Bathymetric Survey and Digital Elevation Model of Little Holland Tract, Sacramento-San Joaquin Delta, California

Open-File Report 2016–1093

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Cover. Photograph of the Little Holland Tract in the Sacramento-San Joaquin Delta, California (U.S. Geological Survey photograph by Andrew Stevens).

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
hectare (ha)	0.003861	square mile (mi^2)
	Volume	
cubic meter (m^3)	1.308	cubic yard (yd^3)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)(2011).

Elevation, as used in this report, refers to distance above the vertical datum.

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Abstract

The U.S. Geological Survey conducted a bathymetric survey in Little Holland Tract, a flooded agricultural tract, in the northern Sacramento-San Joaquin Delta (the "Delta") during the summer of 2015. The new bathymetric data were combined with existing data to generate a digital elevation model (DEM) at 1-meter resolution. Little Holland Tract (LHT) was historically diked off for agricultural uses and has been tidally inundated since an accidental levee breach in 1983. Shallow tidal regions such as LHT have the potential to improve habitat quality in the Delta. The DEM of LHT was developed to support ongoing studies of habitat quality in the area and to provide a baseline for evaluating future geomorphic change. The new data comprise 138,407 linear meters of real-time-kinematic (RTK) Global Positioning System (GPS) elevation data, including both bathymetric data collected from personal watercraft and topographic elevations collected on foot at low tide. A benchmark (LHT15_b1) was established for geodetic control of the survey. Data quality was evaluated both by comparing results among surveying platforms, which showed systematic offsets of 1.6 centimeters (cm) or less, and by error propagation, which yielded a mean vertical uncertainty of 6.7 cm. Based on the DEM and time-series measurements of water depth, the mean tidal prism of LHT was determined to be 2,826,000 cubic meters. The bathymetric data and DEM are available at http://dx.doi.org/10.5066/F7RX9954.

Introduction

The confluence of the Sacramento and San Joaquin Rivers, known as the Sacramento-San Joaquin Delta (the "Delta") is the tidal freshwater region inland of the San Francisco Estuary. The Delta is an important source of freshwater for much of California. Water supply from the Delta to agricultural, industrial, and municipal users, as well as flows through the Delta, are managed by large water projects operated by the State of California and Federal Government. The Delta also supports a complex and fragile ecosystem. In recent decades, fisheries in the Delta have declined (Sommer and others, 2007), and several resident native fish species including the delta smelt (*Hypomesus transpacificus*) are threatened or endangered. The water projects must provide a reliable water supply and are also required to protect the ecosystem, particularly threatened species. As a result, extensive habitat restoration is underway in the Delta, and much more restoration is planned. Many of the restoration sites are previously diked off agricultural tracts, where tidal action has been (or will be) restored through unintentional or planned breaching of levees. Little Holland Tract (LHT), the site of this study, is one such area in the north Delta located between Liberty Island and the Sacramento Deep Water Ship Channel (fig. 1)—it has been tidally inundated since levees were accidentally breached in 1983.

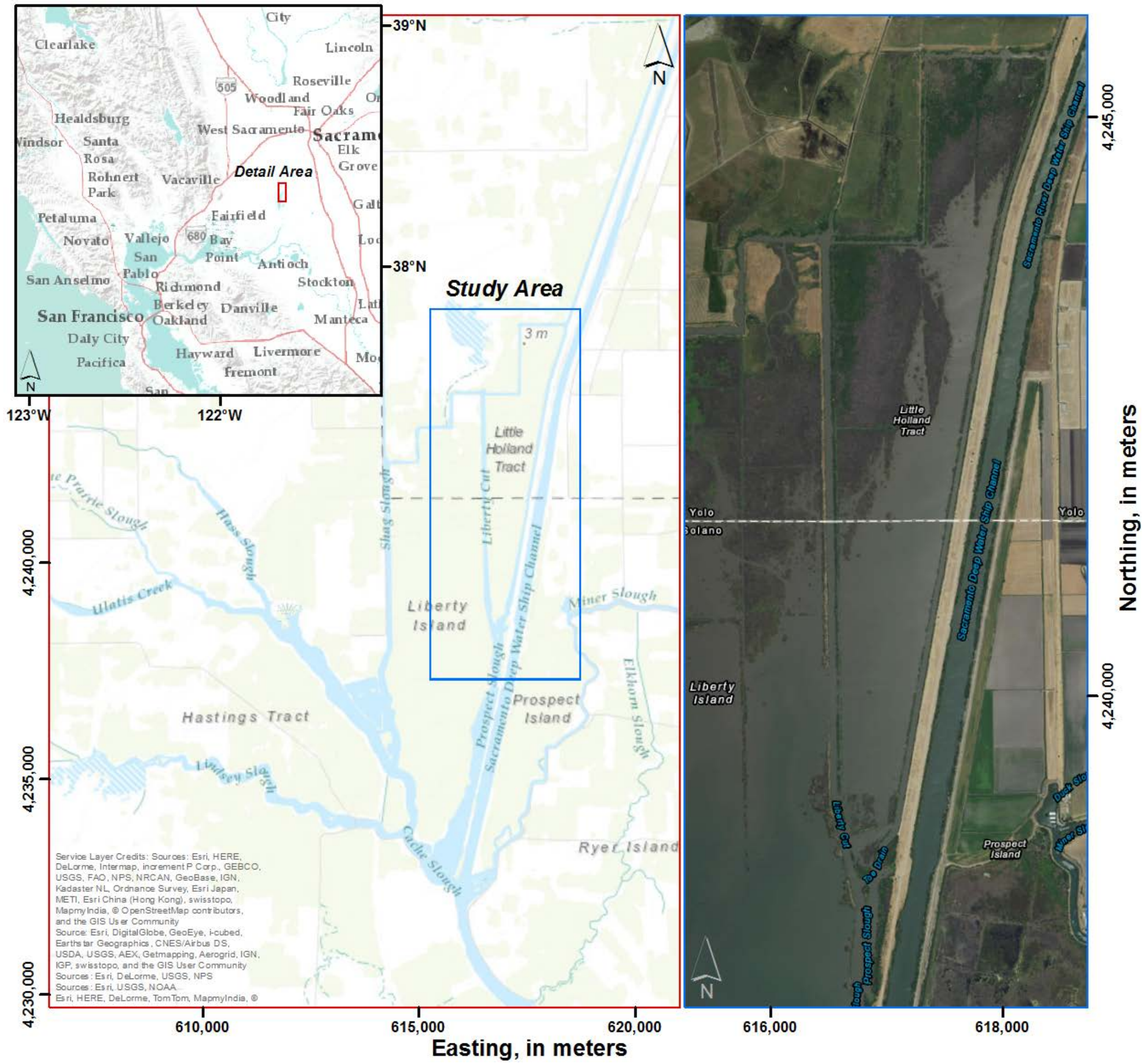


Figure 1. Composite maps and satelite image showing an overview of the Little Holland Tract (LHT) in the Sacramento-San Joaquin River Delta, California. The LHT study site is adjacent to the Sacramento Deep Water Ship Channel, Prospect Slough, and Liberty Island.

The U.S. Geological Survey (USGS), in collaboration with other Federal and State partners, is working to advance the understanding of how to improve habitat within the Delta ecosystem and better support threatened species. LHT is one of the sites for these studies. LHT covers approximately 6,114,188 square meters (m^2) and is located in the Cache Slough complex in the north Delta (fig. 1), which has been identified as a promising region for habitat restoration because it is characterized by a relatively high diversity of fish species. Before this study, very limited bathymetric data were available for LHT. Bathymetry is crucial baseline data for habitat studies, as it is required to determine basin volume, tidal prism, and the spatial distribution of regions of subtidal, intertidal, and marsh-plain elevations. In this study, we collected bathymetric data and developed a digital elevation model (DEM) of the bathymetry and topography of LHT based on new as well as existing data. The DEM is intended to support habitat studies in LHT and provide a baseline for monitoring bathymetric change over time.

Methods

During May and June of 2015, a team of scientists from the USGS Pacific Coastal and Marine Science Center (PCMSC) conducted multiple surveys (USGS Field Activity 2015-642-FA) to collect topographic and bathymetric data in LHT. Much of LHT is intertidal. Topographic data were collected on foot during low tides, and bathymetric data were collected using two personal watercraft (PWC) during high tides. Positioning for both types of survey methods was established using survey-grade global navigation satellite systems (GNSS).

Geodetic Control

A benchmark was established adjacent to the study area to provide horizontal and vertical control for the bathymetric and topographic measurements. The benchmark, designated LHT15_b1, was installed on May 8, 2015, on the top of a levee just outside the LHT in an area with an unobstructed view of the sky (fig. 2*C*). The benchmark consisted of a 3-foot (ft) section of rebar that was pounded into the soil and capped with a plastic monument marker.

Figure 2. Photographs showing field equipment used by the U.S. Geological Survey during the 2015 bathymetric survey of the Little Holland Tract in the Sacramento-San Joaquin River Delta, California. *A*, Backpack-mounted global navigation satellite system (GNSS); *B*, single-beam sonar mounted on a personal watercraft; and *C*, base station with a fixed-height tripod with GNSS antenna set up on benchmark LHT15_b1. (U.S. Geological Survey photographs.)

The position and elevation of the benchmark were derived from two static GNSS occupations on May 22 and June 8, 2015, with durations of 6 and 4 hours, respectively. The equipment for the static occupations consisted of a Trimble R7 GNSS receiver, a fixed-height tripod, and Trimble Geodetic Model 2 antenna. The static observations were processed using the National Geodetic Survey Online Positioning User Service (OPUS). The processed positions from each occupation were averaged, and the final reported position of the benchmark (table 1) conforms with level-1 quality according to published USGS standards (Rydlund and Densmore, 2012). Although the benchmark remained stable during the surveys, it is located in an area of questionable stability.

Table 1. Benchmark information used for U.S. Geological Survey 2015 bathymetric survey of the Little Holland Tract, Sacramento-San Joaquin River Delta, California.

[LHT, Little Holland Tract; NAD 83 (2011), North American Datum of 1983; UTM, Universal Transverse Mercator; m, meters]

Property	Value
Benchmark designation	LHT15_b1
Reference frame	NAD83 (2011)
Latitude	N 38° 17' 40.73201"
Longitude	W 121° 40' 3.44908"
Northing (UTM Zone 10)	616511.857 m
Easting (UTM Zone 10)	4239347.227 m
Ellipsoid height	−25.8395 m
Orthometric height (Geoid12A)	6.0605 m

Bathymetric-Survey Summary

The USGS survey of the LHT was designed to collect bathymetric data along transect lines spaced 100 meters (m) apart, trending parallel to the levee east of the survey area (fig. 3), running approximately northeast-southwest. We also planned to measure elevations at the edge of water throughout the survey area. In addition, we included diagonal transect lines for quality control, and higher-resolution coverage in areas of interest, particularly near the primary southern breach where the bathymetric gradient is higher. Complete coverage by survey method is depicted in figure 3*A*.

Bathymetric data were collected from two PWCs equipped with single-beam echosounders and dual-frequency GNSS receivers (fig. 2). The sonar systems consisted of Odom© Echotrac CV-100 single-beam echosounders and 200 kilohertz (kHz) transducers with a 9° beam angle which digitize depth returns at a resolution of 1.25 centimeters (cm). Positioning of the survey vessels was determined at 10-Hz using Trimble® R7 GNSS receivers with Zephyr 2 antennas operating in autonomous mode. Outputs from the GNSS and sonar systems were combined in real time on the PWC by a computer running HYPACK® (version 13.0.0.6) hydrographic survey software. Navigation and data-quality information was displayed on a video monitor, allowing PWC operators to navigate along survey lines at speeds of 2–3 meters per second (m/s).

Depths from the echosounders were computed using a sound velocity of 1,488.80 m/s, measured during the survey on May 22, 2015, with a YSI Castaway conductivity, temperature, and depth sensor. Digitized depths were compared to the raw acoustic backscatter signal using a graphical user interface (GUI) developed with the computer program Matlab® to ensure the accuracy of depths produced by the echosounder. In areas where the automated echosounder signal processing failed, as was typical in very shallow regions, the GUI was used to digitize the bathymetry by hand. Once the raw depths were adjusted, a running mean with a window length of 5 points (approximately 1 m along track distance) was used to remove high-frequency vertical fluctuations, such as those caused by pitch and roll of the survey vessels.

Survey-grade positioning of the PWCs was obtained using a post-processed kinematic (PPK) methodology, whereby the software Waypoint Grafnav (version 8.50) was used to make differential corrections referenced to the LHT15_b1 benchmark. The post-processed positioning data were then merged with sonar depths to determine the elevation of the bed. Orthometric elevations relative to the North American Vertical Datum of 1988 (NAVD88) were computed using National Geodetic Survey

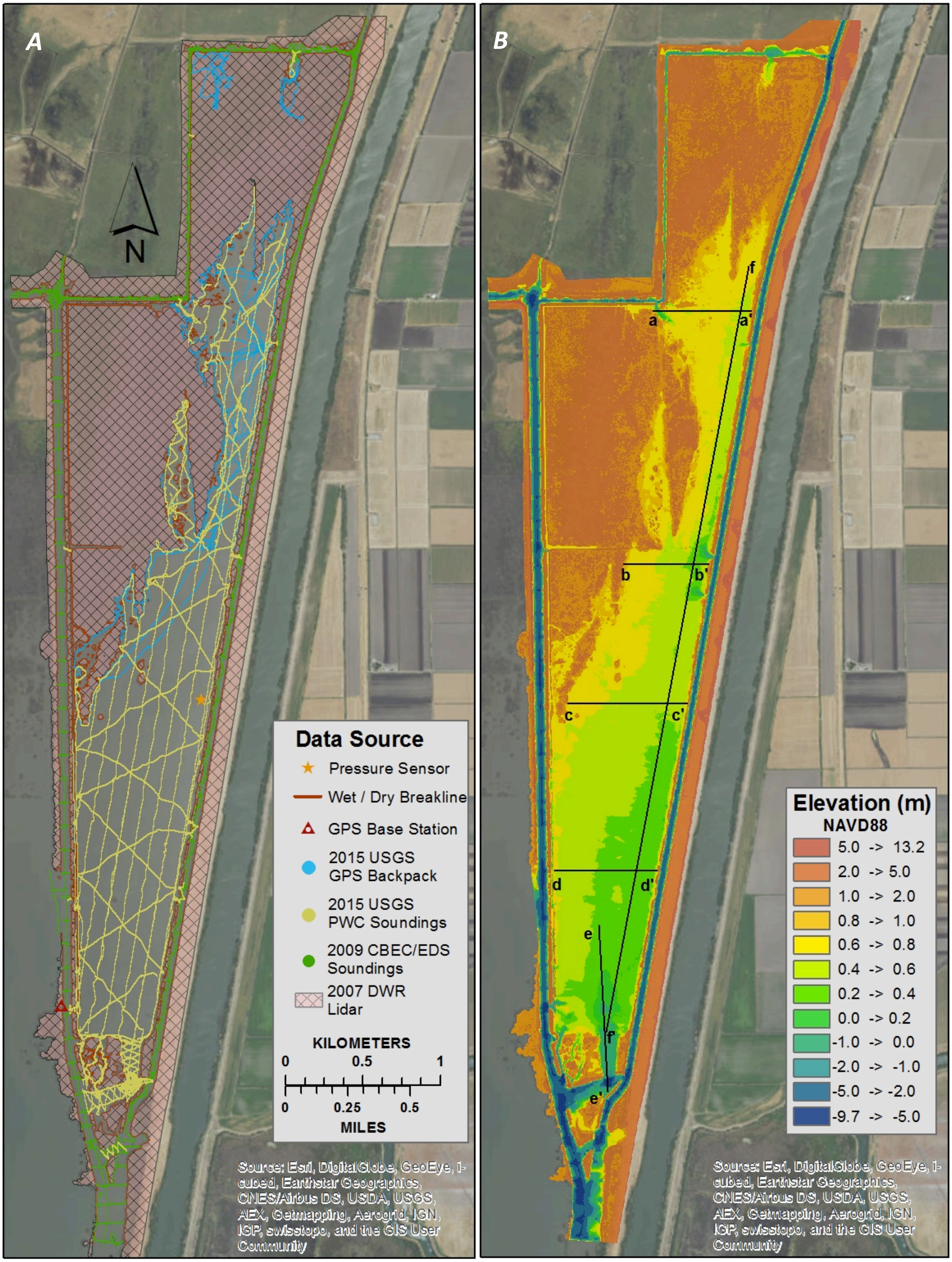
Geoid12a offsets and the final data were projected in Cartesian coordinates using the Universal Transverse Mercator (UTM) Zone 10 North (meters) coordinate system.

Topographic data were collected on foot using Trimble R7 and R10 GNSS backpack-mounted receivers in areas above the waterline or where water was too shallow for PWC use. We walked parts of the northeast to southwest transect lines and the shoreline, where accessible. A small area of the northernmost, low-lying topography was also measured using this method, although tall brush made most areas inaccessible or impractical to walk. Backpack-survey data were post-processed using Trimble Business Center (version 3.21) referenced to the LHT15_b1 geodetic control.

Quality Assurance

Repeatability tests were conducted across survey vessels, dates, and methods to verify configuration settings and to check for potential offsets related to survey method. The magnitude of these offsets was evaluated by comparing the surveyed elevations of overlapping points, defined as points separated by a horizontal distance of 0.5 m or less. We used the equations provided in Willmott (1982) to quantify the systematic and random differences among elevation data (fig. 4). The systematic and random components of the difference between data collected from the two separate PWCs were 1.1 and 4 cm, based on 2,453 overlapping points. For data collected from PWC and backpack-survey platforms, the systematic and random components of the difference were 1.6 cm and 6 cm, based on 2,105 overlapping points. The PWC data were, on average, 1 cm lower than the backpack data.

Figure 3. Annotated sattelite images of the Little Holland Tract (LHT), Sacramento-San Joaquin River Delta, California, surveyed by the U.S. Geological Survey (USGS) in 2015. *A*, Image showing data collected as part of the 2015 USGS bathymetric survey, as well as preexisting data used to generate a digital elevation model (DEM). *B*, the LHT DEM. *B* shows the locations of the profiles in figure 5. GPS, Global Positioning System; EDS, Environmental Data Solutions; DWR, California Department of Water Resources; lidar, light detection and ranging; m, meters; NAVD88, North American Vertical Datum of 1988. ►


A
N
Data Source
Pressure Sensor
Wet / Dry Breakline
GPS Base Station
2015 USGS GPS Backpack
2015 USGS PWC Soundings
2009 CBEC/EDS Soundings
2007 DWR Lidar
KILOMETERS
0
0.5
1
0
0.25
0.5
MILES
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
B
f
a
a'
b
b'
c
c'
d
d'
e
f'
e'
Elevation (m)
NAVD88
5.0 -> 13.2
2.0 -> 5.0
1.0 -> 2.0
0.8 -> 1.0
0.6 -> 0.8
0.4 -> 0.6
0.2 -> 0.4
0.0 -> 0.2
-1.0 -> 0.0
-2.0 -> -1.0
-5.0 -> -2.0
-9.7 -> -5.0
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

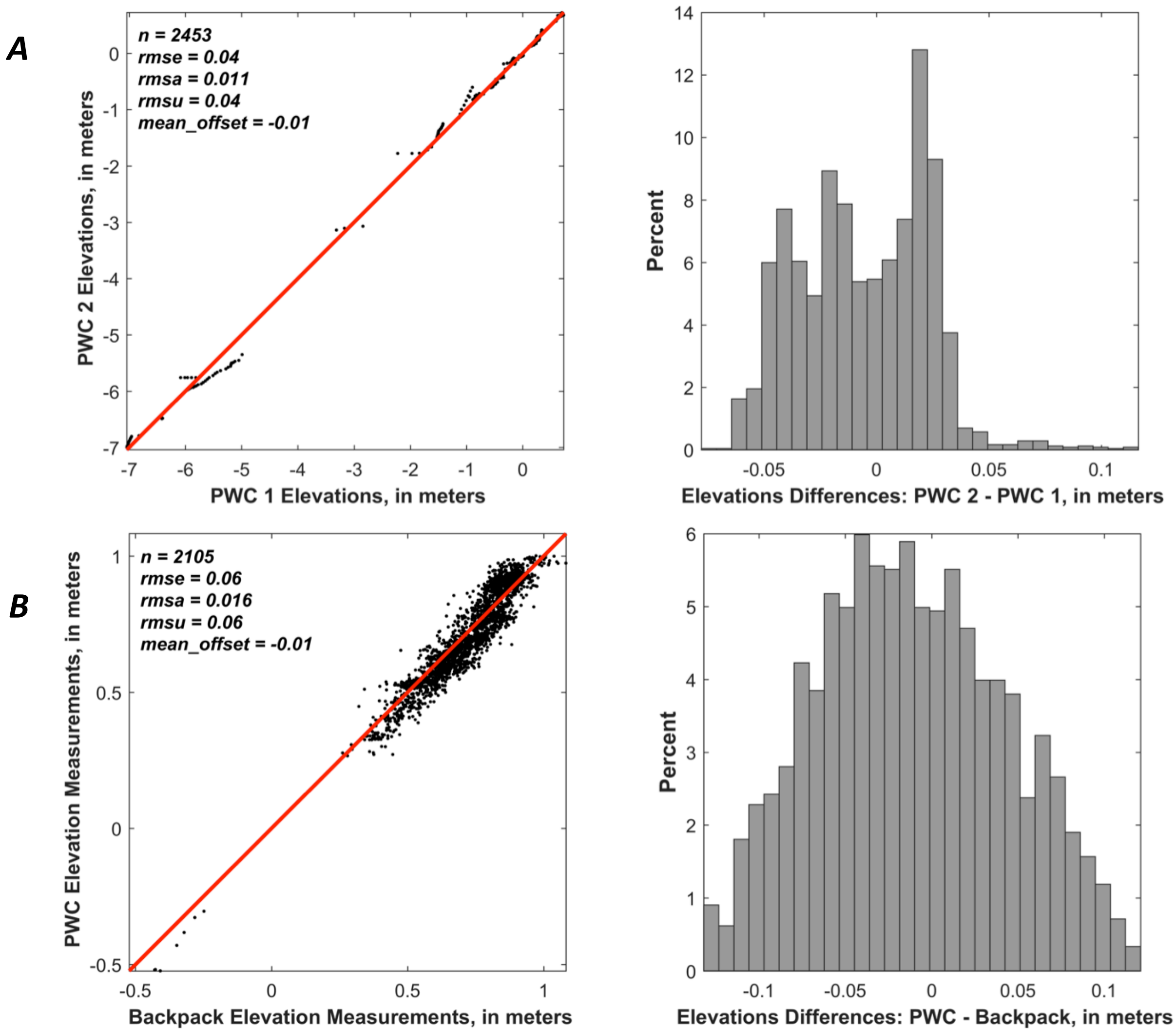


Figure 4. Graphs showing results of repeatability tests comparing depth data collected by the U.S. Geological Survey in the 2015 bathymetric survey of the Little Holland Tract in the Sacramento-San Joaquin River Delta, California. *A*, Comparing data collected from personal watercraft (PWC) 1 and 2. *B*, Comparing data from the PWC platforms to data from Global Positioning System (GPS) backpacks. Statistical measures compare elevation values collected from the two platforms (PWC and backpack) within a horizontal distance of 0.5 meters of each other. Statistical measures include the root-mean square error (rmse), as well as the systematic (rmsa) and unsystematic portions (rmsu). *n* is the number of data points.

Horizontal and Vertical Accuracy

In addition to the repeatability tests, the horizontal and vertical accuracy of the data were quantified by propagating the uncertainties associated with the survey methodology. The uncertainty associated with positioning of the survey platforms was estimated by computing the standard deviations of the GNSS rover positions relative to the benchmark using Waypoint Grafnav software. The mean horizontal and vertical accuracy of GNSS positions at the 95-percent confidence interval (1.96 times the standard deviations assuming a normal distribution) were 4.1 and 6.3 cm, respectively. Depths measured using sonar are subject to additional sources of uncertainty, including fluctuations in the speed of sound and variations in the pitch and roll of the survey vessels. Given the relatively calm water surface and low range of water depth present in this survey, we estimate depth-sounding uncertainty to be 1 percent of the water depth. The total vertical uncertainty σ_{total} of each elevation was calculated as:

$$\sigma_{\text{total}} = \sqrt{a^2 + (b \times d)^2}$$

where a is the uncertainty of the GPS elevation at the 95-percent confidence interval, b is the estimated uncertainty (0.01), and d is water depth (International Hydrographic Organization, 2008). Vertical and horizontal uncertainties were calculated for each survey point. The total estimated vertical uncertainty varied from 3.5 to 12.3 cm, with a mean of 6.7 cm. This is consistent with Gelfenbaum and others (2015), who reported a total vertical uncertainty of ±7 cm using the same surveying methodology.

Digital Elevation Model Generation

The bathymetric data collected in this survey were combined with existing data to generate a DEM. Existing data were used to model the topography of the exposed areas of LHT, which we did not map using ground-based survey methods due to dense vegetation (fig. 3*A*). Subaerial elevations in the study area were estimated from topographic aerial light detection and ranging (lidar) data collected in 2007 (California Department of Water Resources, 2007). The lidar dataset required some processing, which included removing returns from the water surface and from vegetation. Vegetative interference was reduced by using the minimum elevation in a 2-m grid space. In addition, existing single-beam bathymetry data from 2009 (Environmental Data Solutions, 2009) were used to estimate the bathymetry of the channels surrounding LHT. The wet/dry line was digitized from an aerial photo (National Oceanic and Atmospheric Administration, 2012). The elevation of the wet/dry line was estimated as the average value measured during the survey at locations along the digitized line. After combining the three point datasets (USGS bathymetry collected in 2015, California Department of Water Resources lidar data from 2007, and Environmental Data Solutions bathymetry from 2009), a triangular irregular network (TIN) was generated within ArcMap 10.2.2, using the digitized shoreline as a breakline, which is a line of continuous data. The TIN was then converted to a 1-m resolution grid.

Measurement of Tidal Stage

A time series of pressure data was collected using a Richard Brancker Research, Ltd. (RBR), RBRduo tide and wave gauge (S/N 51002) from July 21 to November 5, 2014, near the southeast edge of the study region (38.31234° N, −121.65702° E). The pressure sensor was mounted 0.36 m above the bottom, and was submerged throughout the collection period, except for short periods during the lowest 4 percent of tides. The instrument collected bursts of 1,024 readings at 6 hertz (Hz) every 15 minutes. The burst data were averaged to remove the effects of surface-wind waves, producing a mean value every 15 minutes. The pressure readings were corrected for fluctuations in atmospheric pressure and converted to depth, accounting for the instrument height above the bed. Tidally varying water-surface elevation (WSE) was determined by adding the time series of water depth to the bed elevation at the sensor location determined from the DEM.

Results

The bathymetric survey conducted in this study produced a total of 138,407 linear meters of data over an area of approximately 866 hectares (8.66 square kilometers, km^2), collected over the course of 3 days by five USGS personnel (fig. 3*A*, table 2). The overall morphology of the LHT revealed by the survey is characterized by levees surrounding a gently sloping, shallow interior (fig. 3*B*). The elevation of the study area ranges from 13 m along the levees to −9.7 m in the surrounding channels, relative to the NAVD88 datum. The majority of the interior LHT bathymetry is between 0 and 1 m with little variation. Locally deeper areas occur around breaches in the levees, apparent in figure 3*B*. The shallow bathymetry slopes slightly downward toward the east and south, as depicted in figures 5*A*–*C*.

Table 2. Personnel and survey equipment used by the U.S. Geological Survey in the 2015 bathymetric survey of the Little Holland Tract in the Sacramento-San Joaquin River Delta, California.
[GPS, Global Positioning System; PWC, personal watercraft]

Date	Platform	Survey coverage, in meters	Personnel
May 22, 2015	Backpack GPS	22,280	4
June 8, 2015	PWC Sonar	32,012	2
June 19, 2015	Backpack GPS	26,834	4
June 19,2015	PWC Sonar	57,281	2

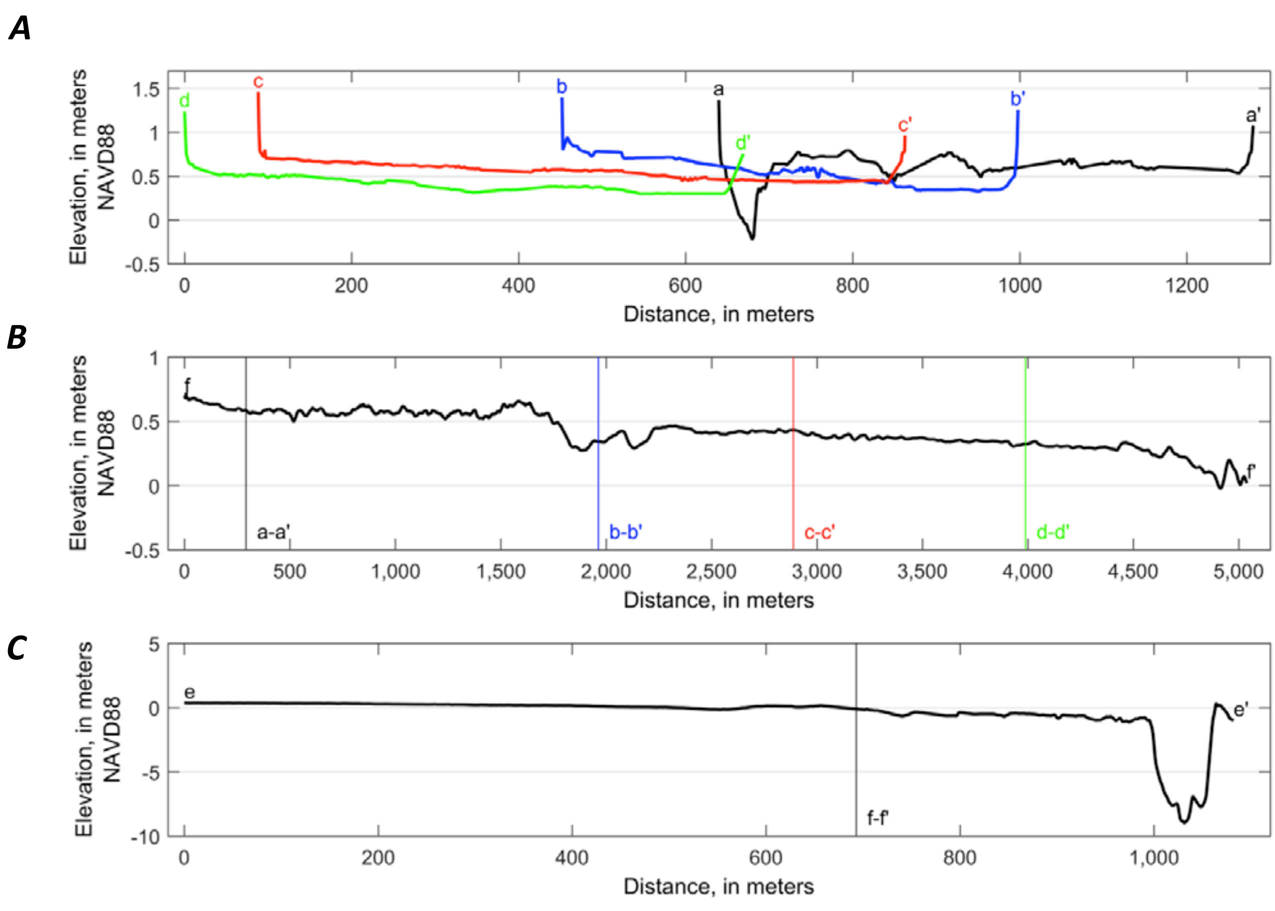


Figure 5. Graphs showing bathymetric profiles of the transects of the Little Holland Tract in the Sacramento-San Joaquin River Delta, California, depicted in figure 3*B*. *A*, Four profiles trending west-east (a-a', b-b', c-c', d-d'); *B*, one profile trending northeast-southwest (f-f'); and *C*, one profile trending north-south (e-e'). Note the relatively low variation in elevation over the submerged part of the study area. NAVD88, North American Vertical Datum of 1988.

Tidal Prism

Tidal-stage data combined with the DEM were used to determine the tidal prism of LHT. The tidal prism is defined as the difference in volume of a tidal body between low and high tide. WSE at the sensor location was assumed to apply to all of LHT, neglecting the small, tidally driven gradient in WSE. Figure 6 displays two sample snap-shots of the distribution of water depth in LHT during low tide and high tide.

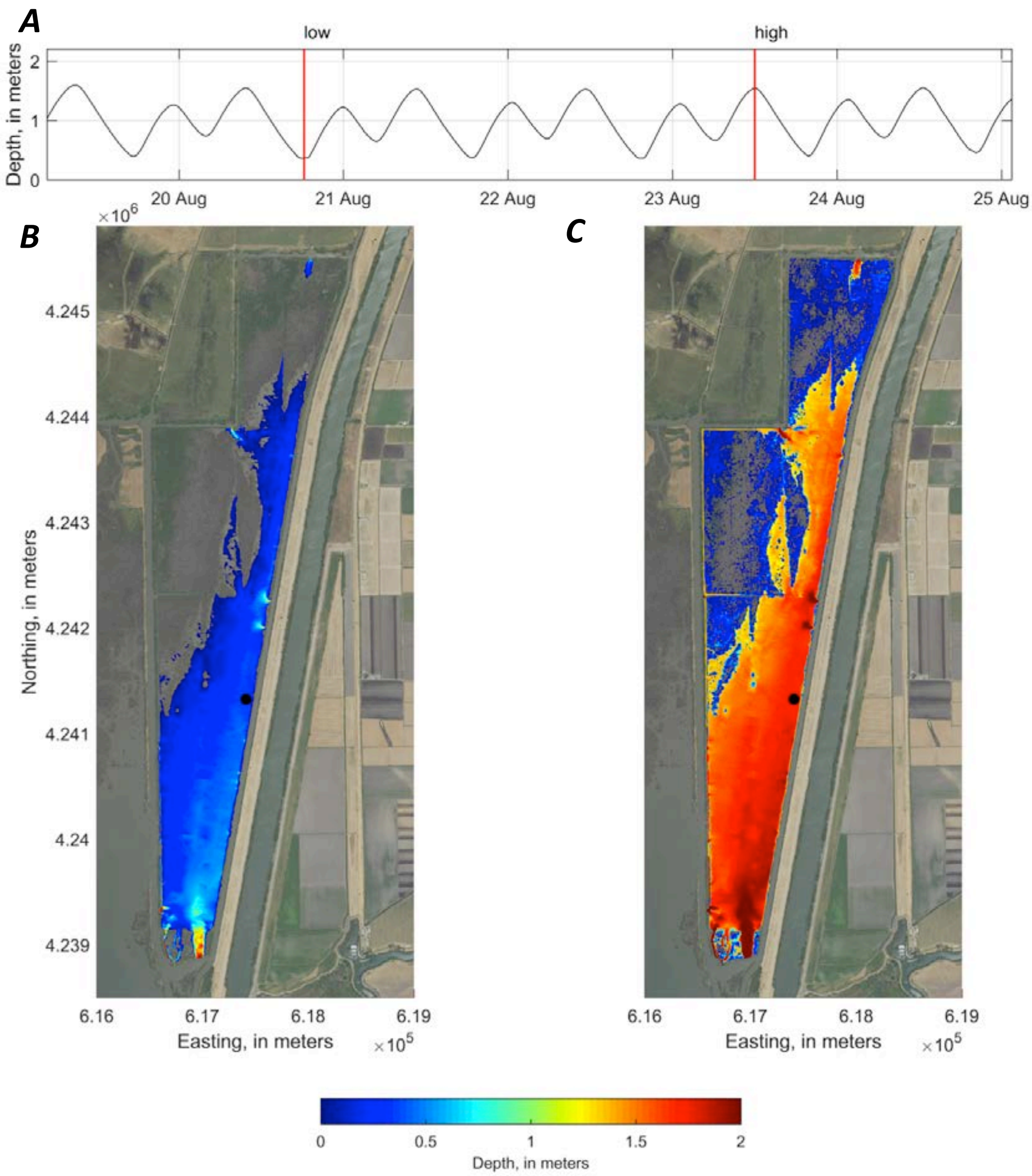


Figure 6. Graph and annotated sattelite images of the Little Holland Tract (LHT), Sacramento-San Joaquin River Delta, California, surveyed by the U.S. Geological Survey in 2015. *A*, Depth of water at the sensor location from August 19 to 25, 2014. *B*, Water depth in LHT at low tide indicated by the vertical red-line labeled “low” in *A*. *C*, Water depth in LHT at high tide indicated by the vertical red-line labeled “high” in *A*. Sensor location indicated by black dot.

The depth of water at each grid cell in the DEM was determined by subtracting the bed elevation for each grid cell from the WSE for each point in time. The result is a map of the distribution of water depth in LHT at the time of each burst of the pressure sensor through the duration of the deployment from July 22 to November 5, 2014. As seen in figure 6, when the depth calculated in this way produced a grid cell with a negative value, indicating that the WSE was lower than the ground elevation, that grid cell was assigned a depth of zero. We developed a time series of the total volume of water in LHT by multiplying the depth of water in each grid cell by the cell area (1 m^2) and summing the volumes for each point in time (fig. 7). High tide and low tide were determined by finding the local minima and maxima of the time series shown in figure 7*B*. The tidal prism is taken as the rising difference, which is the volume of water at high tide minus the volume of water at the previous low tide. The tidal prism changes with each tidal cycle, reflecting the mixed, predominately semidiurnal tides that characterize the San Francisco Bay estuary. The mean tidal prism of LHT is 2,814,000 cubic meters (m^3), the standard deviation is 720,340 m^3, the range is 2,755,800 m^3, and the mean volume is 2,221,000 m^3, based on the period August 13 to November 5, 2014, which spans three 28-day lunar tidal cycles. The mean high-tide volume of LHT is 3,625,300 m^3, and the mean tidal prism represents 78 percent of this volume, indicating that on average more than three quarters of the water in LHT drains into the adjacent channels during the ebb tide. Note that during 4 percent of low tides, the pressure sensor did not remain submerged, resulting in an overestimate of water depth during the lowest tides and a slight underestimate of the tidal prism. Additional data collected in LHT indicate that the volume of water unaccounted for during the lowest of tides is a volume equivalent to 6 percent of the mean tidal prism and 8 percent of the mean volume. From these results we can conclude that the low bias in our estimate of tidal prism is less than 1 percent.

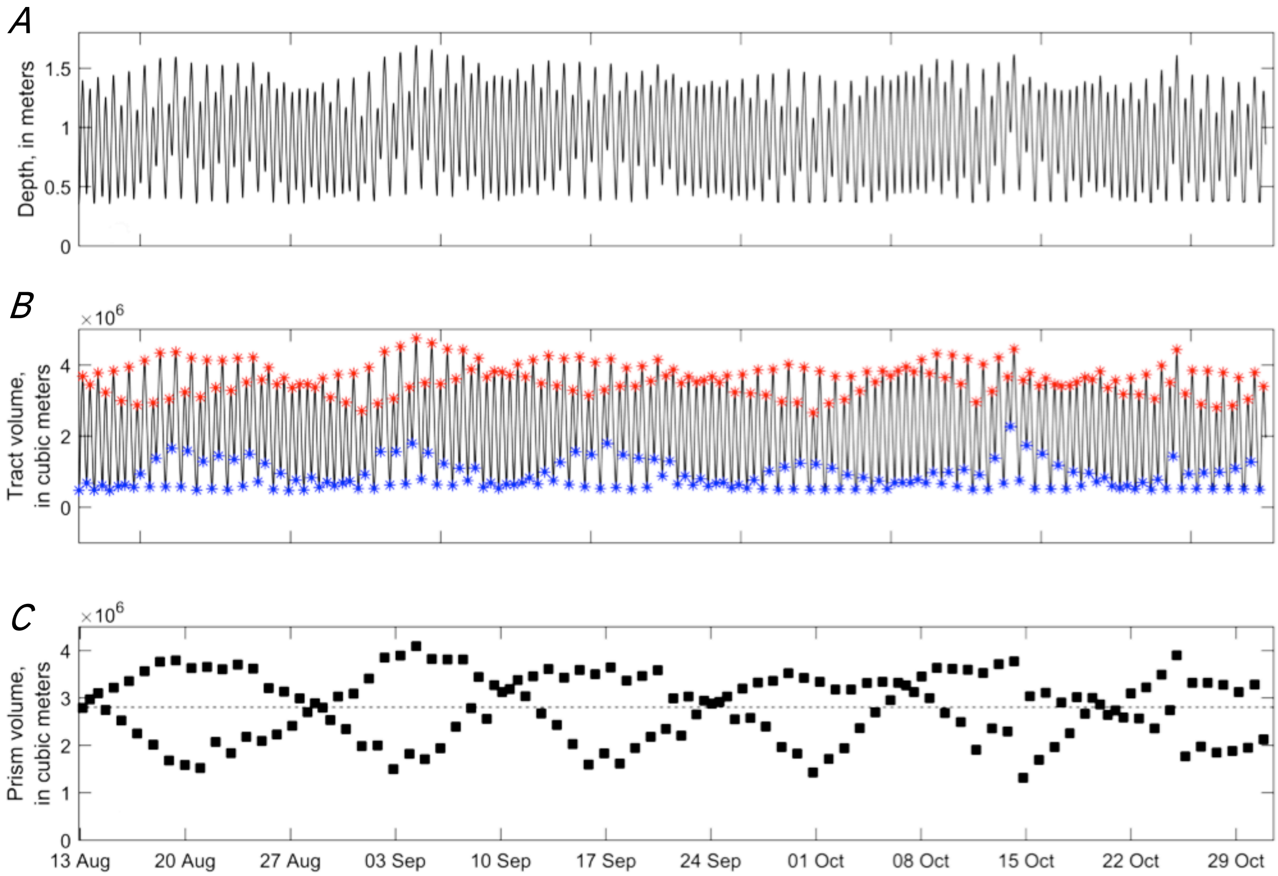


Figure 7. Graphs of time-series data from the Little Holland Tract, Sacramento-San Joaquin River Delta, California, surveyed from August 13 to October 31, 2015, by the U.S. Geological Survey. *A*, Depth of water at sensor; *B*, volume of water in the tract with the red and blue stars indicating high and low tides, respectively; *C*, tidal prism volume for each tide with the horizontal dashed line indicating the mean prism volume.

Conclusions

A bathymetric survey of LHT, a flooded agricultural tract in the northern Sacramento–San Joaquin Delta, was conducted in the summer of 2015. A DEM of the LHT region was developed using both new and existing data. The data and resulting DEM show that the interior of LHT is very shallow and slopes gently down towards the south and east. The deepest area is a shallow channel connected to the largest of several levee breaches, at the southeast corner of LHT. Slight depressions occur adjacent to some of the other breaches, indicating scour. The tidal prism was determined to have a mean of 2,826,000 m^3 and a standard deviation of 720,340 m^3 from the DEM and time-series measurements of water depth. More than three quarters of the water in LHT drains into the adjacent channels during an average ebb tide. This project was conducted to support studies seeking to improve habitat quality in the Delta, and to provide baseline data for monitoring morphologic change. The bathymetric data and DEM are available at http://dx.doi.org/10.5066/F7RX9954.

Acknowledgments

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References Cited

California Department of Water Resources, 2007, 2007 Sacramento-San Joaquin Delta LiDAR Acquisition: Sacramento, California Department of Water Resources database, accessed July, 21, 2015, at https://coast.noaa.gov/dataviewer/index.html?action=advsearch&qType=in&qFld=ID&qVal=2523#/.

Environmental Data Solutions (EDS), 2009, West Delta condition bathymetric surveys—Field data collection procedures: Environmental Data Solutions report prepared for cbec, Inc, p. 1–14.

Gelfenbaum, G., Stevens, A.W., Miller, I., Warrick, J.A., Ogston, A.S., and E. Eidam, 2015, Large-scale dam removal on the Elwha River, Washington, USA—Coastal geomorphic change: Geomorphology, 246, p. 649–668.

International Hydrographic Organization, 2008, IHO standards for hydrographic surveys, 5th ed.: International Hydrographic Bureau, Special Publication No. 44, 36 p.

National Oceanic and Atmospheric Administration, 2012, 2012 NOAA ortho-rectified color mosaic of Sacramento Deep Water Ship Channel, California: Silver Spring, Maryland, National Oceanic and Atmospheric Administration dataset, accessed July, 21, 2015, at https://data.noaa.gov/dataset/2012-noaa-ortho-rectified-color-mosaic-of-sacramento-deep-water-ship-channel-california.

Sommer, T., Armor, C. Baxter, R., Breuer, R., Brown, L., Chotkowski, M., Culberson, S., Feyrer, F., Gingras, M., Herbold, B., Kimmerer, W., Mueller-Solger, A., Nobriga, M., and Souza, K., 2007, The collapse of pelagic fishes in the upper San Francisco Estuary: Fisheries, v. 32, no. 6, p. 270–277.

Rydlund, P.H., Jr., and Densmore, B.K., 2012, Methods of practice and guidelines for using survey-grade global navigation satellite systems (GNSS) to establish vertical datum in the United States Geological Survey: U.S. Geological Survey Techniques and Methods, book 11, chap. D1, 102 p. with appendixes, http://pubs.usgs.gov/tm/11d1/.

Willmott, C.J., 1982, Some comments on the evaluation of model performance: Bulletin of the American Meteorological Society, v. 63, no. 11, p. 1309–1313.

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