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TECHNICAL REPORT 3341
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Administrative Statement:
This document was authored in January 2023 by NIWC Pacific Code 71750 and 71760 staff for the Water Quality Section Head, Environmental Security, Marine Corps Base Camp Pendleton. This work is being conducted under project order M330002121666 (Encore No. PEMEC2743). For any project-related questions, please contact Kara Sorensen, Ph.D.

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EXECUTIVE SUMMARY

The Marine Corps Base Camp Pendleton (MCBCP) Environmental Security (ES) division is committed to the maintenance of good water quality conditions in the Santa Margarita River Estuary (SMRE) and to better understand the relative loading contributions to the SMRE from adjacent stakeholders. To achieve these goals, it is important to characterize the morphology of the SMRE, specifically the bathymetric conditions, as the geomorphological dynamics directly affect physical dynamics and how inputs such as nutrients and sediments are mixed and distributed throughout the estuary. The SMRE bathymetry is a dynamic region (Sorensen et al., 2021; Sorensen et al., 2022), particularly in response to heavy rainfall events and high episodic flows down the river into the estuary. The last bathymetric survey was conducted by the Naval Information Warfare Center (NIWC) Pacific staff in 2015. Since then, significant rainfall events have been recorded, resulting in large-scale scouring and sedimentation deposition events. As a result of this, and as part of their overall commitment to better understanding possible contamination loading on the SMRE, MCBCP requested a more recent bathymetric survey to evaluate the current morphology of the SMRE.

In September 2022, a bathymetric survey of the SMRE was conducted using a small remotely operated surface vessel with an integrated geographic positioning system (GPS) and single-beam echosounder, with shoreline and kayak-based support. The raw data were processed to produce x, y (position) and z (depth/elevation) files for the accessible portions of the SMRE. The survey consisted of 367,069 depth measurements covering an approximate area of 0.38 km2. This report outlines the methodology and provides the data from the survey. In addition, curvilinear grids have been generated for future hydrodynamic modeling efforts, and corresponding bathymetric data have been calculated by populating these grids with survey data and interpolating spatially to create seamless maps of the SMRE’s bathymetry. In general, the mean bottom elevation was consistent between the two surveys, with a value of -0.133 m mean sea level (MSL) in September 2022 and -0.110 m MSL in 2015. However, overall topography was drastically different between the two surveys.

ACRONYMS

DO	Dissolved Oxygen
EFDC	Environmental Fluid Dynamics Code
ES	Environmental Security
GPS	Global Positioning System
HDOP	Horizontal dilution of precision
IO	Investigative Order
MCBPC	Marine Corps Base Camp Pendleton
MS4	Municipal Separate Storm Sewer System
MSL	Mean sea level
NNE	Nutrient Numeric Endpoints
NIWC	Naval Information Warfare Center
NIWC SME HM	Naval Information Warfare Center Pacific Santa Margarita Estuary hydrodynamic model
NMEA	National Marine Electronics Association
RDO	Rugged Dissolved Oxygen
SDRWB	San Diego Regional Water Board
SMR	Santa Margarita River
SMRE	Santa Margarita River Estuary
SSC Pacific	Space and Naval Warfare Systems Center Pacific
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey

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1. INTRODUCTION

The California Regional Water Quality Control Board, San Diego Region (SDRWB) placed the Santa Margarita River Estuary (SMRE) on the Clean Water Act Section 303(d) List of Water Quality Limited Segments in 1986 due to eutrophic conditions. Throughout the years, multiple studies have been conducted within the Santa Margarita River Watershed with the primary interest of quantifying total nitrogen and phosphorous, the primary constituents of concern associated with eutrophication, likely related to the proximity of the SMRE to old agricultural fields. The SDRWB issued an Investigative Order in May 2019 (IO, No. R9-2019-0007) in which allowable nutrient discharge thresholds were established for each of the Santa Margarita River Watershed Stakeholders based on the overall assimilative capacity of the SMRE. Further, according to the IO, designated dischargers, which include Marine Corps Base Camp Pendleton (MCBCP), are currently required to assess the condition of the SMRE and to evaluate the linkage between the nutrient loading trends as a result of implementation actions taken by each of the Santa Margarita River Stakeholder discharges (Cities of Murrieta, Temecula, and Wildomar, the Counties of San Diego and Riverside, the Riverside County Flood Control and Water Conservation District, and MCB CamPen). As a result, in 2020, a four-year monitoring program of the SMRE and watershed was initiated.

As part of their continuing commitment to maintain good water quality conditions in the SMRE and an overall desire to better understand their relative loading contributions, Environmental Security (ES) at MCBCP initiated a retrospective and prospective evaluation and assessment that quantifies and projects into the future MCBCP's current daily nutrient loading contribution to the SMRE (kg/day of total phosphorus and nitrogen). As part of this initiative, ES requested the Navy's Environmental Sciences Branch of the Naval Information Warfare Center (NIWC) Pacific (formerly Space and Naval Warfare Systems Center [SSC] Pacific) update their NIWC Pacific Santa Margarita Estuary hydrodynamic model (NIWC SME HM).

One of the key driving variables included in NIWC SME HM is the establishment of the physical domain (bathymetric conditions). Incidentally, the NIWC SME HM and subsequent physical domain at that time were used in the calculation of the loading capacity of the SMRE by the SMRE Stakeholder Group and SDRWB to establish the overall assimilative capacity as defined under the IO (No. R9-2019-0007 SDRWB, 2019). The last update to the SMRE model occurred in 2015 but utilized data from a 2013 bathymetry survey (SSC Pacific, 2016). It should be noted that an additional bathymetry survey was conducted by NIWC Pacific Staff in 2015, but minimal differences between the 2013 and 2015 surveys were observed (Katz et al. 2018). As a result, the SMRE Stakeholder Group opted not to invest the added resources into updating the NIWC SME HM at that time. Since then, there have been significant rain events that have occurred in subsequent years, resulting in large sedimentation deposits and scouring events that have substantially modified the physical domain (bathymetry) of the SMRE (Sorensen et al., 2021; and Sorensen et al., 2022). As a result, MCBCP ES requested that NIWC Pacific Scientific staff perform a bathymetry survey of the SMRE. The purpose of performing this survey was twofold: (1) to establish the current physical domain of the SMRE and (2) to determine changes in bathymetry compared to prior surveys.

1.1 BACKGROUND

In 1986, the SMRE was listed as an impaired water body on the Environmental Protection Agency's (EPA) 303(d) listing for the State of California, citing that due to excessive eutrophication, the SMRE was unable to sustain beneficial uses. As specified in the San Diego Water Quality Basin Plan (Basin Plan; SDRWB, 1994), beneficial uses for the SMRE include Contact Water Recreation

(REC-1), Non-Contact Water Recreation (REC-2), Estuarine Habitat (EST), Wildlife Habitat (WILD), Rare, Threatened, or Endangered Species (RARE), Marine Habitat (MAR), Migration of Aquatic Organisms (MIGR), and Spawning, Reproduction, and/or Early Development (SPWN). Access to the SMRE is maintained and controlled by the MCBCP because this region is used for active military training. Due to this region being an active military training site, contact and non-contact recreation activities are not authorized within the SMRE.

The SMRE received an impaired classification and was determined to undergo eutrophication based on the assumptions that the observed over-abundant algal growth and decreases in oxygen levels were a result of excess nutrient (total nitrogen and total phosphorus) inputs into the SMRE. Over the course of the last three decades, via a stakeholder-driven process, the SMRE has undergone an extensive evaluation to better understand the causes of impairment as well as establish numeric targets to better manage the watershed and SMRE and improve overall water quality (SDRWB, 2006; SDRWB, 2017; SDRWB, 2019; CDM, 2007; CDM, 2009; McLaughlin et al., 2007; Katz et al., 2007; Katz et al., 2018). This total maximum daily load (TMDL)-driven program (McLaughlin et al., 2007) ultimately culminated in the development of several modeling tools, including the NIWC SME HM (SSC Pacific, 2016; SCCWRP, 2016), which were used in the establishment of nutrient numeric endpoint (NNE) targets under an alternative TMDL approach (SDRWB, 2019).

The NIWC SME HM (formally SSC Pacific Santa Margarita Lagoon Hydrodynamic Model; SML HM) is a linked hydrodynamic and water quality numeric model for the SMRE. The linked model's aim is to provide a predictive tool to assess the SMRE's water quality under changing conditions and thereby aid in more effective management decisions to better maintain good water quality. Initial calibration of the model utilized nutrient, dissolved oxygen (DO), and macroalgal biomass water quality[1] data collected between 2007 and 2009. However, SMRE boundary information was not available for that time frame, so a bathymetric survey was conducted by NIWC Pacific (formerly SSC Pacific) in 2013 to determine water depths referenced to mean sea level (MSL) and establish the physical boundaries of the SMRE. The bathymetry data from 2013 was assumed to represent the bathymetry for 2008 and 2009. The SMRE's overall loading capacity used in the establishment of numeric targets was based on results from the resulting 2016 report (SSC Pacific, 2016; SDRWB, 2019).

In 2020, as mandated under the 2019 IO (SDRWB, 2019; No. R9-2019-0007), a four-year monitoring program was initiated by the Santa Margarita Stakeholder Group. Subsequent to the initiation of the four-year monitoring program, MCBCP ES commenced a linked modeling effort that focused on the area of the SMRE located directly within MCBCP boundaries and included updates to the NIWC SME HM model. The overall goal of this modeling initiative is to better understand current conditions and make more effective management decisions for maintaining good water quality conditions. Following the completion of the first two monitoring years under the IO, it became clear that there had been significant changes to the SMRE's overall bathymetric conditions (Sorensen et al., 2021; Sorensen et al., 2022). Changes in bathymetric conditions can be caused by both anthropogenic (e.g., evolving land usage, flood controls, water diversions) and natural forces (e.g., wind, tidal, precipitation, sea level rise, and climate changes). These bathymetric changes have the potential to dramatically impact the overall assimilative capacity of the SMRE for nutrient influx. Without a better understanding of these changes, the ability to effectively model current water quality

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[1] In addition to the water quality parameters used during calibration, key hydrodynamic parameters included water surface elevation, salinity, and temperature.

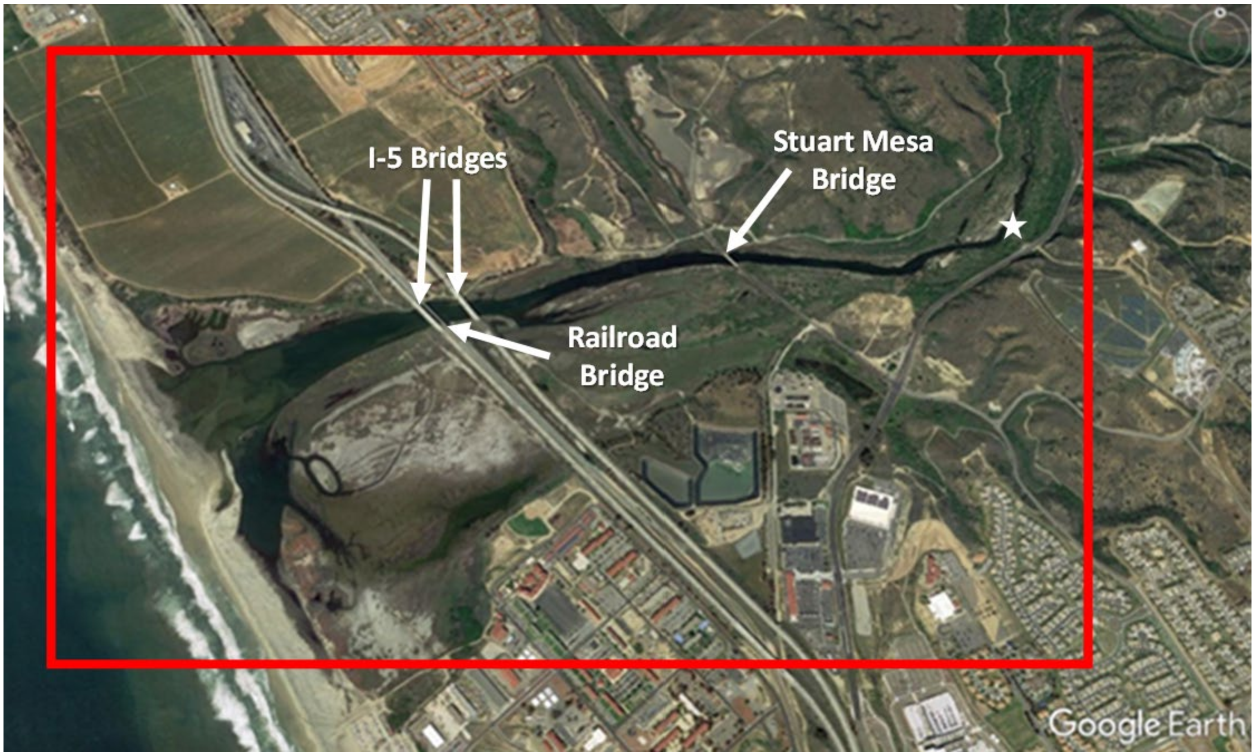
conditions in the SMRE and predict the impacts of condition changes and implemented management decisions becomes limited.

In September 2022, under project order M330002121666 (Encore No. PEMEC2743), NIWC Pacific Staff conducted a bathymetric survey of the SMRE on behalf of MCBCP ES. The overall goal in obtaining this information is first to ensure the modeling initiative currently being conducted on behalf of ES contains models that accurately reflect the current conditions of the SMRE, and second, to determine if the overall loading capacity of the SMRE has changed.

This report describes methods used to conduct the bathymetric surveys, axial water quality conditions collected within the SMRE while conducting the bathymetric survey, current bathymetric conditions of the SMRE, and changes from prior monitoring events. To provide a quantitative comparison, the methods used to measure current bathymetric conditions were consistent with prior bathymetric surveys. Water quality data (dissolved oxygen [RDO], conductivity/salinity, temperature, turbidity, and chlorophyll-A fluorescence) collected at the time of the survey as well as survey data are included in the appendices. For reference, bathymetry data from the past two surveys of the SMRE (included in Katz et al., 2016) have also been included in the appendices of this report.

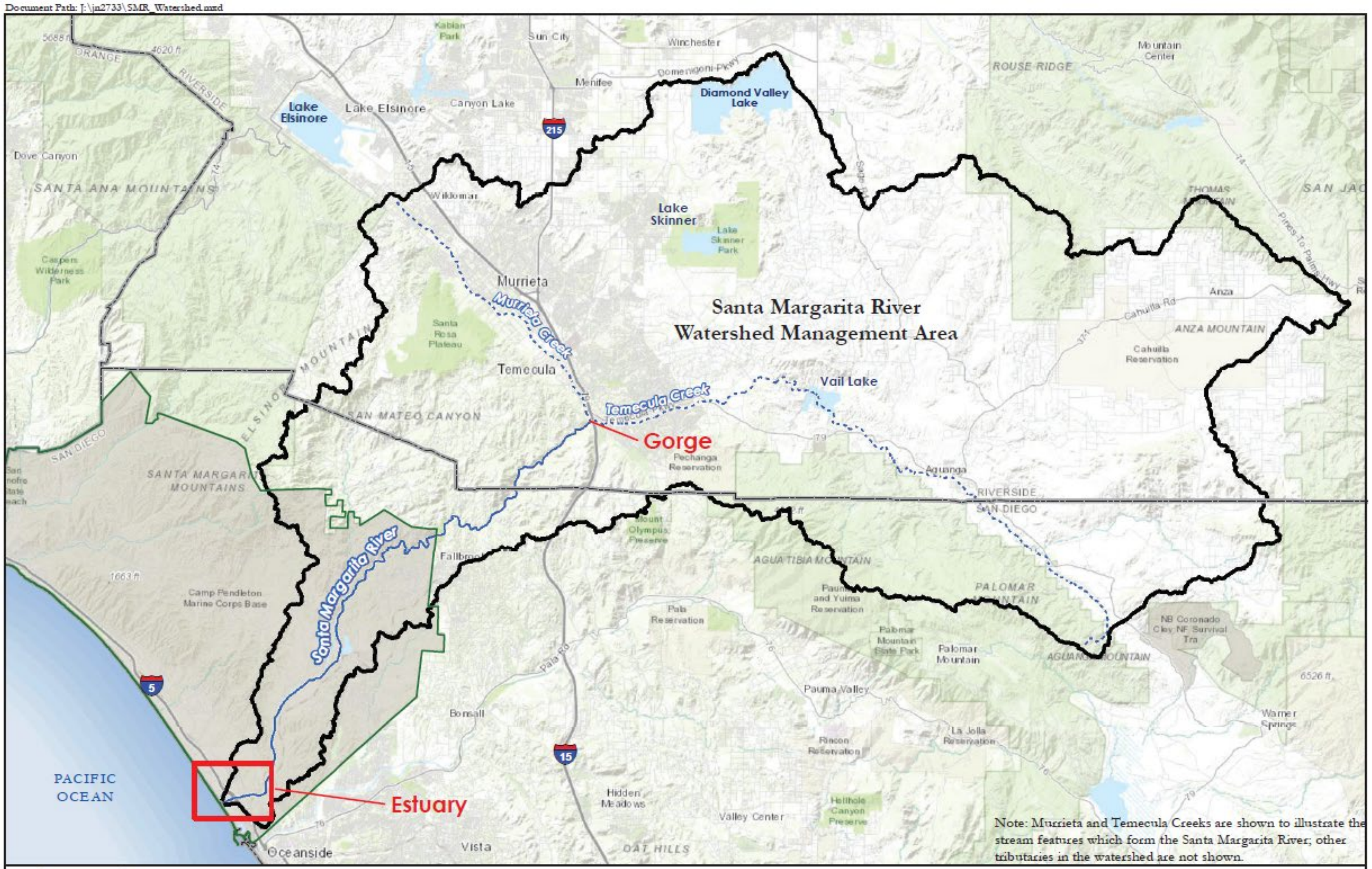
1.2 LOCATION

The bathymetric survey for this project was conducted within the SMRE (Figure 1), which is located at the furthest western point of the Santa Margarita River Watershed (Figure 2) and is situated entirely within MCBCP boundaries. Because ES's model initiative includes linkages between the Santa Margarita River (SMR) and the SMRE, as well as a large portion of the lower reach of the river, a brief description of both the watershed and the SMRE is provided below.



- Notes: Four bridges—the north and southbound Interstate Highway I-5, the North County Transit District Railroad Bridge, and the Stuart Mesa Road Bridge—cross over the SMRE and provide key geographical landmarks for the study. The star indicates the approximate location of SMRE sampling site MA6.

Figure 1. Field work domain for the SMRE bathymetric survey.



Note: Murrieta and Temecula Creeks are shown to illustrate the stream features which form the Santa Margarita River; other tributaries in the watershed are not shown.

FIGURE 2. SANTA MARGARITA RIVER WATERSHED

Figure by Stetson Engineers from Sorensen et al., 2021.
Red Box indicates location of Estuary relative to rest of watershed and location of this study.
Grey shaded area indicates MCBCP base boundaries related to the watershed.

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Figure 2. SMRE and Watershed.

1.2.1 Santa Margarita Watershed

The Santa Margarita Watershed covers 750 square miles in northern San Diego County and includes the SMR and SMRE. The SMR drains from the San Jacinto and Palomar Mountain slopes, as well as the Santa Rosa Plateau, to the Temecula Valley. The Santa Margarita Watershed includes the Murrieta Creek systems, which come to a confluence in Temecula, California, to form the SMR, which flows outside of Riverside County into San Diego County, including MCBCP. Additional tributaries that feed into the SMR include Rainbow, Sandia, and De Luz Creeks. Within MCBCP, the SMR meets the Pacific Ocean and creates the SMRE.

1.2.2 Santa Margarita Estuary

The SMRE is the primary focus region of this study and resides entirely within the jurisdiction and boundaries of MCBCP. The SMRE is the region defined from the Pacific Ocean to about 2.4 miles northeast of the Pacific Ocean boundary. The SMRE's western boundary encompasses a beach berm that is usually open to oceanic exchange through a narrow section of the sand berm, although there are periodic times when the mouth of the SMRE is closed to oceanic exchange. The eastern boundary of the SMRE undergoes maximum tidal exchanges, impacting the physiodynamics of this boundary. The exact location where this occurs was identified in the 2015 NIWC Pacific bathymetric survey (Katz et al., 2016).

The SMRE is a dynamic and relatively narrow body of water, changing in physical parameters semi-annually with storm events. Currently, the SMRE is about 0.6 miles wide at its widest portion and roughly encompasses about 98 acres in the perennial wetted portion. There are two major markers that roughly define major physical changes for the SMRE: the Interstate 5 (I-5) bridge and the Stuart Mesa Bridge (SMB). The I-5 bridge is located about one-third mile northeast of the Pacific Ocean boundary. At the I-5 bridge, the SMRE significantly narrows, whereas northeast of the I-5 bridge, headed to the SMB, the SMRE widens.

Water depths for the SMRE change semi-annually, depending on storm events. However, the dynamics of the region aside, it tends to be less than 5 meters deep, even in its deepest sections. The deepest section of the SMRE occurs near the I-5 bridge around the bridge support pilings. Based off of NIWC Pacific's 2015 bathymetry report, the SMRE was last measured to be roughly 20 feet across at its narrowest section and with a depth of a few inches, if even wetted, during low tide, closed mouth, or drought conditions. The bathymetry of this region is very dynamic and impacts the physiodynamics and distribution pathways of brackish waters.

Freshwater flow received by the SMRE can be found on the publicly available site (usgs.gov) maintained and provided by the United States Geological Services (USGS) stream gauges. USGS gage 11046000 is the closest gaged location to the SMRE and represents the best estimate of freshwater flow into the SMRE. However, the gage is 5 miles upstream from the head of the SMRE, and therefore freshwater flows between the gage and the SMRE may also be affected by evapotranspiration, phreatophytes, MCBCP-maintained diversions upstream, and groundwater pumping. Based on the historical period of record at USGS 11046000, the SMRE received a median daily discharge of about 6.5 cubic feet per second (cfs). The maximum flow measured at that gage was 44,000 cfs during the largest storm event. However, the USGS gage often measures 0 cfs during the summer and early fall seasons, especially during dry years.

1.3 HISTORICAL SALINITY AND BATHYMETRY

Bathymetric and water quality surveys can provide insights into the physical dynamics and the physiochemical processes that contribute to nutrient distributions (the primary constituents of concern) throughout the SMRE. Because estuaries occur where freshwater and saltwater mix, salinity is an important indicator of mixing conditions throughout the SMRE. Historic studies have indicated that the SMRE is a hydrographically dynamic region. Prior to the 2022 survey, the most recent estuary-axial survey of salinity and bathymetry data was collected by NIWC Pacific scientists on the May 19 and 20, 2015. Those surveys were conducted during closed-mouth conditions, with axial surveys conducted by zigzagging toward each shoreline while moving longitudinally along the estuary axis. Spatial variation in salinity (Figure 3, Figure 4) was observed primarily along the longitudinal axis of the SMRE, showing a predominantly oceanic regime west of the I-5 Bridge, a freshwater regime east of the SMB, and a transitional area between these areas. Comparing the longitudinal salinity pattern between different survey periods shows that the relative influence of seawater and freshwater varies based on whether or not the SMRE mouth is open or closed and whether there has been recent rainfall causing the SMR to flow. For example, the spatial distribution of salinity observed in 2015 and 2016 was generally comparable to previous observations made by NIWC Pacific scientists in 2006 and 2007 (Katz et al., 2007). However, in a March 2010 survey, a different pattern was observed, with freshwater conditions measured all the way to the I-5 bridge, associated with the SMRE mouth being closed (Katz and Rivera, 2012).

In March 2013 and May 2015, two bathymetric surveys were conducted to assess how spatial variations may impact the distribution of constituents within the SMRE (Figures 5 and 6). For the May 2015 survey, the average depth below the MSL vertical datum was 0.25 m, with maximum depths measured at the I-5 bridge and SMB at 3.7 m and 4.6 m below MSL, respectively (Katz et al., 2018). Towards the mouth of the SMRE, the water depth was very shallow, at less than 0.3 m below MSL, which was of note as the SMRE mouth was closed and SMRE water levels were relatively elevated (Figure 6; Katz et al., 2018). Overall, the SMRE bathymetry was similar between 2013 and 2015; the average difference of measured depths was about -0.16 m, suggesting either the SMRE was slightly fuller in 2015 relative to 2013, but this difference is small enough that it could represent measurement or map interpolation error (Katz et al., 2018). The largest differences in depths observed in 2015 relative to 2013 were near the I-5 Bridge, with some depths varying by more than 4 m between the two surveys (Katz et al., 2018). This difference was attributed to the influence of a large earthen dam that was present between the two I-5 bridges during the 2013 survey but was removed before the 2015 survey (Katz et al., 2018). Due to the CALTRAN railroad construction bridge project that took place in 2013–2014, the temporary earthen dam was constructed.

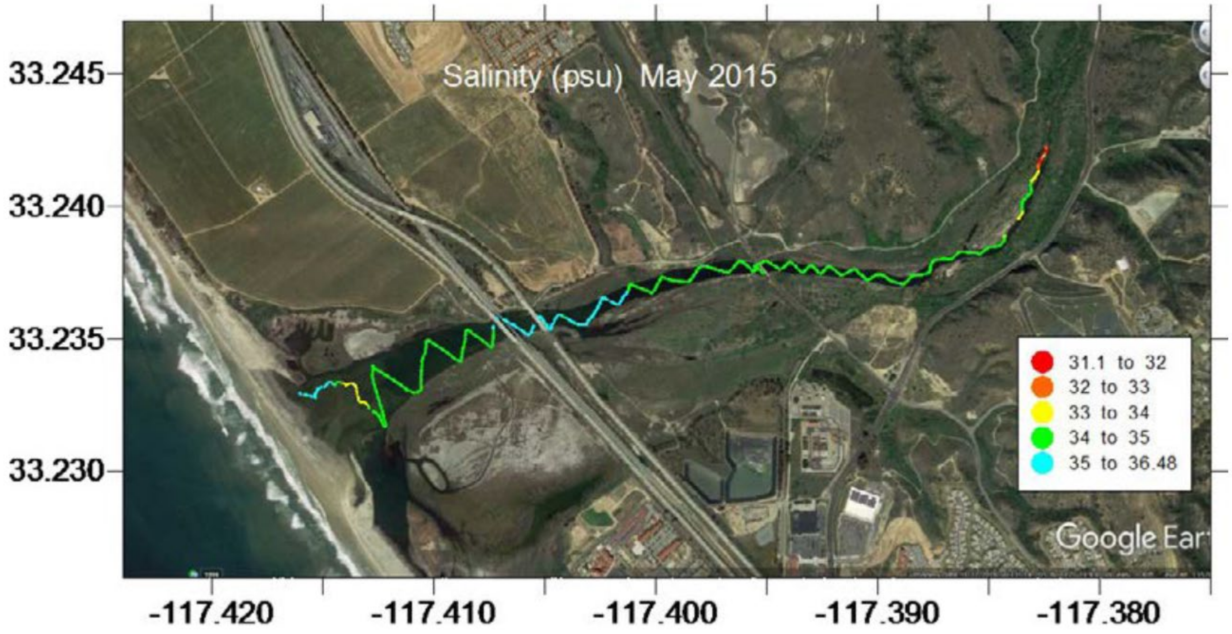


Figure 3. SMRE salinity variability observed in May 2015 (from Katz et al., 2018).

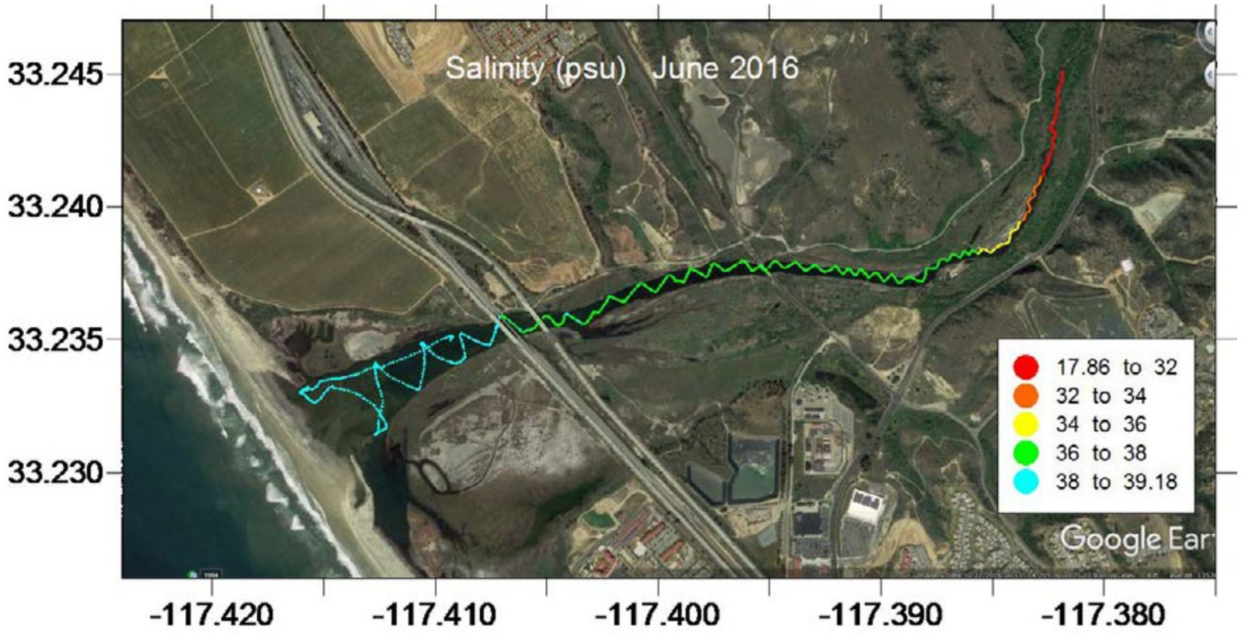


Figure 4. SMRE salinity variability observed in June 2016 (from Katz et al., 2018).

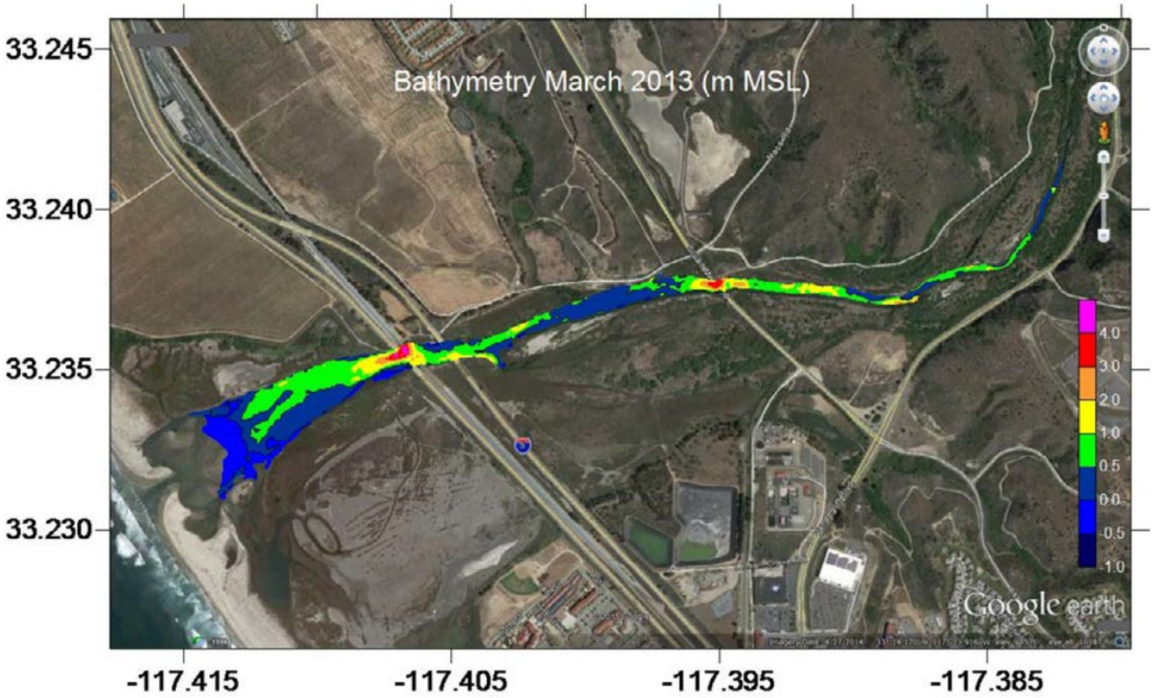


Figure 5. Map of SMRE bathymetry from the May 2013 survey (from Katz et al., 2018).

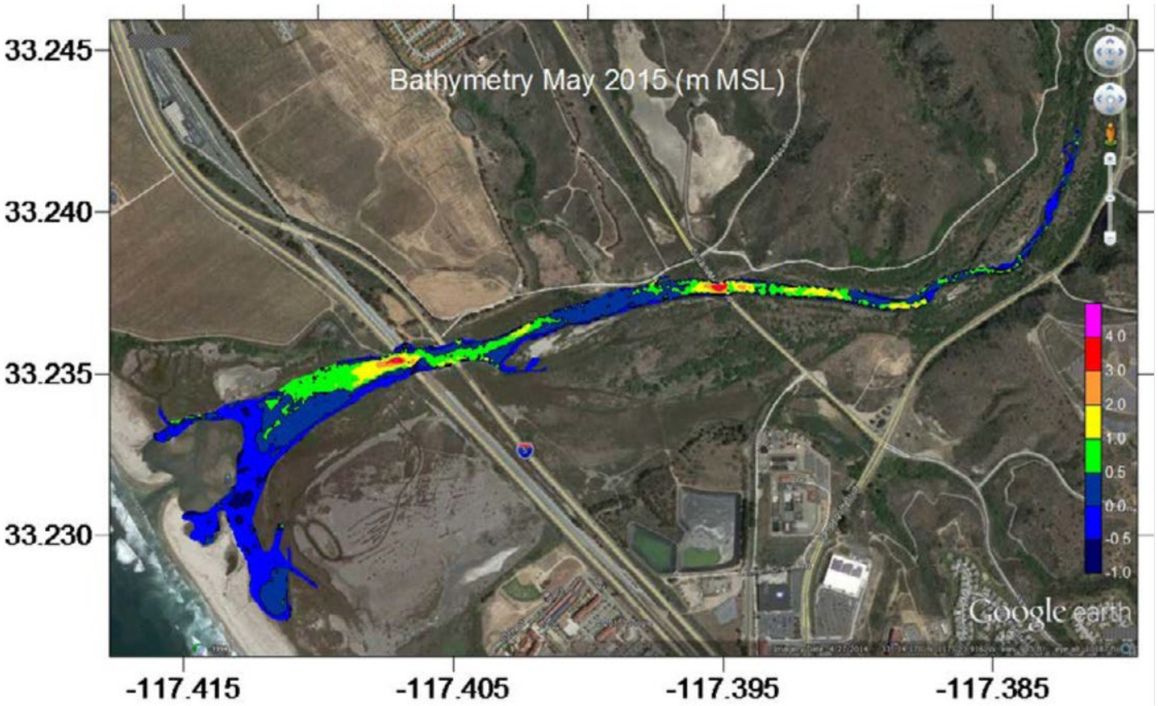
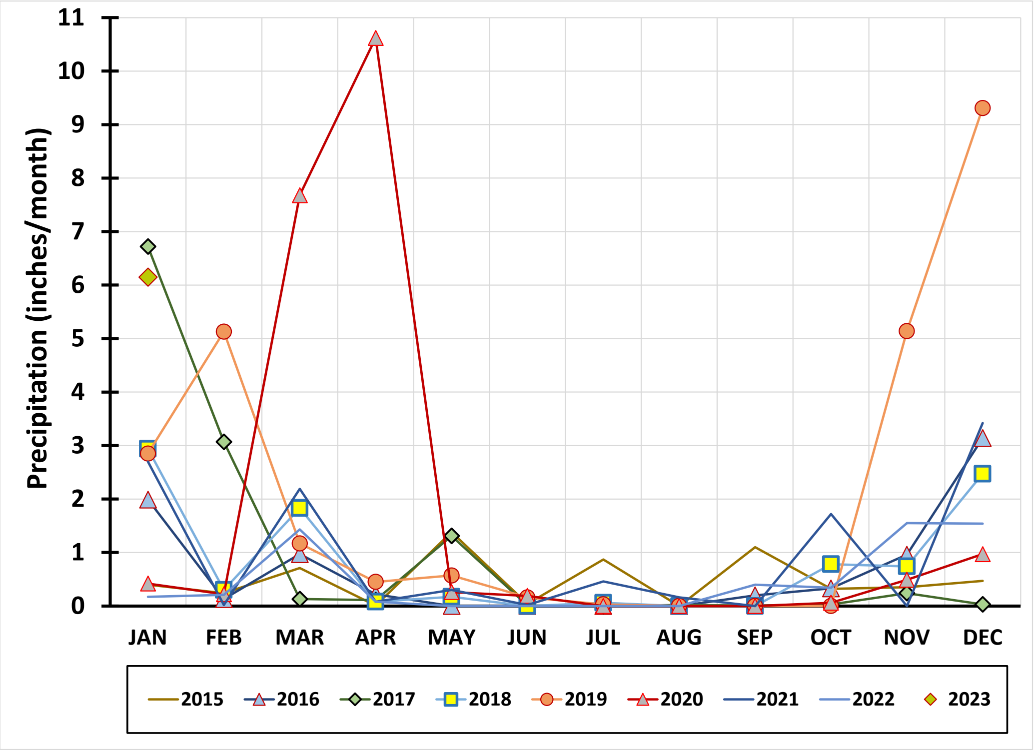


Figure 6. Map of SMRE bathymetry from May 2015 (from Katz et al., 2018).

1.4 HISTORICAL PRECIPITATION AND RIVER FLOW

While there have been periods of drought between 2015 and 2022, there have also been several 30- to 100-year precipitation events resulting in large runoff events, scouring, and heavy sedimentation events in the SMRE. Up until 2017, the hydrogeomorphology of the SMRE was visually fairly similar to previous years. This was characterized by the presence of mostly black silt-sized sediments along the shorelines and a tendency for low visibility in the water, observed during water quality monitoring events. In contrast, a significant rain event in January 2017 (1.40 inches on January 20, 2017; NOAA National Weather Service Forecast Office, https://w2.weather.gov/climate/xmacis.php?wfo=sgx) with a monthly total rainfall of 6.72 inches (Figure 7) and flow greater than 25,000 cubic feet per second (cfs, Figure 8) changed the SMRE conditions to mostly larger-grained sandy sediments with clear water. The January 2017 storms also visually affected the bathymetry of the SMRE, as some water quality monitoring stations that had previously been covered by water were observed to be on sandy beaches after these storms. A similar effect on hydrogeomorphology and bathymetry resulted from the storm in February 2019 and those in March and April 2020. Incidentally, the recent heavy rains in 2023 may also result in significant impacts on the bathymetry and hydrogeomorphology of the SMRE.



- Note: Measurements from the Oceanside Marina NOAA station OCNC1 (https://www.cnrfc.noaa.gov/rainfall_data.php#monthly)

Figure 7. Total monthly precipitation from January 2015 to January 2023.

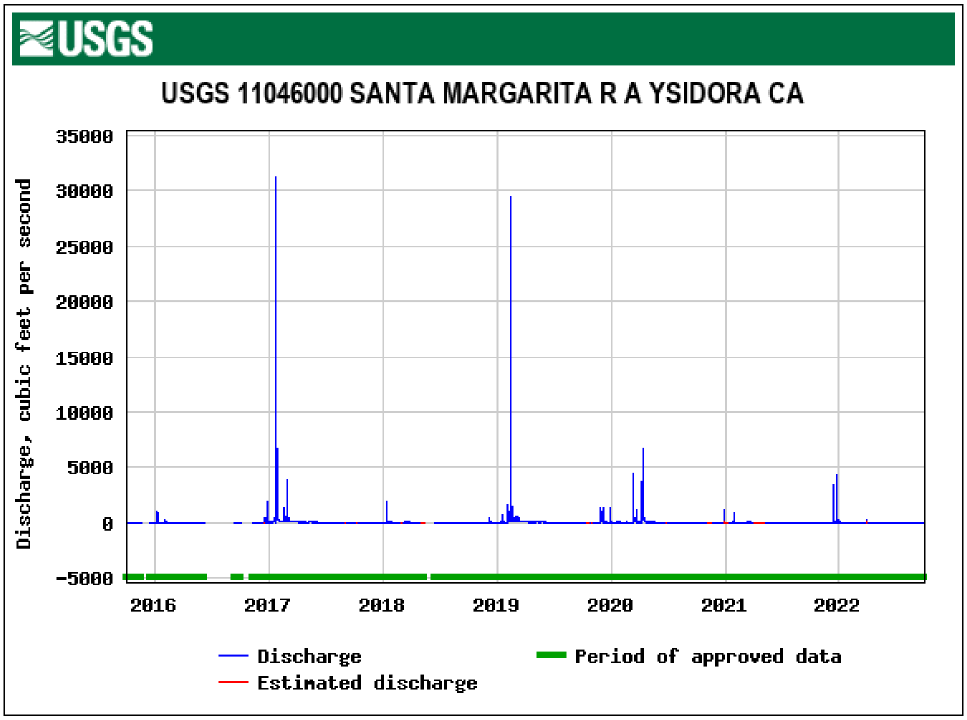


Figure 8. Historical SMR Flows.

2. METHODS

2.1 TECHNICAL APPROACH

The bathymetry of the SMRE was mapped by NIWC Pacific in 2013 and 2015 to support hydrodynamic modeling efforts at that time. This 2022 effort aimed to repeat the same survey approach to assess possible changes in the SMRE’s physical domain. As part of this effort, water quality and temperature data were collected along with depth measurements to aid in the post-processing of depths and also to provide general water quality measurements across the SMRE. The bathymetry data collection and processing methods and a comparison between prior surveys (in 2013 and 2015) as well as water quality collection methods are presented below.

2.2 BATHYMETRY SURVEY

The bathymetric survey was conducted on September 19 and 20, 2022. The area of the SMRE included in this study spanned from the ocean inlet to approximately 0.6 nautical miles north from historic sampling station MA6 (Figure 1; Sorensen et al., 2021; 2022). The approximate study boundaries are provided in Table 1.

Table 1. Bathymetric Survey Study Boundaries.

ID/Description	Latitude (NAD83)	Longitude (NAD83)
Start (Ocean Inlet)	33°13’'54.36	-117°25’'0.21
End (furthest accessible point)	33°14’'52.99	-117°22'48.59
MA6 (historic monitoring site)	33°14'18.60	-117°23'2.04

The SMRE is subject to the influence of ocean tides, which occur in a mixed semi-diurnal pattern in southern California. During the two-day survey, the two high tides occurred during the day (Figure 9), with the higher low tide at midday and the lower low tide overnight. In general, the bathymetric survey was conducted with high tide conditions in the SMRE.

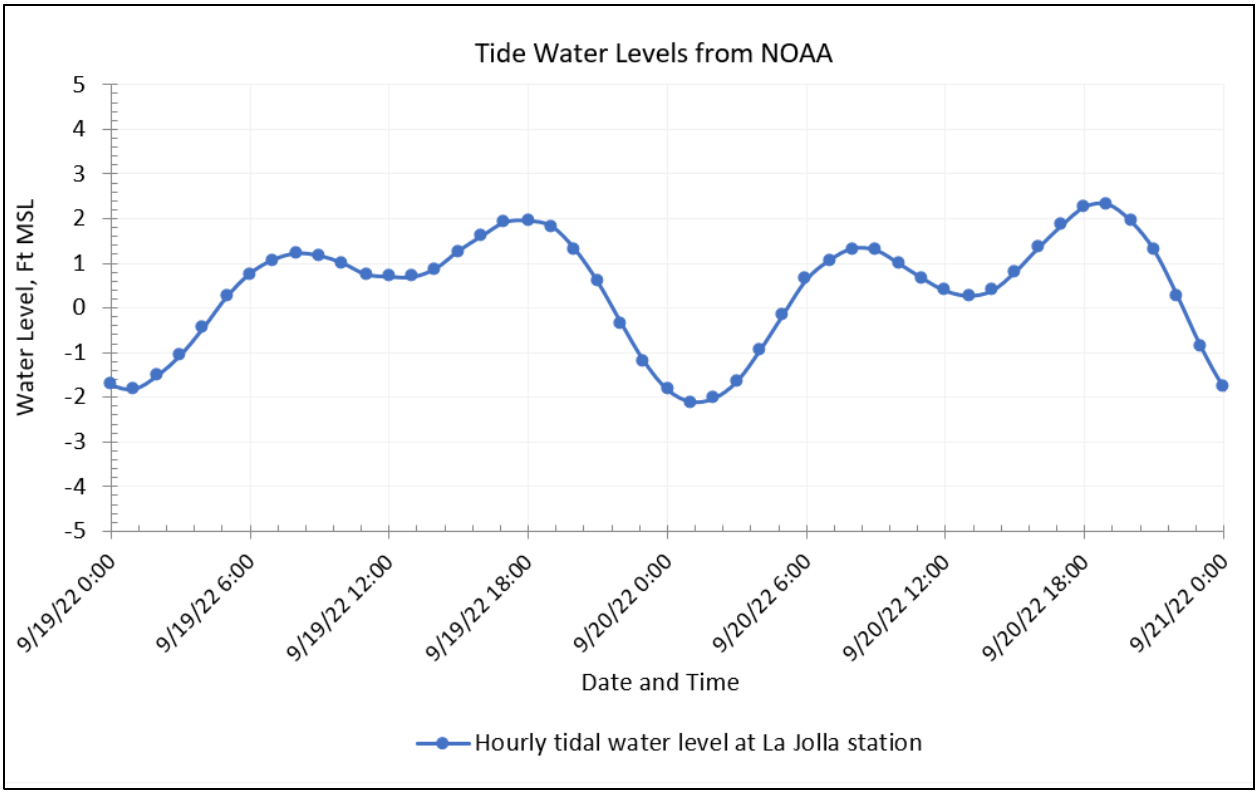


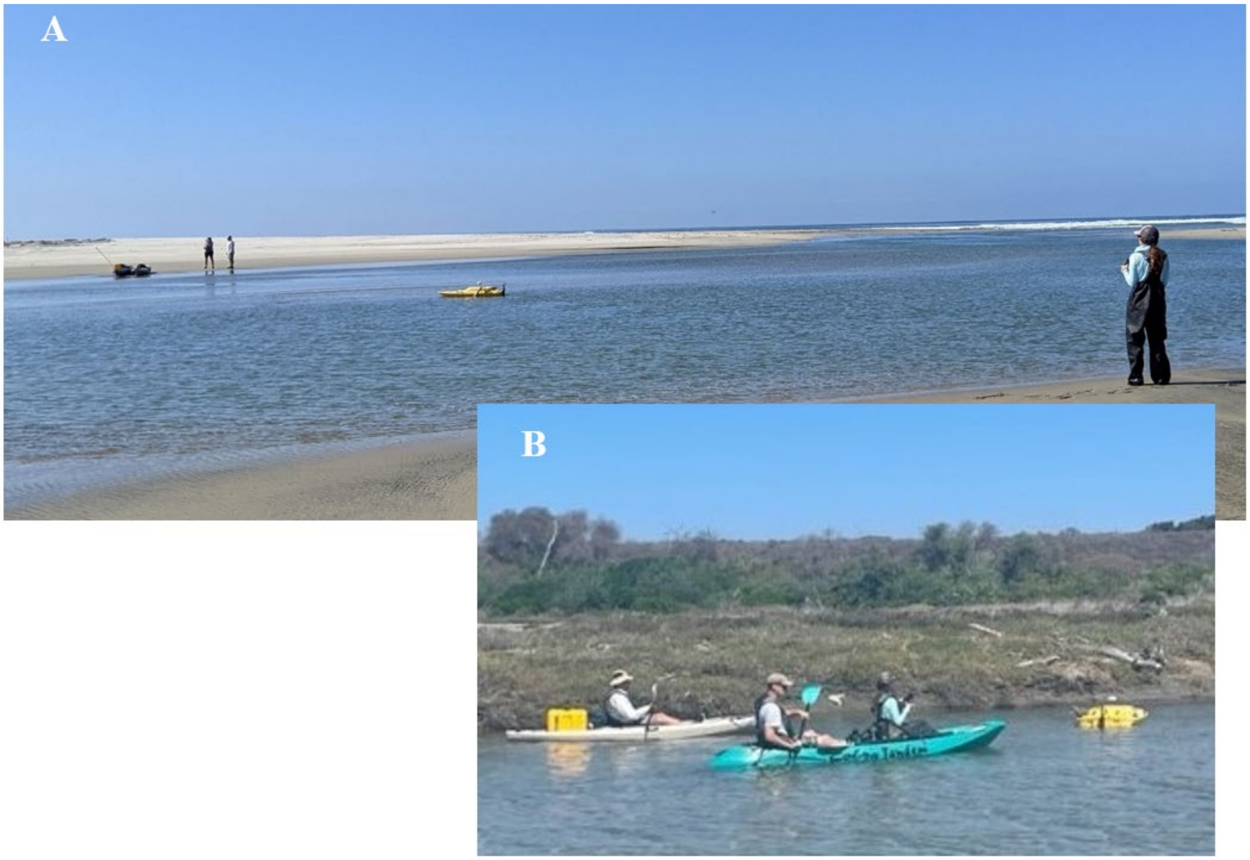
Figure 9. Ocean tides during the bathymetry survey period.

2.2.1 Bathymetry Data Collection

The bathymetry data were collected using a Teledyne Oceanscience Z-Boat® 1800 remote-control hydrographic survey boat with an integrated Hemisphere A101™ Global Positioning System (GPS) and Ceepulse 100™ 20 kHz single beam echosounder (Figure 11). Data were collected along transects that were run primarily in the cross-channel direction, though some locations warranted collecting data along the SMRE's longitudinal axis. The nominal spacing between transects was about 10–20 m but varied as a result of conducting the survey manually using visual cues, wind and current effects on the vessel movement, and working around obstructions and shallow areas. In some locations, the Z-Boat® was towed by a kayak instead of being driven using the remote-control system because of repeated fouling of the propeller with seagrass and other vegetation. The system collected bottom-depth data at a 10-Hz rate and GPS data at 1-Hz. All data were stored on-board the Z-Boat®'s data management system in National Marine Electronics Association (NMEA) sentence format for post-processing.

- Note: The white disk-shaped antenna on top of the vessel is the GPS receiver, located directly above the echosounder placed on the bottom of the vessel.

Figure 10. The Z-boat bathymetric survey vessel.



- Note: Shoreline control of the Z-boat is shown in (A), and kayak control of the Z-boat is shown in (B).

Figure 11. Bathymetric survey configurations.

2.2.2 Data Processing and QA/QC

The bathymetry data processing began by downloading the stored NMEA data as text files from the Z-Boat® data system to a laptop. The data files were further processed with R software (R 4.0.3 GUI 1.73 Catalina build [7892]). Each individual data file was first processed independently; then these were combined into a single file. First, data files were trimmed to remove the beginning and ends of each file to correct for time periods when the Z-Boat® was not yet in the water collecting data or was brought to shore for battery changes or other operational tasks. Next, GPS positions were trimmed by removing all positions that had no current GPS satellite connection at the time the position was recorded (in those cases, the last good position was repeated and was thus stale and not used), or when the horizontal dilution of precision (HDOP, a measure of the accuracy of the reported position) was greater than four. The remaining positions were then plotted to visually check for any outlier positions, and these were removed if they occurred. Similarly, depths were plotted and visually assessed to set thresholds to remove outlier depths. Outliers sometimes occurred when the Z-boat® was too shallow for a good reading (less than about 0.3 m), got stuck on the shoreline or sandbar (Figure 10), or, in rare cases, recorded an extremely large depth reading (possibly from a multi-path return or echo). The best professional judgment was used to make these corrections. Next, the positions and depths were time-matched using the row indices from the original datafiles (each NMEA sentence, which either contains a GPS position, a depth, or another piece of information such as a compass heading, is stored as a single row in the original datafile, ordered as it was recorded in real time during the survey). Positions were then interpolated to provide an x and y position for each depth recording (depths were recorded at about 10 times the frequency of positions).

The bottom depths in the resulting dataset were then corrected for boat transducer depth (3.9 cm below the water surface) and then converted into the NAVD88 vertical datum by subtracting the (interpolated) water surface elevation measured at the same timepoint as each depth measurement in reference to NAVD88 at the I-5 Bridge by the USGS (monitoring location 11046050; https://waterdata.usgs.gov/monitoring-location/11046050). These resulting bottom elevations, referenced to NAVD88, were then converted to bottom elevations referenced to the local MSL vertical datum using a 0.774 m offset between the two vertical datums (NAVD88 + 0.774 m = local MSL), following the same methods used for a prior bathymetric survey in the SMRE in 2015. The conversions used to ensure measured bottom depths are accurately tied to a fixed vertical datum to allow comparison of estuary bathymetry changes between surveys are shown in Table 2 and Figure 12.

Table 2. Conversion from Measured Depth to NAVD88 and Local MSL.

Measured Bottom Depth (meters below echosounder)	True Bottom Depth (meters)	Bottom elevation in relation to NAVD88 fixed vertical datum, corrected for changes in water level (meters above or below NAVD88 zero datum)	Bottom elevation in relation to MSL fixed vertical datum (meters)
X	X+0.039	X – water level in relation to NAVD88	X – water level in relation to NAVD88 +0.774

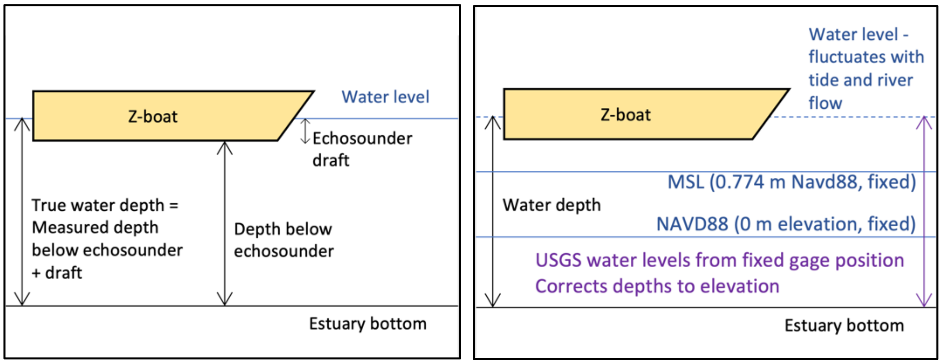


Figure 12. Schematics demonstrating (left) the conversion from measured depth to true water depth and (right) the conversion from depth to elevation in relation to NAVD88 and/or MSL fixed datums.

Finally, the water sound speed was estimated during the survey using the water temperature and salinity measured by a sonde (described in Section 2.3 below). For each temperature and salinity timepoint, the sound velocity was estimated using the simple Mackenzie (1981) equation for speed of sound in the ocean and a water depth of 1 m:

$$\text{speed of sound (m/s)} = 1448.96 + 4.591T - (5.304*10^{-2}T^{2}) + (2.374*10^{-4}T^{3}) + (1.340(S-35)) + (1.630*10^{-2}D) + (1.675*10^{-7}D^{2}) - (1.025*10^{-2}T(S-35)) - (7.139*10^{-13}TD^{3})$$

Where T is temperature in degrees Celsius, S is salinity in parts per thousand, and D is depth in meters.

The percent difference between the calculated sound speed (which ranged from 1,492.7 m/s to 1,542.7 m/s) and the default sound speed (1,500 m/s) used for the calculated depths was calculated for each sonde measurement timepoint. The percent differences between the calculated and default sound speeds ranged from -0.48% to 2.85%. These calculated sound speeds were time-matched to the depth data files and then interpolated linearly between each sound speed point to provide an estimated correction factor for each depth measurement. The draft-corrected depths and bottom elevations in relation to NAVD88 and MSL were then corrected to account for changes in estimated water sound speed by multiplying the original depth values by the calculated correction factor. This correction accounts for estimated differences in the actual versus the default sound speed initially used to calculate the water depth by the echosounder, which is based on the return time of individual sound pings reflecting off of the bottom of the SMRE.

After all of the above post-processing was complete, the individual datafiles were then combined into a single datafile containing a total of 367,069 x, y, and bottom depth (z) records saved as (1) original reported depth, (2) draft corrected depth below water surface, (3) bottom elevation in reference to the NAVD88 vertical datum, (4) bottom elevation in reference to the local MSL vertical datum, and (5-7) draft corrected depth and bottom elevation in reference to the NAVD88 and MSL vertical datums, respectively, all adjusted for estimated sound speed.

2.3 CONTINUOUS WATER QUALITY

Continuous water quality parameters were collected from an Aqua TROLL® 600 sonde mounted to the Z-boat®. The continuous collection of data started at 9:56 a.m. on September 19, 2023, and ended at 2:51 p.m. Continuous data collection resumed on September 20, 2023, between 9:31 a.m. and 3:23 p.m.

2.3.1 Data Collection

Continuous water quality parameters were collected using Aqua TROLL® 600 multi-parameter probes from In-Situ, Inc. The Aqua TROLL® 600's design moves the sensor head to the tip of the cylindrical probe. The unit included optical rugged dissolved oxygen (RDO), conductivity/salinity, temperature, turbidity, chlorophyll A fluorescence, and probe depth sensors.

The probes were installed on the port side of the Z-boat® (see Figure 13). The Aqua TROLL® unit was suspended with the sensor heads approximately six (6) inches below the water surface. Water quality data were collected at one-minute intervals.

Figure 13. Aqua TROLL® 600 sensor mounted to the Z-boat® (orange arrow).

2.3.2 Data processing and QA/QC

Verification of sensor operational conditions and calibration was performed prior to the site visit. The response of the sensor electrodes was verified with the calibration standards and procedures recommended by the manufacturer. The DO sensor was checked with air-sparged 18 Mega-ohms per centimeter (Mega-Ω/cm) water (100% DO) and with saturated sodium bisulfite in 18 Mega-Ω/cm water (0% DO). The conductivity sensor was checked with a 58,760 µS/cm specific conductivity at

25°C. Each reading was generally equilibrated in about two minutes or less, and three replicate measurements of each standard were recorded in the field notebook for calibration verification (Appendix D).

A calibration was considered acceptable if the sensor response was within 10% of expected limits. The calibration results are provided in Appendix E. In general, results were within corresponding QA/QC acceptance ranges and limits. Data collected during periods of inactivity or when the Z-boat® was removed from water were omitted from the final analyses. The calibration and field data logs are provided in Appendices D and E.

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3. BATHYMETRY RESULTS

Bathymetric data were collected in September 2022 throughout the SMRE, similar to the surveys conducted in 2013 and 2015. A 2022 bathymetric surface map was developed using the processing techniques described above in Section 2. The main purpose of generating new bathymetry maps is twofold: to evaluate potential changes to the overall physical domain of the SMRE and to use the updated bathymetric surface to refine the existing SMRE model.

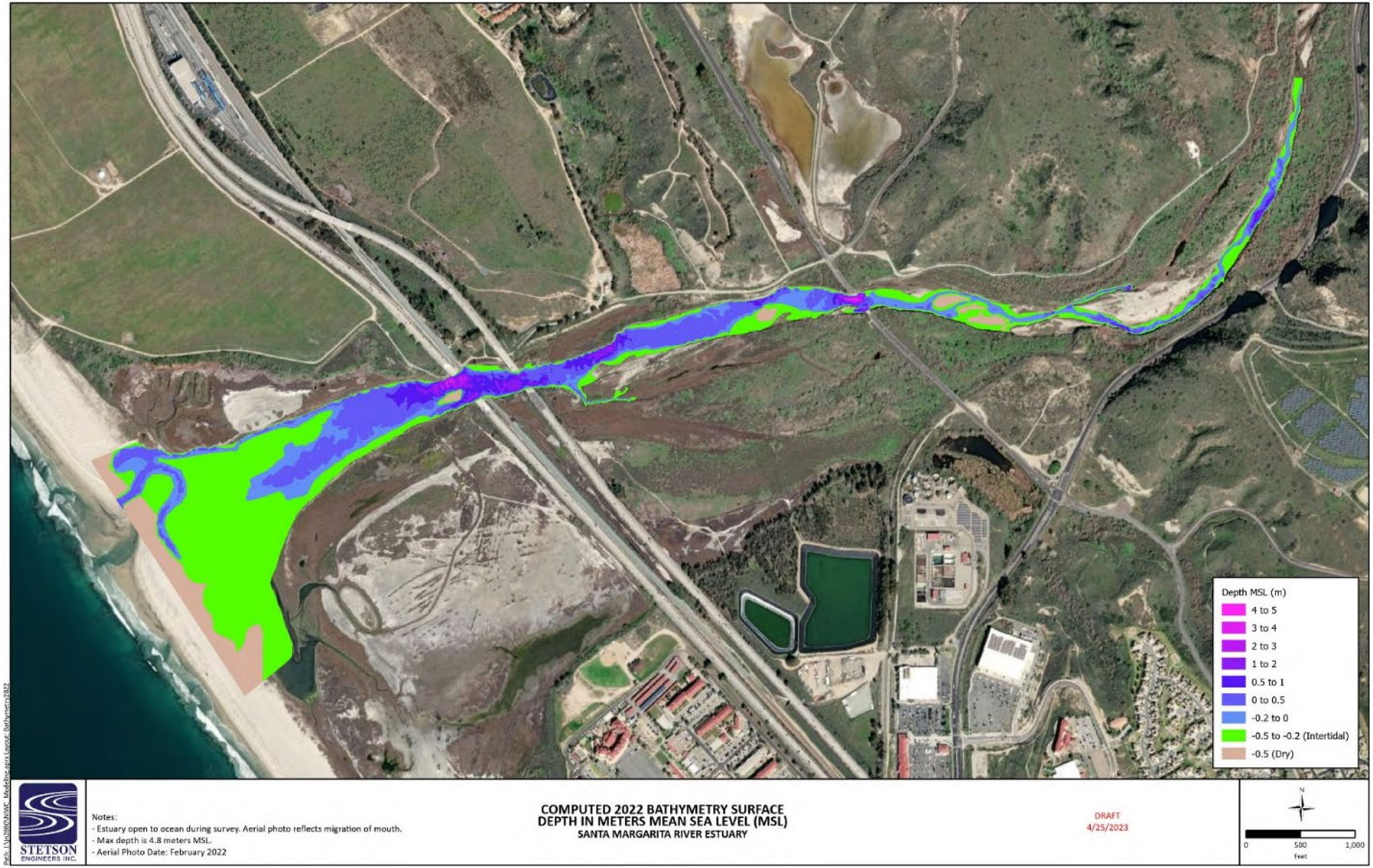
Although bathymetric surface maps of the 2013 and 2015 surveys were previously created (Figures 5 and 6), newly developed GIS-based spatial analyst tools were applied to all three datasets (e.g., 2013, 2015, and 2022) to create updated surfaces. These available tools allow for a more refined surface based on interpolating SMRE depths for 1-foot by 1-foot cell sizes. Additionally, the GIS-mapping tools allow for the integration of aerial datasets that provide absolute elevations of known banks and geomorphic features. The updated bathymetric surface maps provide an improved comparison between datasets based on applying identical analysis and methodologies. Lastly, a statistical analysis of common survey areas was then developed in order to assess changes over time. The tools that were applied to create each surface and the common methodology applied to each set of survey points are described below in further detail.

3.1 DEVELOPMENT OF THE 2022 BATHYMETRIC SURFACE

The bathymetric survey was completed in September 2022. The survey resulted in a total of 367,069 depth measurements in the final dataset used for mapping bathymetry, which covered an area of approximately 0.34 km^2. The minimum, maximum, mean, and median depths measured by the Z-boat® were (in m depth compared to MSL) -0.12, 5.98, 0.20, and 0.01, respectively.

The first step in developing the 2022 bathymetric surface maps of the SMRE was to import the processed survey data and the June 2022 aerial imagery from Google Earth Pro. The data were then converted from MSL back to NAVD88 using the correction factor of 0.774 m (see Section 2.2.2) so that the imagery data and survey data were compared in the same vertical datum. After correcting back to NAVD88, the 0 m depth for all edges was established to ensure the SMRE bottom curved up to the bank. Then, the 2022 aerial image was used to identify areas of shallow vegetation or wet sand where the depth was less than 0.3048m (1ft) or the draft of the survey boat. Areas where dry sand met the shallow vegetation or wet sand were assigned a NAVD88 elevation of 0 m. Boundaries identifying depths less than 0.3048m and 0 m were digitized so spatial analysis tools could identify the transitional edges of the SMRE.

The data were then converted back to MSL before ESRI's "Topo to Raster" three-dimensional (3-D) analysis tool was applied to the 2022 data and boundary files. The interpolated output is created for each cell that is 1-foot by 1-foot in size. The cell size allows for steep gradients along cut banks to be well defined by multiple cells. Additionally, the well-defined bathymetric surface will provide guidance for establishing the hydrodynamic model grid that impacts mixing and water movement. The result of the GIS-based 3-D analysis is a color flood map, as shown in Figure 14. The areas above 0 m MSL are identified as "dry." Those intertidal areas are shown in green, and the remainder of the bathymetric survey is depicted by the colors provided in the legend shown on the map. The deepest areas were located near the bridges that cross the SMRE. The area near the mouth of the SMRE and along the banks, as well as some sections in the middle of the SMRE where sandbars had developed, were too shallow to be measured by the Z-boat®.



COMPUTED 2022 BATHYMETRY SURFACE
DEPTH IN METERS MEAN SEA LEVEL (MSL)
SANTA MARGARITA RIVER ESTUARY

Notes:
- Estuary open to ocean during survey. Aerial photo reflects migration of mouth.
- Max depth is 4.8 meters MSL.
- Aerial Photo Date: February 2022

DRAFT
4/25/2023

Figure 14. 2022 Bathymetric Surface Color Flood Map.

3.2 COMPARISSON OF 2013, 2015, AND 2022 SURVEYS

One goal of the project was to compare the changes in the SMRE over time based on the results of the 2013, 2015, and 2022 surveys. Because the survey areas were not identical between the three surveys, a common grid was developed so new bathymetric surfaces could be developed and compared as described in this section.

3.2.1 Development of a Common Grid

The bathymetric surfaces for 2013 and 2015 were regenerated using the same methodology used to develop the 2022 surface (Section 3.1), so similar results could be compared. The challenge to developing similar surfaces for comparison arose because survey areas were not identical between the three surveys, and a common grid boundary needed to be developed. For this purpose, a common grid boundary, based on the 2013 survey that was used in the 2016 Hydrodynamic Report (NIWC, 2016), was used to define the lateral extent of all three surveys. The available data points for each of the three datasets, along with the common model grid boundary, as shown by the black line, are depicted in Figure 15. The common survey area spans from SMB to the ocean boundary. Above SMB, areas of overlap between the three datasets are small and discontinuous, so they were therefore excluded from the common grid. The 2013, 2015, and 2022 datasets upstream of SMB showed braided channels that did not overlap in a manner that would provide a meaningful comparison.

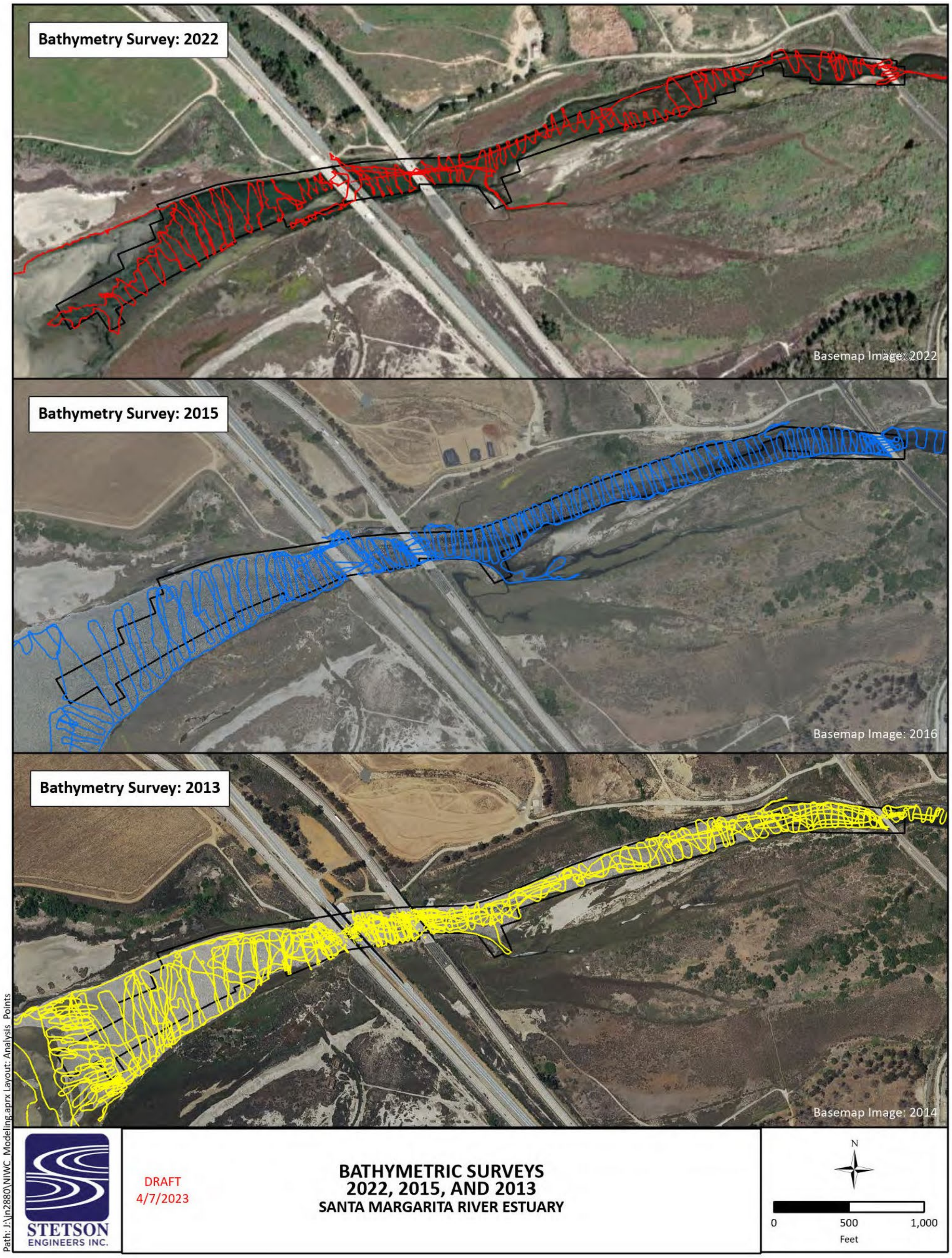


Figure 15. 2013, 2015, and 2022 bathymetric survey points.

3.2.2 Comparison to Prior Maps

The bathymetric maps created for overlapping portions of the survey grids for 2022, 2015, and 2013 are shown in Figures 15 through 17, respectively. The GIS-analyst tool provides a visually smoothed surface for improved visualization of changes between the three surveys. As discussed in Section 3.2.1 above, the common area includes the SMRE between the SMB and the ocean. Areas above SMB are not part of the common survey area because of the braided channels in that area and the lack of continuous overlap between the three surveys. As shown in Figures 16 and 17, there were significant changes in the horizontal shape of the surveyable portion of the SMRE between 2022 and 2015 as the river meanders, eroding some areas and depositing sediment in other areas over time. This results in a reduced overlap of bathymetry survey data points between these two studies. The 2022 area surveyed was smaller compared to the area surveyed in 2015; the survey area was limited due to very shallow areas where the Z-boat® could not operate without running aground.

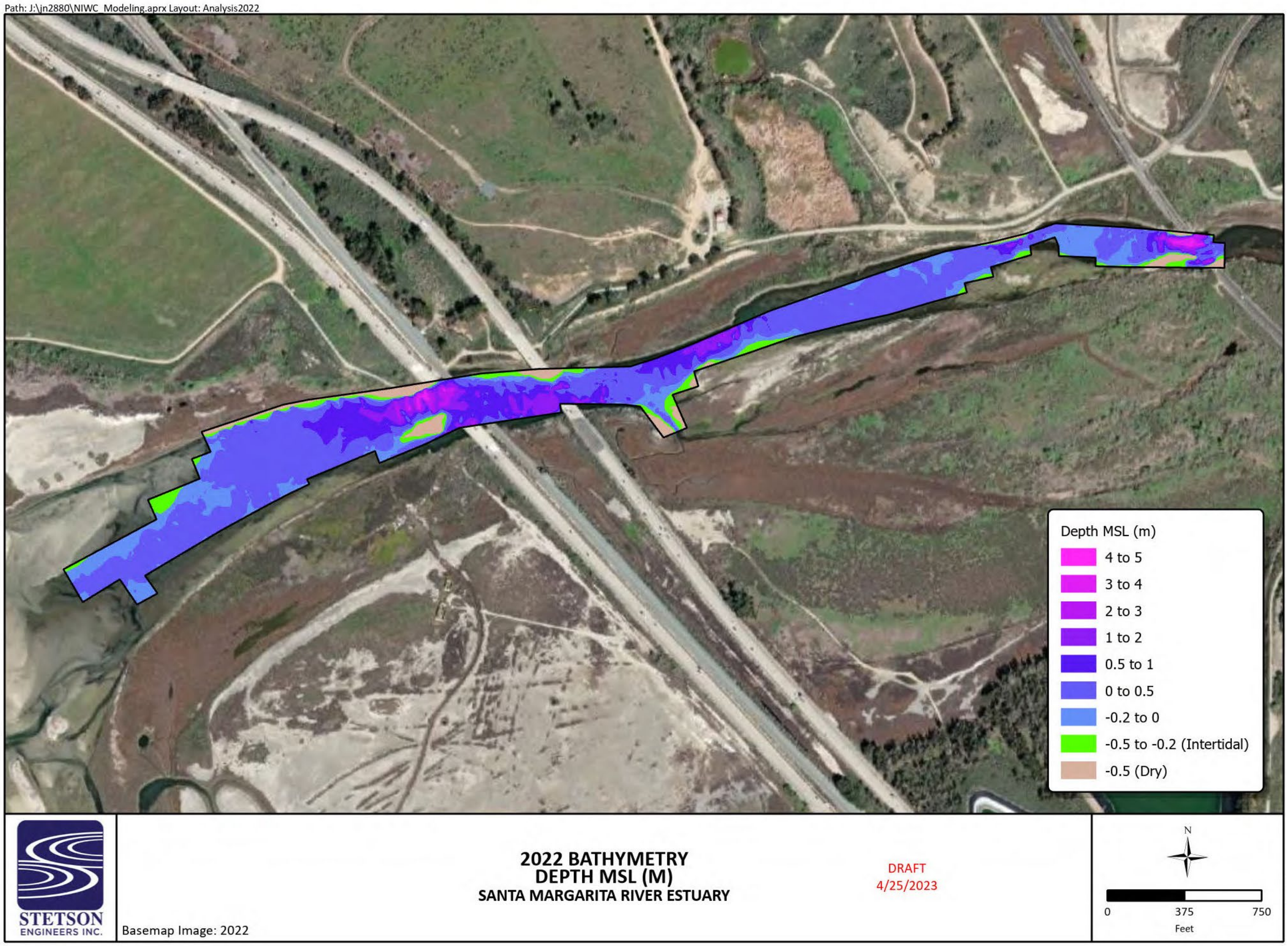


Figure 16. Map of 2022 SMRE bathymetry for overlapping areas.

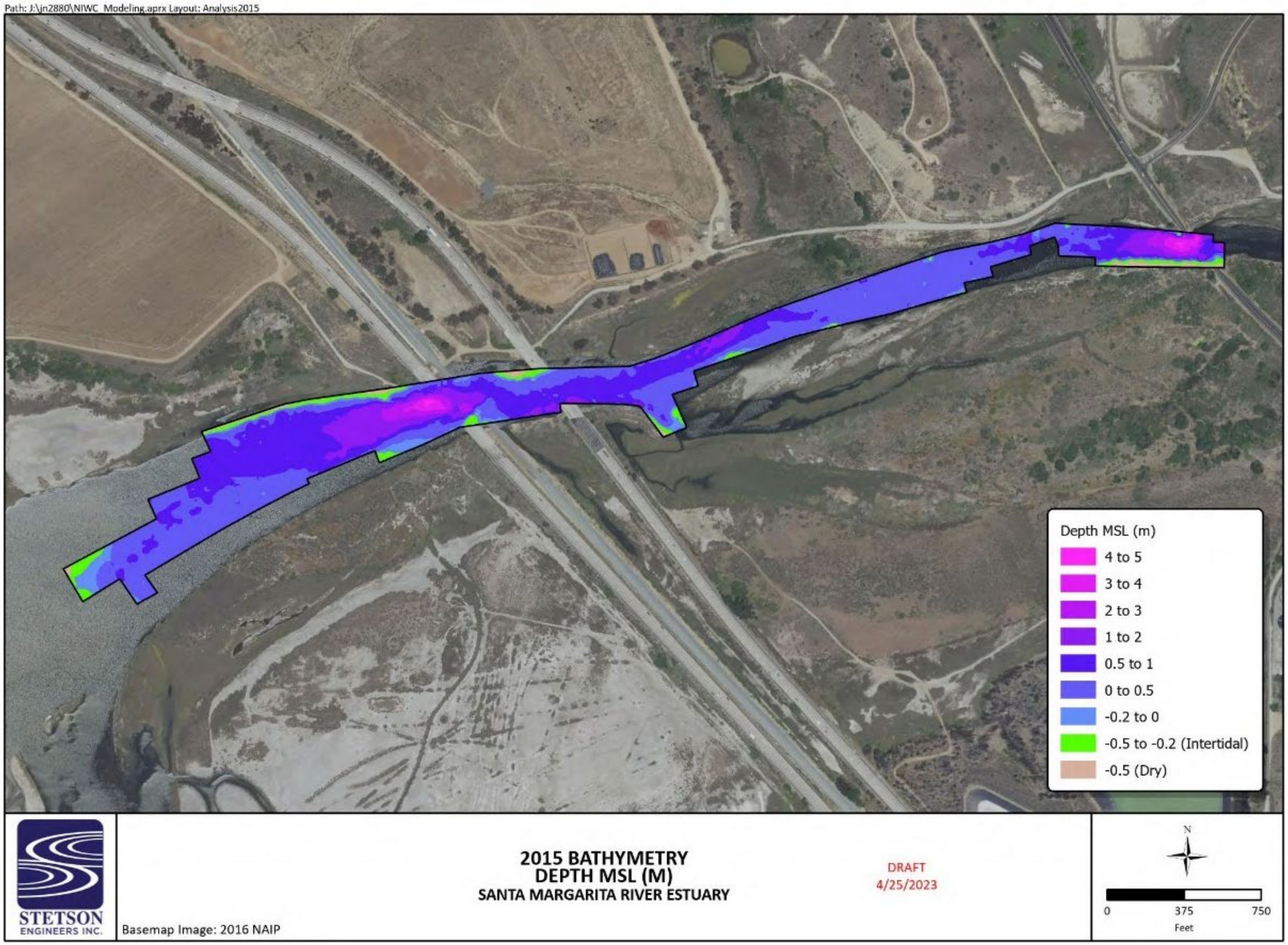


Figure 17. Map of 2015 SMRE bathymetry for overlapping areas.

Figure 18. Map of 2013 SMRE bathymetry for overlapping areas.

The overall average change in elevation between the 2022 and 2015 surveys, for the area of overlap, indicates that the 2022 surface is shallower by -0.289[2] m (Figure 19). The greatest change in depth occurred immediately below SMB and the southbound lane of I-5. Further investigation of the change in elevation between the 2022 and 2013 surveys showed similar results (Figure 19). The overall average change in elevation was -0.377 m, and the greatest changes occurred at the bridges. A comparison of the 2015 and 2013 surveys (Figure 20) indicates that there was a minimal overall change in elevation of -0.087 m, with little or no change in depth at the SMB. The greatest change between 2015 and 2013 was near the North County Transportation Railroad Bridge, which occurred at a different location than the change (i.e., scouring) in surface that occurred in 2022 downstream of I-5.

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[2] The negative number indicates shallower depth in the more recent survey.

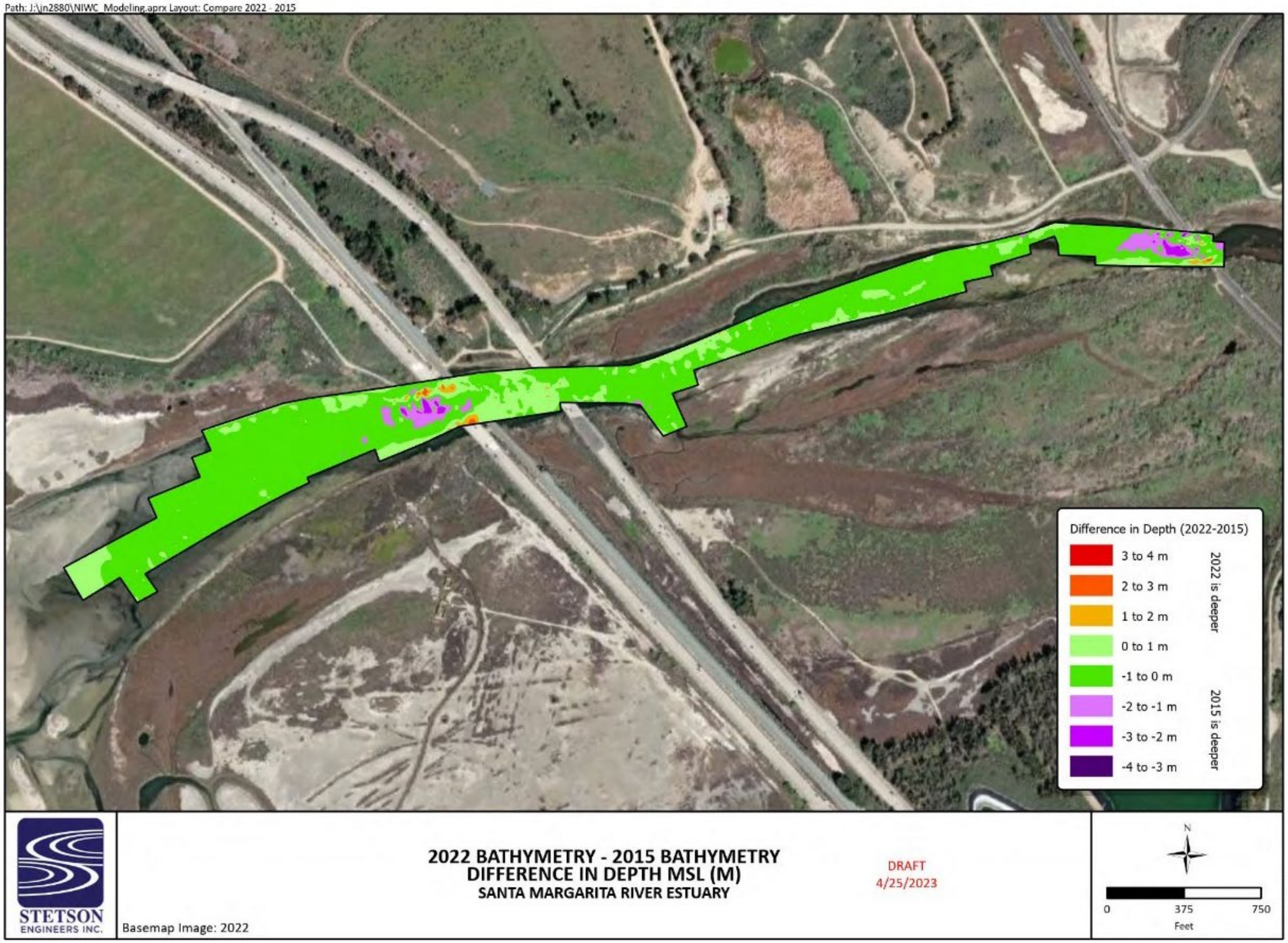

Figure 19. Comparison of 2015 and 2022 bathymetry for overlapping areas.

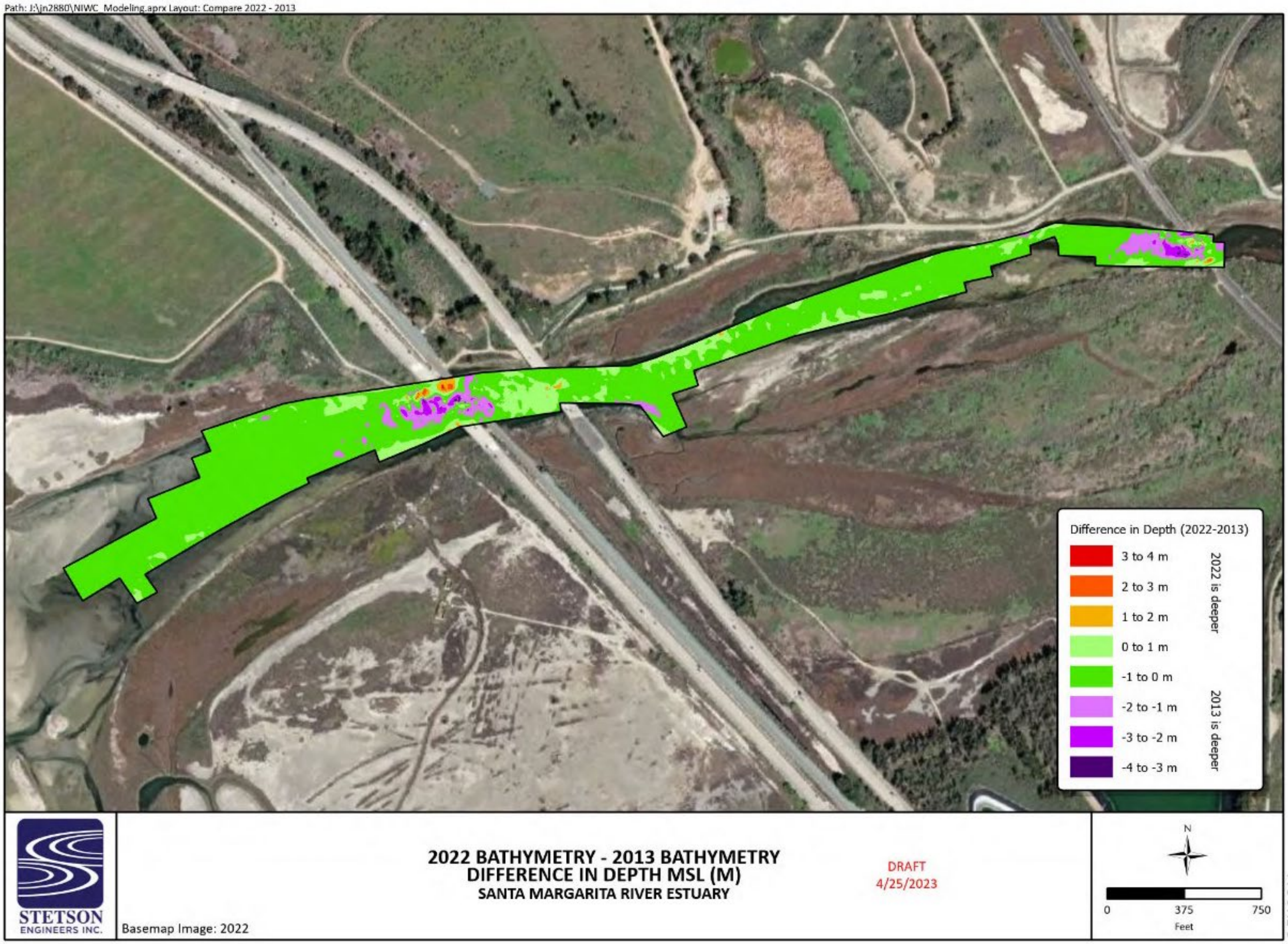

Figure 20. Comparison of 2013 and 2022 bathymetry for overlapping areas.

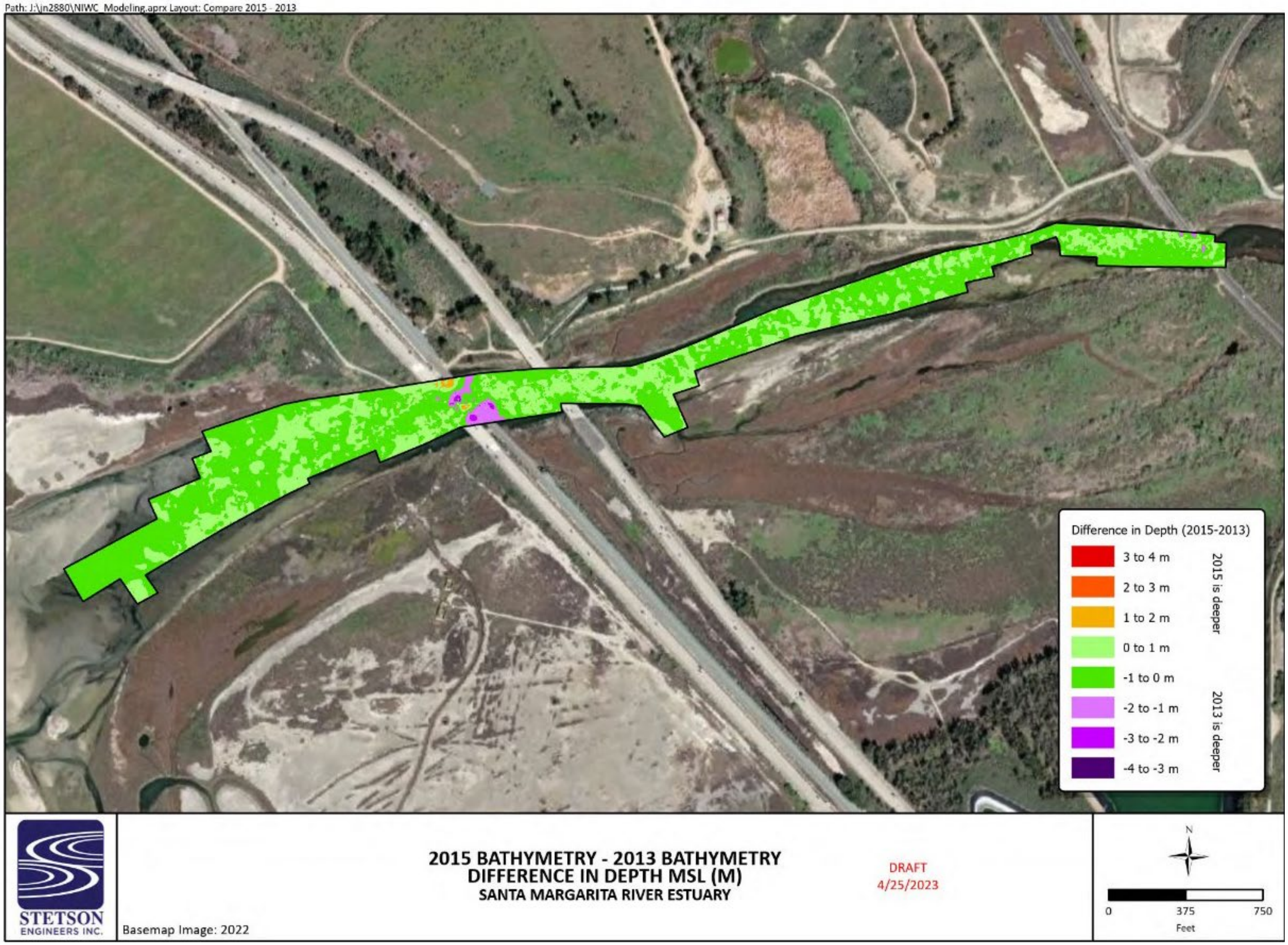

Figure 21. Comparison of 2013 and 2015 bathymetry for overlapping areas.

The changes in the bathymetric surface between the various surveys may also be described as the statistical change in depth at points located more than 100 meters away from the bridges[3]. The elevation of each 1-ft x 1-ft cell used to develop the bathymetric surface was compared to the same cell from the other two surveys to develop a statistical analysis. The results indicate that the change in the average depth between 2013 and 2015 was -0.062 m (i.e., the average depth was shallower in 2015), while the change in the average depth between 2013 and 2022 was -0.307 m (Table 3; shallower depth in 2022). Similarly, the standard deviation of the change between 2013 and 2015 was -0.163, while the standard deviation of the change between 2013 and 2022 was -0.294. The statistics show that the SMRE, on average, has gotten shallower over the time period from 2013 to 2022. This supports the conceptual understanding and visual observations that changes in bathymetry occur following hydrologically wet periods when elevated river inflows result in shifting and deposition of sediment throughout the SMRE.

Table 3. Statistical Results of 2013, 2015, and 2022 Overlapping Areas Outside of Influence from Bridges.

Statistic	Change in Depth from 2013 to 2015 (m)	Change in Depth from 2013 to 2022 (m)	Change in Depth from 2015 to 2022 (m)
Mean	-0.062	-0.307	-0.245
Median	-0.022	-0.313	-0.257
Min	-0.965	-1.493	-1.287
Max	0.736	1.563	1.475
Std. Deviation	0.163	0.294	0.294

- Note: The number of points is 955,820 and excludes points within 100 meters of the bridges.
- Negative numbers indicate shallower depth over the period described.

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[3] 100 meters was chosen to exclude the scouring that occurs near the abutments of the bridges.

4. WATER QUALITY RESULTS

Water quality data were collected for a total of 260 minutes on September 19, 2022, and 327 minutes on September 20, 2022. On September 19, most measurements were recorded between the mouth of the SMRE and between the I-5 and Stuart Mesa bridges (moving west). On September 20, most measurements were recorded from beyond station MA6 to between the I-5 and Stuart Mesa bridges (moving east). The variables measured included depth, temperature (Temp), specific conductivity (Sp Cond), DO, turbidity (Turb), and chlorophyll-A (Chl-A). Salinity and DO equilibrium saturation were derived from the combination of temperature, specific conductivity, and DO data. Table 4 summarizes the statistics of measurements for the selected variables measured. A complete summary of measurements by date is provided in Appendix E. A brief summary of the results for each variable is provided below.

Table 4. Statistics for water quality in the SMRE.

Statistic	Temp (°C)	RDO (mg/L)	RDO (%Sat)	Sp Cond (µS/cm)	Salinity (PSU)	Turb (NTU)	Chl-A (RFU)
September 19, 2022 (n = 260) - WEST							
Average	23.89	6.70	101	49,755	33.05	30	0.22
Std. Dev.	1.31	0.44	7	1,318	0.97	117	0.88
Minimum	21.87	5.59	85	37,662	24.24	0.89	0
Maximum	28.88	7.87	120	51,789	34.69	906	8.45
September 20, 2022 (n = 327) - EAST							
Average	25.11	9.14	142	32,883	21.14	64	3.37
Std. Dev.	2.07	3.80	62	12,955	8.89	125	4.71
Minimum	20.60	2.87	41	6,251	3.45	0.43	0
Maximum	29.58	24.96	413	48,708	32.21	1,004	24.23

- Note: RDO = Rugged Dissolved Oxygen, which is the method used to estimate DO by the sonde probe; %Sat = percent saturation; Sp Cond = specific conductivity; PSU = practical salinity units; NTU = nephelometric turbidity units; RFU = relative fluorescence units.

Overall, the observed levels and variations of these physiochemical water quality parameters were driven mostly by the relatively low freshwater inflow during the monitoring period and the degree of tidal exchange. As mentioned in Section 2.2 above, field measurements were conducted under high tide conditions. The temperature on both sampling dates was fairly consistent across both the west and east sides of the SMRE (mean±SD: 23.89±1.31 and 25.11±2.07 °C, respectively) and was warmest in shallow areas near the middle of the SMRE (Figure 22).

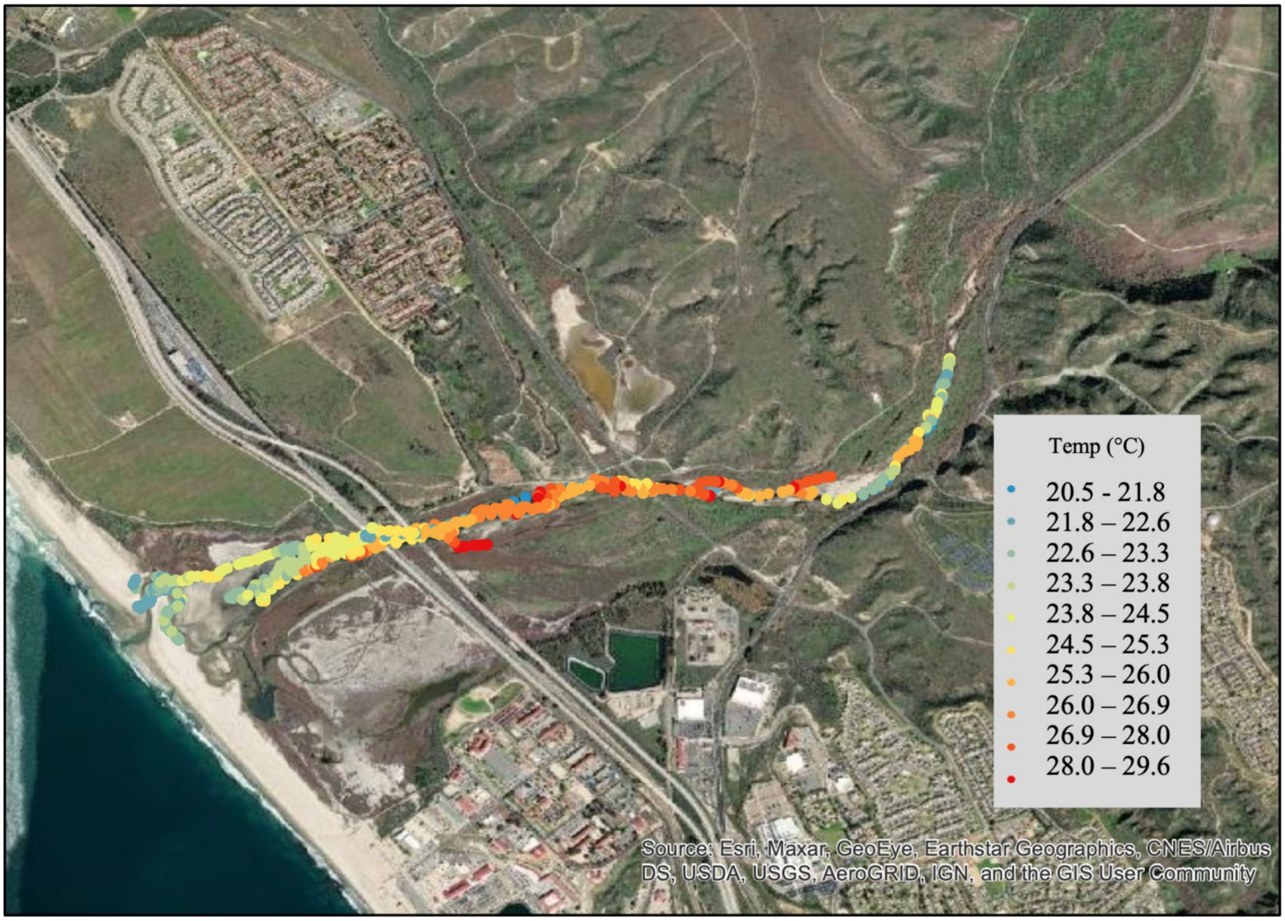
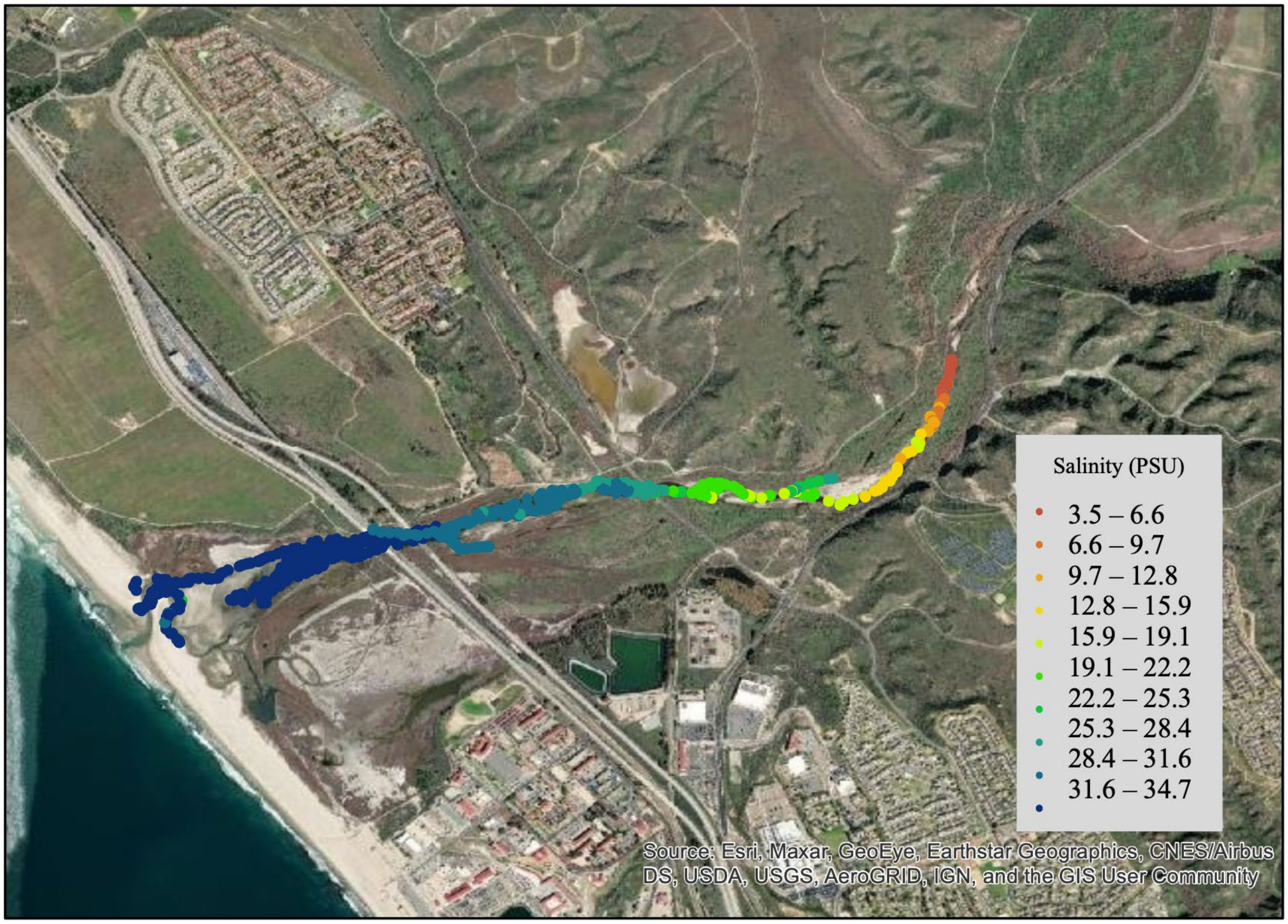


Figure 22. Water temperature recorded during the SMRE survey on September 19–20, 2022; the legend shows values in degrees Celsius.

In contrast, while the measured salinity on the west side of the SMRE remained consistent with seawater (mean±SD: 33.05±0.97 PSU), salinity measurements on the east side of the SMRE presented more variation, with salinity measurements as low as 3.45 PSU reaching closer to seawater conditions of 32.21 PSU, with an average salinity of 21.14±8.89 PSU (Table 4). Lower observed salinities at the extreme ends of the SMRE are also consistent with previous observations at these locations (Katz et al., 2018; Sorensen et al., 2020; Sorensen et al., 2021; Sorensen et al., 2022). The salinity gradient across the entire SMRE survey area is visualized in Figure 22.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 23. Water salinity recorded during the SMRE survey on September 19–20, 2022; the legend shows salinity values in PSU.

Similarly, while the measured RDO on the west side of the SMRE remained fairly consistent (mean±SD: 6.7±0.44 mg/L), measurements on the east side of the SMRE presented more variation in RDO, with measurements as low as 2.87 mg/L reaching as high as 24.96 mg/L, with an average RDO of 9.14±3.8 mg/L (Table 4).

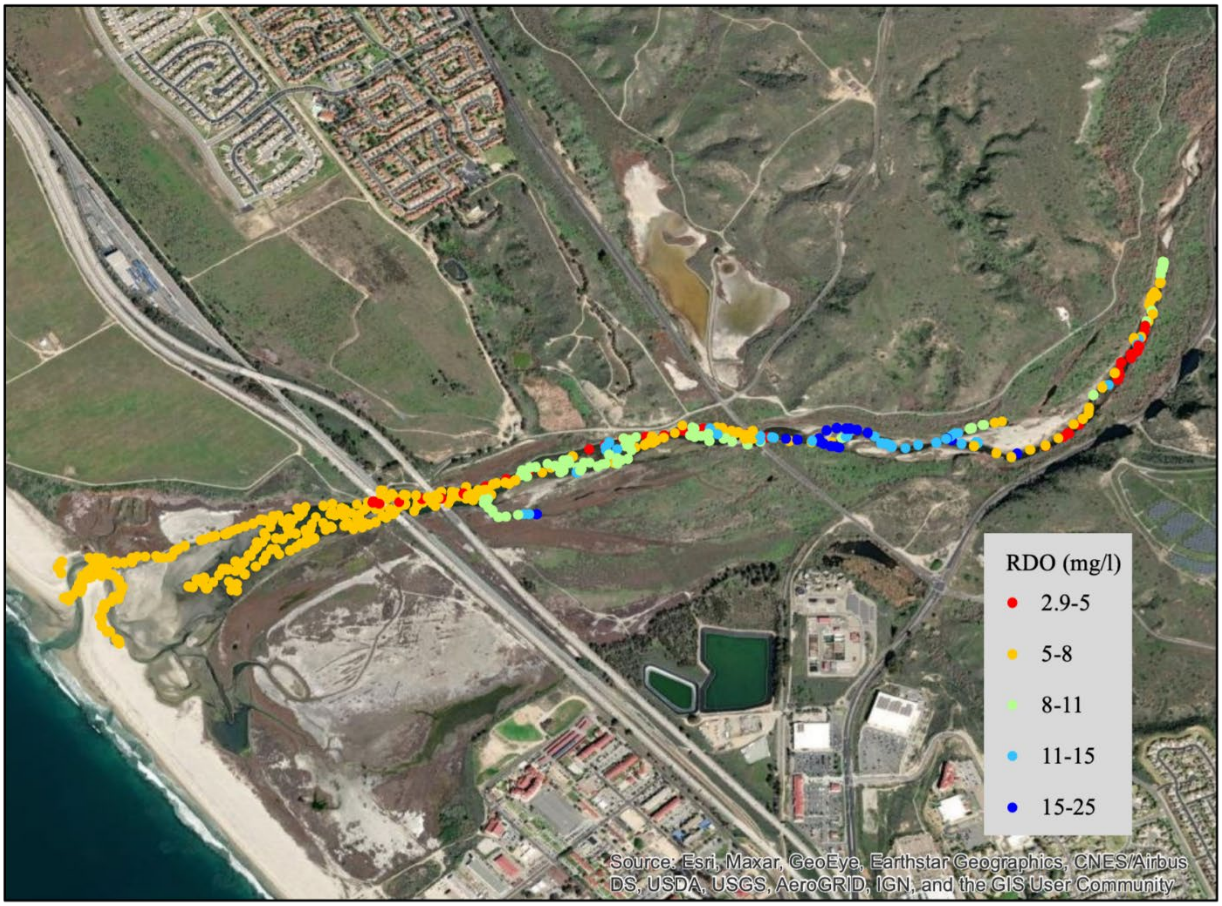


Figure 24. Dissolved oxygen (RDO, mg/L) measurements recorded during the SMRE survey on September 19–20, 2022.

5. DISCUSSION

Overall, the surveyable area in the SMRE was smaller in 2022 (0.339 km^2) than in 2015 (0.377 km^2). For the common area of overlap between the two surveys in 2015 and 2022, the SMRE was shallower by 0.013 m in 2022, but overall differences in average grid-cell depth ranged from about -0.8 m to 0.6 m (1.4 m absolute range of differences; Figure 25). While this average depth difference is very small and could be associated with errors in data collection or processing, other differences between the two surveys, including the smaller surveyable area, differences in bathymetry in particular around the bridges, and visual observations of geomorphic changes, show that the SMRE is a dynamic environment with changing physical conditions over time. Similar depth comparison maps are shown for the 2013 and 2015 surveys (Figure 26) and the 2013 and 2022 surveys (Figure 27). Depth did not change much from 2013 to 2015, whereas the 2022 survey showed more areas of variation compared to the two previous surveys. The observed changes in the SMRE morphology in 2022 may have been at least partially impacted by multiple large storm events in January 2017 and February 2019 (Figure 8), which caused an increase in sediment buildup at the mouth of the SMRE (Harvey et al. 2020).

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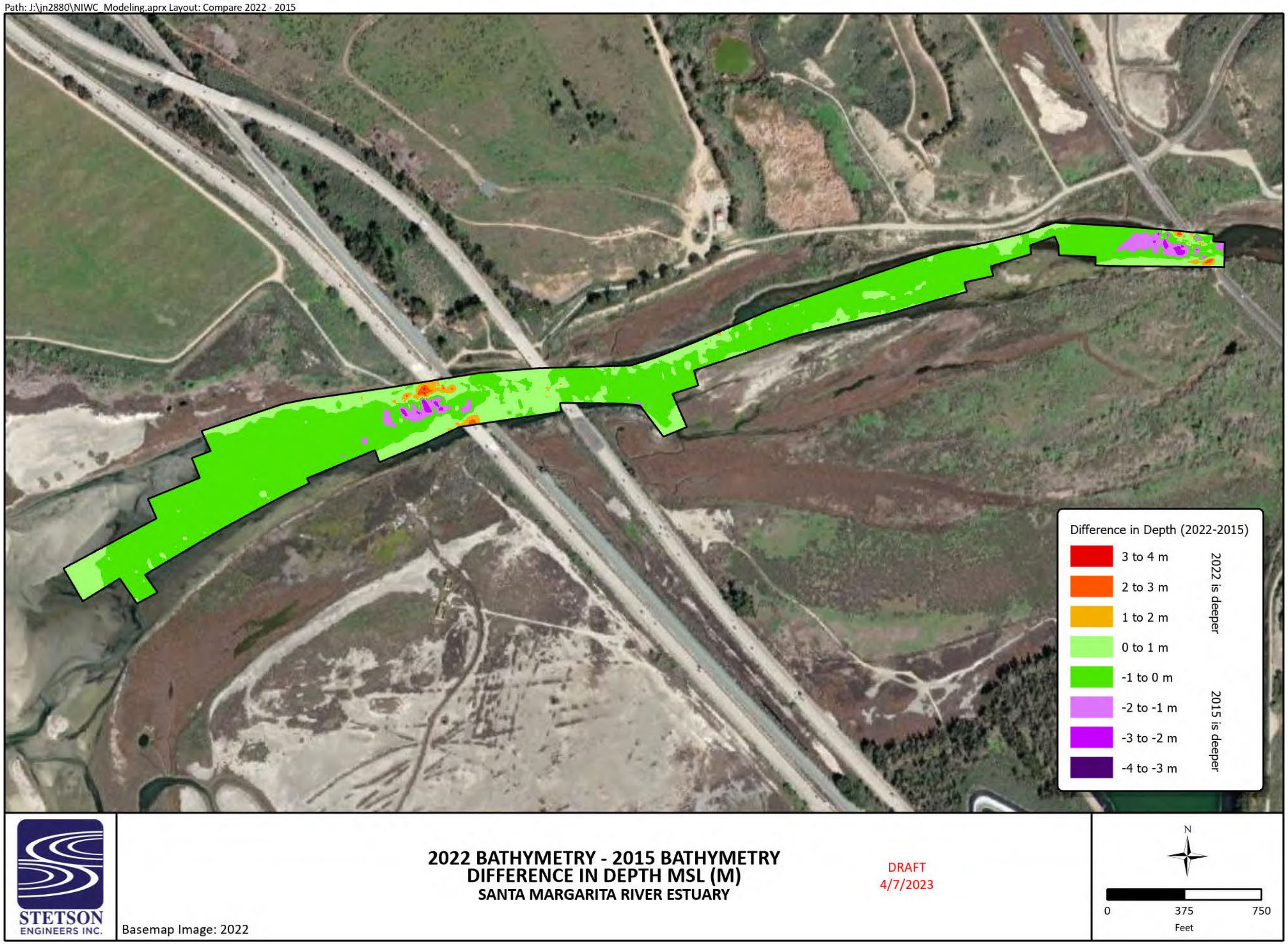

Figure 25. Comparison of SMRE depth in 2015 and 2022.

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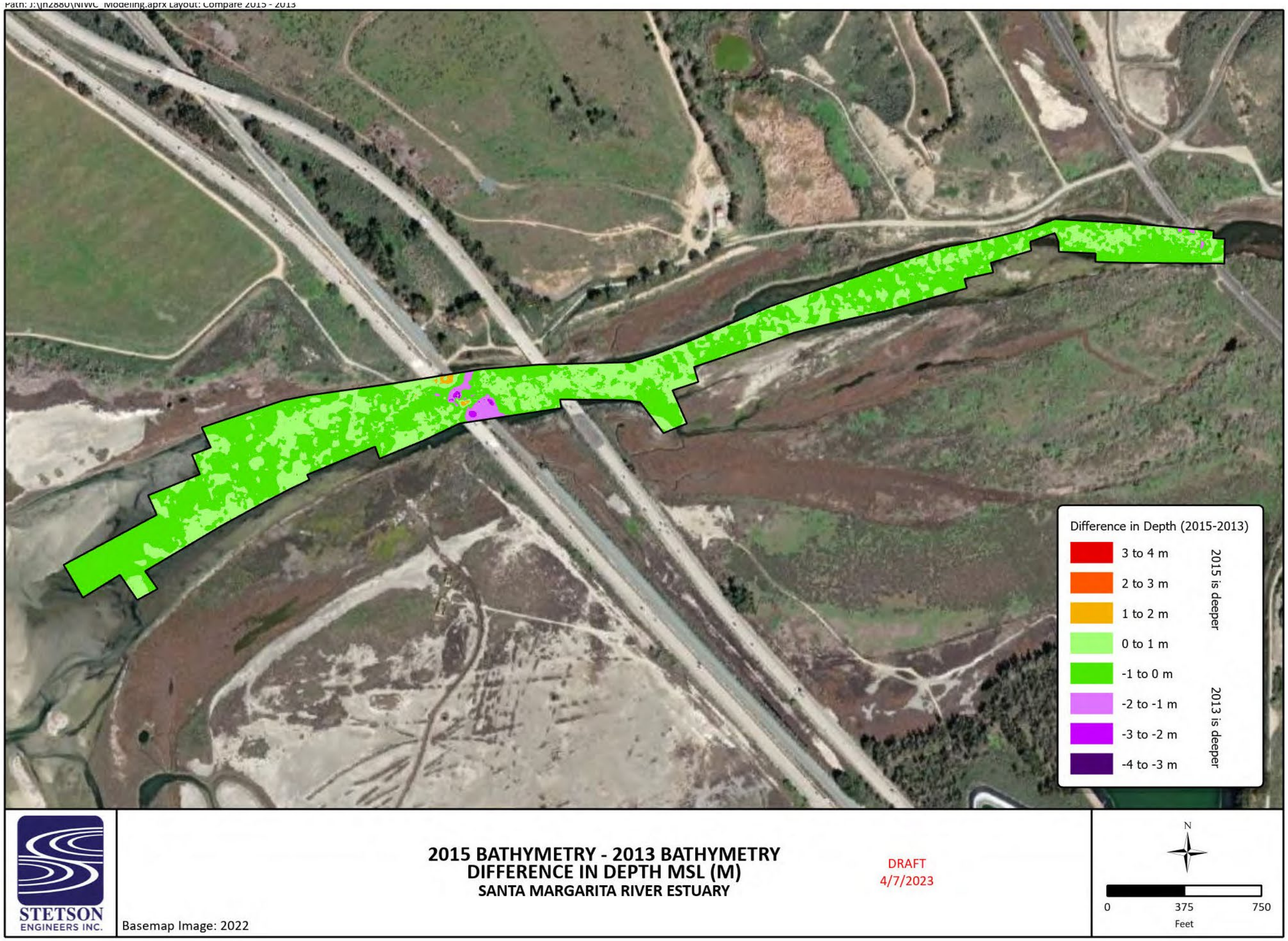

Figure 26. Comparison of SMRE depth in 2013 and 2015.

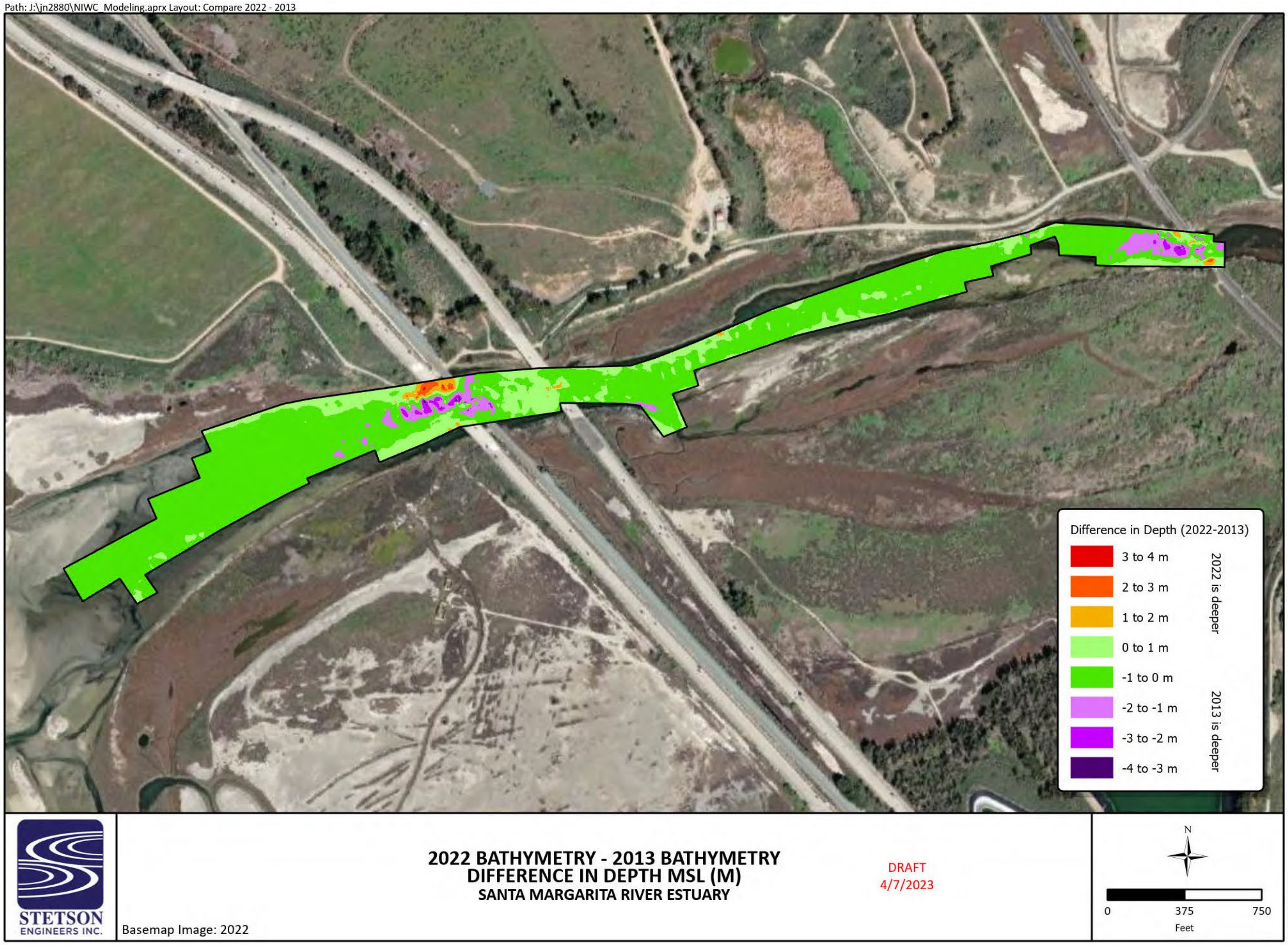

Figure 27. Comparison of SMRE depth in 2013 and 2022.

6. FUTURE DIRECTIONS/RECOMMENDATIONS

One of, if not the most critical, inputs for hydrodynamics studies is bathymetry. This makes simulations in highly dynamic water systems, such as estuaries, where bathymetry can change rapidly with time, particularly difficult. The clear spatial deviation in the shape of the surveyable portion of the SMRE between the 2015 and 2022 surveys strongly suggests that more frequent surveys are necessary for optimum simulation results. That said, the bathymetry measurements in common areas closer to the SMRE mouth do not change significantly over time, whereas putting greater focus on specific areas of greater change, such as near the bridges, will help better compensate for deviations. This means that even with some variability in smaller regions of the area of interest, the overall water quality dynamics may be more precisely simulated if larger contributions to the general water velocity are calibrated properly. Along these lines, future efforts, in addition to more frequent surveys, should focus on more complete surveys of the area where the SMRE mouth meets the ocean and much further into the ocean itself to better account for tidal effects. Grid cell sizes should continue to be reduced, in particular near areas of highly dynamic bathymetry, such as near bridges and areas where monitoring stations are positioned, to increase the accuracy of hydrodynamics in these areas and better simulate water quality scenarios, keeping in mind computational costs.

The bathymetric surface of the SMRE changed much more from 2015 to 2022 compared to 2013 to 2015. Large streamflow events in 2017 and 2019 are believed to be a major contributor to changes in bathymetry. When considering funding for future surveys, updated surveys may be needed more often after wet hydrologic conditions and less often during dry conditions. Because hydrology is just one factor affecting bathymetry, other factors such as water quality and connection to the ocean also need to be monitored when planning future surveys.

During the September 2022 survey, the bathymetric Z-boat® was repeatedly fouled with aquatic vegetation, which required significant time to remove. The Z-boat® also ran aground in several shallow locations. Although the field team worked to mitigate these conditions, for future surveys, it may be beneficial to conduct surveys at different times of the year when less vegetation is present and/or tides are even higher than those present in September 2022.

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APPENDIX A
BATHYMETRY DATA 2022

To request copies of the 2022 Bathymetry raw data, please contact Kara Sorensen, Ph.D., at kara.c.sorensen.civ@us.navy.mil.

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APPENDIX B
BATHYMETRY DATA 2022

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APPENDIX C
BATHYMETRY DATA 2022

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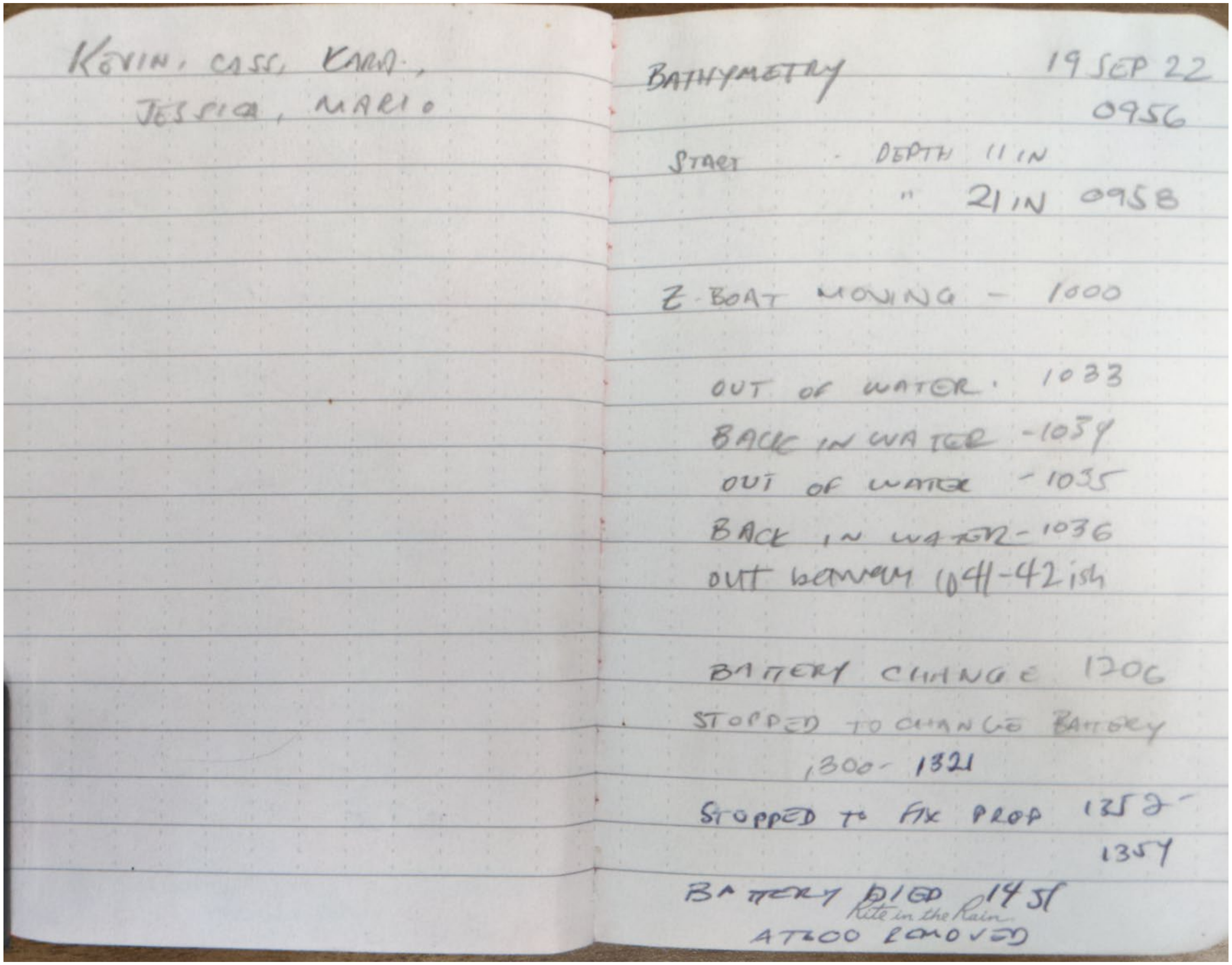
APPENDIX D
FIELD NOTES AND OBSERVATIONS



KEVIN, CASS, KARA,
JESSICA, MARIO

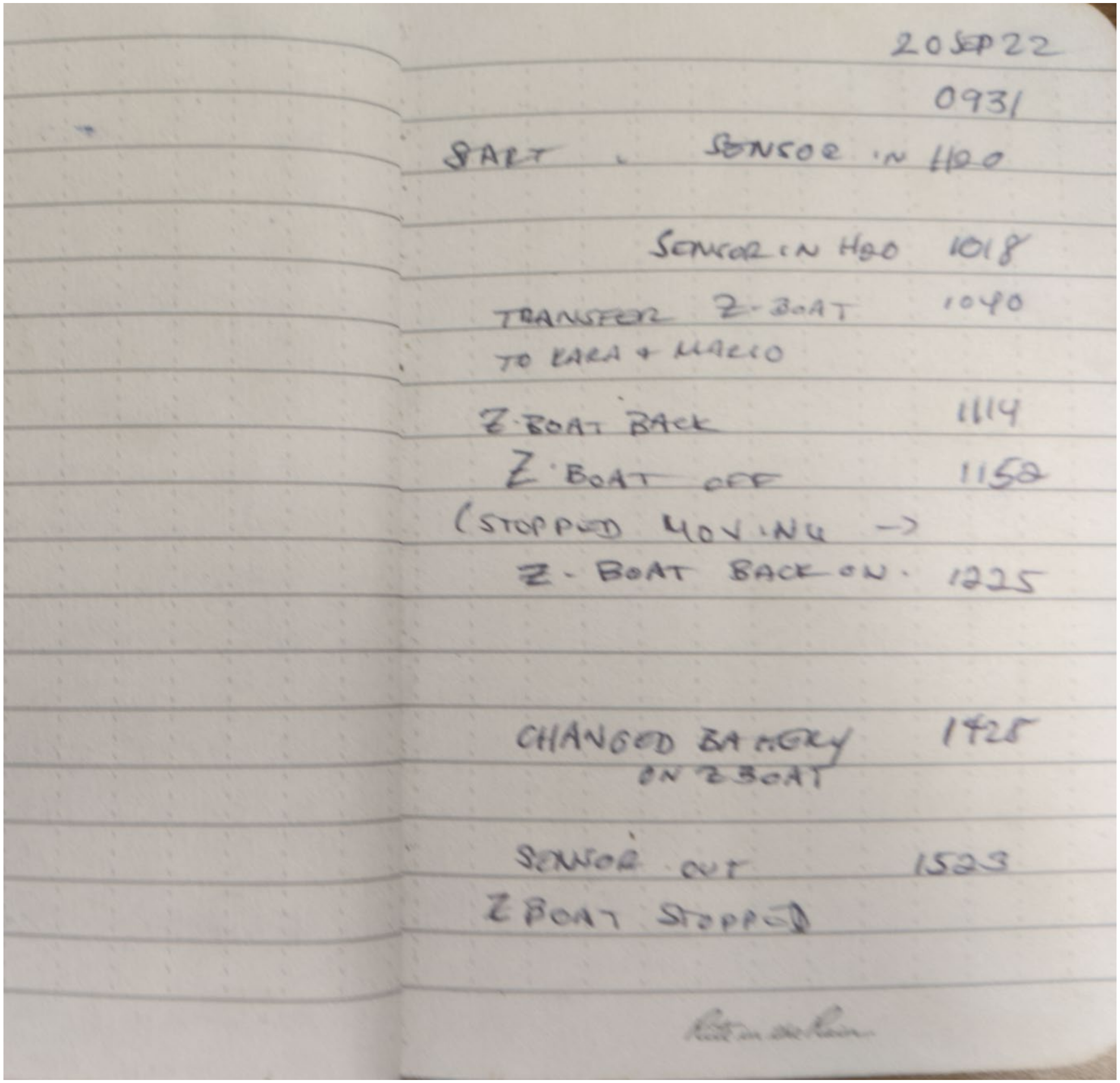
BATHYMETRY 19 SEP 22
0956

START . DEPTH 11 IN
" 21 IN 0958

Z-BOAT MOVING - 1000

OUT OF WATER . 1033
BACK IN WATER -1034
OUT OF WATER -1035
BACK IN WATER-1036
OUT BETWEEN 1041-42ish

BATTERY CHANGE 1206
STOPPED TO CHANGE BATTERY
1300- 1321
STOPPED TO FIX PROP 1352-
1354
BATTERY DIED 1451
Rite in the Rain
AT200 REMOVED



20SEP22

0931

START . SENSOR IN H2O

SENSOR IN H2O 1018

TRANSFER Z-BOAT 1040
TO KARA + MARCO

Z-BOAT BACK 1114

Z-BOAT OFF 1152

(STOPPED MOVING ->

Z-BOAT BACK ON. 1225

CHANGED BATTERY 1425
ON ZBOAT

SENSOR OUT 1523

ZBOAT STOPPED

APPENDIX E
CONTINUOUS WATER QUALITY DATA

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14. ABSTRACT

Due to the dynamic nature of the Santa Margarita Estuary (SMRE), it is important to characterize the morphology of the SMRE, specifically the bathymetric conditions, as the geomorphological dynamics directly affect physical dynamics and how inputs such as nutrients and sediments are mixed and distributed throughout the estuary. The SMRE bathymetry is a dynamic region (Sorensen et al., 2021; Sorensen et al., 2022), particularly in response to heavy rainfall events and high episodic flows down the river into the estuary. The last bathymetric survey was conducted by the Naval Information Warfare Center (NIWC) Pacific staff in 2015. Since then, significant rainfall events have been recorded, resulting in large-scale scouring and sedimentation deposition events. As a result of this, and as part of their overall commitment to better understanding possible contamination loading on the SMRE, MCBCP requested a more recent bathymetric survey to evaluate the current morphology of the SMRE.

In September 2022, a bathymetric survey of the SMRE was conducted using a small remotely operated surface vessel with an integrated global positioning system (GPS) and single-beam echosounder. This study describes the results of that study and compares them with prior bathymetric surveys.

15. SUBJECT TERMS

Santa Margarita River Estuary (SMRE), Marine Corps Base Camp Pendleton (MCPCP), Bathymetric survey, global positioning system (GPS), single beam echosounder, estuary

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