51

For all years prior to 2020, the tidal range decreased as one moves upstream away from the mouth of the SEL (Table 3-1). This is consistent with expectations, as tidal ranges generally become increasingly smaller moving farther inland from the mouth of estuaries due to the effects of friction caused by flow over vegetation, distance, and/or flow through constrictions. Construction activities during 2018 and 2019, such as channel dredging and the removal of constrictions, served to increase the tidal range at stations away from the mouth by making the channel wider and/or deeper throughout much of the lagoon. As a result, the tidal range throughout the lagoon has been nearly identical to the tidal range at the mouth of the lagoon since the construction phase was completed in early 2020.

3.2.1 Tidal Inlet Channel

Water level measurements at the Tidal Inlet Channel contain more noise, or small and short oscillations in the water level records, than measurements at other monitoring stations, which typically indicates agitation of the water surface. The periods of noise at this station often coincide with periods of noise in the water level records at La Jolla and are consequently attributed to water surface agitation during high wind and/or wave events.

As depicted in Figure 3-7, low tide elevations at the Tidal Inlet Channel station during the 2017 tidal month were consistently higher than those at La Jolla, whereas high tides at the Tidal Inlet were similar or slightly larger than those at La Jolla (see Table A-1). This indicates that the main effect of the pre-construction SEL inlet channel was to mute the low tide elevation within the lagoon. Similar muted low tides are evident during all tidal months even though the normalized tidal range dropped briefly during 2018 before rebounding to levels similar to pre-construction variability. These fluctuations in tidal range and elevation illustrate the complex effects of the restoration project construction.

The tidal range at the Tidal Inlet Channel during 2018 was previously noted as being smaller than the tidal range at this location during 2017 (Moffatt & Nichol, 2021). Between 2017 and 2018, the normalized great diurnal range decreased from 0.73 to 0.54, and the normalized spring tide range decreased from 0.54 to 0.45. This is attributed to dredging operations in the Central Basin of SEL and operation of dikes 2A and 2B, across the channel near the Nature Center and Pole Road, respectively, which increased the wetted surface area of the lagoon while the volume of water entering and exiting the lagoon with tides (i.e., the tidal prism) remained unchanged.

The excavation of the inlet channel in the spring of 2019 served to increase the normalized tidal range at the Tidal Inlet Channel from 2018 to 2019 (Table 3-1), as the larger cross-section allows water to move more freely into and out of the lagoon. As a result, the tidal range at the station during neap tides since 2018 has been nearly equivalent to the ‘open ocean’ tidal range at La Jolla (Figure 3-7).

The normalized tidal range at the Tidal Inlet Channel has slowly dropped from 2019 through 2021, though this trend is also observed upstream at the Nature Center (Table 3-1); the reduction in tidal range since 2020 is consistent across all sampling stations. This suggests that the change in tidal range is likely due to changes in the lagoon mouth configuration and/or larger interannual variability. We note that the channel has been routinely dredged to maintain similar depths within the lagoon and no substantial changes in tidal prism due to construction have occurred since early 2019. Consequently, these measurements suggest that the tidal range at the Tidal Inlet Channel has returned to the pre-construction (2017) range.

3.2.2 Las Olas

Measured water levels at the Las Olas monitoring station for 2017- 2021 tidal months are shown in Figure 3-8. Tidal muting at this location during 2017 and 2018 was negligible at high tides but pronounced at low tides; this was similar to the tidal characteristics at the Tidal Inlet Channel. However, low tides at Las Olas were consistently *more* muted than low tides at the Tidal Inlet Channel (see Table A-1 and Table A-2). A similar difference was observed in both 2018 and 2019. This difference in low tide water level elevations was attributed to the shallow bathymetry in the southern portion of the West Basin and was likely influenced by the channel constriction associated with Dike 5 placed at the mouth of this channel as well. Since the removal of Dike 5 in January 2020, the tidal range at the Las Olas station has been consistently similar to the tidal range at the Tidal Inlet Channel station. This suggests that the restoration project has been successful at increasing the tidal exchange within the West Basin.

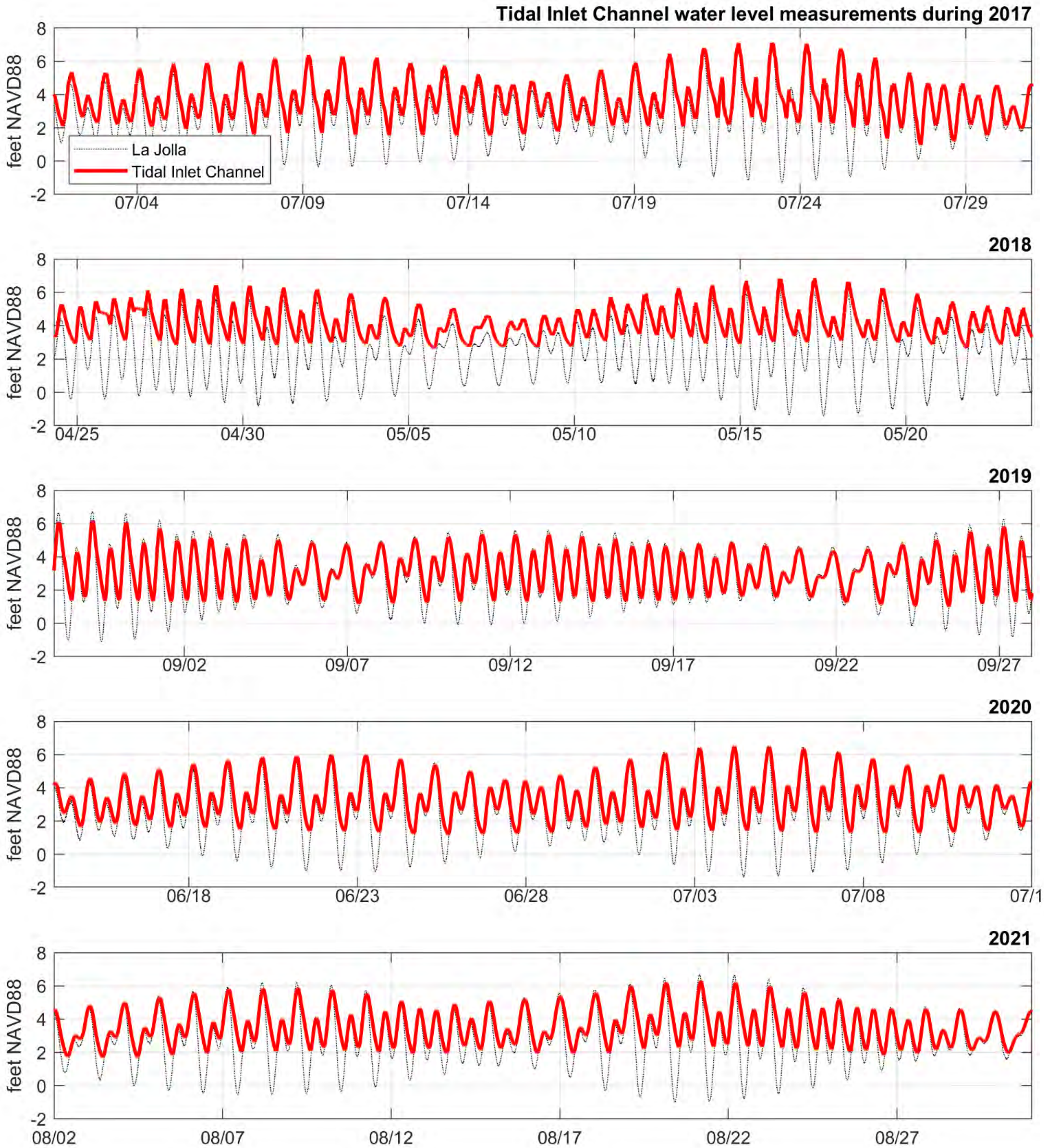

Figure 3-7: Measured water levels at the Tidal Inlet Channel station during 2017-2021 tidal months. Surveyed water level elevations during 2018 are affected by impact to the mooring.

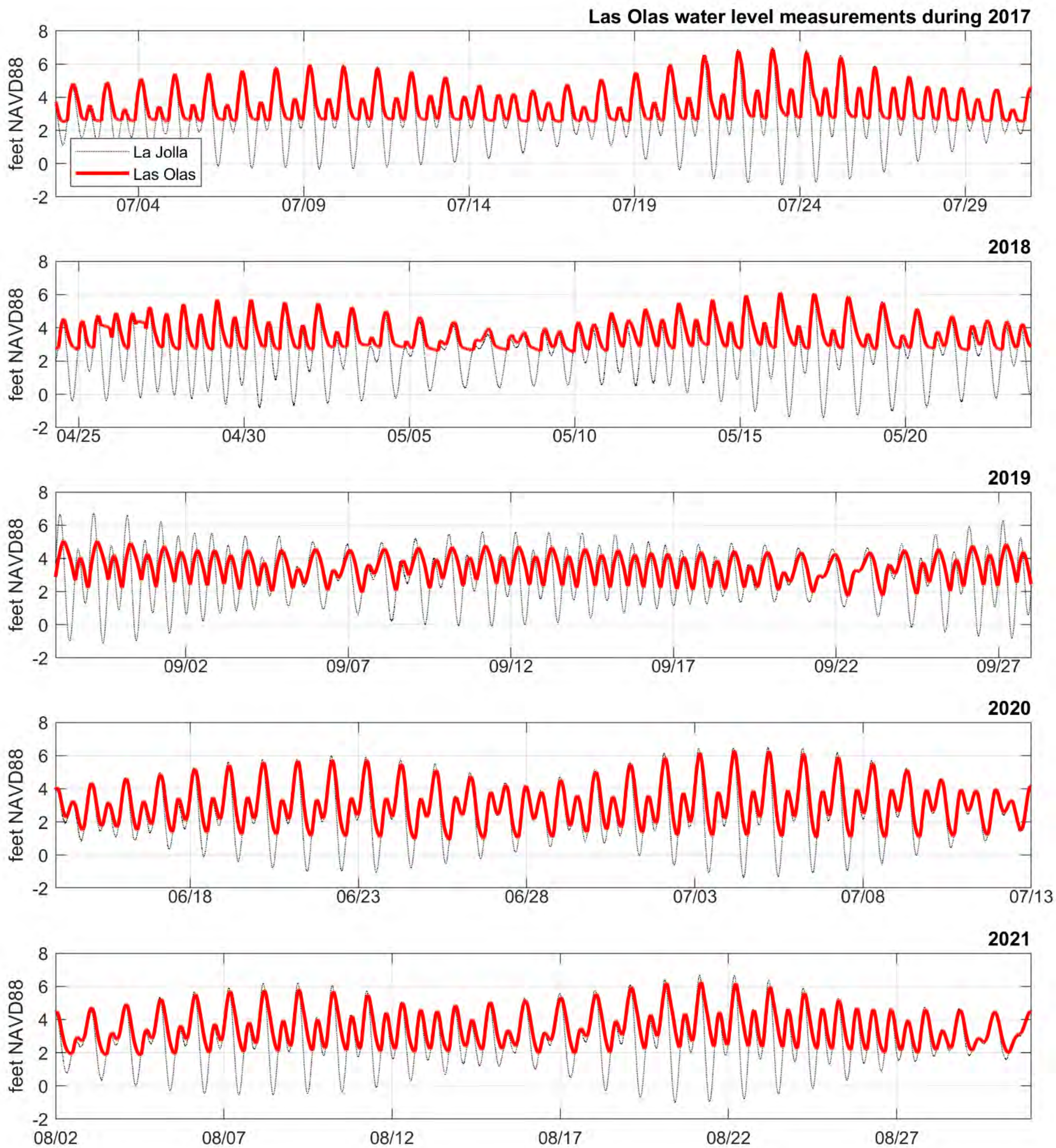

Figure 3-8: Measured water levels at the Las Olas station during 2017-2021 tidal months.

3.2.3 Nature Center

Water levels at the Nature Center station during 2018-2021 tidal months are shown in Figure 3-9. Low tides at the Nature Center are muted during all tidal months, which is similar to tidal characteristics at the Tidal Inlet Channel and Las Olas stations. However, high tides at the Nature Center station are also muted during 2018. This muting occurs primarily during spring tides. As shown in Table 3-1, the great diurnal range at the Nature Center station during 2018 was 50% of the tidal range in the open ocean, whereas the Spring Tide Range was 42% percent of the spring tidal range in the open ocean. The normalized tidal range increased to roughly 60% in 2019 and has since slowly dropped to 55%; for all tidal months after 2018, the normalized tidal range at the Nature Center station is nearly identical to that at the Tidal Inlet Channel station.

The change in the tidal characteristics at the Nature Center station from 2018-2019 is attributed to the excavation of the channel between the mouth of SEL and the Nature Center station location. The larger cross-section at the site since 2018 is thought to permit water to move more freely throughout the lagoon, allowing the tidal range at the Nature Center to be consistently similar to the tidal range at the mouth of the lagoon.

3.2.4 East Basin North Channel

Water levels at the East Basin North Channel station during the 2019, 2020, and 2021 tidal months are shown in Figure 3-10. Low tides in the East Basin North Channel are muted during all tidal months, similar to tidal characteristics at all downstream stations. High tides are also muted in the East Basin North Channel. More muting of high tides is observed during 2019 than 2020 or 2021; this is attributed to the presence of Dike 2A upstream of the Nature Center station throughout 2019. The dike was removed in early February 2020. As a result, the tidal range observed at the East Basin North Channel station in 2020 and 2021 is now similar to that observed at the Nature Center station.

3.2.5 East Basin South Channel

Water levels at the East Basin South Channel station during the 2020 and 2021 tidal months are shown in Figure 3-11. Tidal variability at this station is similar to that observed at all other stations in 2020 and 2021; low tides are muted, while high tides are similar in elevation to high tides in the open ocean measured at La Jolla, particularly within 2020 tidal observations. The tidal range shows a slight decline from 2020 to 2021, but this trend is consistent across all water level monitoring stations.

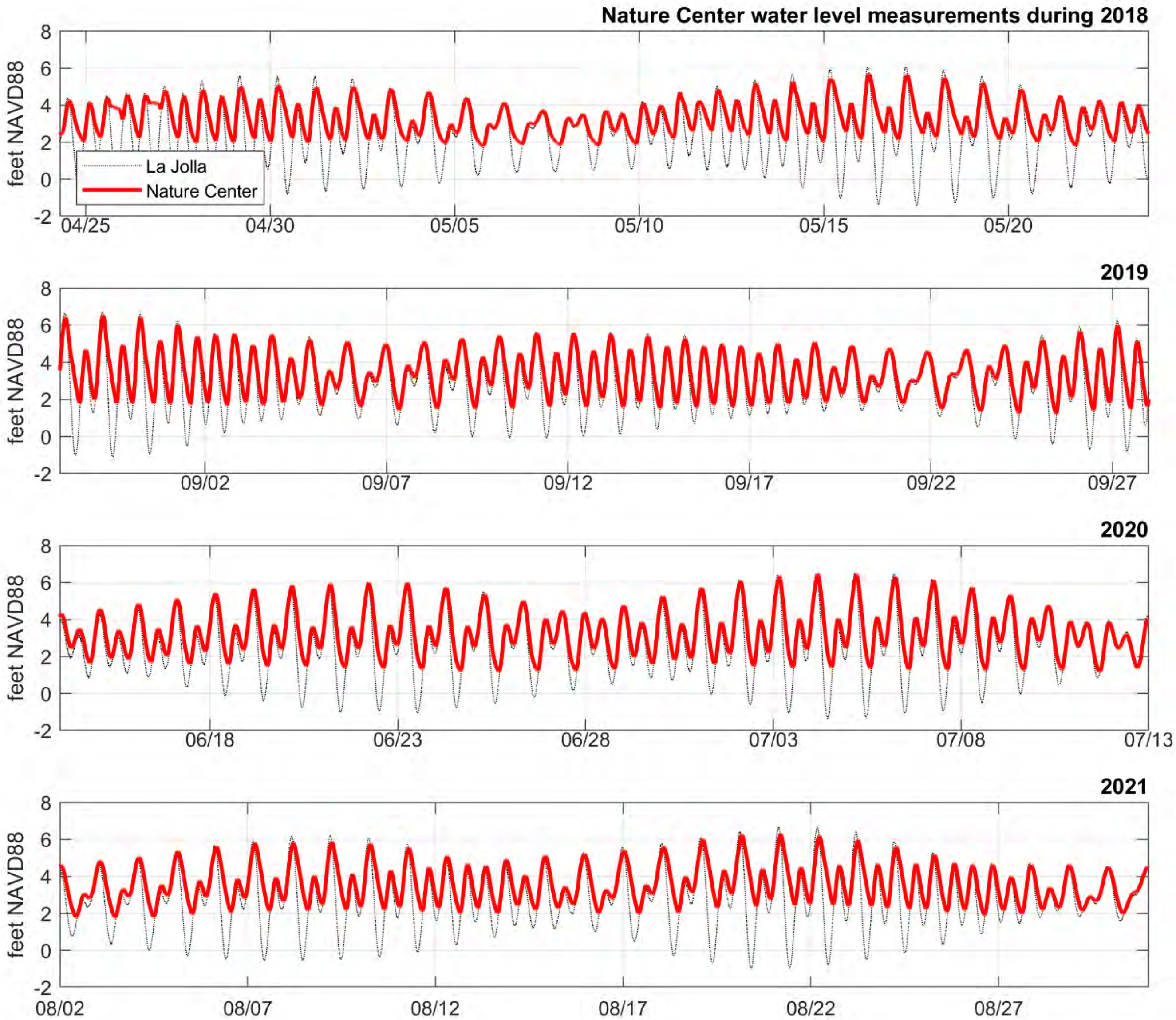

Figure 3-9: Measured water levels at the Nature Center station during 2018-2021 tidal months.

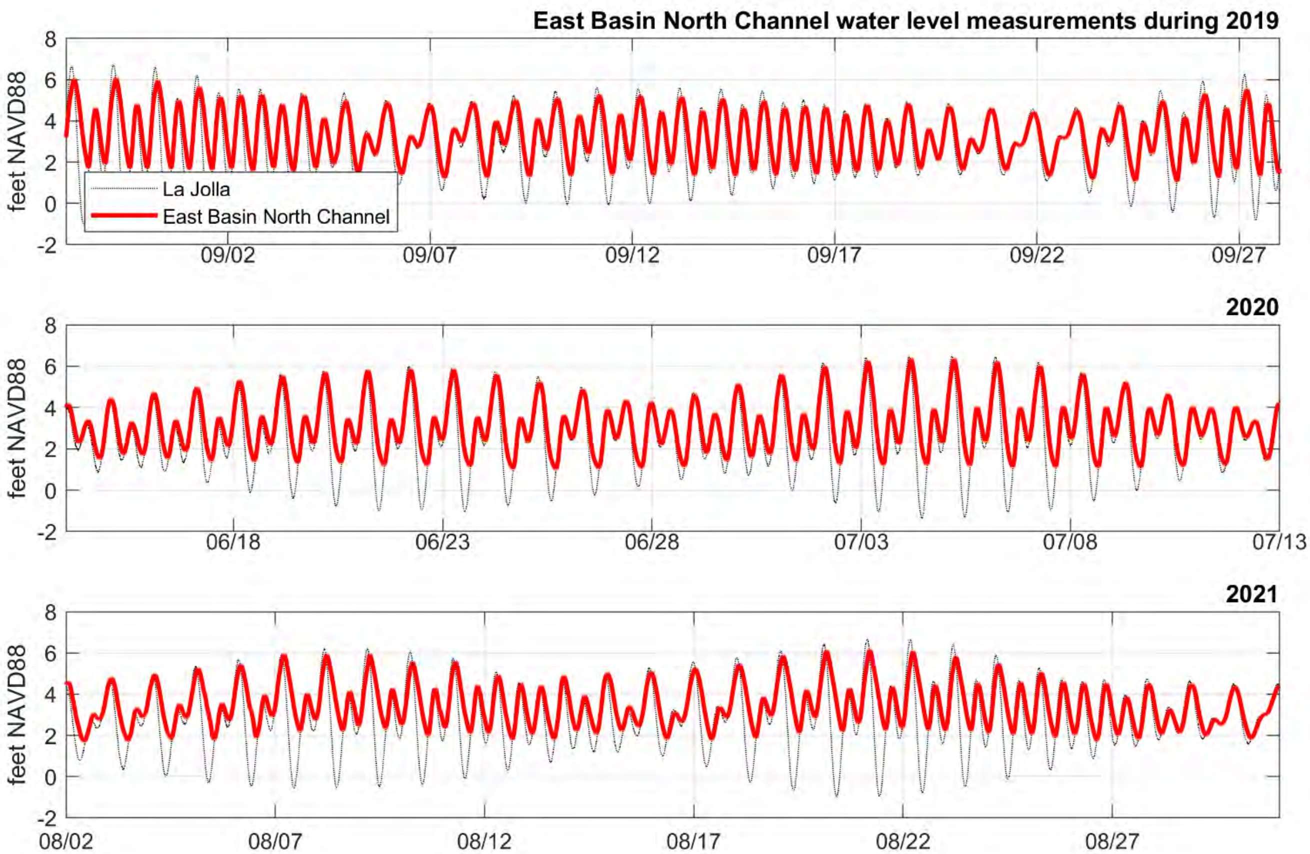

Figure 3-10: Measured water levels at the East Basin North Channel Station during 2019- 2021 tidal months.

Figure 3-11: Measured water levels at the East Basin South Channel Station during 2020- 2021 tidal months.

3.3 Tidal Inundation Frequency

The tidal inundation frequency analysis provides the frequency of inundation statistics over specific elevation thresholds at a given location. It is extremely beneficial in planning marsh restoration activities and habitat designs. The inundation frequency determines the elevations at which specific marsh habitats will be established and the area and distribution of wetland habitats. Figure 3-12 presents the measured inundation frequencies from all tide gauge data in 2021. There are only slight variations between the inundation curves at each gauge location, but all show significant low tide muting when compared to the NOAA tide gauge at La Jolla. There are three inundation percentage breaks, 4%, 20% and 40% for high marsh, mid marsh, and low marsh, respectively. Measured and modeled tidal elevations can hence be used for target design elevations of these habitats when restoring a wetland area such as San Elijo Lagoon.

Table 3-2 lists the habitat break elevations at each tide gauge location for 2021. Each tide gauge locations' habitat break elevations are very similar to one another. Habitat elevations are 2021 based on tidal inundation frequency data are within the ranges designed and expected for salt marsh habitat. Therefore, habitats should occur at locations as expected within the lagoon according to pre-restoration planning documents.

Figure 3-13 shows the total 2021 dataset for all tide gauges located in San Elijo Lagoon as well as the NOAA La Jolla gauge. Data during the June 2021 dredging can be seen in this figure as a much straighter line than the tidal cycles. Figure 3-14 shows an example of a daily tidal cycle measurement at each gauge location.

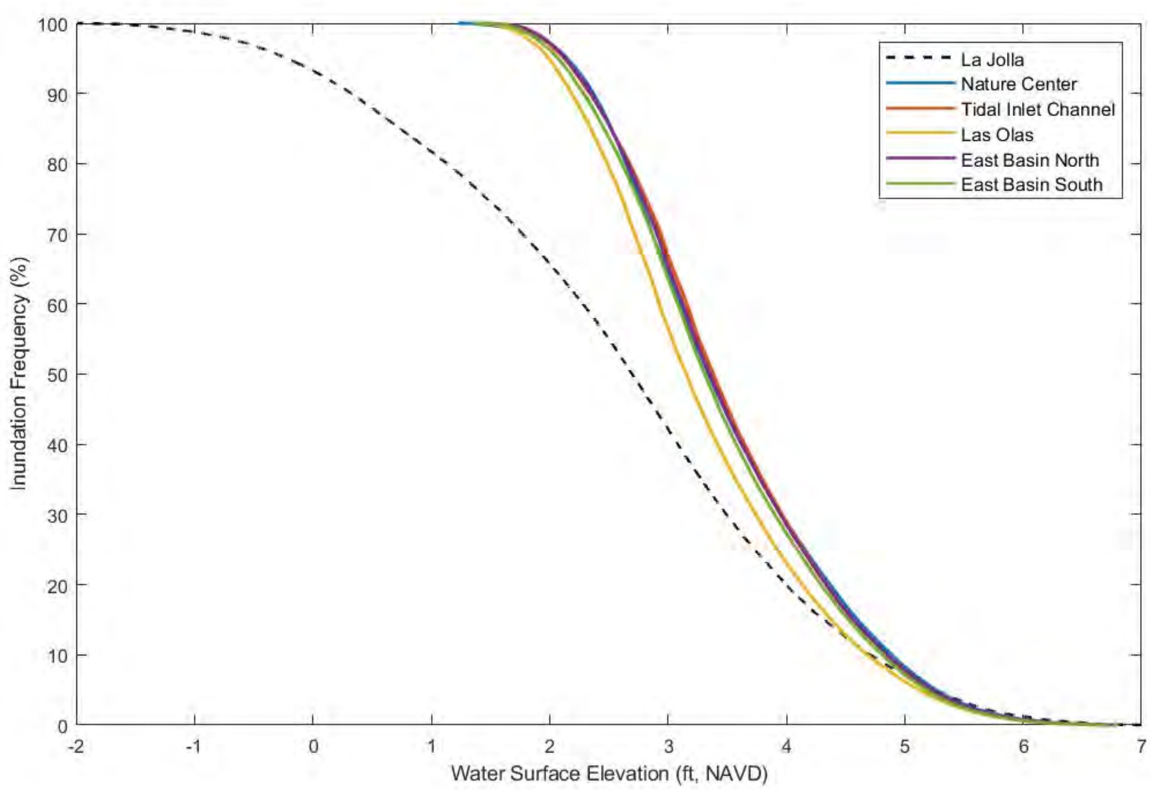

Figure 3-12: San Elijo Lagoon 2021 tidal inundation frequency curves.

Table 3-2: Habitat elevation breaks.

Habitat Type	Freq (%)	Habitat Breaks (WL, ft, NAVD88)				
		Nature Center	Tidal Inlet Channel	Las Olas	East Basin North	East Basin South
Mudflat	100%	1.23	1.43	1.35	1.43	1.36
Low-Marsh	40%	3.62	3.65	3.42	3.62	3.58
Mid-Marsh	20%	4.37	4.34	4.14	4.34	4.30
High- Marsh	4%	5.36	5.33	5.24	5.34	5.27
Transitional	0%	6.75	6.70	6.80	6.77	6.72

Table 3-3: Habitat Elevations at the Nature Center Compared for Pre-Construction and 2021 (NAVD88, feet).

Habitat Type	2021 Conditions	Pre-Construction Measured Conditions	Designed Target Elevations
Subtidal	Below 1.23	2.11	Below 1.6
Mudflat	1.23 to 3.62	2.11 to 3.40	2.44
Low Marsh	3.62 to 4.37	3.40 to 4.1	3.73 (raised to 4.09 for contingency)
Mid & High Marsh	4.37 to 6.75	4.10 to 5.80	5.31
Transitional	6.75 to 8.75	+5.80 and 7.80	Between 5.81 to 7.81
Supra-tidal	Above 8.75	Above 7.80	Above 6.3

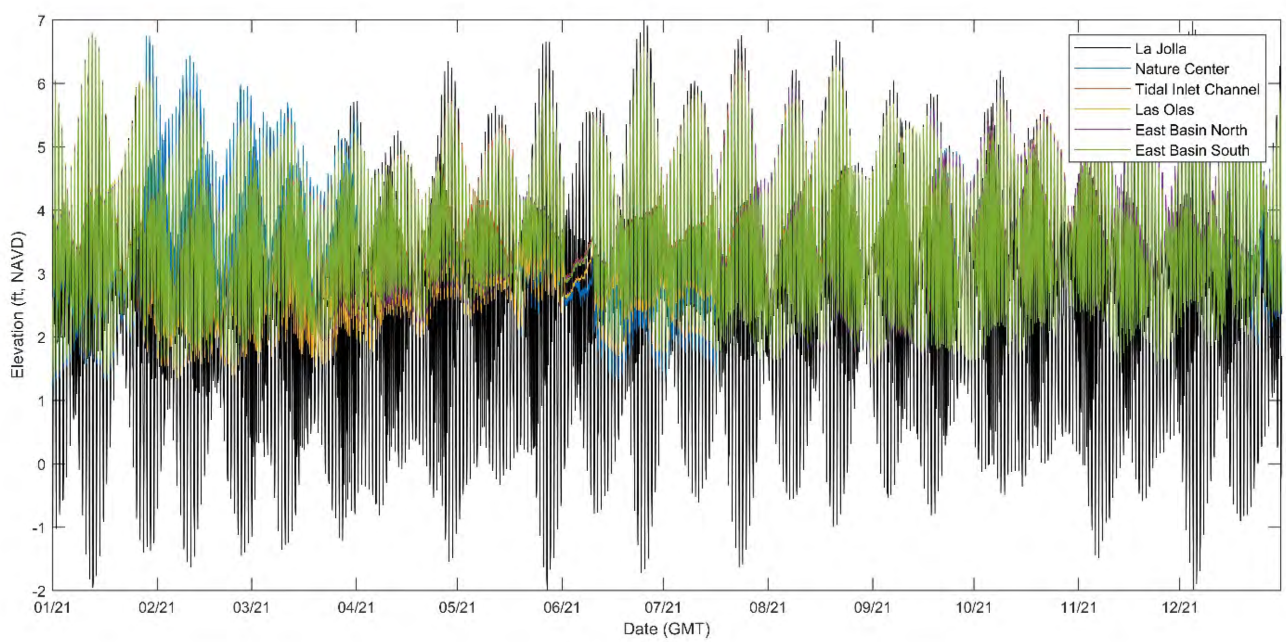

Figure 3-13: 2021 dataset for all tide gauges within San Elijo Lagoon and NOAA La Jolla gauge.

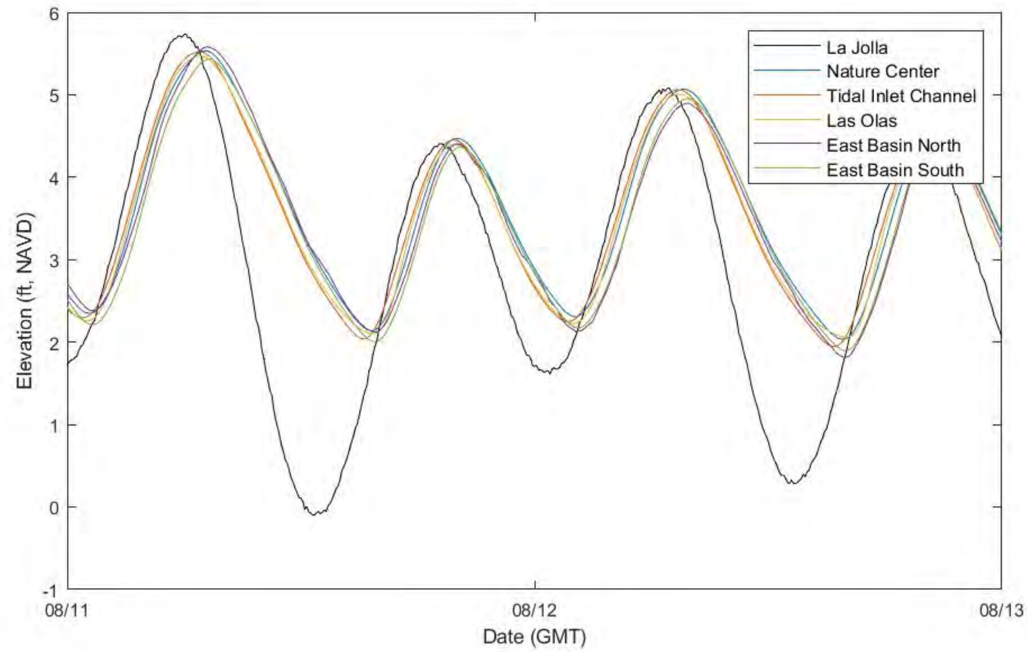

Figure 3-14: Example daily tidal measurements from all tide gauges.

4. SUMMARY / NEXT STEPS

This report documents methods and preliminary results of the tidal water level monitoring campaign conducted in San Elijo Lagoon during 2021 in support of the San Elijo Lagoon Restoration Project. Main findings from the campaign are summarized below.

1. Similar to 2020, effects of construction are no longer present in the tidal series and tidal ranges have returned to an ambient condition post-restoration condition. Tidal ranges showed a slight overall decline from 2020 values, likely due to natural interannual variability and shoaling at the tidal inlet.

2. Tidal ranges are nearly constant throughout the lagoon, suggesting that the depth and width of the mouth of the lagoon are controlling tidal characteristics within the lagoon.

3. Similar tidal ranges on the eastern and western sides of I-5 construction continue to indicate that the effects of the construction on tidal propagation were negligible.

4. Tides successfully reach to the upstream ends of the lagoon in the east basin with amplitudes similar to downstream locations, and the timing shows very little lag. Tidal hydraulics appear to be efficient throughout the lagoon.

5. June 2021 dredging operations to widen and deepen areas near the mouth of SEL led to increases in the tidal range throughout SEL once completed.

6. A short data gap exists for tidal elevations during the June 2021 maintenance dredging period (first two weeks in June).

7. Another data gap exists for the Nature Center and west basin sites in late 2021 when dredging was occurring at the railroad bridge location to remove a shoal. The Las Olas gage data set shows an additional gap starting in September 2021 when the gage malfunctioned. However, data collected by the tidal inlet gage fills that data gap.

8. Habitat elevations are 2021 based on tidal inundation frequency data are similar to what was designed and expected and are within with ranges specified in the engineering plans and specifications. Therefore, habitats should be expected to occur within the lagoon at locations predicted in pre-restoration documents.

9. Continued monitoring of water levels throughout the lagoon is necessary to document local changes in tidal amplitudes and ranges in the post-construction phase of the SELRP.

10. To minimize interruptions in the water level records associated with the instrumentation, inspection of the tide gauges should continue to be conducted approximately every two months. These inspections should include the following activities: surveying the water level before retrieving the instrument, replacing batteries, downloading data, removing biofouling, ensuring a stable mounting system, clearing kelp and debris that may have collected on the mooring, and surveying the water level after re-installing the instrument.

REFERENCES

Moffatt & Nichol. (2021). *San Elijo Lagoon Restoration Project. 2020 Tidal Monitoring Report prepared for the San Elijo Lagoon Conservancy.* Long Beach, CA: Moffatt & Nichol.

NOAA. (2019). *La Jolla, CA - Station ID: 9410230*. Retrieved from Tides & Currents: https://tidesandcurrents.noaa.gov/stationhome.html?id=9410230

APPENDIX A. WATER LEVEL METRICS

Following previous water level reports (e.g., Moffatt & Nichol 2018[1]), water level records from July 1-30, 2017 were selected to represent baseline (pre-construction) conditions. Records from April 24 to May 23, 2018 were selected to represent tidal conditions roughly 4 months into construction. Records from August 29 to September 28, 2019 were selected to characterize tidal conditions following substantial dredging throughout SEL. Records from June 14 to July 13, 2020 were selected to characterize initial post-construction tidal conditions, and records from August 2 to August 31, 2021 were selected to characterize continued post-construction tidal conditions roughly two months after a tidal inlet dredging event. Table A-1 provides tidal characteristics at La Jolla and the SEL monitoring stations during the 2017 tidal month; the same metrics are provided in Table A-2 for the 2018 tidal month, Table A-3 for the 2019 tidal month, Table A-4 for the 2020 tidal month, and Table A-5 for the 2021 tidal month. The tidal metrics shown in these tables are accurate within ±0.1 feet and are defined as follows:

- MHHW[*]: The average of the daily higher-high water levels within the 30-day record.
- MLLW[*]: The average of the daily lower-low water levels within the 30-day record.
- Great Diurnal Range: The difference in height between MHHW and MLLW.
- Spring High Tide: The highest spring high tide within the 30-day record.
- Diurnal Tide Muting: The difference between the Great Diurnal Range at La Jolla and each of the SEL monitoring stations
- Spring Low Tide: The spring low tide that follows the highest of the spring high tides within the 30-day record.
- Spring Tide Range: The difference in height between Spring High Tide and Spring Low Tide.
- Spring Tide Muting: The difference between the Spring Tide Range at La Jolla and each of the SEL monitoring stations.

[1]Moffatt & Nichol. (2018). San Elijo Lagoon Restoration Project. 2017 Tidal Monitoring Report prepared for the San Elijo Lagoon Conservancy. Long Beach, CA: Moffatt & Nichol.

[*] It is noted that the definitions of the MHHW and MLLW datums used in this report differ from those used by NOAA, which are estimated over a period of approximately 19 years (i.e., a tidal epoch).

Table A-1: Tidal datums and ranges from July 1-30, 2017.

Station	MHHW (ft, NAVD88)	MLLW (ft, NAVD88)	Great Diurnal Range (ft)	Diurnal Tide Muting (ft)	Spring High Tide (ft, NAVD88)	Spring Low Tide (ft, NAVD88)	Spring Tide Range (ft)	Spring Tide Muting (ft)
La Jolla, CA	5.41	0.03	5.38	N/A	7.03	-1.29	8.31	N/A
Tidal Inlet Channel	5.75	1.84	3.91	1.47	7.08	2.57	4.52	3.79
Las Olas	5.45	2.62	2.83	2.55	6.91	2.85	4.06	4.25

Table A-2: Tidal datums and ranges from April 24 through May 23, 2018.

Station	MHHW (ft, NAVD88)	MLLW (ft, NAVD88)	Great Diurnal Range (ft)	Diurnal Tide Muting (ft)	Spring High Tide (ft, NAVD88)	Spring Low Tide (ft, NAVD88)	Spring Tide Range (ft)	Spring Tide Muting (ft)
La Jolla, CA	4.77	-0.42	5.19	N/A	6.09	-1.44	7.53	N/A
Tidal Inlet Channel	5.76*	2.96*	2.80	2.39	6.69*	3.32*	3.37	4.16
Las Olas	5.07	2.73	2.34	2.84	6.02	2.90	3.12	4.41
Nature Center	4.71	2.09	2.62	2.57	5.62	2.47	3.15	4.38

*Absolute water levels (relative to NAVD88) are suspect.

Table A-3: Tidal datums and ranges from August 29 through September 28, 2019.

Station	MHHW (ft, NAVD88)	MLLW (ft, NAVD88)	Great Diurnal Range (ft)	Diurnal Tide Muting (ft)	Spring High Tide (ft, NAVD88)	Spring Low Tide (ft, NAVD88)	Spring Tide Range (ft)	Spring Tide Muting (ft)
La Jolla, CA	5.68	-0.36	6.04	N/A	6.72	-1.12	7.84	N/A
Tidal Inlet Channel	5.14	1.32	3.82	2.22	6.19	1.37	4.81	3.03
Las Olas	4.59	2.14	2.45	3.59	5.05	2.23	2.82	5.02
Nature Center Downstream	5.68†	1.89†	3.78	2.26	6.52†	1.80†	4.72	3.12
Nature Center Upstream	5.09	1.46	3.63	2.41	6.00	1.70	4.30	3.54
East Basin North Channel	5.08	1.42	3.66	2.38	6.06	1.71	4.35	3.49

†Water levels at the Nature Center Downstream station were corrected for long-term measurement drift with linear trends; however, the absolute values following the correction (shown here) are suspect.

Table A-4: Tidal datums and ranges from June 14 through July 13, 2020.

Station	MHHW (ft, NAVD88)	MLLW (ft, NAVD88)	Great Diurnal Range (ft)	Diurnal Tide Muting (ft)	Spring High Tide (ft, NAVD88)	Spring Low Tide (ft, NAVD88)	Spring Tide Range (ft)	Spring Tide Muting (ft)
La Jolla, CA	5.91	-0.74	6.65	N/A	6.50	-1.37	7.87	N/A
Tidal Inlet Channel	5.43	1.44	3.99	2.66	6.49	1.44	5.05	2.82
Las Olas	5.20	1.20	4.00	2.65	6.28	1.20	5.08	2.79
Nature Center Downstream	5.50†	1.51†	3.99	2.66	6.50†	1.47†	5.03	2.84
East Basin North Channel	5.29	1.25	4.04	2.61	6.35	1.25	5.10	2.77
East Basin South Channel	5.39	1.36	4.04	2.61	6.45	1.35	5.10	2.77

†Water levels at the Nature Center Downstream station were corrected for long-term measurement drift with linear trends; the absolute values following the correction (shown here) are suspect due to the lower low tide elevations observed upstream.

Table A-5: Tidal datums and ranges from August 2-31, 2021.

Station	MHHW (ft, NAVD88)	MLLW (ft, NAVD88)	Great Diurnal Range (ft)	Diurnal Tide Muting (ft)	Spring High Tide (ft, NAVD88)	Spring Low Tide (ft, NAVD88)	Spring Tide Range (ft)	Spring Tide Muting (ft)
La Jolla, CA	6.02	0.07	5.95	N/A	6.68	-1.00	7.68	N/A
Tidal Inlet Channel	5.33	2.02	3.32	2.63	6.29	2.36	3.93	3.75
Las Olas	5.29	2.07	3.22	2.73	6.25	2.38	3.88	3.80
Nature Center	5.34†	2.09†	3.25	2.70	6.29†	2.47†	3.82	3.86
East Basin North Channel	5.26	1.98	3.27	2.68	6.14	2.28	3.87	3.81
East Basin South Channel	5.25	1.97	3.28	2.67	6.21	2.35	3.86	3.82

†Water levels at the Nature Center Downstream station were corrected for long-term measurement drift with linear trends; the absolute values following the correction (shown here) are suspect due to the lower low tide elevations observed upstream.

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MEMORANDUM

To: Doug Gibson, the Nature Collective

Cc: Tim Stillinger and Bradley Nussbaum, the Nature Collective

From: Chris Webb, Weixia Jin, and Astrid Vargas

Date: May 26, 2022

Subject: Water Quality Analysis for San Elijo Lagoon Restoration Project

M&N Job No.: 7017-07

Introduction

In support of the San Elijo Lagoon Restoration Project (SELRP) Water Quality Monitoring effort, Moffatt and Nichol conducted a water quality analysis with the objective of determining water residence time following construction of the SELRP.

Per the standard established in the SELRP Monitoring Plan, if the residence time is estimated to be longer than 7 days in any location within the lagoon, conditions will need to be more closely monitored within that particular area to determine potential degradation.

Numerical modeling analyses were conducted to determine the water residence time throughout the lagoon for average hydrodynamic conditions during dry weather. A summary of these analyses is provided in the following sections.

San Elijo Lagoon (SEL) Model Update: Post-Construction Condition

Hydrodynamic and water quality analyses conducted to support previous phases of the SELRP were performed with the use of an RMA-2 / RMA-4 numerical model of the lagoon (M&N 2017). For the present study, the model was updated to the Adaptive Hydraulics Modeling System (AdH) developed by the U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC).

While the RMA model uses a fixed mesh, AdH has the 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 computational effort and model accuracy.

Model Bathymetry

The computational domain of the SELRP model was updated to represent the geometry, ground and bed elevations of the lagoon following construction of the SELRP (during the last quarter of 2020). A list of the datasets and sources used to update the model, including post-construction topographic and bathymetric surveys, are provided in Table 1, while Figure 1 depicts the updated model bathymetry. Figure 2 presents post-construction conditions.

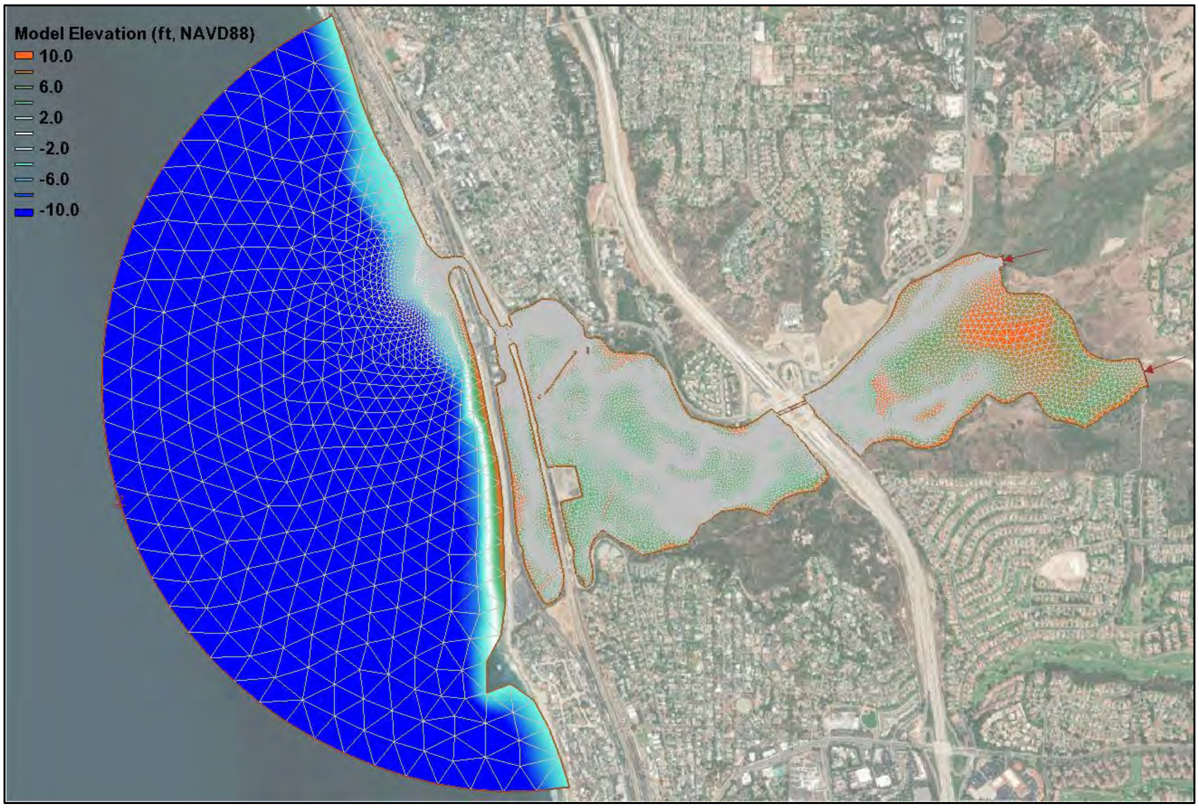

Figure 1 AdH Model of San Elijo Lagoon

Table 1 Datasets and Sources Used to Update the SELRP Numerical Model

No	Data Set	Source	Coverage	Elevation Range (ft., NAVD88)
1	SELRP Post Construction Bathymetry 2020-10-19 to 2020-10-22	CFC, 2020	Subtidal portions of SEL	-13 to 4.4
2	San Elijo Lagoon Final Topomap	KDM, 2020	Tidally-influenced and upland areas within SEL	0.4 to 310
3	San Elijo Lagoon RMA-2 Model Bathymetry	USACE, 2006	Ocean Bathymetry	-1 to -90
4	San Elijo Lagoon RMA-2 Model Bathymetry for Proposed Restoration Alternative: 1B	M&N, 2017	Mouth of SEL	-2 to 0

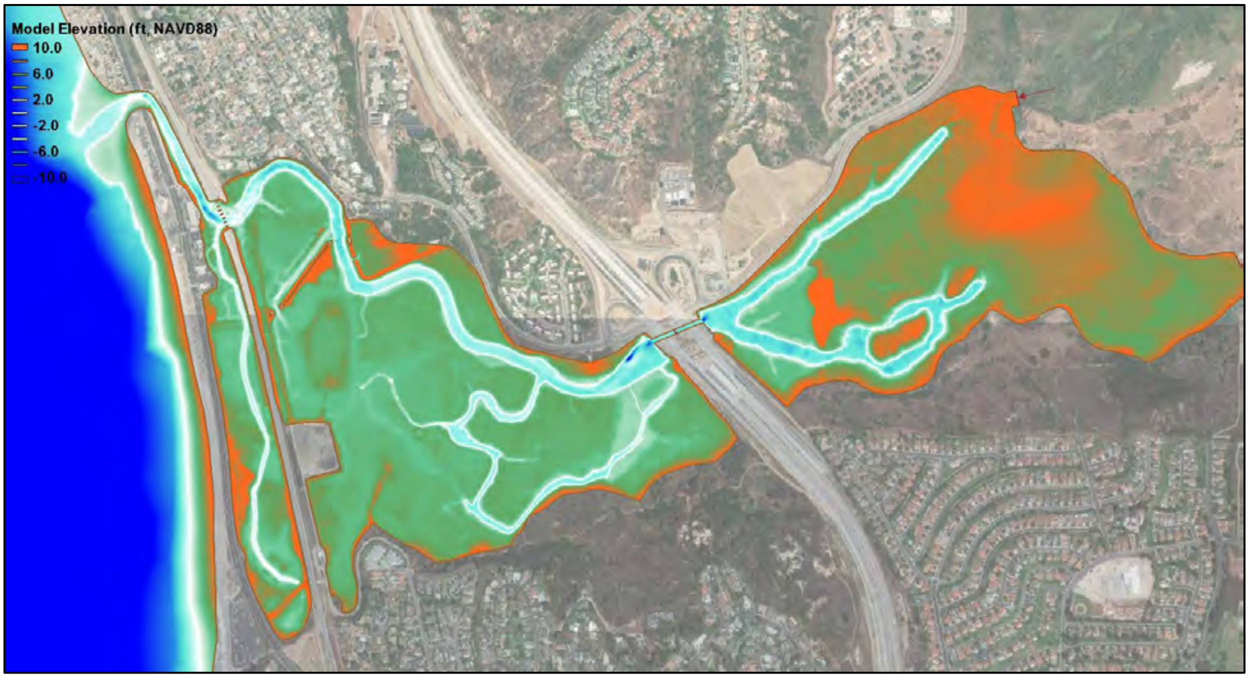

Figure 2 Updated Model Bathymetry Representing Post-Construction Conditions in SEL

The following remarks are made regarding the updated model bathymetry:

- The post-construction surveys used to update the model did not cover the downstream end of SEL (i.e., the area extending from beneath the Pacific Coast Highway Bridge to the open ocean). The morphology of this area is highly dynamic: It is subject to the hydrodynamic regime, which redistributes sediment, and can in turn influence hydrodynamics within the lagoon. Including bathymetric data representing the morphology of this area during the last quarter of 2020 would have therefore been optimal for the subsequent analyses. However, the model bathymetry in this area is carried over from the RMA2 model of SEL (M&N 2017), as indicated in Table 1.
- The updated model reflects the post-construction configuration of the lagoon, during the last quarter of year 2020. At this time, the channel underneath the I-5 bridge was still under its construction-phase configuration, consisting in a narrow channel (about 44-feet wide) confined by sheetpile walls (see Figure 3). For its final configuration, the sheetpile walls will be removed and the channel will be widened per the proposed dimensions corresponding to restoration Alternative 1B (M&N 2017). Construction work to achieve this is planned to be completed by April 25, 2022.

Figure 3 Channel Configuration Underneath the I-5 bridge During Construction (Photo: MN, 08/2021)

Model Calibration

Water Level and current velocity measurements in SEL were used to calibrate the updated numerical model. Model calibration consisted in performing a series of iterative simulations where calibration parameters, namely bed roughness coefficients, were adjusted systematically until modeled data was in optimal agreement with measured water levels and velocities.

Based on availability of water level and velocity measurements, a 17-day simulation period encompassing a spring-neap tidal cycle, was set for the calibration simulations from December 11th to December 28th, 2020. The model was forced by imposing measured water levels from CO-OPS station 9410230: La Jolla, at the offshore boundary of the model. The imposed water level boundary condition is depicted in Figure 4.

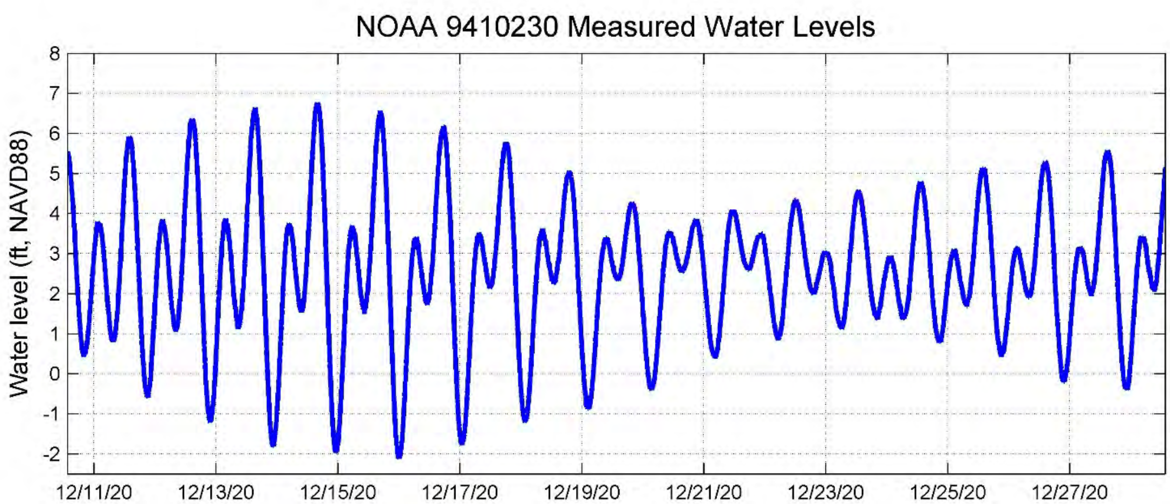

Figure 4 Water Level Offshore Boundary Condition for Calibration of the SEL Hydrodynamic Model

Simulation Setup: Bed Roughness

Definitions of bed roughness were largely carried over from the former RMA-2 model of SEL. Bed roughness, associated with the drag exerted to the flow, is specified by means of the Manning's coefficient (n), which ranges from 0.011 to 0.075, or higher for rivers or estuaries (Chaudhry 1993). Relatively high values are specified for rough surfaces, such as channels with cobbles or riprap, while low values are specified for smooth surfaces, such as concrete. A spatially varying bed roughness was specified in the model, in order to reproduce flow properties more adequately through the different environments in the model domain. The values for Manning's coefficient n, which resulted in the closest agreement to measured water levels and current velocities are listed in Table 2.

Table 2 Calibrated Bed Roughness Coefficients for the Updated SEL Model

Model Environment	Manning's n
Offshore	0.20
Nearshore and Brackish Marsh	0.25
Main Channel and Mudflats	0.030
Low and Mid Salt Marsh	0.035
Riparian	0.04
High Salt Marsh	0.045
Riprap	0.06

Figures 5 and 6 provide a comparison between measured water levels, and depth averaged current velocities at different monitoring stations in SEL. Overall, the model does well in capturing the range and phase of water elevations and velocity.

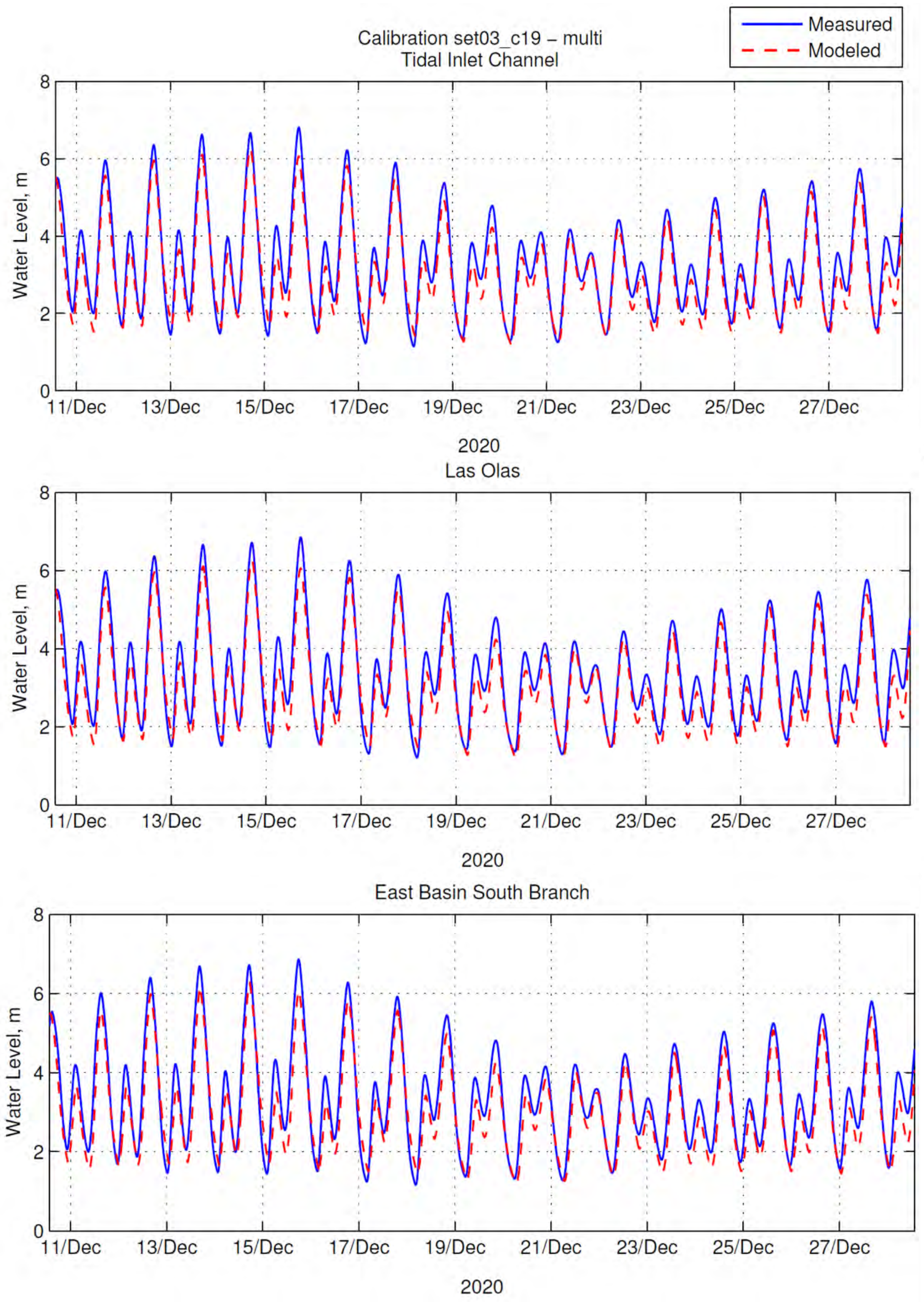

Figure 5 Measured vs Modeled Water Levels in SEL

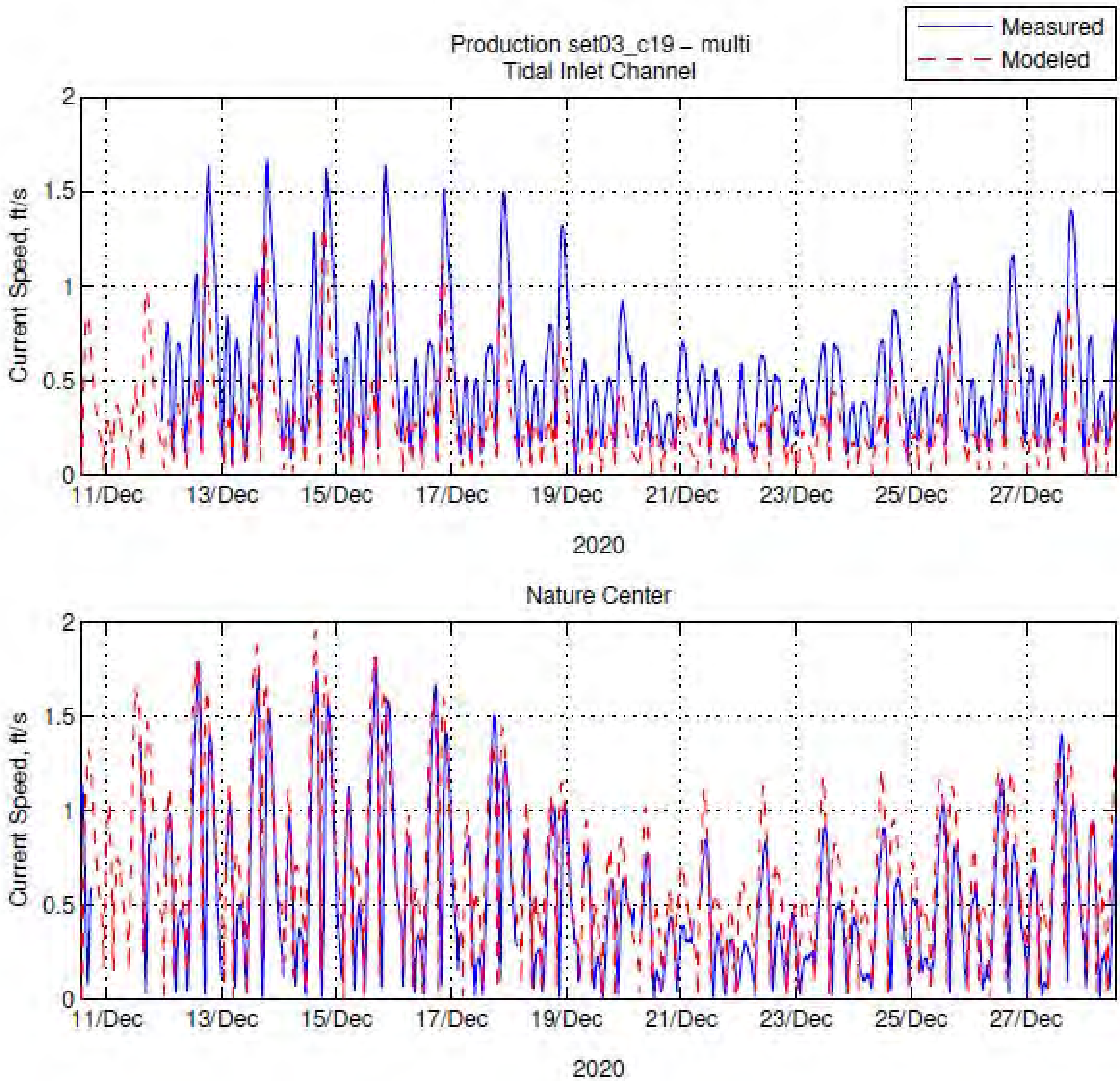

Figure 6 Measured vs Modeled Depth Averaged Current Velocity in SEL

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

Root Mean Squared Error (ft.) $\varepsilon_{RMS} = \sqrt{\overline{(x-y)^2}}$

Mean Absolute Error (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 3 and Table 4. Calibration of the model is limited by the lack of bathymetry data at the beach during the last quarter of 2020, i.e., when the post-construction bathymetric and topographic surveys were performed. Nonetheless, the achieved calibration is deemed adequate for the purpose of evaluating water quality in the lagoon.

Table 3 Statistical Calibration Parameters for Water Level

Parameter	Tidal Inlet Channel	Las Olas	East Basin South Branch
RMSE (ft.)*	0.26	0.27	0.35
MAE (ft.)*	0.20	0.20	0.27
R (-)	0.98	0.98	0.96
D (-)*	0.99	0.99	0.98

* Based on Measured and Modeled Data.

Table 4 Statistical Calibration Parameters for Depth Averaged Current Velocity Magnitude

Parameter	Tidal Inlet Channel	Nature Center
RMSE (ft./s)*	0.192	0.285
MAE (ft./s)*	0.15	0.20
R (-)	0.83	0.71
D (-)*	0.87	0.84

* Based on Measured and Modeled Data.

Residence Time Analysis

Residence time is defined herein as the average time a particle resides in a hydraulic system. It is a measure of the rate to which waters in the lagoon are renewed, which in turn is a proxy for water quality.

For this study, residence time is evaluated with a tracer study, in which the hydrodynamic model of SEL is used to simulate transport of a general constituent, such as a water tracer. Constituent concentrations through time are then assessed throughout the lagoon, reflecting the balance between the rate of constituent supply and the rate of constituent removal by tidal flushing.

Residence time was computed per Fischer, et al. (1979), as follows:

Consider the reduction of a tracer concentration in a tidal embayment due to flushing after being released (Fisher et al. 1979), in which C0 is initial concentration, K is a reduction coefficient and C(t) is the concentration at time t.

$$C(t) = C_0 e^{-Kt} \tag{4.1}$$

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

$$T_r = \frac{\int_0^\infty t\,C(t)\,dt}{\int_0^\infty C(t)\,dt} = \frac{1}{K}. \tag{4.2}$$

Since the concentration at t = Tr is

$$C(T_r) = C_0 e^{-1} = \frac{C_0}{e} \tag{4.3}$$

And the initial tracer concentration is the lagoon C0 is specified as 1,

$$C(T_r) = \frac{1}{e} = 0.37 \tag{4.4}$$

Tr, as defined above, can be found from the tracer concentration time series computed by the hydrodynamic model of SEL.

Based on the above methodology, the general procedure of computing the residence times throughout SEL is as follows:

1. Assign an initial tracer concentration, C0=1 over the entire area corresponding to the lagoon in the modeling domain, and C0=0 over the open water areas and offshore boundaries to simulate a single instantaneous release of a water tracer into the lagoon.

2. Run the numerical model to simulate tidal hydrodynamics in SEL until constituent concentrations throughout the lagoon have substantially decreased.

3. Extract modeled constituent concentrations data at locations of interest in the lagoon.

4. Find the residence times for the locations of interest from the distribution curves according to Equations 4.1 through 4.4.

Model Setup

Water Level Boundary Condition

As for the calibration simulations, measured water levels from CO-OPS station 9410230: La Jolla, were imposed at the offshore boundary. The latest records were analyzed to identify a period in which tidal amplitudes were representative of long-term average tidal conditions, such that the computed residence times were also representative of the long-term average hydrodynamic conditions in the lagoon (during dry weather conditions).

To find a representative tide period, published monthly maximum and minimum tidal elevations at La Jolla from January 2000 to December 2020 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 20-year record, while the representative spring-low tide elevation was similarly found by averaging all minimum low tide elevations. 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, 2020, reached nearly equivalent elevations. Figure 7 plots the recorded water levels for this period. As a reference, the average monthly maximum, minimum, and average water levels, as well as the Mean Higher High Water (MHHW), Mean Lower Low Water (MLW), and Mean Sea Level (MSL) datums are also plotted in the figure.

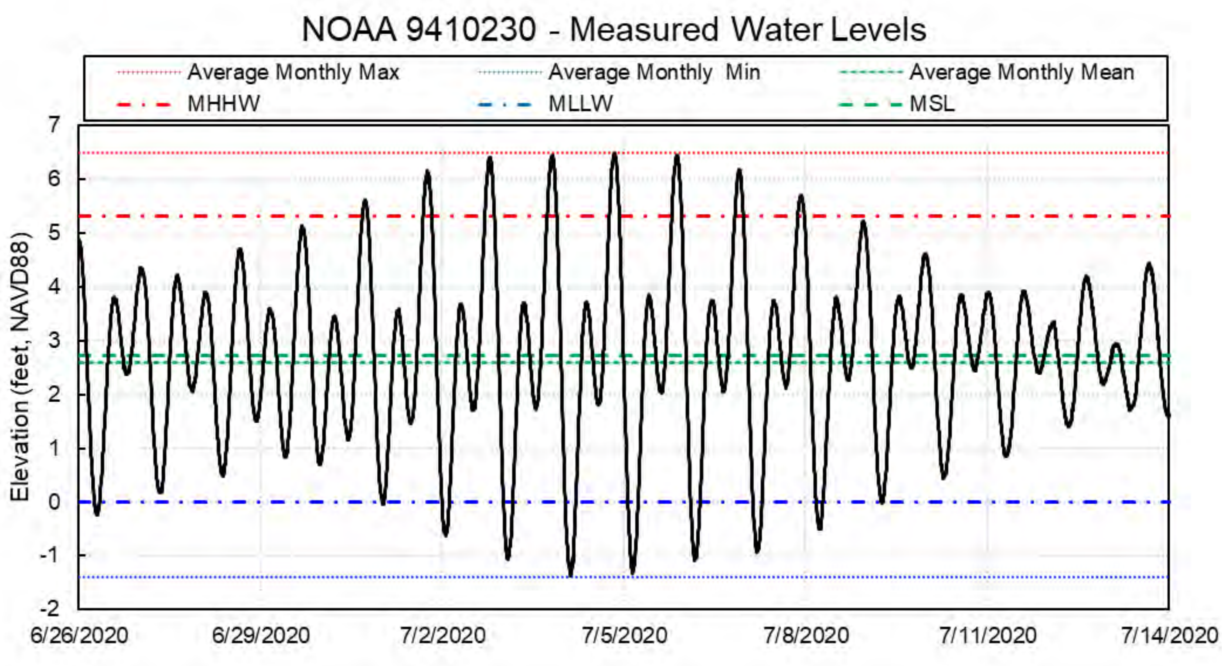

Figure 7 Water Level Boundary Condition

The spring-neap tidal cycle from June 14th to June 16th, 2020 was then assumed to be representative of long-term average conditions and was used as the tidal boundary condition for the hydrodynamic model.

Fresh Water Inflows

The conducted Residence Time Analysis is representative of dry weather conditions. Consequently, no freshwater inflows were specified at the upstream boundaries of the SEL model.

Tracer Concentrations: Boundary and Initial Conditions

As mentioned above, to simulate a single and instantaneous release of a tracer, no tracer concentrations were specified at the offshore boundary of the model. Meanwhile, initial tracer concentrations for the lagoon and open water areas were specified as C_0=1, and C_0=0, respectively. Figure 8 depicts the initial tracer concentration for the simulation

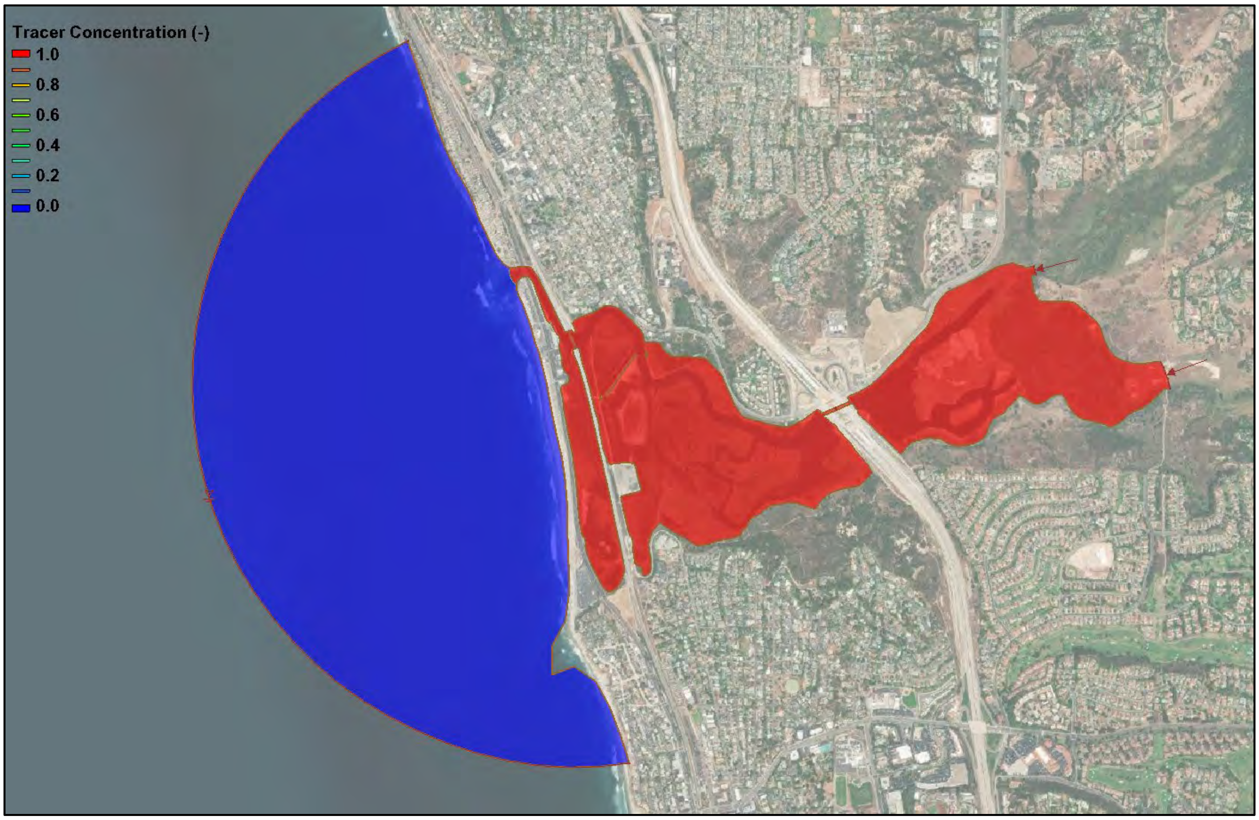

Figure 8 Initial Tracer Concentrations for the Residence Time Analysis Simulation

Diffusion Rates

AdH numerical models compute transport of constituents which is a water tracer for the case of the SEL model; these are based on user specified diffusion rates, which define the degree of spreading of the constituent. Diffusion rates for the different environments in the updated SEL model were based on those specified in the former RMA model of the lagoon (M&N 2017).

Prior to conducting the residence time analysis, preliminary simulations were performed in order to compare results with those obtained with the former RMA-4 model, which was calibrated with measured salinity data. This exercise indicated that for a same diffusion value, results could vary substantially between the two models. Consequently, adjustment to the specified diffusion rates at certain environments in the SEL model domain was done such that the AdH model produces results similar to the calibrated RMA-4 model. For a higher accuracy in the estimates of water residence time, calibration of the model to water quality data, such as salinity measurements is recommended.

The final diffusion setup for the Residence Time Analysis is provided in Table 5.

Table 5 Diffusion Rates Specified for the Updated SEL Model

Model Environment	Diffusion (ft^2/s)
Offshore	1000
Nearshore	300
Main Channel and Mudflats	10
Low and Mid Salt Marsh	10
Riparian	8
High Salt Marsh	5
Brackish Marsh	1
Riprap	1

Model Results: Estimation of Residence Time

Tracer concentrations throughout the lagoon were computed by the updated AdH hydrodynamic model. Results were extracted for a number of representative point locations in order to estimate residence times per Equations 4.1 to 4.4. An example is provided in Figure 9, which plots two curves: 1) in blue, the relative tracer concentration through time, as computed by the model, for location "CC4" in the Central Basin of SEL (see Figure 10 for location); and 2) in black, the 24.6-hour (a lunar day) moving average concentration, which is used to compute the residence time. The rationale for computing daily moving average is to smooth out large fluctuations in the computed concentrations within a daily tidal cycle that could yield in inaccurate residence time estimates. As shown in Equation 4.4 on page 9 of this memo, the average detention time of a tracer in the embayment is 1/e =0.37. Therefore, as indicated in the figure, the residence time for this location was found to be 3.8 days (91 hours).

The estimated residence time for the 16 locations of interest within SEL are provided in Figure 10 and Table 6.

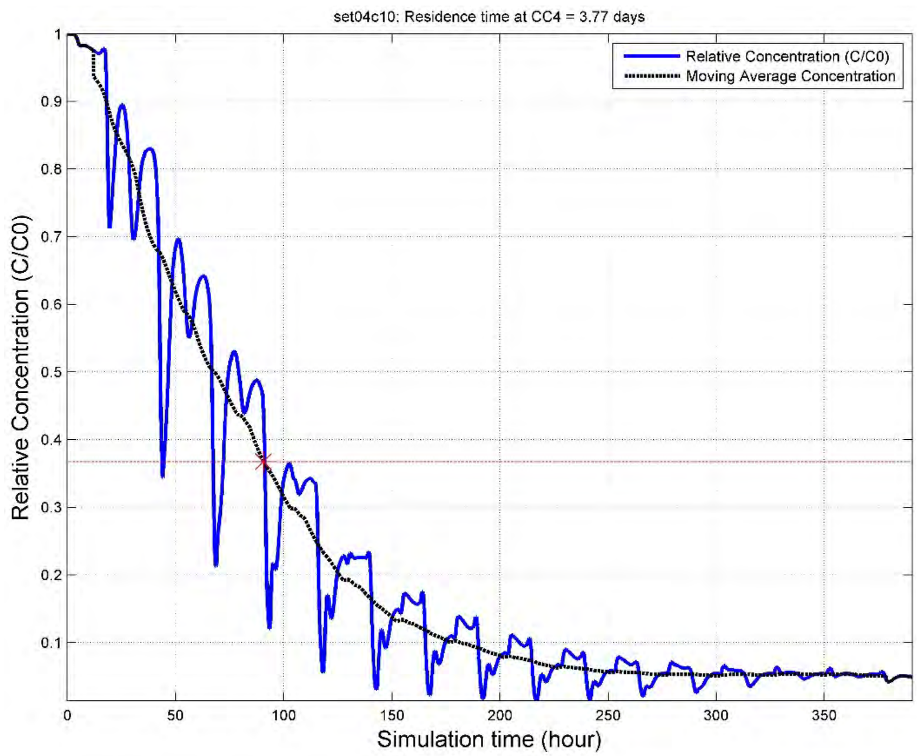

Figure 9 Relative Tracer Concentration and Residence Time at CC4, located in the central basin in SEL

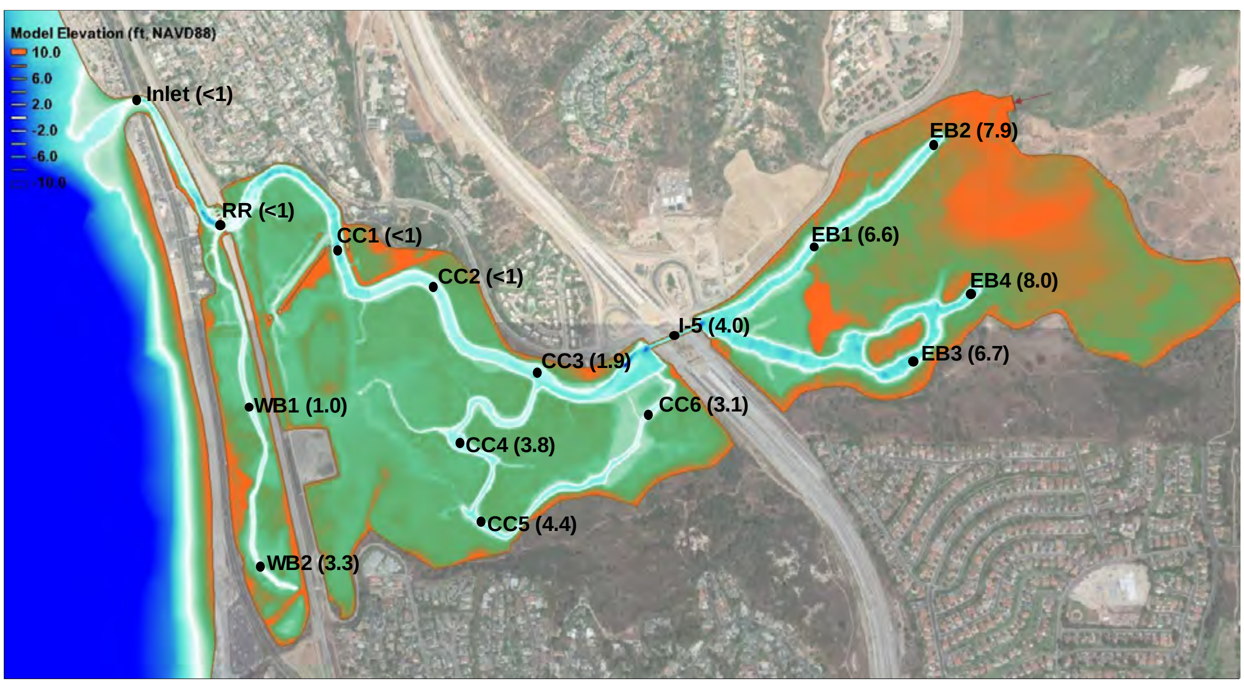

Figure 10 Estimated Residence Time (days) at Various Locations of SEL

Table 6 Estimated Residence Time at Various Locations of SEL

Basin	Location	Residence Time (Moving Average, Days)
West Basin	Inlet	< 1
	RR	< 1
	WB1	1.0
	WB2	3.3
Central Basin	CC1	< 1
	CC2	< 1
	CC3	1.9
	CC4	3.8
	CC5	4.4
	CC6	3.1
East Basin	I-5	4.0
	EB1	6.6
	EB2	7.9
	EB3	6.7
	EB4	8.0

As expected, residence time in the lagoon increases with distance from the inlet, ranging from < 1 day at the Inlet of the lagoon, to 8 days at the far east end of the model domain. This can be explained by the hydrodynamics and the mechanisms in which transport of constituents (e.g., the water tracer) occurs at the different regions of the lagoon. Close to the inlet (ocean), the tracer has a shorter distance to travel to the ocean; hence, the residence time is shorter. Also, tidal current velocities are the highest, and transport primarily is through advection, i.e., following the mean tidal currents: Ebb tidal currents flush out waters with high tracer concentration and flood tidal currents bring in waters from the open coast, which have lower tracer concentrations. This is illustrated in Figure 11 which shows how tracer concentrations at CC6 (Central Basin) follow the main motions of the tide, rapidly decreasing with the outgoing and incoming flows.

Meanwhile tidal current velocities have drastically reduced at the far east end of the lagoon. In this region, diffusion, referring to the transport given by much more smaller scale flow processes, becomes more relevant. This is reflected in Figure 12, which depicts a smoother decrease in tracer concentration for station EB4 (East Basin).

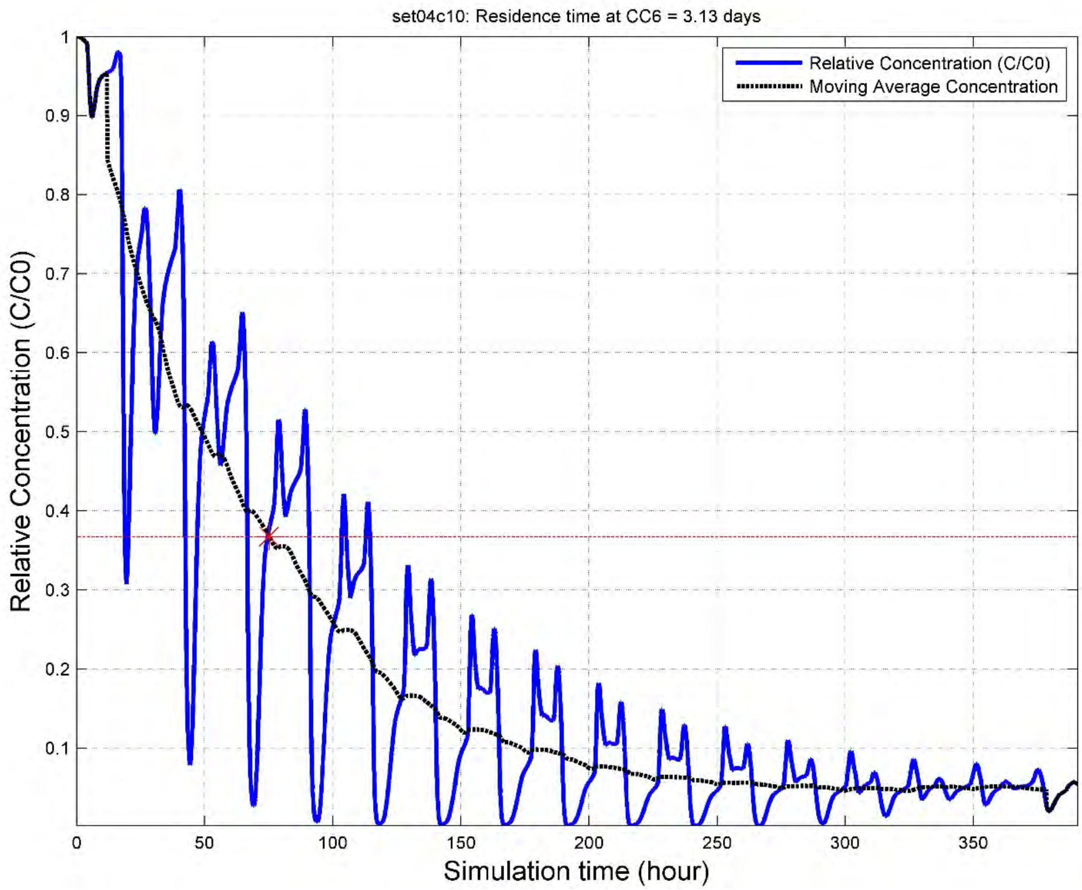

Figure 11 Relative Tracer Concentration and Residence Time at CC6, Located in the Central Basin of SEL

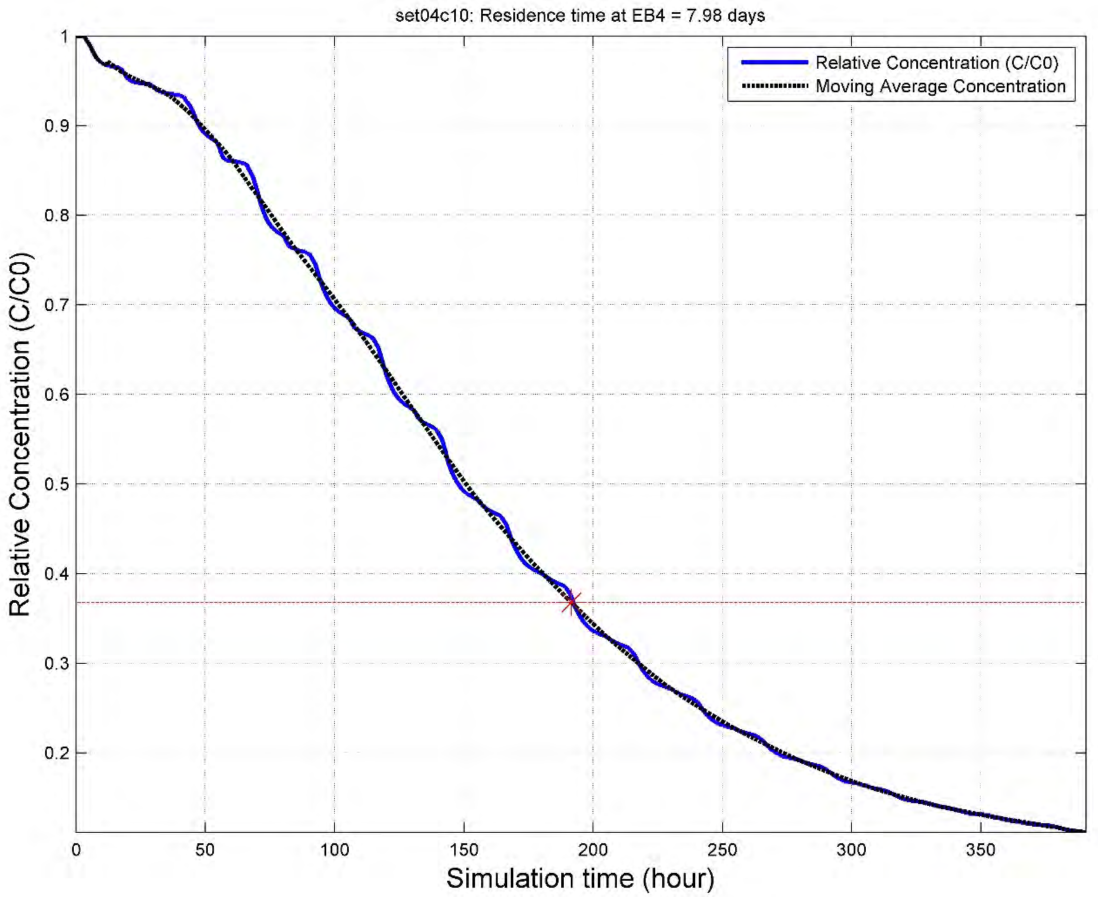

Figure 12 Relative Tracer Concentration and Residence Time at EB4, Located in the East Basin of SEL

Summary

Table 7 summarizes the results of this analysis by providing the average residence time for each basin of SEL (based on the computed residence time for locations in Table 6). Although the estimated residence time at some locations in the East Basin reach values of 8 days, when averaged across stations, residence time remains below the established water quality threshold of 7 days for all Basin of the lagoon.

Table 7 Average Residence time per Basin in SEL

West Basin	Central Basin	East Basin
1.3 days	2.4 days	6.6 days

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Chaudhry, M H. 1993. Open-Channel Flow. Second Edition. New York, NY: Springer.

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