Year 10 (2016) Monitoring Report
Petaluma Marsh Expansion Project

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1 Introduction

The Petaluma Marsh Expansion Project (PMEP or Project) is located in the northeastern corner of Marin County and covers approximately 108 acres of former tidal wetlands that were diked in the late 1950s (Figure 1). **The site was breached to tidal action in two locations along San Antonio Creek in December 2006 (south breach) and February 2007 (north breach).** San Antonio Creek is the Marin-Sonoma County line and a tidal tributary of the Petaluma River (Figure 2). The Marin Audubon Society (MAS) is the project sponsor.

As part of permit conditions for the Project, MAS is required to monitor the evolution of the marsh for ten years following construction to track progress toward desired, projected conditions. Required monitoring attributes (PWA and Baye 2003) include hydrology, geomorphology, and vegetation through 10 years after restoration. MAS contracted Siegel Environmental to conduct the Year 10 monitoring event in the summer/fall of 2016. This report documents the methods and results of the Year 10 monitoring effort and assesses Project progress toward meeting performance criteria for Year 10. **This report is the final monitoring report required under Project permits.**

Previous monitoring activities include the following and provide the basis for analysis of site development over time:

1) Baseline and Year 2 Bathymetric Survey of Mud Slough and San Antonio Creek from PMEP Site to the Petaluma River (WWR 2008) – this non-required monitoring was funded by a separate CALFED grant to support assessing how restoration affects geomorphology of source tidal sloughs.
2) Years 1 and 2 Tide and Geomorphic Monitoring (PWA 2011)
3) Year 3 Vegetation Monitoring (WWR 2011)
4) Year 5 Geomorphic Monitoring (WWR 2011)

A note on vertical datums for reporting elevations: the restoration design, benchmarks established for construction and monitoring, and previous monitoring were performed in the

National Geodetic Vertical Datum of 1929 (NGVD29). Though the National Geodetic Survey replaced this datum with the North American Vertical Datum of 1988 (NAVD88), all design, construction, and benchmark elevations were established by the design firm, Philip Williams and Associates (PWA, now Environmental Science Associates or ESA), in the older NGVD29 datum. The Years 1-2 and Year 5 monitoring efforts (PWA 2011, WWR 2011) held to benchmarks established by PWA in the NGVD29 datum for consistency across time. For this Year 10 report, we have converted all past and current data to NAVD88.

2 Summary of Restoration Objectives and Design

Restoration objectives (PWA and Baye 2003):

1) Enhance salt marsh habitat by reintroducing tidal wetland functions to the diked project site
2) Allow the site to evolve naturally towards a mature salt marsh, resulting in the creation of mature marsh habitat suitable for the California clapper rail, California black rail, salt marsh harvest mouse, and other state and federally listed species.

Pre-restoration elevations within the interior of the subsided property were generally 1.0 ft NGVD29 (3.3 ft NAVD88) or lower, which were below salt marsh vegetation colonization elevations. The restoration project adopted the approach of natural sedimentation to restore subsided site elevations to intertidal marsh heights. During the initial 10-year monitoring period, the marsh was expected to colonize with low marsh vegetation as sediment accretes and tidal channels develop. In 50-80 years the marsh vegetation and geomorphology is projected to reach mature tidal salt marsh conditions, given sea level rise and rates of estuarine sedimentation (PWA and Baye 2003).

Restoration elements (PWA and Baye 2003, Figure 3):

1) Breach at two locations along San Antonio Creek, a tidal tributary to the Petaluma River.
2) Lower the perimeter levee to MHHW
3) Excavate starter channels
4) Install ditch blocks in existing drainage ditches
5) Construct a new levee adjacent to the NWPRA (now SMART) railroad embankment
6) Construct a lower-elevation bench on the eastern side of the new levee
7) Construct a seasonal wetland on the west side of the new levee
8) Excavate on-site borrow trenches

9) Install soil mounds
10) On-site mitigation for 3.0 acres of seasonal wetlands
11) Miscellaneous modifications to site drainage
12) Plant intertidal, upland, and seasonal wetland areas

In addition, limited planting took place on January 22, 2008 along about 300 feet of the northern end of the constructed western levee bench (Baye 2008). The purpose of the transplanting was to establish local on-site "borrow" populations of key native species planned to diversify the high marsh ecotone along the bench.

Species planted were:

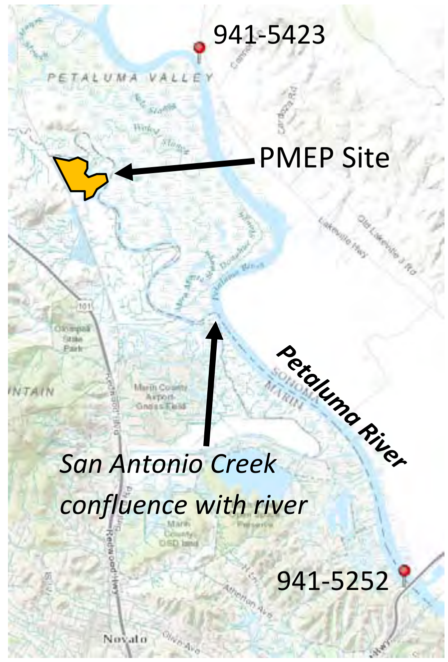
- ***Ambrosia psilostachya***, western ragweed. Source: Sonoma Baylands (spontaneous). Approximately 20 clonal divisions (clumps) and rhizome fragments.
- ***Baccharis douglasii***, marsh baccharis. Source: Sonoma Baylands (spontaneous). 14 bare-root multi-branched and single-stalk plants.
- ***Euthamia occidentalis***, western goldenrod. Source: Sonoma Baylands (spontaneous). 9 clonal divisions (clumps), plus approximately 40 rhizome fragments. Seed of several seed-heads were placed in the high tide line for water dispersal.
- ***Hemizonia congesta* ssp. c*ongesta***, Hayfield tarweed. Source: Carls Marsh levee, Petaluma River mouth. Approximately 80 seedlings, planted on both sides of levee, in 6 clumps.
- ***Leymus triticoides***, creeping wildrye. Source: seed source (wild) near Petaluma Marina at tidal marsh edge, a rare stand producing mostly viable seed. Approximately 40 clonal divisions of at least 20 distinct seedlings (genotypes). Plantings were mostly along the toe of the levee.
- ***Scrophularia californica***, bee-plant (tidal marsh ecotype). Source: Sears Point and Sonoma Baylands bayfront levee. 5 plants.
- ***Symphyotrichum lentum***, marsh (Suisun) aster. Source: Suisun City. 5 clonal divisions of a single genotype were planted in depressions and along the high tide line to determine whether under local high marsh conditions, this species develops the morphological traits of the rare local plant formerly treated as "Aster sonomensis" or "Aster chilensis var. sonomensis", later placed within Symphyotrichum lentum. The single genotype is not expected to produce seed (self-infertile; requires cross-pollination).

<u>Tidal Datums</u>

Table 1 provides the local tidal datums, or elevation of the tides and to which marsh vegetation is closely linked through inundation regime. Though not reported in the design or previous monitoring reports, these data are provided here to allow for utilizing these Year-10 monitoring results regionally. These data are from NOAA[1]. Note that NOAA reports an NAVD88 elevation for the Petaluma River Entrance station and MLLW elevations only for the Lakeville station. These data show that a small increase in tide range (0.36 ft) occurs up the Petaluma River, with the San Antonio Creek confluence being about mid-way between these two NOAA tide stations.

Table 1. Tidal Datums in PMEP Vicinity

	Datum Elevations (ft MLLW)	
Datum	**Petaluma River Entrance (941-5252)**	**Lakeville (941-5423)**
MHHW	6.01	6.37
MHW	5.47	5.88
MSL	3.23	3.44
MTL	3.21	3.38
NGVD29[2]	2.04	NA
MLW	0.94	0.89
MLLW	0.00	0.00
NAVD88	-0.29	NA



3 Performance Criteria

Performance criteria for the Project were established for several hydrologic, geomorphic, and vegetation attributes (PWA & Baye 2003). These criteria are provided below. Performance criteria included times at which they were to be met, and this Year-10 report summarizes performance relative to all the criteria.

1. **Interior Basin Hydrology and Geomorphology**
    a) A dendritic channel layout will develop with at least two 1st-order through sub-tidal 3rd-order channel systems formed by Year 10.

[1] https://www.tidesandcurrents.noaa.gov/stations.html?type=Bench+Mark+Data+Sheets#California
[2] NGVD29 value based on 2011 field surveys that established conversion with NAVD88 elevation of 2.33 ft.

b) Short-circuiting of flow around constructed channel meanders and tributary channel formation will not significantly degrade the sinuosity of the tidal channel network prior to Year 5.

c) Tidal hydrology will have a tidal range in sub basins of 90% of the tidal range of San Antonio Creek by Year 3.

d) Ecologically significant sedimentation (at least three inches averaged over the site) will occur by Year 5.

e) The interior basin will exhibit no net erosion over more than 50% of its area by Year 5.

f) Approximately 1 ft of sedimentation (averaged over the site) will have occurred by Year 10.

2. Constructed Western Levee Hydrology and Geomorphology

a) The sacrificial slope protection berm will not erode by more than 50% (25 ft) by Year 10.

b) No levee sag or sectional deformation shall occur.

c) No vertical land movements (subsidence or heave) will be discerned in the adjacent drainage channel and railway.

3. Interior Basin Vegetation

a) Cordgrass shall expand at a minimum average lateral rate of spread of approximately 1.5 ft/year (15 ft by Year 10).

b) Vegetation cover of cordgrass-bulrush marsh shall reach at least 50% absolute cover in a minimum of two patches, each at least 5 contiguous acres, by Year 10.

c) Overall tidal marsh vegetation of the interior basin below the high tide line (HTL) shall reach at least 25% absolute cover by Year 10.

4. High Marsh and Transitional Area Vegetation

a) The graded perimeter levee shall support native high brackish marsh vegetation of at least 70% absolute cover by the end of Year 5 and over 90% cover by the end of Year 10.

b) The average height of at least 70% of high marsh vegetation shall not differ significantly from corresponding vegetation types at Carl's Marsh or Toy Marsh.

5. Constructed Western Levee Vegetation

a) Survivorship of planted cordgrass shall be at least 70% overall by Year 2, with no more than a 30 ft long section supporting less than 50% survivorship.

b) The area of the levee bench between the HTL and the edge of cordgrass marsh shall support native high brackish marsh vegetation of at least 70% absolute cover by the end of Year 5 and over 90% cover by the end of Year 10.

c) The average height of at least 70% of high marsh vegetation shall not differ significantly from corresponding vegetation types at Carl's Marsh or Toy Marsh.

6. Seasonal Wetlands Vegetation

a) Constructed seasonal wetlands shall not support more than 5% absolute or relative cover by any noxious wetland or terrestrial weeds identified by the vegetation management plan (Baye 2005) or the CA Department of Fish and Wildlife.

b) Constructed seasonal wetlands shall support a prevalence of seasonal wetland vegetation native or typical of the North Bay diked baylands during more than half of monitoring years, and shall not support a prevalence of flooding-intolerant, waterlogging-intolerant terrestrial forbs, shrubs, or graminoid vegetation.

4 Methods

This section describes the methods employed for the aerial photography, geomorphology, hydrology and vegetation monitoring activities in the Year 10 monitoring event.

4.1 Aerial Photograph Acquisition

The geomorphology and vegetation monitoring activities in Year 10 required current aerial photography of the Project site. Natural color and color-infrared (CIR) aerial photographs were acquired on July 6, 2016 by TerrAvion, Inc. of San Leandro, CA (www.terravion.com). The images were collected at low tide when the maximum extent of the marsh surface would be exposed to facilitate geomorphic and vegetation attributes. The aerial images were georectified and delivered in digital GeoTiff format at a 0.8 ft horizontal resolution.

4.2 Geomorphology and Hydrology

Year-10 geomorphic monitoring activities included aerial photograph acquisition and interpretation, topographic surveys of channel, marsh plain, and levee cross sections, sediment plate measurements, and tidal water level monitoring in the marsh interior. The individual data collection and analysis methods are described in detail below. The locations of specific geomorphology monitoring elements are displayed in Figure 4.

4.2.1 Channel Order

The 2016 aerial photographs were used to map the tidal channel networks on the Project site. The channel networks were digitized in ArcGIS 10.3.1 from the natural color photograph, with recent aerial imagery from Google Earth used to corroborate the alignment of the digitized channels. All channel segments were assigned a channel order, utilizing the Strahler Order approach (Strahler 1952, Horton 1945), to assess attainment of the performance criterion for channel network development.

4.2.2 Topographic Surveys

Cross Section Surveys

PWA established 14 topographic cross sections throughout the site to track evolution of site elevations and geomorphology over time. Though the year-10 performance criteria do not specifically require data from these topographic cross sections, the Mitigation and Monitoring Plan (PWA & Baye 2003) recommends that they be surveyed in Year 10. Therefore, a subset of six of the original 14 cross sections were surveyed to assess changes in sediment deposition/scour across the site (Figure 4). A topographic survey of the six cross sections was performed on December 2, 2016. However, this survey was accidentally referenced to an incorrect benchmark. Improvements to the railroad tracks as part of the SMART project resulted in the original PWA benchmarks along the tracks being destroyed. The benchmark used in the December 2nd survey (now BM-5) was a new benchmark set by the railroad in a similar location that matched the description of one of the original PWA marks. This error was not discovered until the data were post-processed.

The re-survey of the cross sections was performed by James Kulpa and Kyle Berger of CLE Engineering (CLE) on February 8, 2017. The cross sections were surveyed using a combination of topographic (land-based) and hydrographic (water based) survey methods. Topographic survey data were collected in upland areas and vegetated areas of the marsh plain. The data were collected using a *Leica Geosystems 1200* real-time kinematic (RTK) Global Positioning System (GPS) survey rover, which was referenced to a *Leica Geosystems 1200* GPS base station set up over local benchmark BM-5, the new benchmark set along the adjacent railroad tracks (Figure 4). CLE established the position and elevation of this mark by static GPS survey during the December 2nd survey (see OPUS report in Appendix A). The survey checked in to local National Geodetic Service (NGS) benchmark JT0774, set in a boulder outcropping on the west side of the railroad tracks, which had been surveyed in all previous monitoring efforts at the Project site. The survey was held to the elevation of JT0774 from the August 18, 2011 survey (9.76 ft NGVD29), which was tied to the original PWA survey control network, to maintain consistency with all prior survey events. Many of the cross section endpoints are marked with PVC poles, thus allowing easy re-occupation of the original transect alignments. The positions of the cross section endpoints were also loaded into the GPS rover to allow point-to-point navigation, and to allow location of un-marked cross section endpoints.

Within open water areas of the site, the cross sections were surveyed using U.S. Army Corps of Engineers Class-1 hydrographic survey methods (USACE 2002). The survey crew utilized a 10-ft Lowe Jon Boat powered by a 10-horsepower outboard specifically constructed for shallow water surveys. Bathymetric data were collected using an *Ohmex SonarMite* survey-grade fathometer with a 4°, 200-kHz transducer. The transducer was mounted on the port side of the vessel utilizing an over-the-side mount and placed with a 0.60-ft draft. Position data were measured and recorded utilizing a *Leica System 1200* RTK-GPS rover mounted directly above the fathometer. The rover positions were referenced to the base station set up over control point BM-5. The GPS elevations were internally corrected for vessel motion and heave for each sonar ping of the transducer, thus providing an accurate seafloor elevation for each ping.

The accuracies of the survey fathometers were checked using two methods: (1) speed of sound profiles and (2) fathometer barcheck calculations. Depth-integrated sound velocity measurements were taken at the start and end of the survey utilizing an *Odom Digi-Bar Pro* speed of sound probe. The sound velocity profile was then programmed directly into the survey control software. The barcheck calibrations consisted of lowering a 36-inch diameter, weighted steel plate below the fathometer transducer and recording the actual depth of the disc (via markings on a cable) and the fathometer nadir output (corrected for the transducer depth offset). The results of the pre- and post-survey bar-check calibration measurements were all within 0.1 ft for each checked depth.

The 2017 topographic and hydrographic survey data were post processed and corrected to hold to BM-5. The data were then plotted against the data from all previous surveys to visually assess changes in site elevations, channel geometries, and areas of sediment erosion and accretion.

Extracting Sedimentation Data from Cross Sections

The topographic data were also used to assess the amount of sediment accretion within depositional areas of the restored tidal basin. Segments of cross sections 5, 6, 9, and 14 (i.e., non-breach sections) that covered marsh plain and mudflat habitats, away from the influence of scour by channels and dominant flow paths, were identified. The average ground elevations within these segments were calculated for the 2007 and 2017 datasets, and then subtracted to determine the overall amount of sediment accretion in each segment over the 10-year period. The weighted average sediment accretion[3] across all segments was then calculated for the site.

Converting NGVD29 Data to NAVD88 Data

The National Geodetic Survey established the North American Vertical Datum of 1988 (NAVD88) to replace the old National Geodetic Vertical Datum of 1929 (NGVD29). PMEP was designed in the early 2000s and constructed in 2006 utilizing elevations referenced to NGVD29. The Years 1-2 and Year 5 monitoring maintained use of the NGVD29 datum in order to maintain consistency with design and construction elevations. Today, all restoration practitioners utilize NAVD88.

For this Year 10 report, we have made the conversion of all past NGVD29 data to NAVD88 and collected new data in NAVD88, so that these data are comparable regionally. To undertake that conversion, we applied the following approach. The 2011 (Year 5) topographic surveys (WWR 2011) employed a static GPS survey of a local control point (CP1) with RTK GPS surveys of multiple previously-established benchmarks at the site. BM2 was selected for use as the reference point for prior survey data, as that benchmark was determined to be the most stable of the available benchmarks at the site. The 2011 GPS survey yielded an NAVD88 elevation for BM2, which was then compared to the PWA-reported elevation for BM2 in NGVD29. The calculated elevation difference applied was "NAVD88 - NGVD29 = 2.33 ft" and has been used here to convert all prior data to NAVD88.

4.2.3 Sediment Plate Measurements

PWA installed two sediment plates prior to levee breaching to measure net sediment accretion throughout the ten-year monitoring period. Both sediment plates are located in the southern extent of the site, one (SP-E) northeast of the south breach within a wide, non-channelized mudflat and the other (SP-W) at the southern reach of the wide western-borrow ditch, adjacent to (directly east of) the constructed western levee (Figure 4). The sediment plates consist of a 12-inch PVC plate mounted to a 36-inch length of rebar to secure the plate to the mudflat and a vertical 3 – 4' tall marker pole set into the center of the plate to visually mark the plate's position after burial. Sediment plate accretion is determined by lowering a measuring stick through the loose sediment to the plate and reading the depth.

Neither of the sediment plates could be recovered during the Year 10 monitoring event, as the marker poles were no longer visible, having either been buried by sedimentation, or broken off/knocked down. To make up for the lack of the sediment plate measurements, spot

[3]Weighted average sediment accretion = $\frac{\sum_1^n(accretion\ x\ segment\ length)}{\sum segment\ lengths}$

measurements of sediment thickness above the original farm field surface were made in the vicinity of SP-W. These measurements were made by lowering a wooden dowel rod through the sediment until the hard-packed field surface was reached, marking the surface of the marsh plain (sediment surface) on the rod, and then measuring the distance from the sediment surface mark to the bottom of the rod with a measuring tape. These measurements were used in combination with the topographic survey data to determine overall sediment accretion on the marsh plain, and changes since previous monitoring events.

4.2.4 Tidal Water Level Monitoring

The performance criterion related to tidal hydrology within the restored wetland was met in Year 2. However, the Mitigation and Monitoring Plan indicates that tidal hydrology should be monitored in Year 10 to document conditions at the end of the monitoring program.

To monitor tidal water levels within the project site, a non-vented *In-Situ Level Troll 500* pressure transducer was deployed at the south channel tide gauge location, established by PWA (Figure 4). As the original stilling well structure was no longer present, the transducer was deployed within a 2” PVC pipe (perforated at the bottom), which was screw-clamped to a 3” galvanized pipe driven ~5 ft into the channel bottom. The transducer was programmed to collect data at 6-minute intervals on-the-hour and deployed from November 18 to December 2, 2016.

Converting non-vented transducer water depth readings to water surface elevation is a three-step process. First, water surface elevations were independently determined on concurrent 6-minute transducer depth reading times at both deployment and retrieval, using RTK GPS equipment (see description of survey methods in Section 4.2.2 above). This step provides “calibration” water surface elevations. Second, raw water depths from the non-vented transducer are corrected for atmospheric pressure using data from an on-site barometer (*Level Troll 500* deployed in the open air), yielding absolute water depth data. Finally, the concurrent water surface elevation calibration data are paired with the absolute water depth data to yield a conversion factor which is then applied to all the absolute water depth data to convert the entire time series data set to water surface elevations.

The water surface elevation time series was then plotted along with the time series from the permanent National Ocean Service (NOS) water level monitoring station at Richmond Oil Pier (Station No. 9414863). The data were visually inspected for signs of tidal muting and were compared to the Year 2 data to assess any visible changes in site hydrology since the site met the performance criterion of full tidal exchange.

4.2.5 Western Levee Structural Condition

To evaluate performance criteria 2a through 2c (Section 3), the structural condition of the constructed western levee was assessed by Dan Gillenwater (environmental scientist) during a site visit on June 15, 2017. The entire length of the western levee was walked and visually inspected for signs of structural deformation, sagging, major cracking or sectioning, and other structural abnormalities that could require additional evaluation by a registered engineer to determine if the levee integrity has been compromised. The inspection was conducted by first walking along the constructed levee bench from south to north to view the marsh-front (eastern) face of the levee, then walking from north to south along the levee crown to evaluate the levee top and western face.

4.2.6 San Antonio Creek Bathymetry and Erosion and Deposition

Though not required as part of project monitoring nor with associated performance criteria, funds from a California Department of Fish and Wildlife Ecosystem Restoration Program grant were obtained and utilized to conduct two bathymetric surveys of San Antonio Creek and Mud Slough, from the railroad bridge downstream to the Petaluma River. One survey was conducted on October 9, 2006, prior to breaching the PMEP site and the second survey was conducted on September 24 and 25, 2008, not quite two years following levee breaching. These surveys utilized Class 1 methods and accuracies as outlined in the U.S. Army Corps of Engineers Hydrographic Surveying Manual (USACE 2002), with data collected from a 17' Boston Whaler. Full methods are provided in WWR (2008). Following completion of these two bathymetric surveys, the survey data were used to develop Digital Elevation Models (DEMs) of each data set with aligned pixel geometry, and these two DEMs were overlaid to determine elevation change. Volumes of erosion and deposition were then calculated as the elevation change multiplied by the area of the DEM pixel.

4.3 Vegetation Monitoring

Vegetation monitoring activities included a combination of aerial photograph interpretation, field vegetation surveys, and fixed-perspective photograph collection. The monitoring activities are described below in detail for the different habitats that were assessed in this effort in support of performance criteria evaluation. Figure 5 presents locations of the various vegetation monitoring elements.

4.3.1 Interior Basin, High Marsh, and Transitional Areas

The bulk of the restored tidal marsh and transitional areas were monitored by aerial photograph interpretation, coupled with ground-truthing field surveys to determine species composition, percent cover, and vegetation height. The July 2016 CIR photograph of the site, collected by TerrAvion, Inc. was the basis for the analysis. TerrAvion used the CIR image to generate a Normalized Difference Vegetation Index (NDVI) layer of the site at the native image resolution of 0.8 ft/pixel. The NDVI provides an indication of the degree of reflectance in the near-infrared and red bands, and can be used to determine areas containing live, green vegetation. The NDVI layer created by TerrAvion contained raw NDVI values and was not classified into vegetated and non-vegetated areas, as this requires calibration to ground conditions at a particular site.

In order to calibrate the NDVI layer to ground conditions so that vegetation cover at the project site could be accurately mapped, and to determine the vegetation composition and percent cover within the restored tidal and transitional habitats, a ground-truthing field survey was conducted. The CIR aerial image and NDVI layer were reviewed to determine areas (polygons) with unique photo and NDVI signatures for ground inspection. A total of 11 polygons were selected for analysis, covering the interior basin, high marsh, and transitional areas (Figure 5). The ground-truthing field visit was conducted on September 21, 2016, and involved identifying all species, percent cover, and average vegetation height within each polygon. The specific measurements were made within three 1-meter quadrats distributed throughout each polygon. A similar survey of vegetation composition, percent cover, and vegetation height was performed within similar habitats at nearby Carl's Marsh, on the Petaluma River, on September 20, 2016. These data were used to assess the vegetation performance criteria related to vegetation height.

The ground-truthing data were used to guide the classification of the NDVI layer into vegetated and non-vegetated areas and a preliminary layer of vegetation cover within the restored tidal marsh habitats was created in ArcGIS 10.3.1. This layer was inspected for areas of obvious misclassification and manually edited accordingly to create the final vegetation cover dataset. This vegetation cover dataset, along with the field data on vegetation composition, cover, and height, were used to analyze vegetation changes over time, and assess progress toward the various vegetation performance requirements.

4.3.2 Constructed Western Levee Bench

To address performance criterion 5b (see Section 3), the vegetation composition along the constructed western levee was assessed on September 21, 2016 along three line-intercept transects that ran perpendicular to the shoreline (Figure 5). The transects began within the cordgrass (*Spartina foliosa*) marsh at the bottom of the levee, and continued westward up the levee to the point where previous road maintenance grading clearly altered the vegetation patterns. The species present and length of coverage along each transect were recorded. A single quadrat was placed within the cordgrass marsh at the eastern end of each transect and the average height of the vegetation within the quadrat was determined. These data were compared to the data from Carl's Marsh (see discussion above) to assess the vegetation performance criterion related to vegetation height. In addition, a general floristic survey was conducted along the western levee bench to record any specific rare species or non-native species of concern that were not captured by the line-intercept surveys. As performance criterion 5b focuses explicitly on vegetation below the high tide line (HTL), the location of this line was field-determined based on the position of the "wrack line" along the levee, which is defined by the US Army Corps of Engineers as a more or less continuous deposit of fine shell or debris on the foreshore or berm, indicating the general height reached by a rising tide. The HTL encompasses spring high tides and other high tides that occur with periodic frequency but does not include storm surges in which there is a departure from the normal or predicted reach of the tide (33 CFR Part 328).

4.3.3 Seasonal Wetlands

The vegetation composition and percent cover within the seasonal wetlands on the west side of the constructed levee was assessed on September 21, 2016 along three line-intercept transects that ran perpendicular to the levee alignment (Figure 5). These transects were continuations of the transects on the east side of the levee, and began at the top of the levee and continued west to the western edge of the seasonal wetland area. The species present and length of coverage along each transect were recorded. In addition, a general floristic survey was conducted within the seasonal wetlands to record any specific rare species or non-native species of concern that were not captured by the line-intercept surveys.

4.3.4 Fixed-Perspective Photography (Photo Benchmarks)

PWA established six fixed-perspective photographic benchmarks (photo benchmarks, or PBMs) prior to breaching to document the surficial evolution of the interior basin and the constructed western levee (Figure 5). PBM 1 and 2 are located directly west of the north and south levee breaches, respectively. PBM 3, 4, and 5 are all stationed along the constructed western levee from south to north, respectively. Finally, a panoramic view of the site is re-photographed from the top of the hill (PMB 6) in the southwest corner of the site. Previous photos have been collected at these PBMs in 2007, 2008, 2009, and 2011. Photographs were taken from these PBMs during the September 21, 2016 field visit. These photographs were compared to photographs from prior monitoring years to assess general changes in vegetation cover and composition, as well as site geomorphology, over time.

4.4 Acid Sulfate Soils on Constructed Levee

Acid sulfate soils can develop when highly sulfidic anoxic bay muds are exposed to the air, oxidizing soil sulfides which produces sulfuric acid (Pons 1972). Acidic soils in turn directly impair the ability for most vegetation to colonize species, resulting in largely unvegetated areas. Over time, the soil acidity declines as the sulfuric acid is diluted and dispersed by rainfall and infiltration and vegetation can begin to colonize, beginning with species tolerant of soil acidity.

This problem occurred at PMEP, from placement of bay mud soils excavated from borrow pits as surface soils on the constructed western levee (Figure 2). The Monitoring Plan did not include any monitoring for the adverse effects of acid sulfate soils impeding vegetation establishment. Soil samples were collected in 2008 and laboratory tested for iron sulfides, pH and sulfate. Monitoring was limited to vegetation species composition as captured in three line transects on the western levee surveyed in 2016, and photographs taken in 2010.

5 Results and Discussion

This section presents the results of the Year 10 geomorphology, hydrology, and vegetation monitoring efforts, and discusses those results relative to the performance criteria for the various monitoring elements.

5.1 Geomorphology

The results of the geomorphology monitoring effort are presented by individual data collection effort.

5.1.1 Channel Network Interpretation from Aerial Photography

The July 6, 2016 natural color aerial photograph is presented in Figure 2, while the tidal channel networks mapped from this image are presented in Figure 6. Dendritic tidal channel networks have developed from both the north and south breaches, with each network containing 1^{st}-order through 3^{rd}- or 4^{th}-order tidal channel systems. There may be a nascent meander cutoff forming in the south area of the site (Figure 6), but more likely the two naturally formed channels are fairly small and shallow compared to the constructed main channel.

These data support achievement of performance criterion 1a of at least two 1st-order through sub-tidal 3rd-order channel systems formed by Year 10 and performance criterion 1c of no significant degradation of channel sinuosity by Year 5.

5.1.2 Tidal Water Level Monitoring

As displayed in Figure 7, the interior of the project site is experiencing full tidal hydrology and there are no indications of tidal muting.

These data support ongoing achievement of performance criterion 1c of tidal range being 90% that of San Antonio Creek.

5.1.3 Topographic Surveys

The topographic cross section plots are presented in Figure 8 through Figure 13. The observations of topographic/geomorphic change are discussed for each individual cross section below.

Cross section 1 covers the south breach of the site (Figure 8). The overall breach geometry has remained relatively stable since 2011; the breach thalweg depth is unchanged and there has been a minor increase in breach width. There has been some minor erosion on the east channel bank, and some minor accretion on the west bank.

Cross section 10 covers the north breach of the site (Figure 12). The breach geometry has remained fairly above about 1 ft NAVD88. Below this elevation there has been a significant change in channel geometry. A ridge has formed in the center of the channel, creating a split in the channel thalweg. This ridge could have formed from sedimentation within the channel bottom, but it's geometry suggests that it is more likely a slump block from the west bank that has become lodged at the bottom of the channel. There has also been some sediment accretion on the west bank (above 4 ft NAVD88). As there was very little change in breach geometry from 2007 to 2011, it is likely that the breach was originally oversized relative to the marsh tidal prism. The reduction in breach cross sectional area has not led to any tidal muting within the site interior (see Section 5.1.2, above).

Cross sections 5 and 6 (Figure 9 and Figure 10) cover the southern channel network and adjacent marsh plain/mudflat areas. Cross section 5, which passes through several meanders of the main southern channel, indicates that there has been a reduction in the cross-sectional area (i.e., shallowing and narrowing) of the main channel in segments furthest from the breach (see channel segments at ~75 and ~200 ft along the cross section). The historic drainage ditch at the west end of the cross section has also experienced significant accretion since 2011. The main channel segment closest to the breach (~450 ft along the cross section) has remained fairly stable over time. The marsh and mudflat areas between the channel segments have experienced variable erosion and accretion since 2011. The most obvious changes are apparent between ~350 and 500 ft along the cross section, where a natural channel-side levee is forming, and a new channel is forming along the west side of the existing soil mound. Cross section 6 also indicates a shallowing of the main southern channel, and a modest amount of sediment accretion on the adjacent marsh plain/mudflats since 2011. The reduction in the cross sectional area of the channel in the upper reaches has not caused any reduction in tidal exchange, or led to tidal muting within the site interior (see Section 5.1.2, above).

Cross section 9 (Figure 11) covers the main northern channel and adjacent marsh plain/mudflat areas. Similar to the observations made on the southern channel, while the channel geometry was relatively stable from 2007 – 2011, there has been a notable reduction in channel cross sectional area since 2011. There has been a modest amount of sedimentation on the marsh plain/mudflat to the east of the channel since 2011.

Cross section 14 (Figure 13) covers the upland and intertidal areas to the west of the project site, including the railroad tracks, historic drainage ditch, and constructed seasonal wetland depression, western levee, and levee bench. The alignment of cross section 14 in 2017 was slightly off from previous monitoring years, so the changes visible in the data should be seen as general, and not exact. The most obvious difference is in the geometry of the railroad berm. Significant work on the railroad has occurred since 2011 for the SMART train, so this change is expected. Other changes to upland features are relatively minor and may be due to the slight variation in the cross section alignment. There has been some sedimentation on the marsh plain/mudflat at the east end of the cross section.

The topographic cross section data were also used to provide an estimate of sediment accretion within depositional reaches of the restored tidal basin between 2007 and 2017 (Table 2). As indicated in Table 2, approximately 1 ft of sediment has accreted in depositional areas of the restored tidal basin since 2007.

Table 2. Sediment Accretion within Depositional Segments of Topographic Cross Sections

Cross Section	XS Segment (ft)	Segment Length (ft)	Avg Elevation (ft NAVD)		Accretion (ft)
			2007	2017	
5	580 - 605	25	2.63	3.79	1.16
6	0 - 55	55	3.29	3.91	0.63
6	105 - 180	75	2.18	2.66	0.48
9	15 - 120	105	3.96	4.45	0.49
9	210 - 375	165	1.57	3.27	1.70
14	300 - 385	85	1.81	2.87	1.06
				Average Accretion	**0.92**
				Average Accretion Weigted by Segment Length	**1.02**

These data support achievement of performance criterion 1d of at least 1 ft average sedimentation by Year 10.

5.1.4 Sediment Plate and Sediment Thickness Measurements

As mentioned in the methods section, neither of the sediment plates could be located in Year 10, so measurements of the thickness of the sediment above the underlying farm field were made in the vicinity of SP-W. Based on these measurements, approximately 3 ft of sediment has accumulated on the marsh plain since the site was breached in 2006. This assessment is not highly accurate as it assumes that the true ground surface at the time of breaching was accurately located.

Table 3 presents the sediment plate data from prior monitoring events. These measurements indicate that by 2011 (Year 5), about 0.8 and 0.9 ft of sediment had accumulated at the east and west sediment plates, respectively. If the sedimentation rate remained the same in the five years since the 2011 monitoring event, about 2 ft of sediment would have accreted since site breaching. The less accurate sediment thickness measurement made in 2016 at the west sediment plate of 3 ft exceeds the projected accretion based on the 2011 accretion rates.

These data support achievement of performance criterion 1d of at least 1 ft average sedimentation by Year 10.

Table 3. Sediment Plate and Sediment Thickness Measurements

Year	Total Sediment Thickness Above Plate[1] or Ground[2] (ft)	
	West	East
2007	0.28	0.11
2009	0.38	0.22
2011	0.89	0.80
2016	3	--
	Sediment Elevation Gain (ft)	
2007 - 2009	0.10	0.11
2009 - 2011	0.51	0.58
2011 – 2016	2	--
2007 - 2011	0.61	0.69
2007 - 2016	2.6	--
	Sedimentation Rate (ft/yr)	
2007 - 2009	0.05	0.06
2009 - 2011	0.25	0.29
2011 – 2016	0.4	--
2007 - 2011	0.30	0.34
2007 - 2016	0.3	--

Notes:

1) *Sediment plates were measured in 2007, 2009 and 2011*
2) *Sediment thickness was measured in 2016, as sediment plates were not recoverable*

5.1.5 Western Levee Condition

No potential indictors of levee structural failure or compromise, requiring additional evaluation by a registered engineer, were observed during the June 14, 2017 site visit. No erosion of the sacrificial slope protection berm greater than 25ft was observed during the June 14, 2017 site visit. Vertical land movement in the adjacent drainage channel and railway are no longer applicable, due to reconstruction of the rail line for the new SMART commuter train. There were no instances of discernible levee deformation, erosion, sagging, major surface cracking, or sectioning along the length of the levee. The notable surface cracking observed at the north end of the levee in 2009 (not observed in 2011) was not apparent in the June 2017 site visit. Some minor surface cracking was observed in a few locations, but these small cracks did not appear to pose a threat to levee integrity. The levee was very heavily vegetated at the time of the site visit, so the extent of the minor surface cracking could not be evaluated. Photographs of the levee and bench conditions at the time of the June 2017 site visit are presented in Appendix E.

The only observation made during the site visit that may warrant follow-up in future years was a small seasonal wetland depression that has formed along the eastern levee toe near the north end of the levee. There is no record of this depression being observed in prior years, but that does not mean that it is a new feature. The depression was isolated from the wetlands along the restored tidal marsh fringe and was saturated (but no standing water) at the time of the site visit on June 14, 2017. The ground surface elevation at the toe of the levee in this general area is ~7-8 ft NAVD88, so it is possible that the ground surface may have become saturated by the high tides earlier in the week of the site visit. As indicated above, there were no signs of levee sag, slumping, or other potential structural problems in the area of this wetland depression.

These data support achievement of performance criteria 2a of sacrificial slope berm protection erosion no more than 50% (25 feet) by Year 10 and 2b no levee sag or sectional deformation. Note that performance criterion 2c, no vertical land movements (subsidence or heave) in the adjacent drainage channel and railway, is no longer applicable due to reconstruction of the rail line by the new SMART commuter rail.

5.1.6 San Antonio Creek Bathymetric Change 2006 to 2008

The expansion of tidal prism in San Antonio Creek as a result of the several hundred acre-feet of water that would flood and drain the PMEP site after restoration twice each day has the potential to enlarge San Antonio Creek to accommodate the larger flows. In addition, restoration also has the potential to reduce flows upstream of levee breaches due to the restoration site capturing flows. Such a phenomenon has been observed at other restoration projects in the region, perhaps most well documented at Warms Springs restoration in the far South Bay.

The baseline and Year-2 bathymetric surveys funded by the CALFED Ecosystem Restoration Program were intended to provide insight into these processes and provide additional restoration site data to complement knowledge gained from other projects.

These data showed erosion of about 69,000 cubic yards, deposition of about 35,000 cubic yards, and yielded a net erosion of about 34,000 cubic yards of channel sediment. The spatial distribution of this erosion and deposition is shown on the maps in Appendix B. In general, the lower reaches of San Antonio Creek exhibited a greater degree of sediment dynamics, with areas of scour and deposition of 2 to 3 feet with even more scour in some locations. In contrast, the upper reaches of San Antonio Creek and including Mud Slough, both upstream of the South Breach, exhibited lesser magnitudes of scour and deposition and overall more depositional areas than scour areas. These findings are consistent with expectations and compare well to other restoration areas where such monitoring has taken place.

5.2 Vegetation

The results of the vegetation monitoring efforts are presented by habitat/site feature type. The raw vegetation monitoring data are provided in Appendix C. The fixed-perspective photographs from 2008 to 2016 are provided in Appendix D.

5.2.1 Interior Basin Percent Cover from Aerial Photograph Interpretation

The July 2016 CIR aerial photograph of the project site and the derived NDVI dataset are presented in Figure 15. The final vegetation cover dataset for the restored tidal habitats, below the HTL, is presented in Figure 16. As indicated in Figure 16, 23.05 ac (24.6%) of the restored tidal areas below the HTL are covered with brackish marsh vegetation. The fixed-perspective photographs from September 2016 (Appendix D) corroborate the vegetation cover mapping results.

These data support achievement of performance criterion 3c of 25% absolute cover below HTL by Year 10.

The 2009 and 2016 vegetation cover datasets are overlaid in Figure 17. This figure provides measurements of lateral cordgrass expansion between 2009 and 2016 in several representative areas around the site perimeter. Cordgrass has generally expanded between 15 and 30 ft in the seven years since the 2009 monitoring event, thus exceeding the performance criterion of 15 ft of total lateral expansion by Year 10. However, the performance criterion requiring two ≥ 5-ac patches of cordgrass marsh with ≥ 50% cover by Year 10 has not been achieved. Figure 18 displays the four major cordgrass marsh patches within the interior basin, the largest of which is only 3.41 ac. The 5-ac area could be met at the two largest patches, if the patches were expanded to include adjacent cordgrass marsh along the perimeter levee, but that may not be an appropriate delineation method for this performance criterion.

These data support achievement of performance criterion 3a of 15 feet of lateral cordgrass spread by Year 10.

These data do not support achievement of performance criterion 3b of 50% absolute cover in a minimum of two 5-acre patches by Year 10.

5.2.2 High Marsh and Transitional Areas

Table 4 presents the vegetation composition and percent cover data within ground-truth polygons 9-11, which fall within the high marsh on the graded perimeter levee, while Table 5 presents the average vegetation height data for these polygons along with the data from Carl's Marsh. These polygons were located within areas representative of the various vegetation cover and density signatures present throughout this habitat feature. The vegetation within the high marsh is dominated by native species, and the vegetation height is similar to (*Bolboschoenus maritimus*) or greatly exceeds (*Salicornia pacifica*) the height of the same species in similar habitats at Carl's Marsh, indicating similar or greater vegetation vigor and satisfying the performance criteria for species composition and height. While the vegetation cover dataset, derived from aerial photograph interpretation, indicates >90% cover within the high marsh on the graded perimeter levee, at the ground-level the average vegetative cover is 69%. The fixed-perspective photographs taken of the lowered levee at PBM 2 indicate almost complete (>90%) wetland vegetation cover in this area.

These data support achievement of performance criterion 4a of 90% cover by Year 10.

These data support achievement of performance criterion 4b of average height at least 70% that of Carl's Marsh or Toy Marsh by Year 10.

Table 4. Graded Perimeter Levee Vegetation Composition and Percent Cover

Species[1]	Percent Cover									
	Polygon 9			Polygon 10			Polygon 11			Average
	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	
Bolboschoenus maritimus	0	0	--	15	10	20	15	2	35	12
Salicornia pacifica	95	96	--	40	55	50	25	85	0	56
Distichlis spicata	3	0	--	0	0	0	0	0	0	<1
Bare ground	2	4	--	45	35	30	60	13	65	31
Average Total Cover - Native Wetland Species:										**69**

[1] *All species are native*

Table 5. Average Vegetation Height on Graded Perimeter Levee and Similar Habitats at Carl's Marsh

Species[1]	Average Height (cm) PMEP Marsh	Average Height (cm) Carl's Marsh	PMEP Veg Height as % of Carl's Veg Height
Bolboschoenus maritimus	107	111	96%
Salicornia pacifica	63	39	162%

[1] *All species are native*

5.2.3 Constructed Western Levee Bench – Wetland Vegetation

Table 6 presents a summary of the vegetation cover data from the line-intercept transects along the constructed western levee bench, between the edge of cordgrass marsh and the HTL, while Table 7 presents the average vegetation height data from these transects along with the data from Carl's Marsh in similar habitats. As indicated in Table 6, the performance criterion for a minimum of 90% cover by native high marsh vegetation is met and exceeded. Also, the average vegetation height is similar to (*B. maritimus and S. foliosa*) or greatly exceeds (*S. pacifica*) the height of the same species in similar habitats at Carl's Marsh, indicating similar or greater vegetation vigor and satisfying the performance criteria for vegetation height. The floristic survey within the tidal portions of the western levee did not identify any specific rare species, or non-native species of concern.

These data support achievement of performance criterion 5b of 90% cover by Year 10.

These data support achievement of performance criterion 5c of average height at least 70% that of Carl's Marsh or Toy Marsh.

Performance criterion 5a, planted cordgrass survivorship, was not evaluated because no cordgrass was planted.

Table 6. Summary Line-Intercept Transect Data – Western Levee Bench Below HTL

Species	Wetland/ Upland*	Native	Total Linear Cover (ft)	% Total Cover
Atriplex prostrata	W	No	3	0.2
Bolboschoenes maritimus	W	Yes	100	5.3
Salicornia pacifica	W	Yes	1,652	87.2
Spartina foliosa	W	Yes	90	4.7
Bare	NA	NA	50	2.6
		Total Cover	**1,895**	**100.0**
Total Cover, Native Brackish Wetland Species			**1,842**	**97.2**

**W = wetland (FAC, FACW, OBL status); U = upland (FACU, UPL status)*

Table 7. Average Vegetation Height on Western Levee Bench and Similar Habitats at Carl's Marsh

Species	Average Height (cm) PMEP Marsh	Average Height (cm) Carl's Marsh	PMEP Veg Height as % of Carl's Veg Height
Bolboschoenus maritimus	107	111	96%
Salicornia pacifica	54	39	139%
Spartina foliosa	100	96	104%

5.2.4 Constructed Western Levee – Transitional and Upland Vegetation

Above the high tide line, the development of acid sulfate soils from oxidized sulfidic bay muds excavated from the nearby borrow pits and used to construct the western levee resulted in impairment to vegetation colonization. This same impairment occurred to a lesser extent in the lower elevation slope of the western levee that received tidal inundation, as the tidal action mitigated the acidic soils. MAS has reported that it had difficulty with plant survivorship in these areas.

The Monitoring Plan did not include monitoring of the constructed western levee above the high tide line. Consequently, quantitative data for these areas over the course of the 10-year monitoring period consist of one topographic cross section surveyed in 2007, 2009, 2011, and 2016 (Figure 13) and three vegetation line transects surveyed on September 21, 2016 (Tables C-4 and C-5 in Appendix C). Photographs of the north and south end of the constructed levee were taken in 2010 (Appendix F). In 2008, soil samples were collected and composited into a single sample. Lab results found a pH level of 3.1, which is very acidic, and extremely elevated sulfate levels of 12,300 mg/kg.

Vegetation in 2010 was absent at the southern end of the constructed levee above the tidal marsh and was moderately vegetation at the northern end (Appendix F). The 2010 monitoring report stated that the majority of the western levee bench was unvegetated with small patches of brass buttons (*Cotula coronopifolia*) and sand spurrey seedlings (*Spergularia* spp.). Some areas had been planted with creeping wild rye (*Elymus triticoides*) along with some California sagebrush (*Artemisa california*) and coyote bush (*Baccharis pilularis*). Wild radish seedlings (*Raphanus sativus*) were also present in sparse amounts.

Vegetation in 2016 was more diverse than in 2010. Bare ground was still present, at 13% to 15% on the east side of the levee and 0% to 17% on the west side of the levee. The east side was slightly dominated by non-native species (49% non-native vs. 37% native), whereas the west side was almost entirely non-native species (91%). One of the more common species was sand spurrey, which varied from 12% to 38% cover on the east side. Identification was not definitive but believed to be the non-native *S.* rubra, which is tolerant of relatively acidic soils (Calflora 2017).

5.2.5 Seasonal Wetlands

Table 8 presents a summary of the vegetation cover data from the line-intercept transects within the seasonal wetlands on the west side of the constructed levee. The seasonal wetland area was dominated primarily by upland species (facultative-upland [FACU], or upland [UPL] indicator status), with very little wetland vegetation (facultative [FAC], facultative-wet [FACW], or obligate wetland [OBL] indicator status). Specific vegetation observed in the seasonal wetland area was primarily non-native grasses such as Italian ryegrass (*Festuca perenne*), ripgut brome (*Bromus diandrus*), and annual fescue (*Festuca myuros*). Within the seasonal wetland and dominating up the western side of the levee were non-native herbaceous forbs such as cultivated radish (*Raphanus sativa*), black mustard (*Brassica nigra*), and Italian thistle (*Carduus pycnocephalus*).

In the January 2010 monitoring of the seasonal wetland area, a good portion of cover was brass buttons (*Cotula coronopifolia*), a species with an “obligate wetland” status. No evidence of this species was observed in the 2016 monitoring. Although the time of year of the 2016 monitoring was not the best for targeting this species, the general condition of the area indicated that the intervening years of drought between the monitoring events had shifted the community to a more upland composition. There were scattered patches of pickleweed, which is an obligate wetland species, but the majority of cover was weedy, non-native upland species and there was not the evidence of extended inundation that was observed in 2010. The seasonal wetland performance criteria state that “the wetland basin should support a prevalence of seasonal wetland vegetation… during more than half of monitoring years, and shall not support a prevalence of flooding-intolerant, waterlogging-intolerant terrestrial forbs, shrubs, or graminoid vegetation”. This criterion has not been met, as conditions in 2016 (Year 10) failed to meet these standards, and there have been only two vegetation monitoring events at the site. However, the intense, prolonged drought that occurred between the 2011 and 2016 monitoring likely contributed to the evolution of the plant community towards dominance by upland species. Therefore, the Year 10 monitoring year can be seen as having “atypical” conditions. With return of normal (or above normal) rainfall, wetland conditions may return.

These data do not support achievement of performance criterion 6b of supporting a prevalence of native or typical North Bay diked baylands seasonal wetland vegetation and not supporting flooding- and water logging-intolerant species.

Table 8. Summary Line-Intercept Transect Data - Seasonal Wetlands

Species	Wetland/ Upland*	Native	Total Linear Cover (ft)	% Total Cover
Atriplex prostrata	W	No	10	0.2
Brasica nigra	U	No	450	10.1
Carduus pycnocephalus	U	No	30	0.7
Festuca myuros	U	No	430	9.7
Foeniculum vulgaris	U	No	66	1.5
Non-native grasses & *Brassica sp.*	U	No	870	19.6
Raphanus sativa	U	No	1,860	41.8
Raphanus sativa & nonnative annual grasses	U	No	360	8.1
Salicornia pacifica	W	Yes	110	2.5
Spergularia sp. (CF S. rubra)	W	No	20	0.4
Bare	NA	NA	239	5.4
		Total Cover	**4,445**	**100.0**
		Total Cover, Native Wetland Species	**140**	**<1.0**

**W = wetland (FAC, FACW, OBL status); U = upland (FACU, UPL status)*

Two of the upland weeds found within the seasonal wetland area, radish and fennel (*Foeniculum vulgare*), are prioritized for control in the project vegetation management plan (Baye 2005). These two species together account for over 50% of the vegetative cover within the seasonal wetlands and adjacent habitats. One of the criterion for the constructed seasonal wetlands is that they “…shall not support more than 5% absolute or relative cover by any noxious wetland or terrestrial weeds identified by the vegetation management plan (Baye 2003)…”. The seasonal wetlands have not met this criterion. The prolonged drought and conversion of this area to uplands has allowed for invasion of the former wetland habitats with upland noxious weeds. It is likely that these weeds will become less prevalent with a return to normal hydrologic (i.e., rainfall) conditions.

These data do not support achievement of performance criterion 6a of not more than 5% cover by noxious wetland or terrestrial weeds.

The floristic survey within the seasonal wetland and upland portions of the western levee identified a small amount of Australian saltbush (*Atriplex semibaccata;* Cal-IPC ranking = moderate) on the levee top, and small populations of yellow star thistle (*Centaurea solstitialis;* Cal-IPC ranking = high) and stinkwort (*Dittrichia graveolens;* Cal-IPC ranking = moderate) at the extreme north end of the levee. These occurrences were very limited in scope and were located outside of the seasonal wetland basin. Marin Audubon Society has been doing manual removal of the stinkwort, which appears to have been very successful as only a few individual plants were observed in this far northern area. It is notable that there were no observed occurrences of French broom (*Genista monspessulana*) on the west side of the levee in 2016. This species was prominent during the Year 3 monitoring event (WWR 2010). Control efforts for this species appear to have been successful.

6 Restoration Performance Evaluation

This section summarizes the results of the Year 10 monitoring effort relative to the project performance criteria, and provides recommendations for long-term management actions at the end of the monitoring program. Table 9 provides a summary of the project performance relative to the performance criteria.

Table 9. Summary of Project Performance Criteria Attainment at Year 10

Performance Criterion		Year-10 Assessment
Hydrology and Geomorphology – Interior Basin		
1a	A dendritic channel layout will develop with at least two 1st-order through sub-tidal 3rd-order channel systems formed by Year 10	**Achieved.** Dendritic tidal channel networks with 1st through 3rd order channels have formed from both the north and south breaches. See Figure 6.
1b	Short-circuiting of flow around constructed channel meanders and tributary channel formation will not significantly degrade the sinuosity of the tidal channel network prior to Year 5.	**Achieved.** Constructed channel sinuosity had been retained at Year 5. By Year 10, two small channels had formed at either side of a meander bend near the south breach and joined. These channels appear very small compared to the large constructed channel and even if they do ultimately enlarge, they should not significantly alter any marsh functions. See Figure 6.

Performance Criterion		Year-10 Assessment
1c	Tidal hydrology will have a tidal range in sub basins of 90% of the tidal range of San Antonio Creek by Year 3.	**Achieved.** Tides measured in 2007 (Year 2) should high tides in the site interior matching those of San Antonio Creek, and low tides not dropping as low, by 1-3 feet. By 2016, interior tides exhibited the full rise and fall of the tidal cycle. See Figure 7.
1d	Ecologically significant sedimentation (at least three inches [0.25 ft] averaged over the site) will occur by Year 5.	**Achieved.** More than 0.25 ft of sedimentation had occurred by Year 5 from the cross section data, 0.8-0.9 ft by Year 5 from the sediment plate data. See Figure 8 to Figure 13, Table 2, Table 3.
1e	The interior basin will exhibit no net erosion over more than 50% of its area by Year 5.	**Achieved.** Analysis of the topographic cross section data show that in general the marsh plain is predominantly depositional and areas of elevation loss are not widespread or large in magnitude. See Figure 8 to Figure 13.
1f	Approximately 1ft of sedimentation (averaged over the site) will have occurred by Year 10.	**Achieved**. Spot measurements of sediment accumulation in the vicinity of SP-W (3 ft by Year 10), analysis of past sedimentation trends at the sediment plates through Year 5, and analysis of topographic cross section data within depositional areas of the restored tidal basin (average of 1 ft by Year 10) all indicate at least 1 ft of sediment deposition has occurred by Year 10. See Figure 8 to Figure 13, Table 2, Table 3.
Hydrology and Geomorphology – Constructed Western Levee		
2a	The western levee sacrificial slope protection berm will not erode by more than 50% (25 ft) by Year 10.	**Achieved.** No major signs of erosion were observed in the 2017 site inspection
2b	No levee sag or sectional deformation shall occur along the western levee	**Achieved.** No levee sag or sectional deformation was observed in the June 2017 site visit.
2c	No vertical land movements (subsidence or heave) will be discerned in the adjacent drainage channel and railway.	**No longer applicable.** Reconstruction of the rail line for the new SMART commuter train altered these areas.
Vegetation – Interior Basin		
3a	Cordgrass shall expand within the interior basin at a minimum average lateral rate of spread of approximately 1.5 ft/year (15 ft by Year 10).	**Achieved.** Over 15 lateral feet of cordgrass expansion has been observed around almost the entire marsh perimeter since site breaching. See Figure 17.
3b	Vegetation cover of cordgrass-bulrush marsh shall reach at least 50% absolute cover in a minimum of two patches, each at least 5 contiguous acres, by Year 10.	**Not Achieved**. Several contiguous patches of cordgrass marsh have formed within the interior tidal basin, but the largest of these is 3.41 ac. However, lack of achievement is not deemed an adverse outcome. The site has extensive cordgrass-bulrush marsh forming and the fact that the large patches are not quite 5 acres in size in no manner diminishes the ecological functions nor indicates a problematic trajectory of marsh establishment. See Figure 18.
3c	Overall tidal marsh vegetation of the interior basin below the HTL shall reach at least 25% absolute cover by Year 10.	**Achieved**. The total cover of tidal marsh vegetation within the interior basin is 24.6%. Rounded to the nearest whole-percent, this is 25% cover. See Figure 16.
Vegetation – High Marsh and Transitional Area		
4a	The graded perimeter levee shall support over 90% cover by native	**Likely Achieved.** The graded perimeter levee is dominated by native high brackish marsh vegetation. The percent cover appears to be ≥ 90% based on aerial photo and ground photo interpretation. However, the

Performance Criterion		Year-10 Assessment
	high brackish marsh vegetation by the end of Year 10.	ground-truthing data within this area indicates that the percent cover is approximately 69%.
4b	The average height of at least 70% of high marsh vegetation shall not differ significantly from corresponding vegetation types at Carl's Marsh or Toy Marsh	**Achieved.** Vegetation height at the project site is similar to (within 5%), or substantially greater than the height of vegetation at Carl's Marsh, indicating similar or greater vegetation vigor. See Table 5.
Vegetation – Constructed Western Levee		
5a	Survivorship of planted cordgrass shall be at least 70% overall by Year 2, with no more than a 30 ft long section supporting less than 50% survivorship.	**Not Applicable.** MAS did not plant cordgrass as part of the project.
5b	The area of the levee bench between the HTL and the edge of cordgrass marsh shall support at least 90% absolute cover by native high brackish marsh vegetation by the end of Year 10.	**Achieved.** The levee bench between the HTL and edge of cordgrass is dominated by native brackish marsh vegetation with > 90% cover.
5c	The average height of at least 70% of high marsh vegetation shall not differ significantly from corresponding vegetation types at Carl's Marsh or Toy Marsh.	**Achieved.** Vegetation height at the project site is similar to (within 5%), or substantially greater than the height of vegetation at Carl's Marsh, indicating similar or greater vegetation vigor. See Table 7.
Vegetation – Seasonal Wetlands		
6a	Constructed seasonal wetlands shall not support more than 5% absolute or relative cover by any noxious wetland or terrestrial weeds identified by the vegetation management plan (Baye 2003) or the CA Department of Fish and Wildlife.	**Not Achieved.** Two noxious upland weeds identified for priority control in the vegetation management plan (fennel and radish) make up more than 50% of the vegetative cover within the seasonal wetlands at Year 10. This invasion of upland weeds is likely due to the conversion of the seasonal wetlands to uplands during the prolonged drought since the last monitoring event (see discussion below). See Table 8.
6b	Constructed seasonal wetlands shall support a prevalence of seasonal wetland vegetation native or typical of the North Bay diked baylands during more than half of monitoring years, and shall not support a prevalence of flooding-intolerant, waterlogging-intolerant terrestrial forbs, shrubs, or graminoid vegetation.	**Not Achieved.** The seasonal wetland area was dominated by non-native upland vegetation in Year 10. As there was only one other monitoring event, in 2009 (where wetland vegetation was dominant), the >1/2 of monitoring years criteria is not reached. However, the years between the 2009 and 2016 monitoring event were marked by intense drought, resulting in atypical conditions. With return of normal (or above normal) rainfall, wetland conditions may return.

7 Recommendations

The following recommendations address lessons learned regarding monitoring strategies, performance criteria, and restoration design and construction.

7.1 Monitoring Strategies

- Sediment plate marker poles, 3 to 4 ft in height, were no longer visible in year 10, either due to burial, knock-down, or removal by unknown entities. If sediment plates are used in the future, taller and more sturdy marker poles would be recommended at a minimum. An alternative low-cost monitoring strategy is sedimentation pins, which can be simple 2-inch PVC pipe installed very firmly into the pre-breach substrate and tall enough to account for accretion to high marsh elevations and allowing for long-term sea level rise.
- Elevation benchmark installations:
    - When planning locations to install benchmarks, consider possible future land surface changes that may affect benchmark integrity. In this case, the new SMART rail line reconstruction destroyed several benchmarks.
    - Install benchmarks with deep-seated benchmark rods using standard NGS methodology. This approach greatly improves the stability of benchmarks, which in turn allows them to provide long-term vertical control which can be readily verified with periodic static GPS surveys.

7.2 Performance Criteria

- For the most part, the established performance criteria served assessment well. The primary criterion that did not yield an effective assessment finding was Performance Criterion 3b, which required two cordgrass-bulrush marsh patches at least 5 acres in size. The two largest patches were 3.41 ac and 2.04 ac. What is clearly evident at the site is that cordgrass-bulrush marsh is establishing around the perimeter levee on the accreting marsh plain, and directly on the accreting marsh plain, both desirable outcomes supporting achievement of the underlying project goals and objectives. Perhaps an alternative approach to such a performance criterion focuses on developing cordgrass-bulrush marsh both along the perimeter levee (the “edge of the bowl”) and independently colonizing and expanding on the accreting marsh plain, de-emphasizing a hard acreage number.

7.3 Recommendations Related to Restoration Design and Construction

- Always use current vertical datums in design and construction. At present and since the early 1990s, that is NAVD88. NGS is planning a new datum in 2022. In this case, tremendous analytical resources had to be expended to resolve conversions between the outdated NGVD29 and the current NAVD88. Had the original design and construction been done using the NAVD88 as was standard at the time, none of these problems would have arisen.

- Stating the intended purpose of restoration elements in the restoration plan should always be included, so that outcomes assessments such as this report can examine the extent to which the design basis achieved its intended results. Such information is very helpful in informing future restoration designs.
- The vegetation data indicate that the soil mounds placed between the meander bends of the constructed channels were effective in promoting marsh vegetation establishment in the marsh interior. Variations on features like these should be incorporated into projects where possible to promote emergent marsh establishment.
- Acid sulfate soils developed on the constructed western levee due to reuse of highly sulfidic bay mud soils excavated from nearby deep soil borrow areas. Audubon had difficulty with plant colonization and survivorship in these areas. Future restoration projects should effectively segregate soils taken from the surface vs. from depth in borrow pits and ensure that high-sulfide deeper bay mud borrow soils are not placed on the surface where they can impede vegetation community establishment.

8 Report Preparers

The following entities prepared this report:

- Stuart Siegel, Siegel Environmental – overall monitoring and reporting
- Dan Gillenwater, Siegel Environmental – hydrology and geomorphology monitoring, GIS analysis, reporting
- Diana Benner, The Watershed Nursery – vegetation monitoring, reporting
- CLE Engineering – topographic and bathymetric surveys

Peter Baye also provided insight regarding vegetation and soils conditions incorporated into this report.

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Pons. L.J. 1972. Outline of genesis, characteristics, classification, and improvement of acid sulfate soils. Pp. 3-27 in H. Dost, ed., *Acid Sulfate Soils – Proceedings of the International Symposium on Acid Sulfate Soils, 13-20 August 1972, Wageningen, The Netherlands.* Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. Available at http://library.wur.nl/WebQuery/wurpubs/fulltext/183771#page=15.

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______. 2012. Year 5 Geomorphic Monitoring Report, Petaluma Marsh Expansion Project. Prepared for Marin Audubon Society.

Figures

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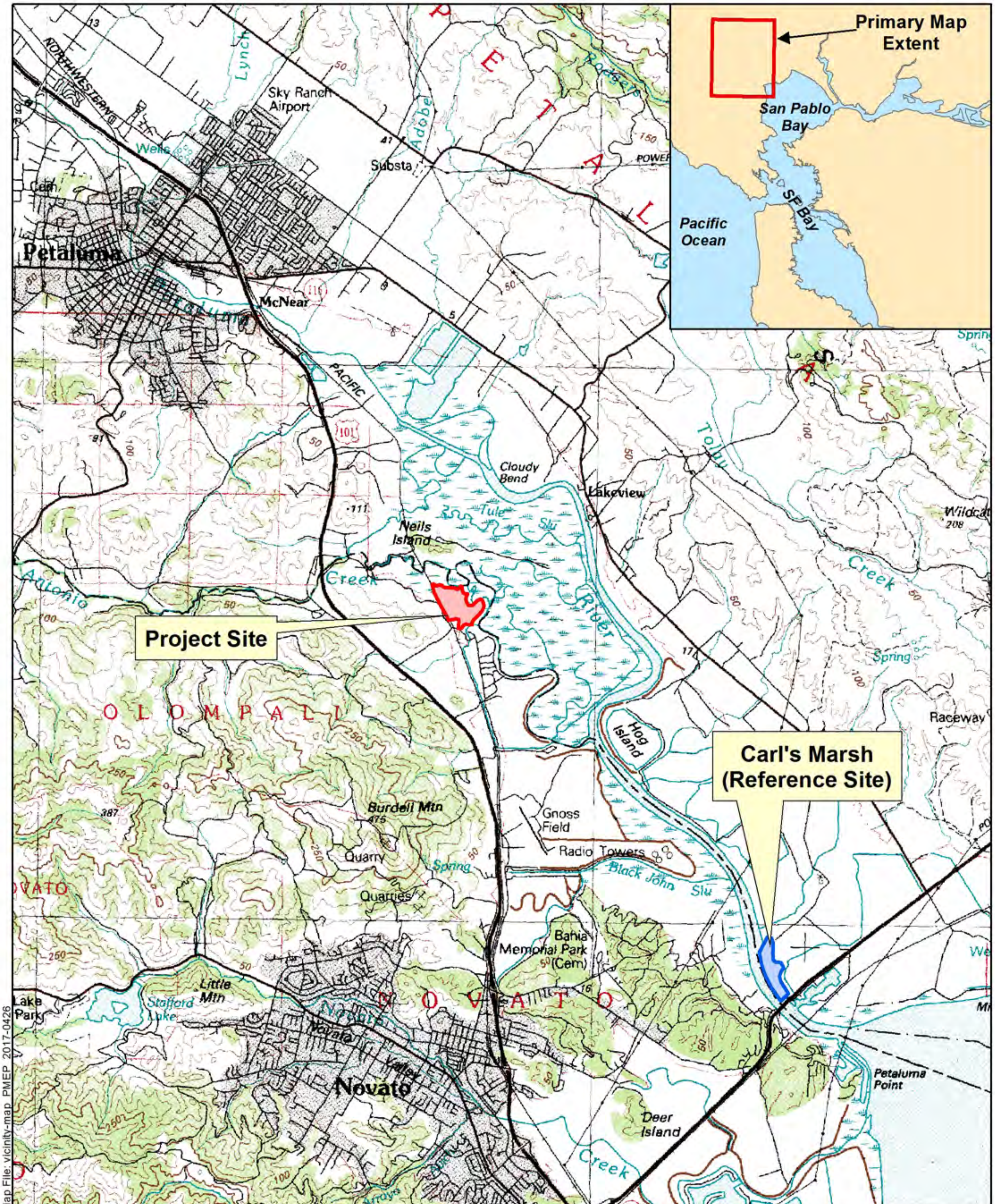


Data sources: basemap (USGS)

Petaluma Marsh Expansion

1:95,040 (1" = 1.5 mi at letter size)

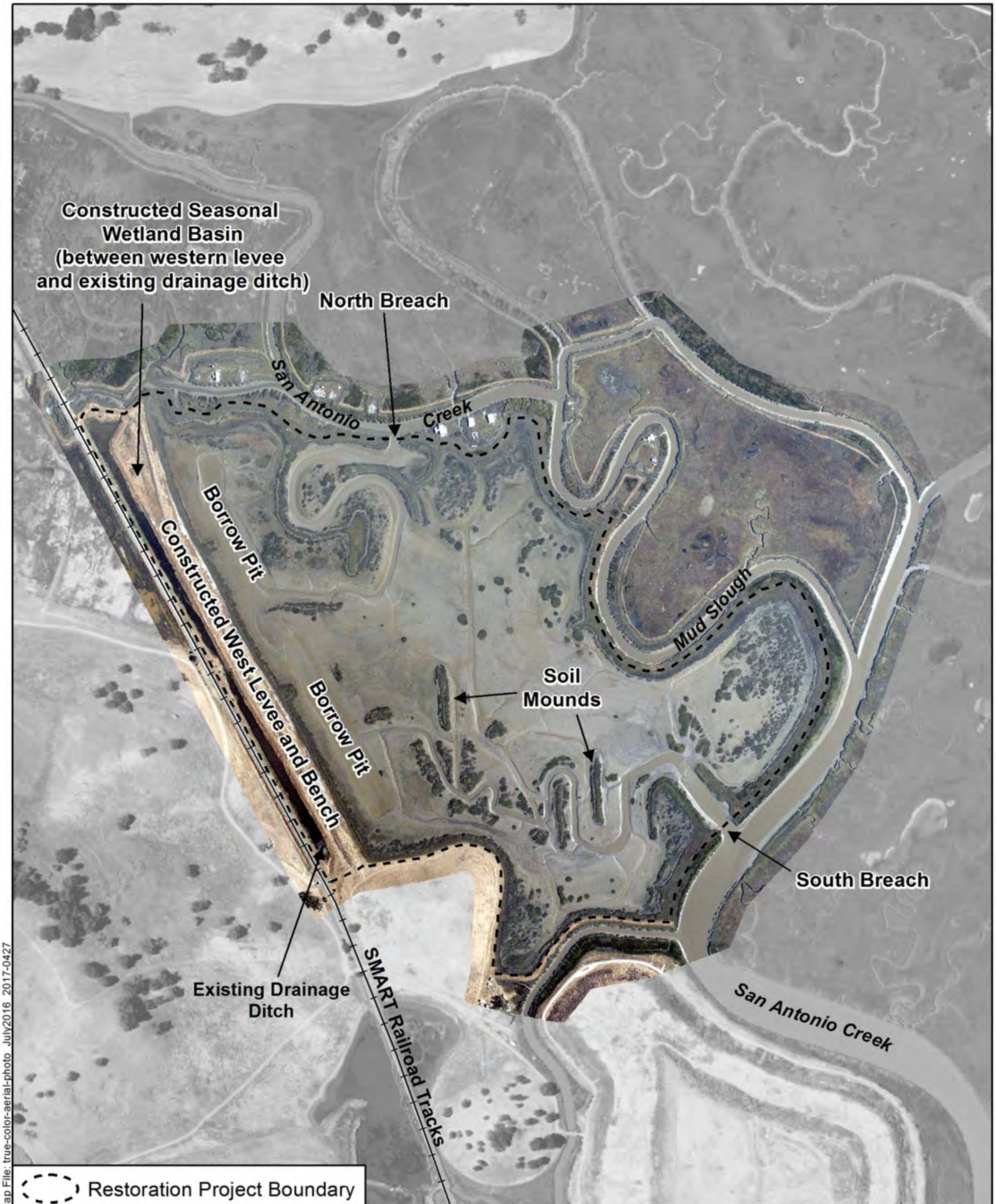
0 0.75 1.5 Miles

0 1 2 Kilometers

SIEGEL ENVIRONMENTAL

Figure 1

Project Vicinity



Map File: true-color-aerial-photo July2016 2017-0427

Data sources: air photo (Terravion, 2016); background photo (NAIP, 2012)

Petaluma Marsh Expansion

1:7,200 (1" = 600' at letter size)

0 300 600 ft

0 100 200 m

SIEGEL ENVIRONMENTAL

Figure 2

July 6, 2016 Color Aerial Photograph with Site Features

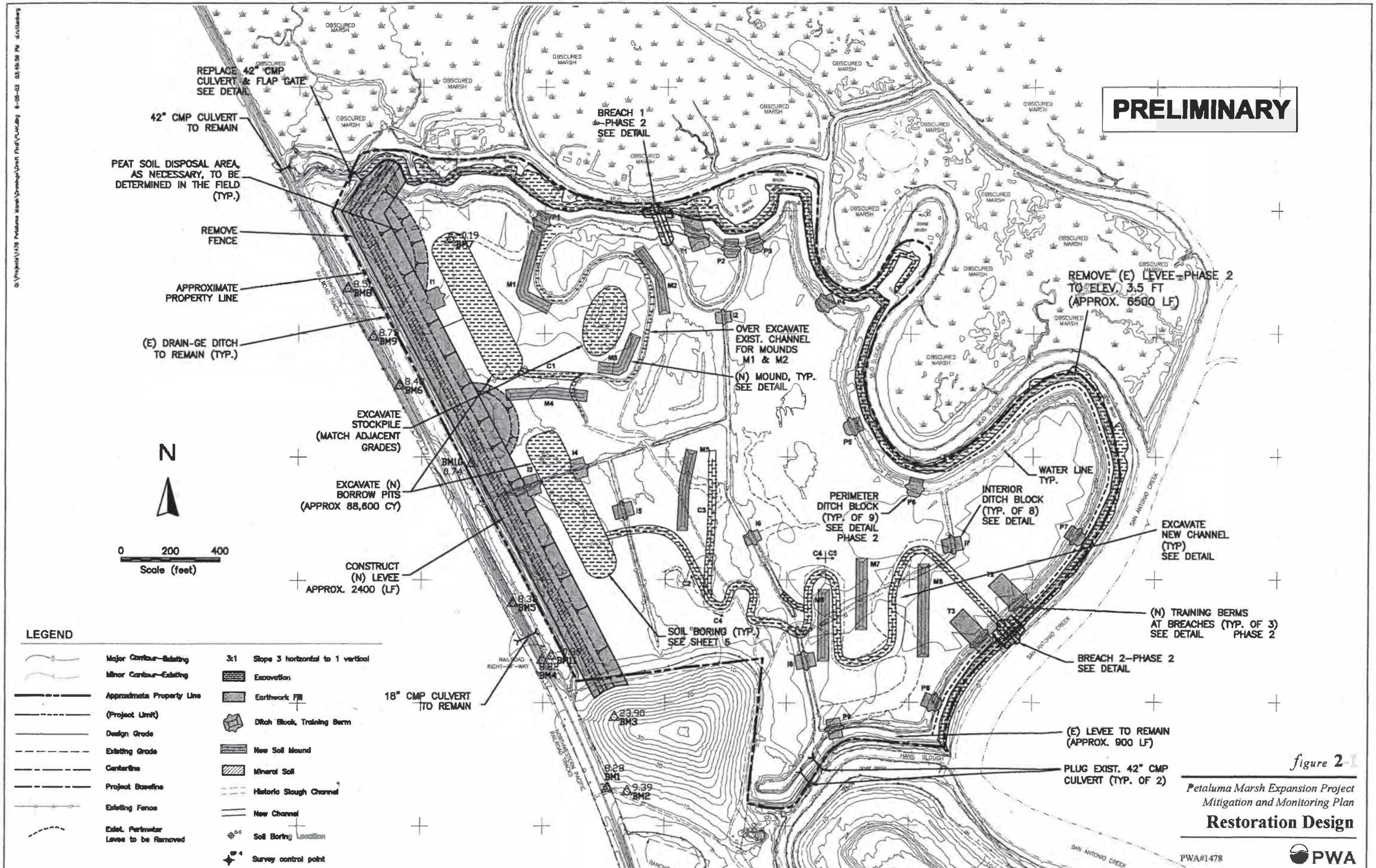


figure **2-1**

Petaluma Marsh Expansion Project Mitigation and Monitoring Plan

Restoration Design

Source: PWA 2003

Map File: physical-monitoring-elements_PMEP_2017-0427

Data sources: air photo (Terravion, 2016); monitoring elements (SE, 2016)

1:6,000 (1" = 500' at letter size)

0 250 500 ft

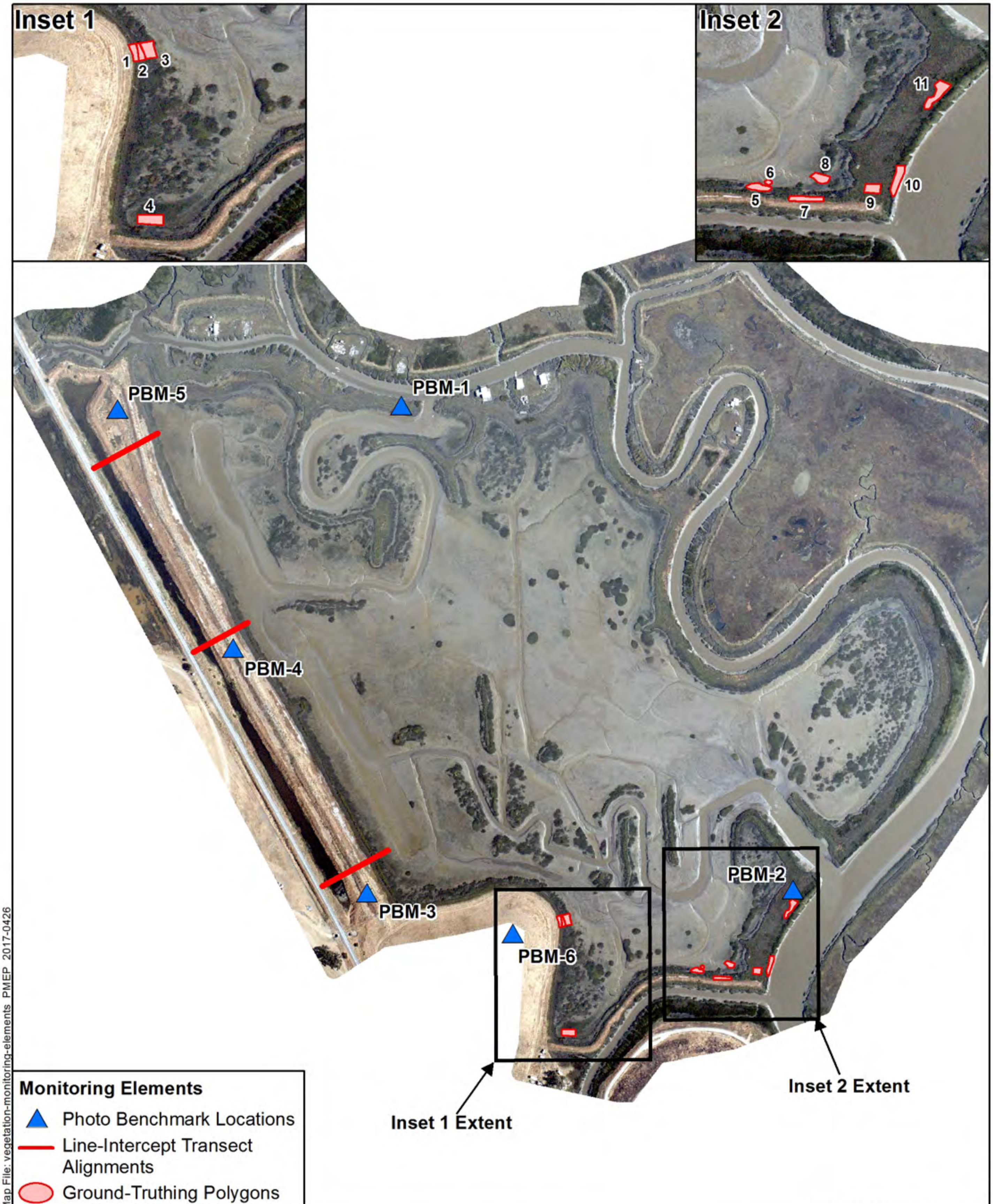
0 75 150 m

SIEGEL ENVIRONMENTAL

Petaluma Marsh Expansion

Figure 4

Year 10 Hydrology and Geomorphology Monitoring Elements



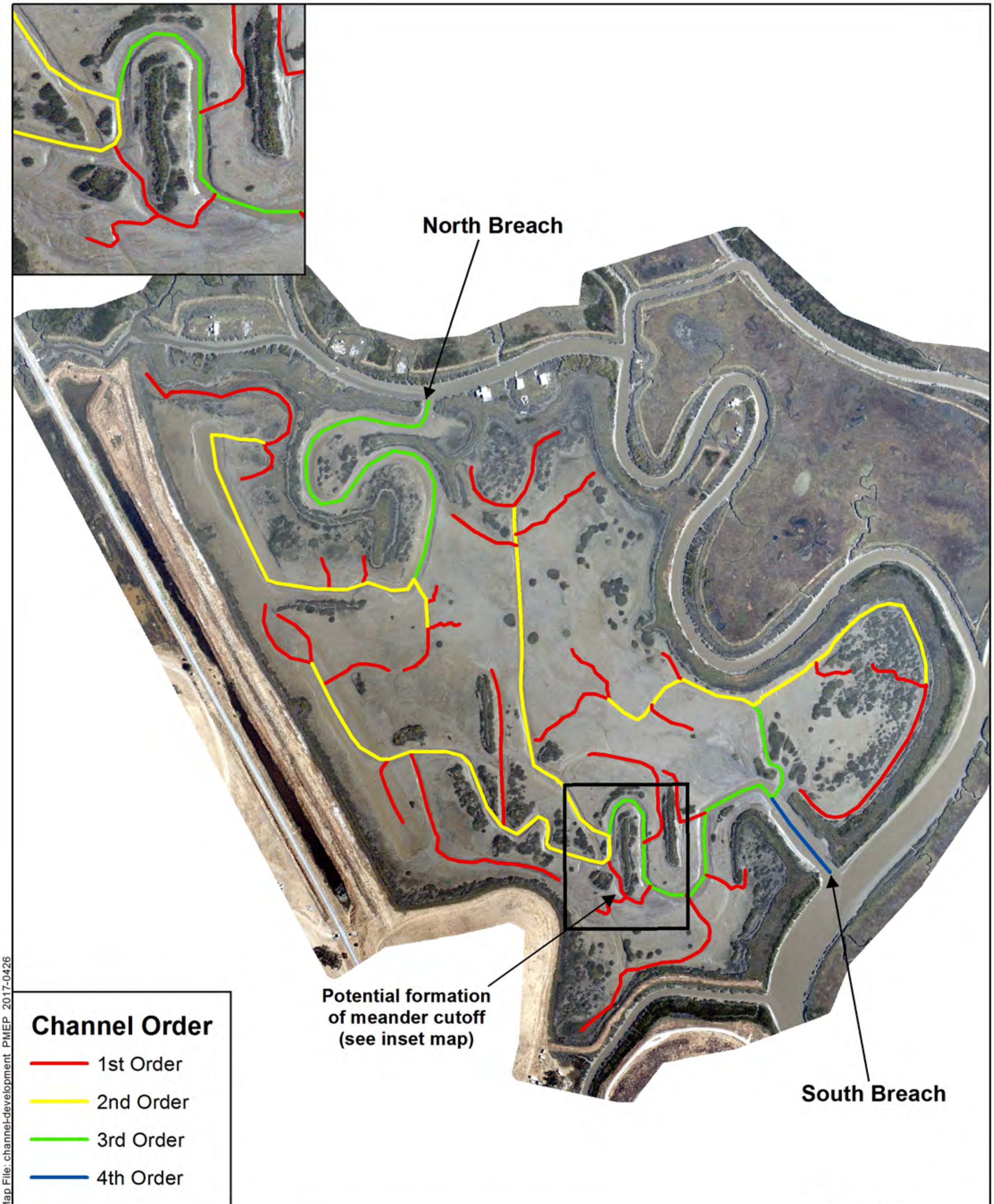
Data sources: air photo (Terravion, 2016); monitoring elements (SE, 2016)

SIEGEL ENVIRONMENTAL

Petaluma Marsh Expansion

Figure 5

Year 10 Vegetation Monitoring Elements



Data sources: air photo (Terravion, 2016); channels (SE, 2017)

Petaluma Marsh Expansion

1:6,000 (1" = 500' at letter size)

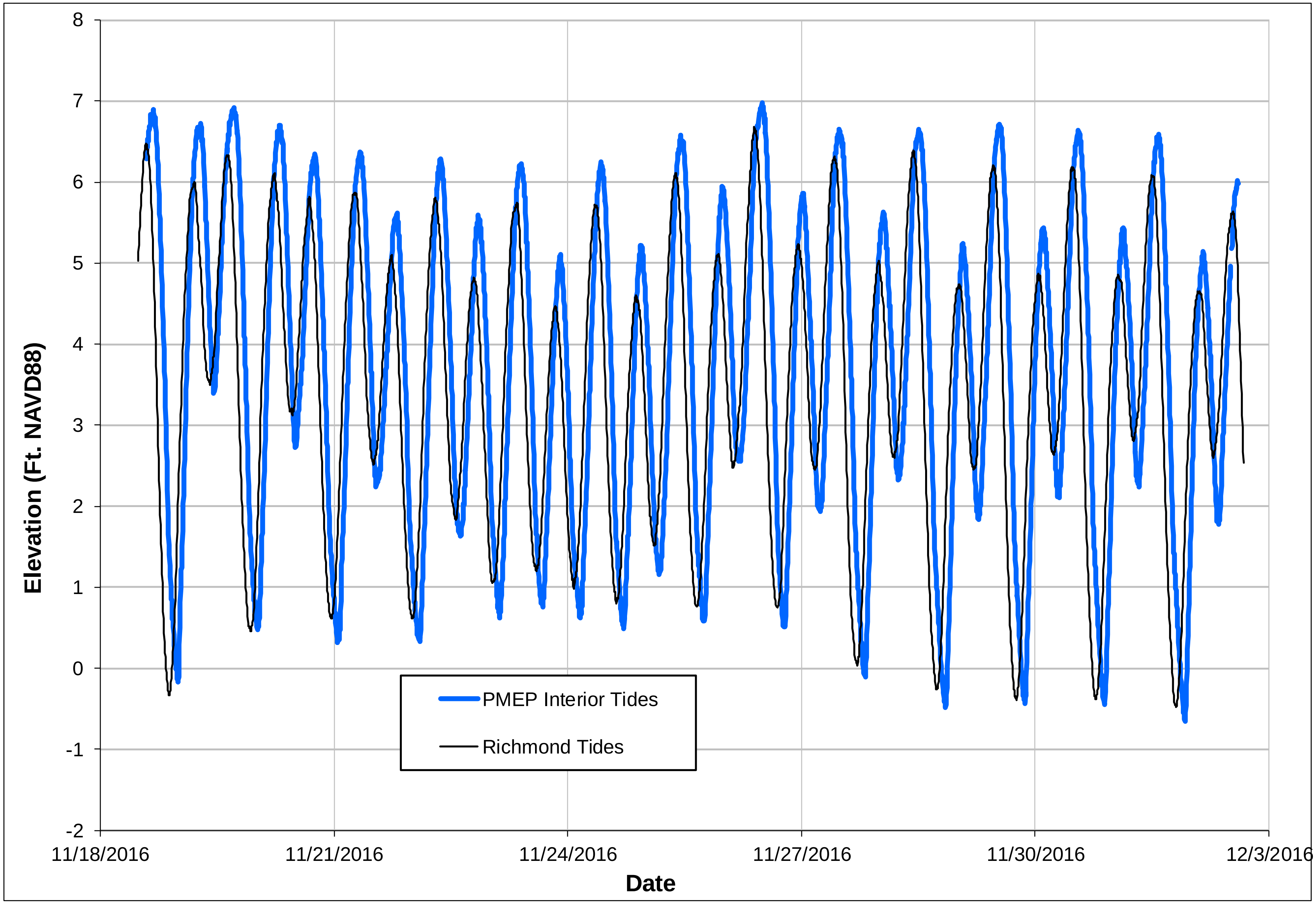
0 250 500 ft

0 75 150 m

Siegel Environmental

Figure 6

Channel Network Development, 2016



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

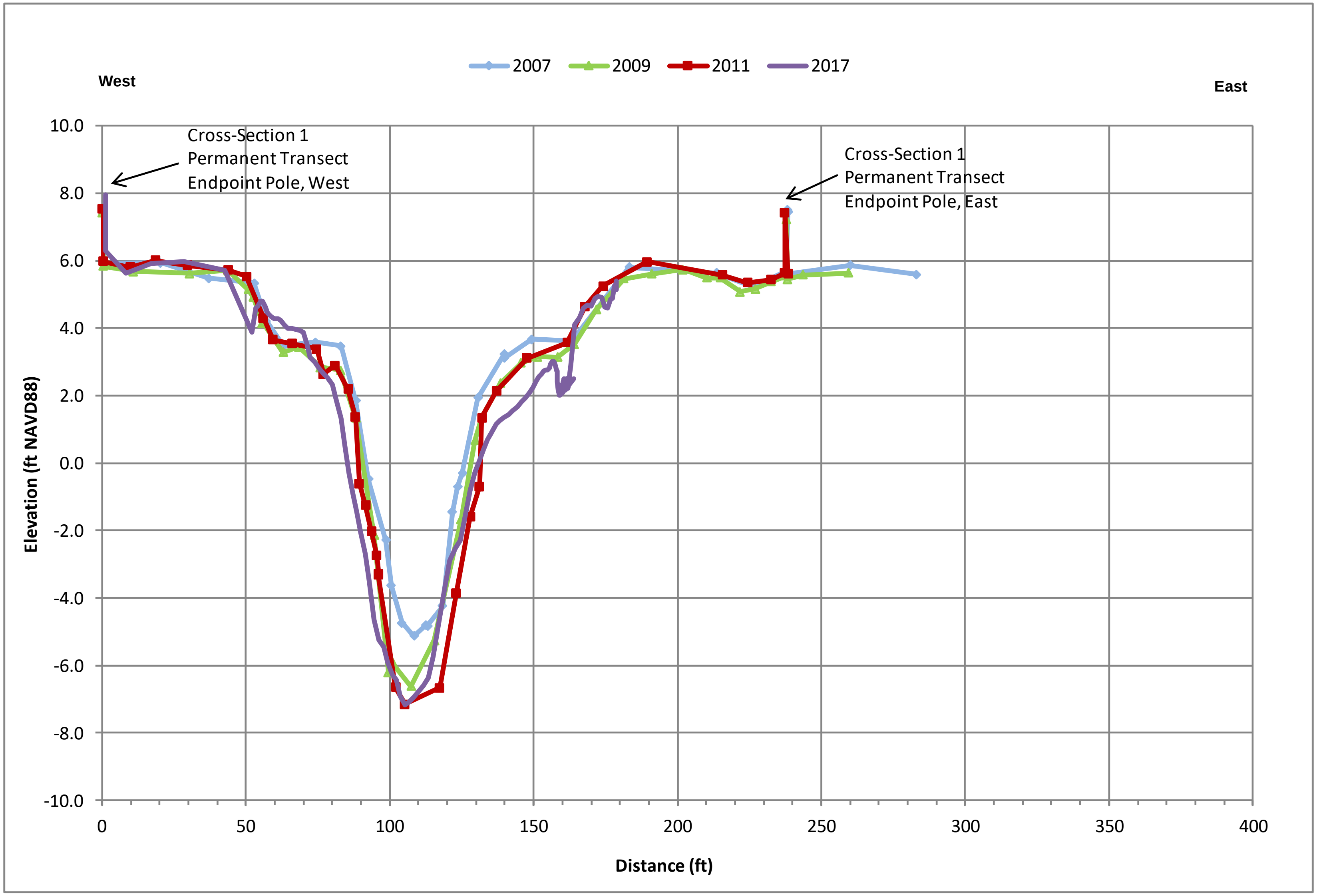
Data Source: PMEP tides (SE, 2016); Richmond tides (NOS, 2016)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 7

Tidal Water Levels, November 18 – December 2, 2017



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

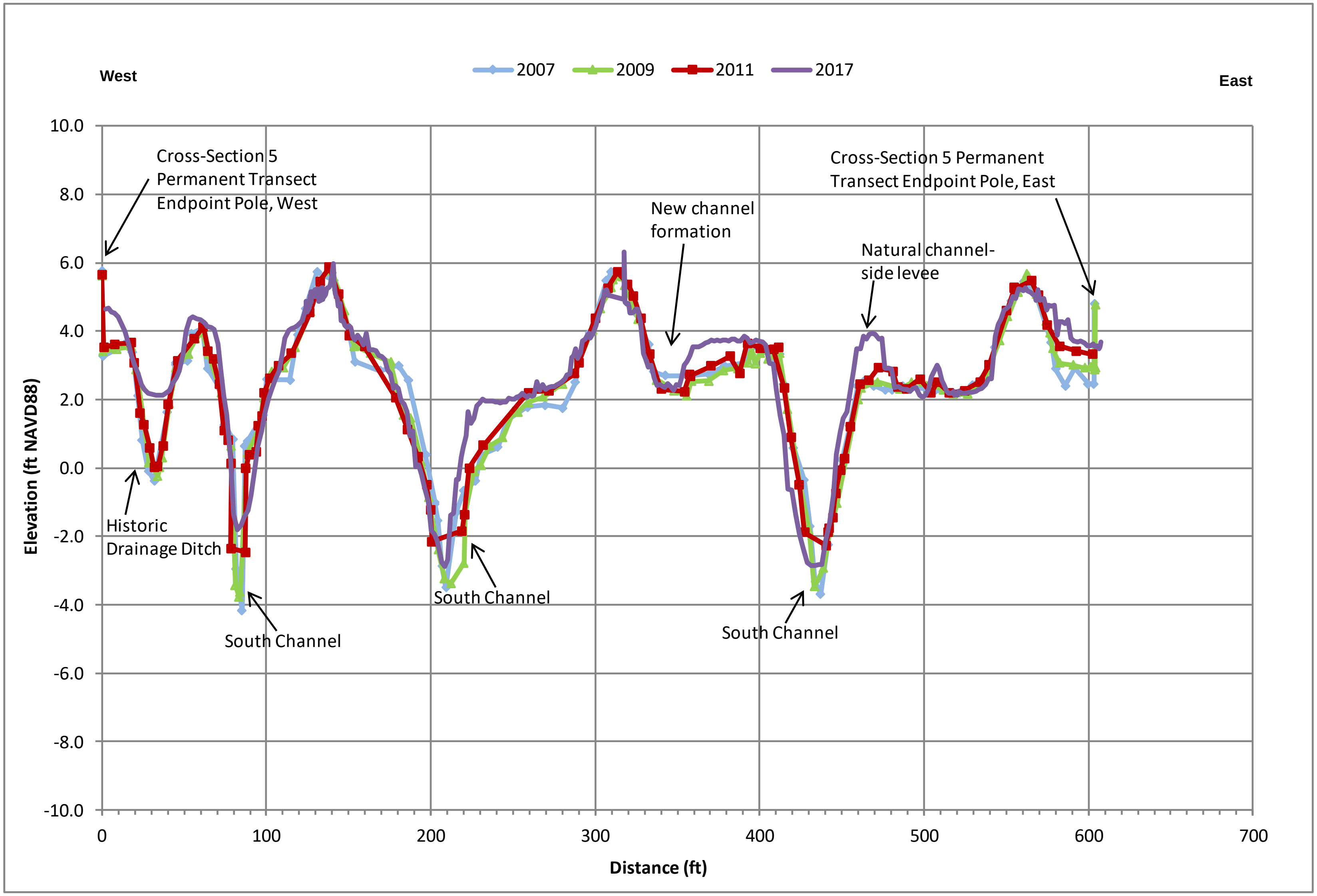
Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 8

Cross Section 1: South Breach



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

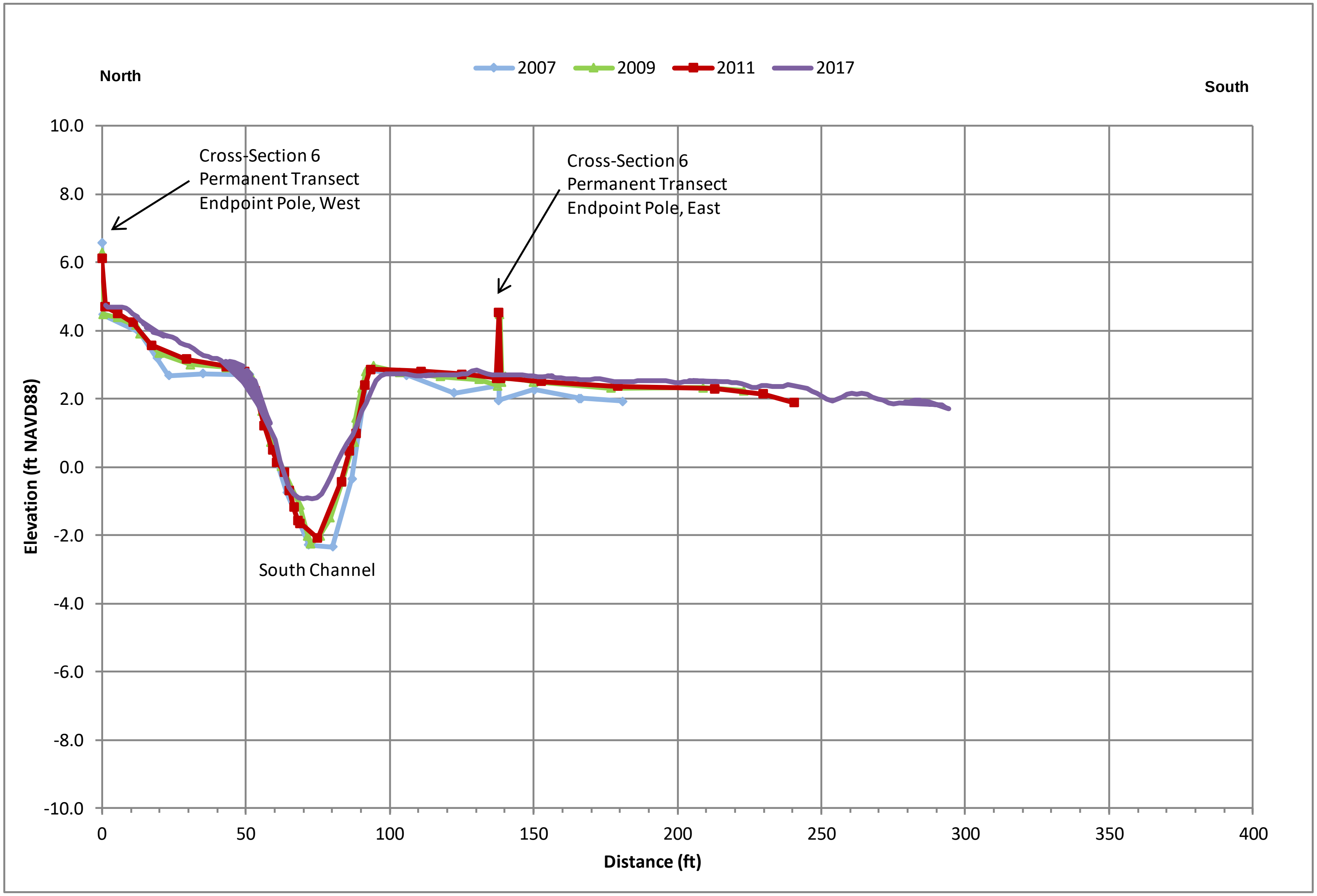
Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

SIEGEL ENVIRONMENTAL

Petaluma Marsh Enhancement Project

Figure 9

Cross Section 5: South Channel Complex



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

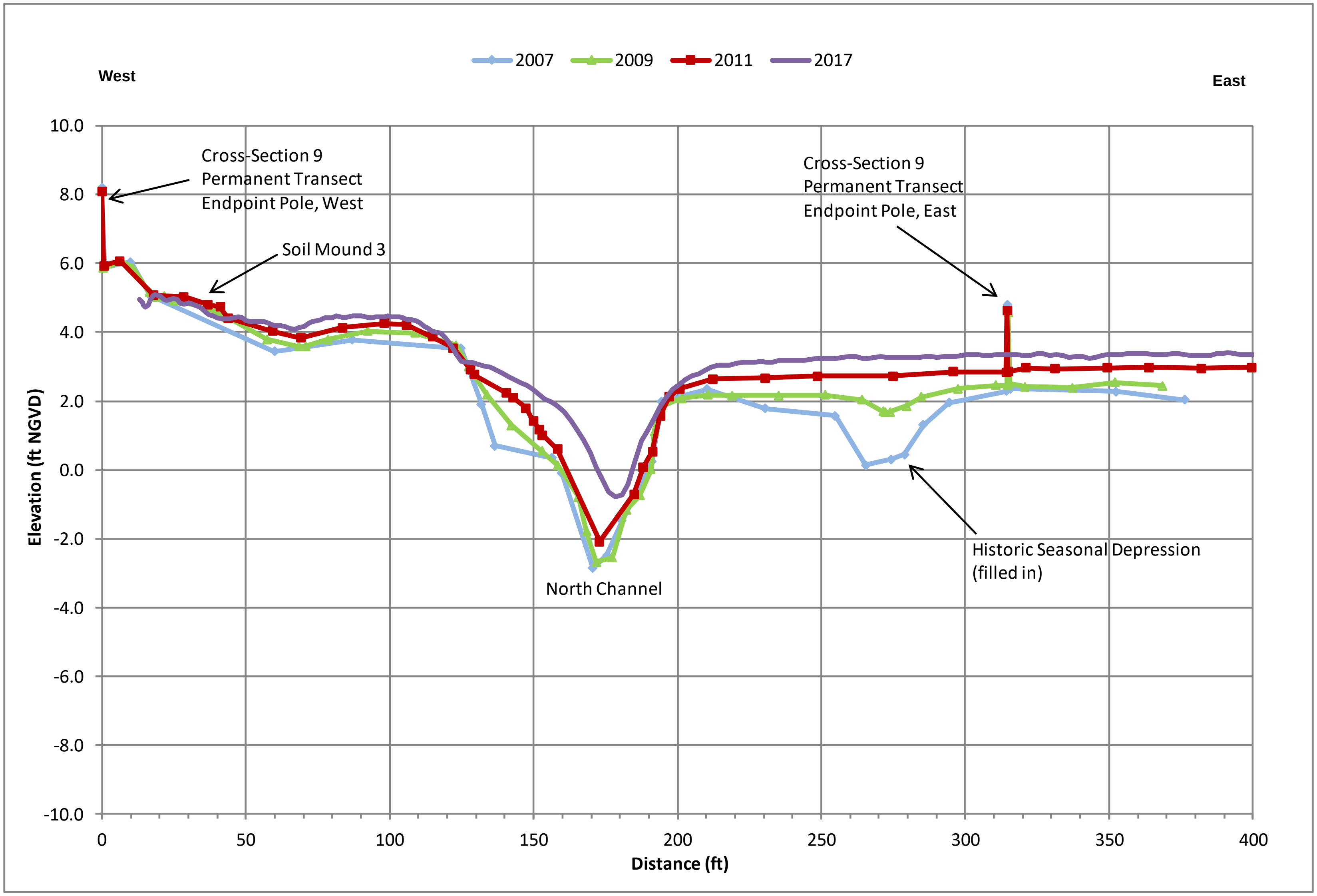
Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 10

Cross Section 6: South Channel Complex



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

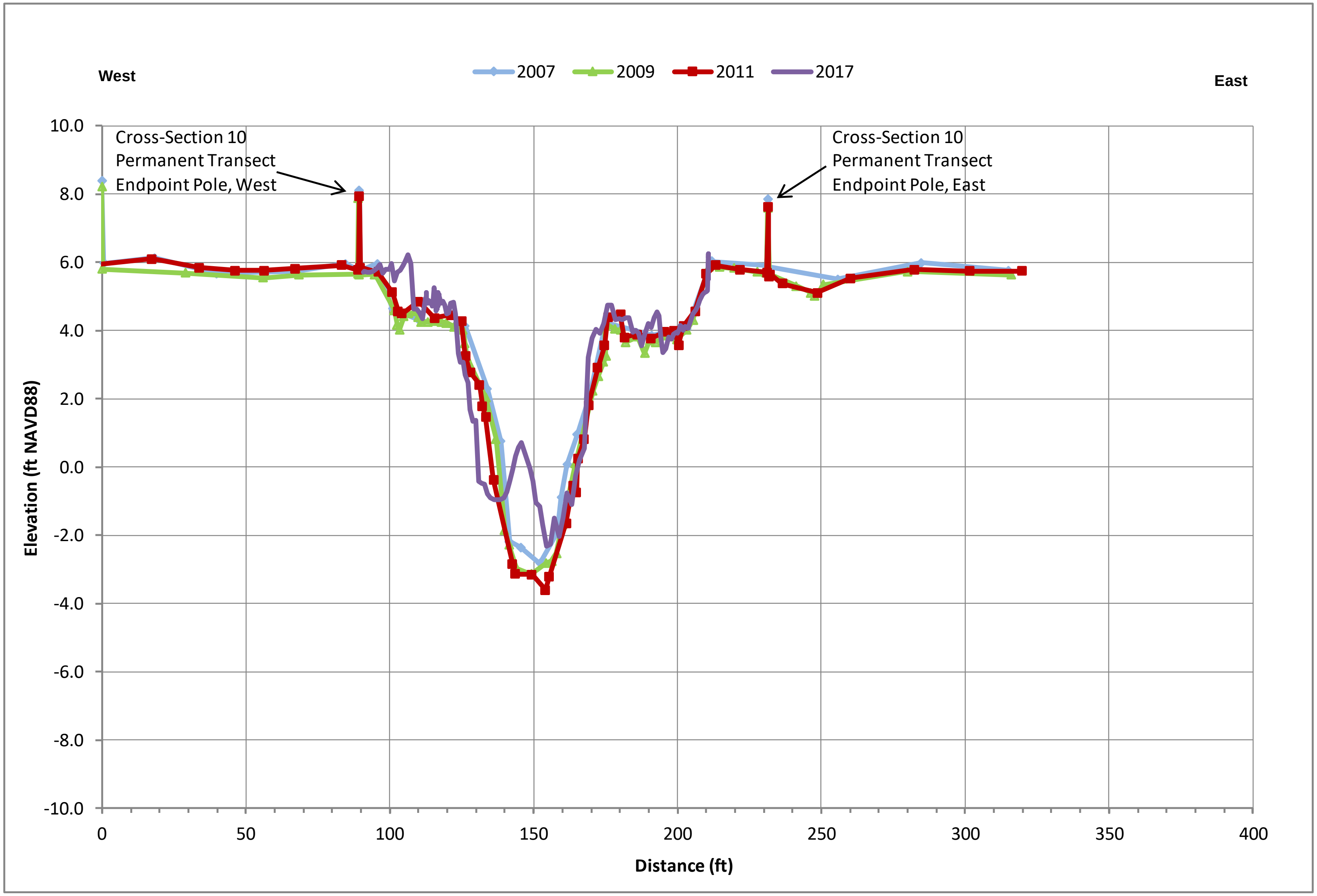
Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 11

Cross Section 9: North Channel Complex



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

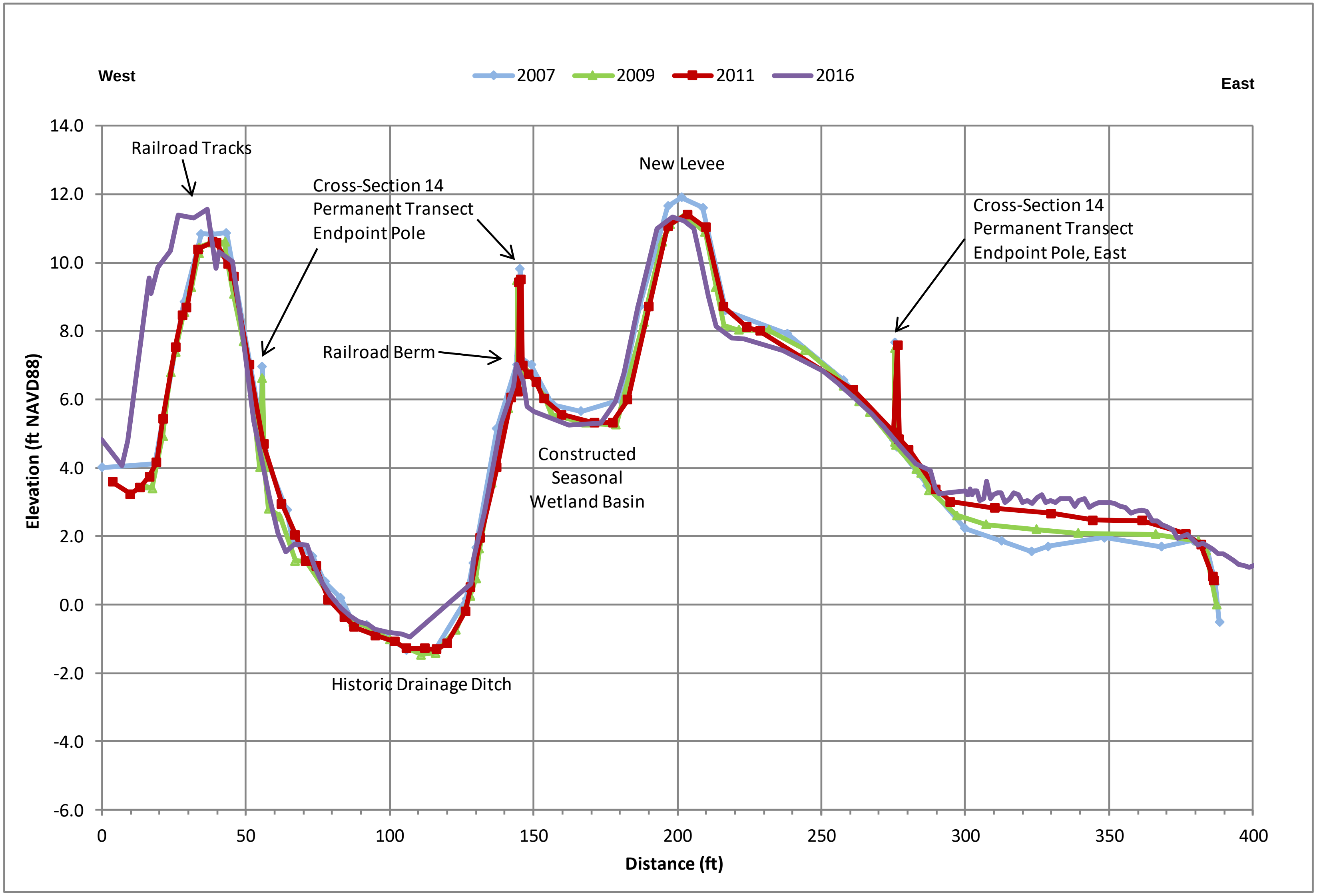
Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 12

Cross Section 10: North Breach



File: Fig-07-13_WL and XS_PMEP 3024_2017-0428sws.pptx

Data Source: 2007, 2009 (PWA); 2011 (WWR); 2017 (SE)

Petaluma Marsh Enhancement Project

SIEGEL ENVIRONMENTAL

Figure 13

Cross Section 14: Western Levee

Data sources: air photo (Terravion, 2016); background photo (NAIP, 2012); Wetland loc (SE, 2017)

1:3,600 (1" = 300' at letter size)

0 150 300 ft

0 50 100 m

SIEGEL ENVIRONMENTAL

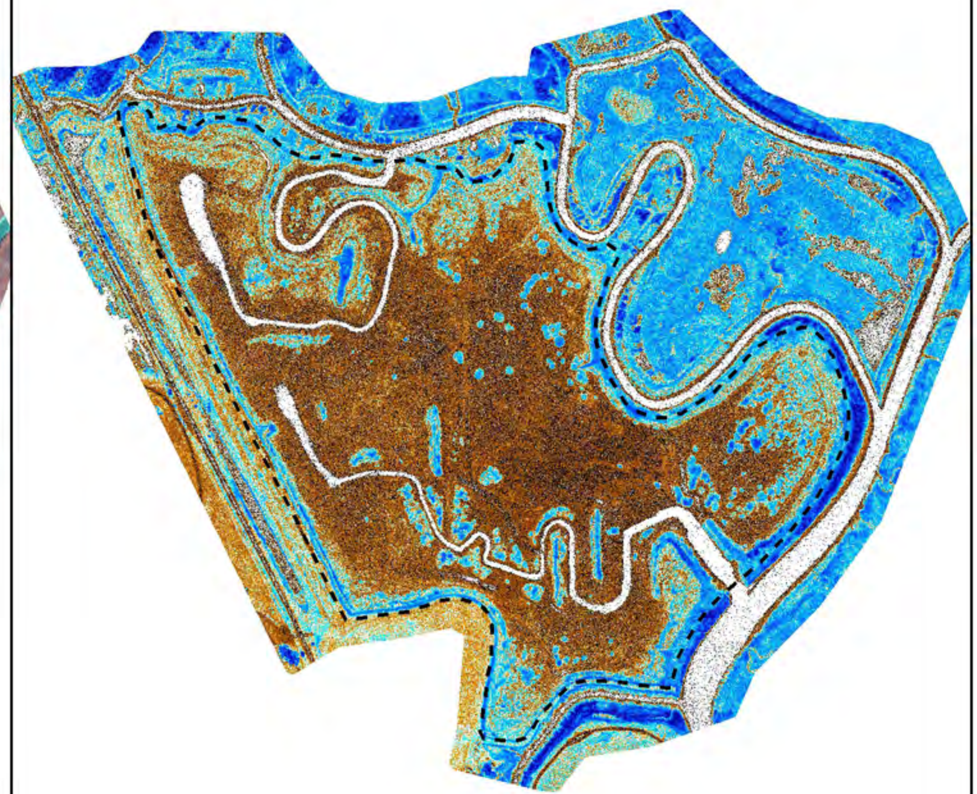
Petaluma Marsh Expansion

Figure 14

Location of Seasonal Wetland Along Levee Toe

Color Infrared Photograph

NDVI Dataset



Tidal Marsh Restoration Boundary

Map File: CIR-photo-and-NDVI_July2016_2017-0426

Data sources: air photo/NDVI dataset (Terravion, 2016);
restored boundary (SE, 2016)

1:9,600 (1" = 800' at letter size)

0 400 800 ft

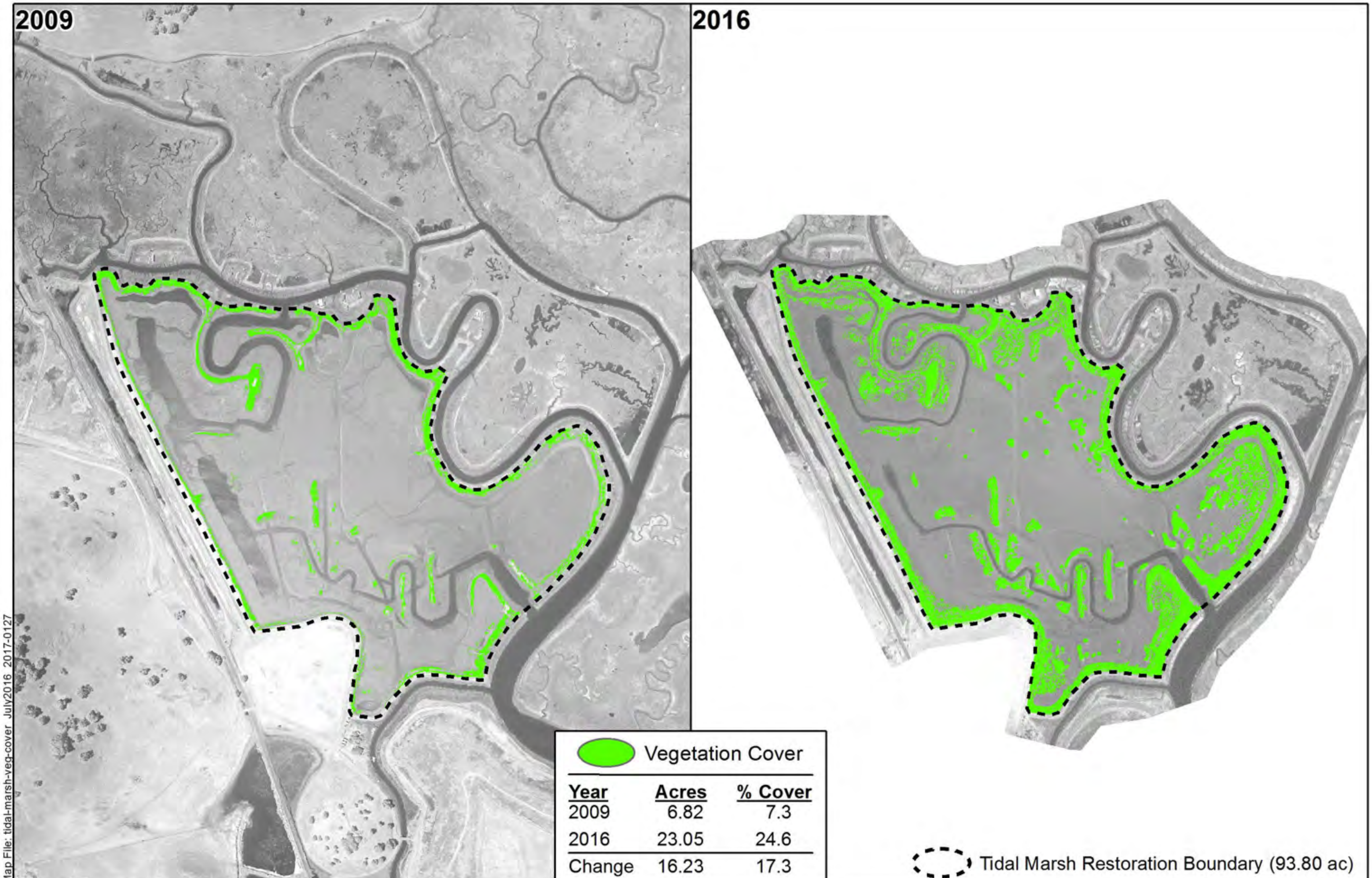
0 125 250 m

SIEGEL ENVIRONMENTAL

Petaluma Marsh Expansion

Figure 15

July 2016 Color Infrared Aerial Photograph and Derived NDVI Dataset



Map File: tidal-marsh-veg-cover July2016 2017-0127

Data sources: Air photo (Terravion, 2016); Veg cover (SE, 2017)

Petaluma Marsh Expansion

1:9,600 (1" = 800' at letter size)

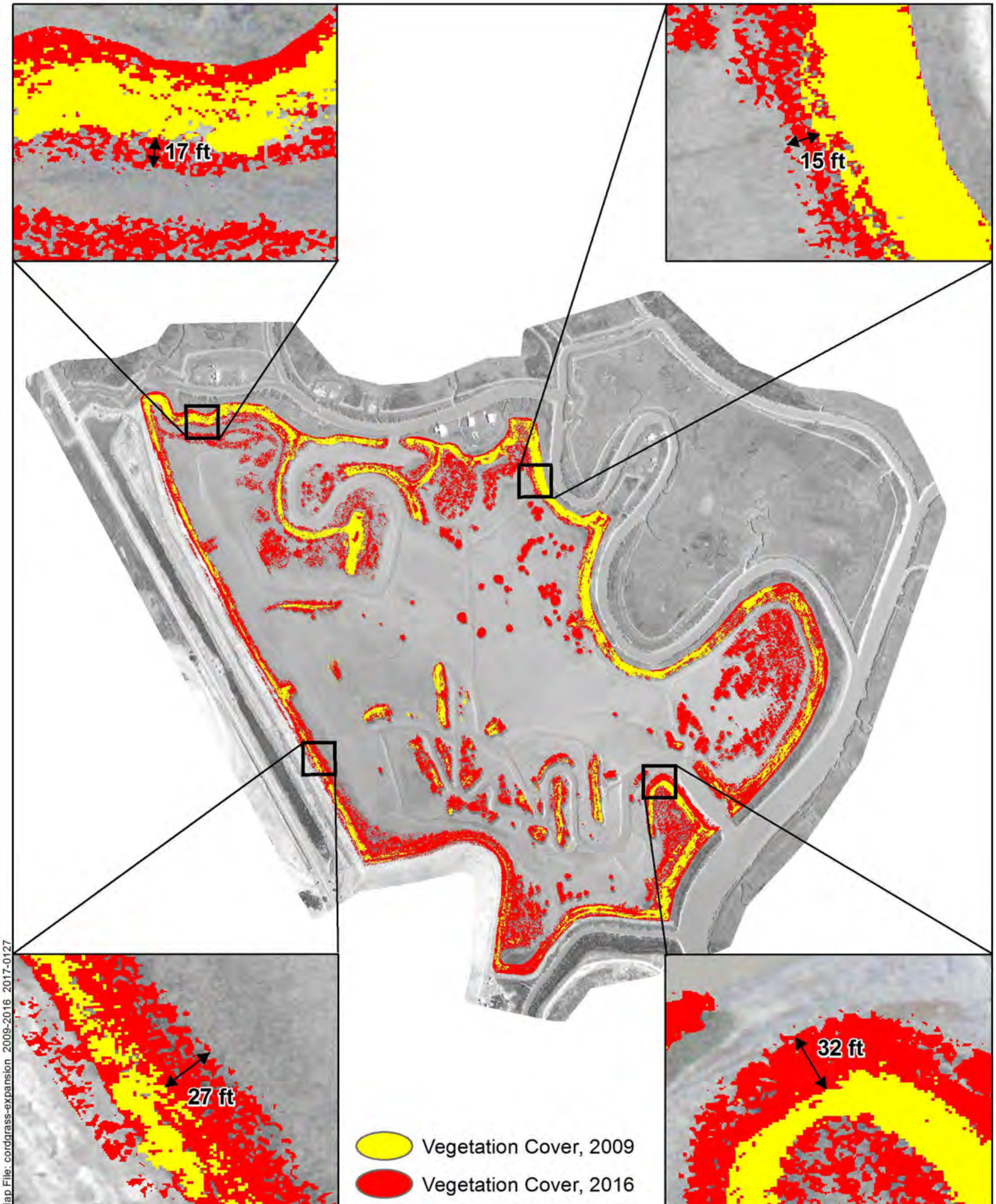
0 400 800 ft

0 125 250 m

SIEGEL ENVIRONMENTAL

Figure 16

Tidal Marsh Vegetation Cover 2009 vs. 2016



Map File: cordgrass-expansion 2009-2016 2017-0127

Data sources: air photo (Terravion, 2016); Vegetation Cover (WWR, 2009; SE, 2017)

Petaluma Marsh Expansion

1:7,200 (1" = 600' at letter size)

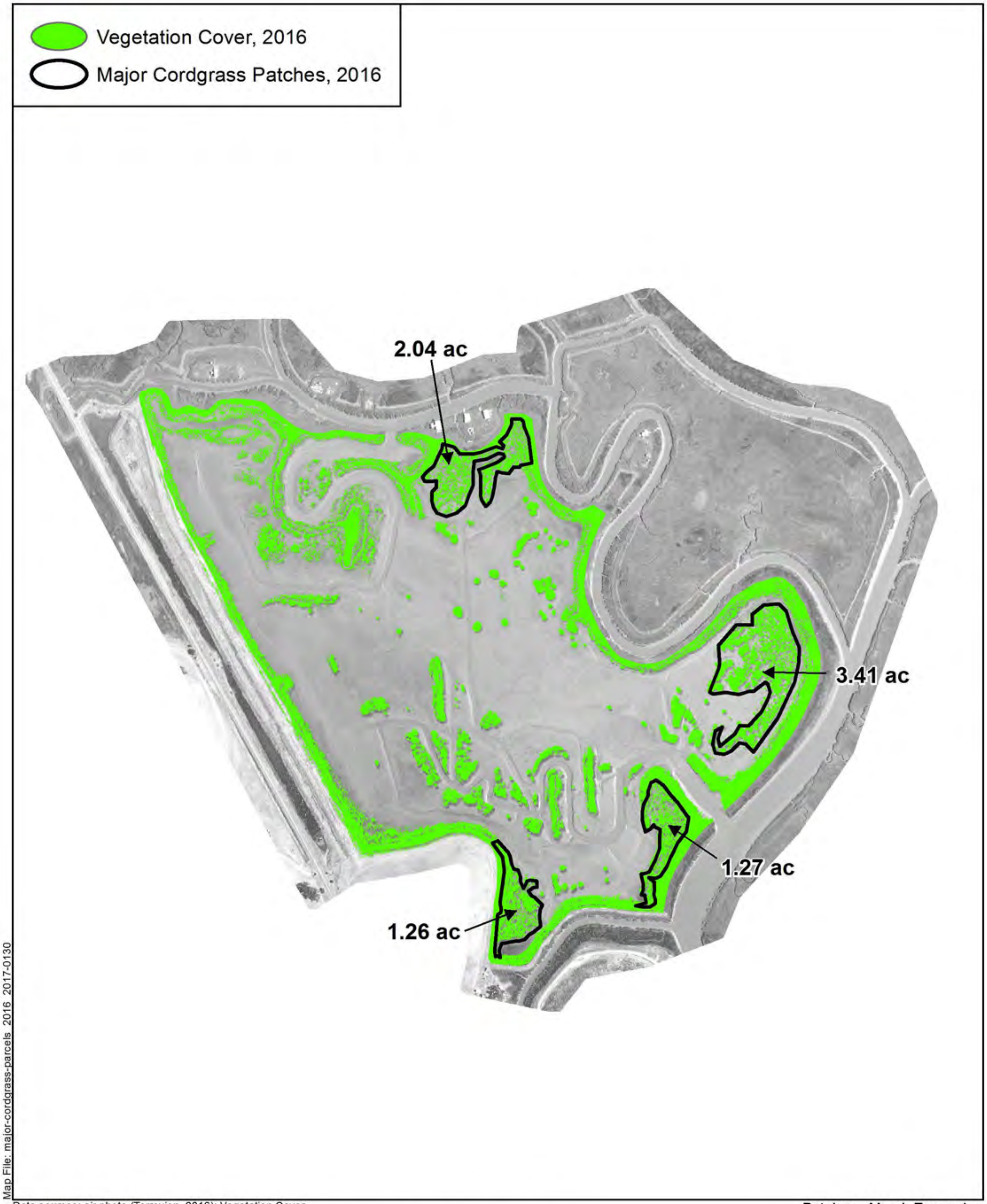
0 300 600 ft

0 100 200 m

SIEGEL ENVIRONMENTAL

Figure 17

Vegetation Cover Change and Cordgrass Expansion: 2009 - 2016



Map File: major-cordgrass-parcels_2016_2017-0130

Data sources: air photo (Terravion, 2016); Vegetation Cover (WWR, 2009; SE, 2017)

SIEGEL ENVIRONMENTAL

Petaluma Marsh Expansion

Figure 18

Cordgrass Patch Size, July 2016

APPENDIX A. OPUS SOLUTION REPORT FOR LOCAL BENCHMARK BM-5

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Daniel Gillenwater

From: Jimmy Kulpa <jkulpa@clegroup.com>
Sent: Tuesday, April 25, 2017 10:18 AM
To: Daniel Gillenwater
Subject: FW: OPUS solution : cp1_0390.17o OP1491497464820

-----Original Message-----
From: opus [mailto:opus@ngs.noaa.gov]
Sent: Thursday, April 06, 2017 9:52 AM
To: Jimmy Kulpa <jkulpa@clegroup.com>
Subject: OPUS solution : cp1_0390.17o OP1491497464820

FILE: cp1_0390.17o OP1491497464820

NGS OPUS SOLUTION REPORT
========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

```
     USER: jkulpa@clegroup.com                 DATE: April 06, 2017
RINEX FILE: cp1_039r.17o                      TIME: 16:51:38 UTC


  SOFTWARE: page5  1209.04 master95.pl 160321      START: 2017/02/08  17:46:00
 EPHEMERIS: igs19353.eph [precise]                 STOP: 2017/02/08  20:30:00
  NAV FILE: brdc0390.17n                      OBS USED:  7027 /  8066   :  87%
  ANT NAME: LEIAX1202GG     NONE            # FIXED AMB:    48 /    52   :  92%
ARP HEIGHT: 1.66                          OVERALL RMS: 0.015(m)


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)            IGS08 (EPOCH:2017.1063)

        X:    -2702871.992(m)   0.022(m)        -2702872.932(m)   0.022(m)
        Y:    -4230514.037(m)   0.036(m)        -4230512.612(m)   0.036(m)
        Z:     3920954.584(m)   0.031(m)         3920954.643(m)   0.031(m)

      LAT:   38 10 39.89681      0.004(m)       38 10 39.91224      0.004(m)
    E LON:  237 25 31.88544      0.017(m)      237 25 31.82137      0.017(m)
    W LON:  122 34 28.11456      0.017(m)      122 34 28.17863      0.017(m)
   EL HGT:         -28.849(m)   0.049(m)             -29.358(m)   0.049(m)
 ORTHO HGT:          2.952(m)   0.086(m) [NAVD88 (Computed using GEOID12B)]

                    UTM COORDINATES    STATE PLANE COORDINATES
                     UTM (Zone 10)        SPC (0403 CA 3)
Northing (Y) [meters]     4225622.497         688215.948
Easting (X)  [meters]      537269.573        1818257.041
```

Convergence [degrees] 0.26302059 -1.27006083
Point Scale 0.99961711 0.99995684
Combined Factor 0.99962163 0.99996137

US NATIONAL GRID DESIGNATOR: 10SEH3726925622(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DM7542	P196 MEACHUMLFLCN2006 CORS ARP	N381753.304	W1224433.456	19882.6
DO7031	CASR SANTA ROSA CA CORS ARP	N382626.414	W1224449.164	32854.5
DH7229	P198 PETALUMAIRCN2004 CORS ARP	N381535.534	W1223626.768	9561.6

NEAREST NGS PUBLISHED CONTROL POINT

JT0774 M 107 N381042. W1223430. 79.4

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

APPENDIX B. 2006-2008 SAN ANTONIO CREEK BATHYMETRIC SURVEY CHANGE DETECTION FINDINGS (WWR 2008)

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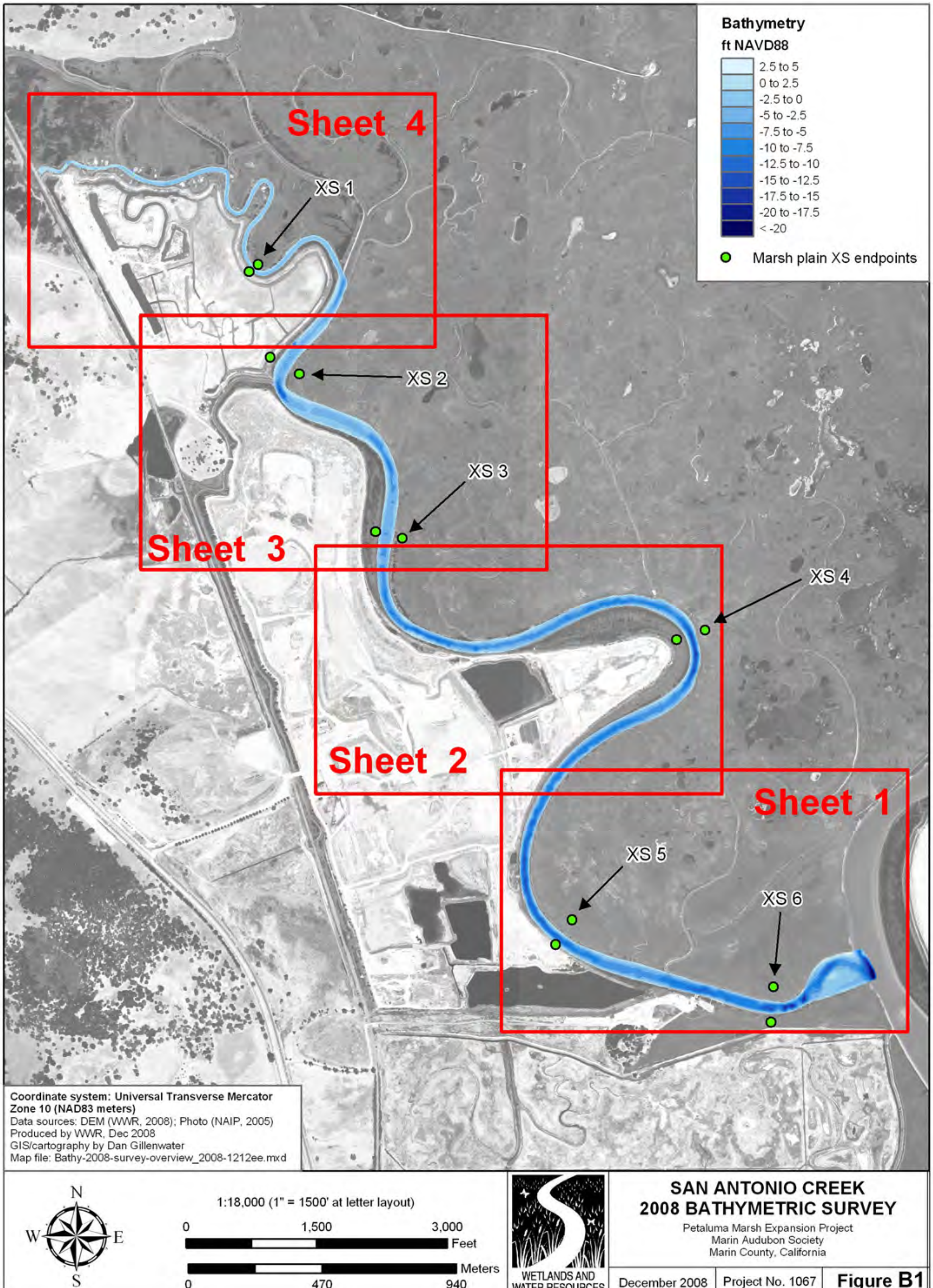
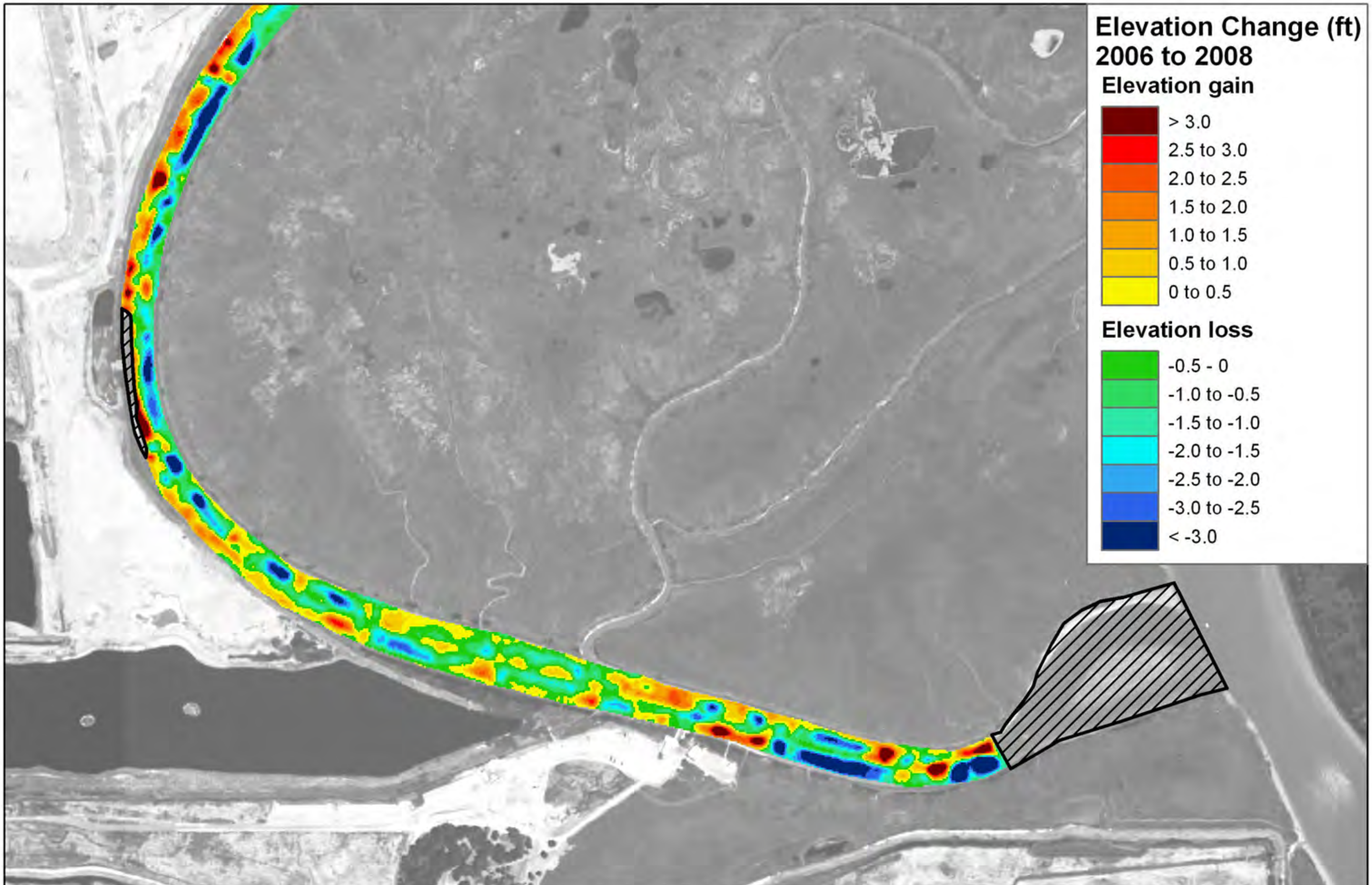


SAN ANTONIO CREEK
2008 BATHYMETRIC SURVEY

Petaluma Marsh Expansion Project
Marin Audubon Society
Marin County, California

December 2008	Project No. 1067	**Figure B1**



Insufficient 2006 data for analysis

Data sources: Data (WWR 2008); Photo (NAIP 2005)
Produced by WWR, December 2008
GIS/Cartography by Dan Gillenwater
Map file: Bathy-change-sheet1_2008-1215lee.mxd

N W E S

1:6,000 (1" = 500' at letter layout)

0 250 500 1,000 Feet

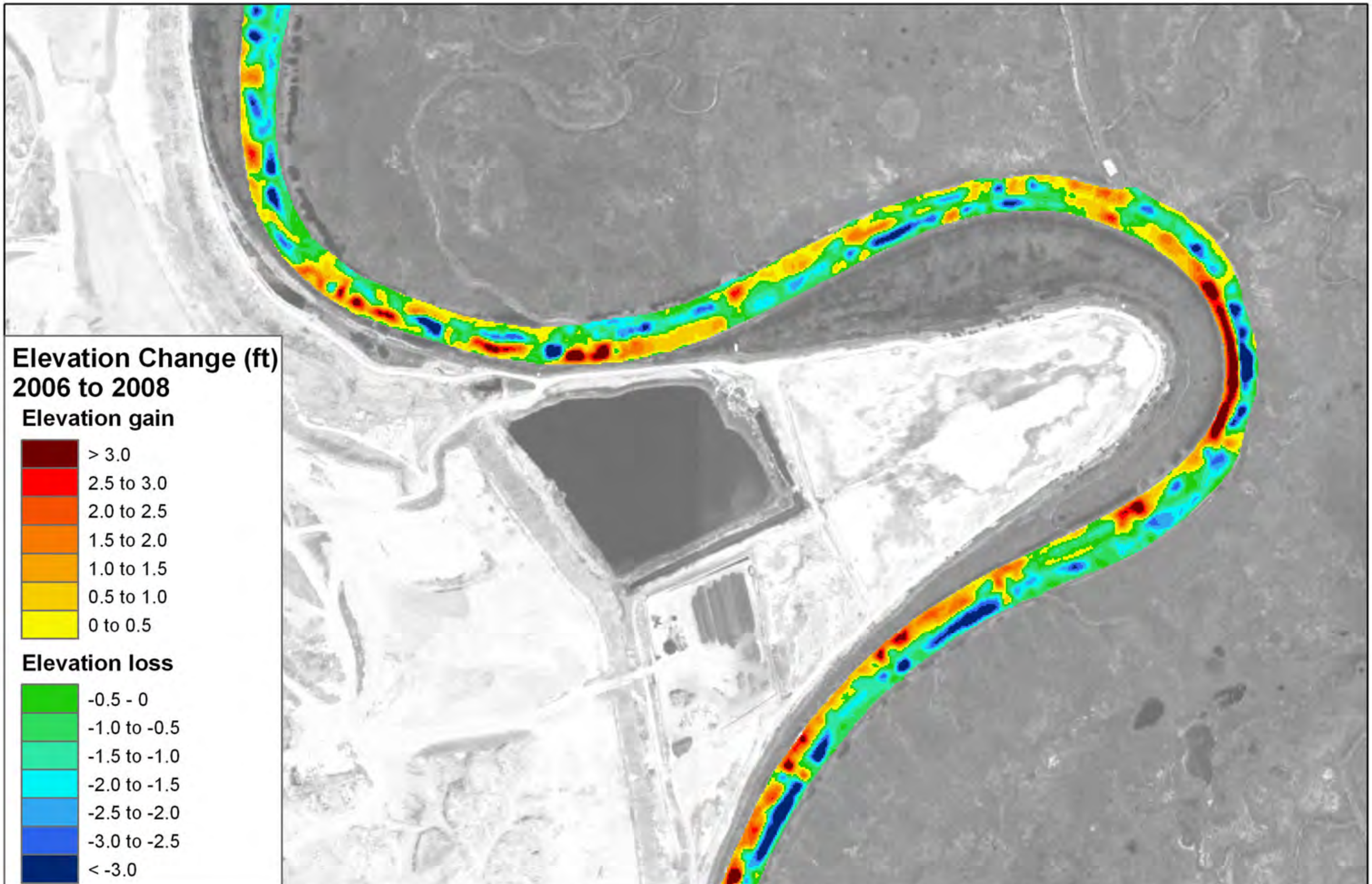
0 75 150 300 Meters

WETLANDS AND WATER RESOURCES

SAN ANTONIO CREEK BATHYMETRY CHANGE DETECTION (2006 TO 2008) SHEET 1

Petaluma Marsh Expansion Project
Marin Audubon Society, Marin County, California

December 2008	Project No. 1067	**Figure B2**



Data sources: Data (WWR 2008); Photo (NAIP 2005)
Produced by WWR, December 2008
GIS/Cartography by Dan Gillenwater
Map file: Bathy-change-sheet2_2008-1215lee.mxd

N W E S

1:6,000 (1" = 500' at letter layout)

0 250 500 1,000 Feet

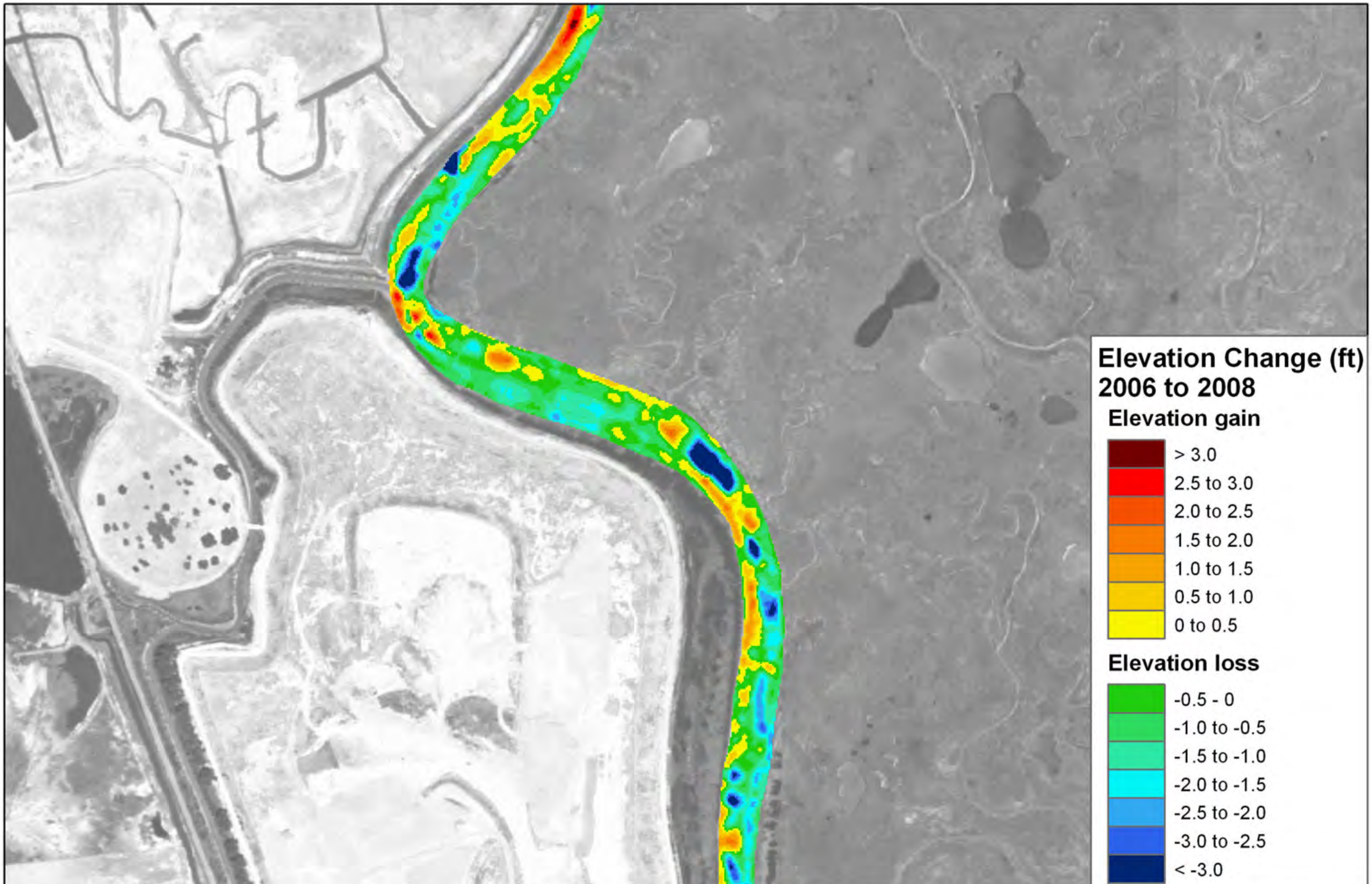
0 75 150 300 Meters

WETLANDS AND WATER RESOURCES

SAN ANTONIO CREEK BATHYMETRY CHANGE DETECTION (2006 TO 2008) SHEET 2

Petaluma Marsh Expansion Project
Marin Audubon Society, Marin County, California

December 2008	Project No. 1067	**Figure B3**



Data sources: Data (WWR 2008); Photo (NAIP 2005)
Produced by WWR, December 2008
GIS/Cartography by Dan Gillenwater
Map file: Bathy-change-sheet3_2008-1215lee.mxd

N
W E
S

1:6,000 (1" = 500' at letter layout)

0 250 500 1,000 Feet

0 75 150 300 Meters

WETLANDS AND WATER RESOURCES

SAN ANTONIO CREEK BATHYMETRY CHANGE DETECTION (2006 TO 2008) SHEET 3

Petaluma Marsh Expansion Project
Marin Audubon Society, Marin County, California

December 2008	Project No. 1067	**Figure B4**

Data sources: Data (WWR 2008); Photo (NAIP 2005)
Produced by WWR, December 2008
GIS/Cartography by Dan Gillenwater
Map file: Bathy-change-sheet4_2008-1215lee.mxd

N W E S

1:6,000 (1" = 500' at letter layout)

0 250 500 1,000 Feet

0 75 150 300 Meters

WETLANDS AND WATER RESOURCES

SAN ANTONIO CREEK BATHYMETRY CHANGE DETECTION (2006 TO 2008) SHEET 4

Petaluma Marsh Expansion Project
Marin Audubon Society, Marin County, California

December 2008	Project No. 1067	**Figure B5**

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APPENDIX C. VEGETATION SURVEY DATA

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C-1: Vegetation Percent Cover and Height, Sorted by Polygon and Quadrat

Date: 9.21.16
Surveyor: Diana Benner & Claire Brown

Polygon	Quadrat	Species name	Percent cover	Height (cm)	Notes
11	1	Bolboschoenus maritimus	15	133	
11	1	Salicornia pacifica	25	97	
11	1	Bare	60		
11	2	Bolboschoenus maritimus	2	84	
11	2	Salicornia pacifica	85	42	
11	2	Bare	13		
11	3	Bolboschoenus maritimus	35	142	
11	3	Bare	65		
10	1	Bolboschoenus maritimus	15	132	
10	1	Salicornia pacifica	40	81	
10	1	Bare	45		
10	2	Bolboschoenus maritimus	10	45	
10	2	Salicornia pacifica	55	50	
10	2	Bare	35		
10	3	Bolboschoenus maritimus	20	145	
10	3	Salicornia pacifica	50	75	
10	3	Bare	30		
9	1	Salicornia pacifica	95	41	
9	1	Distichlis spicata	3	35	
9	1	Bare	2		
9	2	Salicornia pacifica	96	53	
8	n/a	bare mud with algae	100		
7	1	Salicornia pacifica	10	55	rocky edge of levee
7	1	Raphanus sativa	35	49	dead
7	1	Bare	55		
7	2	Salicornia pacifica	40	68	
7	2	Raphanus sativa	30	87	
7	2	Polypogon monspliensis	1	83	
7	2	Lepidium latifolium	2	77	
7	2	Bare	27		
7	3	Salicornia pacifica	10	59	
7	3	Raphanus sativa	35	61	dead
7	3	Bare	55		
6	n/a	Spartina foliosa			can't reach this polygon, photo taken at cardinal direction of 43°
5	1	Spartina foliosa	15	109	
5	1	Bolboschoenus maritimus	1	79	
5	1	Bare	84		
5	2	Spartina foliosa	20	107	
5	2	Bolboschoenus maritimus	1	93	

C-1: Vegetation Percent Cover and Height, Sorted by Polygon and Quadrat

Date: 9.21.16
Surveyor: Diana Benner & Claire Brown

Polygon	Quadrat	Species name	Percent cover	Height (cm)	Notes
5	2	Bare	79		
5	3	Spartina foliosa	20	108	
4	n/a	bare mud with algae	100		photo taken at cardinal direction of 10°
3	1	Spartina foliosa	20	98	
3	1	Bare	80		
3	2	Spartina foliosa	15	108	
3	2	Salicornia pacifica	4	59	
3	2	Bare	81		
3	3	Spartina foliosa	15	100	
3	3	Bare	85		
2	1	Salicornia pacifica	25	41	
2	1	Bare	75		
2	2	Salicornia pacifica	35	40	
2	2	Bare	65		
2	3	Salicornia pacifica	30	39	
2	3	Bare	70		
1	1	Salicornia pacifica	85	39	
1	1	Bromus diandrus	1	52	
1	1	Bromus hordeaceus	1	49	
1	1	Festuca perennis	1	50	
1	1	Polypogon monspliensis	1	27	
1	1	Bare	11		
1	2	Salicornia pacifica	75	44	
1	2	Bare	25		
1	3	Salicornia pacifica	80	35	
1	3	Bare	20		

C-2: Vegetation Height, Sorted by Species

Date: 9.21.16
Surveyor: Diana Benner & Claire Brown

Polygon	Quadrat	Species name	Percent cover	Height (cm)	Notes
5	1	Bolboschoenus maritimus	1	79	
5	2	Bolboschoenus maritimus	1	93	
10	1	Bolboschoenus maritimus	15	132	
10	2	Bolboschoenus maritimus	10	45	
10	3	Bolboschoenus maritimus	20	145	
11	1	Bolboschoenus maritimus	15	133	
11	2	Bolboschoenus maritimus	2	84	
11	3	Bolboschoenus maritimus	35	142	
		Average Height		**107**	
1	1	Salicornia pacifica	85	39	
1	2	Salicornia pacifica	75	44	
1	3	Salicornia pacifica	80	35	
2	1	Salicornia pacifica	25	41	
2	2	Salicornia pacifica	35	40	
2	3	Salicornia pacifica	30	39	
3	2	Salicornia pacifica	4	59	
7	1	Salicornia pacifica	10	55	rocky edge of levee
7	2	Salicornia pacifica	40	68	
7	3	Salicornia pacifica	10	59	
9	1	Salicornia pacifica	95	41	
9	2	Salicornia pacifica	96	53	
10	1	Salicornia pacifica	40	81	
10	2	Salicornia pacifica	55	50	
10	3	Salicornia pacifica	50	75	
11	1	Salicornia pacifica	25	97	
11	2	Salicornia pacifica	85	42	
		Average Height		**54**	
3	1	Spartina foliosa	20	98	
3	2	Spartina foliosa	15	108	
3	3	Spartina foliosa	15	100	
5	1	Spartina foliosa	15	109	
5	2	Spartina foliosa	20	107	
5	3	Spartina foliosa	20	108	
		Average Height		**105**	

C-3: Vegetation Height Data, Carl's Marsh Reference Site

Date: 9.20.16
Surveyor: Diana Benner & Claire Brown

Coordinates	Species	ave height (cm)
nk	Salicornia pacifica	48
nk	Salicornia pacifica	32
nk	Salicornia pacifica	37
nk	Salicornia pacifica	39
average		**39**
std dev		**7**
nk	Bolboschoenus maritimus	107
nk	Bolboschoenus maritimus	128
nk	Bolboschoenus maritimus	109
nk	Bolboschoenus maritimus	115
nk	Bolboschoenus maritimus	96
average		**111**
std dev		**12**
38.11831, -122.50467	Spartina foliosa	85
38.11872, -122.50498	Spartina foliosa	107
38.11922, -122.50522	Spartina foliosa	85
38.11948, -122.50536	Spartina foliosa	107
38.11981, -122.50567	Spartina foliosa	85
38.12022, -122.50579	Spartina foliosa	107
38.12088, -122.50620	Spartina foliosa	85
average		**94**
std dev		**12**

C-4: Species Composition and Cordgrass Height, Western Levee Transects

Date: 9/21/2016
Surveyor: Diana Benner & Claire Brown
Transect Area:Western Levee
Transect Length: Variable (based on width of levee and adjacent habitats)

Transect position	Cordgrass average quadrat height (cm)	Species	Distance along transect (cm)	Notes
1E	122	Bolboschoenes maritimus	100	
1E		Salicornia pacifica	537	
1E		Atriplex prostrata	3	
1E		Spergularia sp. (CF S. rubra)	380	
1E		Festuca myuros	60	
1E		Bare	70	
1E		Spergularia sp. (CF S. rubra)	30	
1E		Non-native grasses (Avena sp, Festuca perennis, Hordeum, ..)	370	
1E		Elymus triticoides	380	
1E		Carduus pycnocephalus	20	
1E		Non-native grasses (Avena sp, Festuca perennis, Hordeum, ..)	50	
1E		Bare	250	
1E		Spergularia sp. (CF S. rubra)	150	
		Total Length of Transect	**2400**	
2E	107	Spartina foliosa	50	
2E		Water	10	
2E		Salicornia pacifica	565	
2E		Bare	245	
2E		Spergularia sp. (CF S. rubra)	160	
2E		Festuca myuros	30	
2E		Spergularia sp. (CF S. rubra)	50	
2E		Non-native grasses (Festuca perennis, Bromus diandrus, ..)	260	
2E		Frankenia salina	70	
2E		Non-native grasses (Festuca perennis, Bromus diandrus, ..)	20	
2E		Frankenia salina	60	
2E		Non-native grasses & Foeniculum vulgaris (Festuca perennis, Br	470	
2E		bare	70	
2E		Spergularia sp. (CF S. rubra)	100	
2E		Non-native grasses (Festuca perennis, Bromus diandrus, ..)	340	
		Total Length of Transect	**2500**	
3E	97	Spartina foliosa	40	
3E		water	40	
3E		Salicornia pacifca	550	
3E		Bare	240	
3E		Spergularia sp. (CF S. rubra)	660	
3E		Non-native grasses (Festuca perennis, Bromus diandrus, ..)	50	
3E		Elymus triticoides	370	
3E		Raphanus sativa	50	
3E		Bare	100	
3E		Spergularia sp. (CF S. rubra)	300	
3E		Non-native grasses & Raphanus sativa (Festuca perennis, Bromu	100	
		Total Length of Transect	**2500**	

C-4: Species Composition and Cordgrass Height, Western Levee Transects

Date: 9/21/2016
Surveyor: Diana Benner & Claire Brown
Transect Area: Western Levee
Transect Length: Variable (based on width of levee and adjacent habitats)

Transect position	Cordgrass average quadrat height (cm)	Species	Distance along transect (cm)	Notes
1W	n/a	Non-native grasses & Brassica sp. (Avena sp, Festuca spp. .)	250	
1W		Brasica nigra	450	
1W		Non-native grasses (Festuca perennis, Bromus diandrus, ..)	620	
1W		Salicornia pacifica	30	OBL
		Total Length of Transect	**1350**	
2W	n/a	Foeniculum vulgare	66.25	FACUPL
2W		Bare	188.75	
2W		Atriplex prostrata	10	FACW
2W		Raphanus satiUS & nonnative annual grasses	360	TBD
2W		Carduus pycnocephalus	20	
2W		Festuca myuros	430	FACU
2W		Spergularia sp. (CF S. rubra)	20	FAC
		Total Length of Transect	**1095**	
3W	n/a	Raphanus sativa	1860	TBD
3W		Carduus pycnocephala	10	
3W		Salicornia pacifica	80	OBL
3W		bare	50	
		Total Length of Transect	**2000**	

C-5: Vegetation Percent Cover, by Transect and Species

Date: 9/21/2016
Surveyor: Diana Benner & Claire Brown
Transect Area:Western Levee
Transect Length: Variable (based on width of levee and adjacent habitats)

Transect 1E

Species	Total cover	% cover
Atriplex prostrata	3	0%
Bolboschoenes maritimus	100	4%
Carduus pycnocephalus	20	1%
Elymus triticoides	380	16%
Festuca myuros	60	3%
Non-native grasses (Avena sp, Festuca perennis, Hordeum, ..)	420	18%
Salicornia pacifica	537	22%
Spergularia sp. (CF S. rubra)	560	23%
Bare	320	13%
	2400	100%

Transect 2E

Species	Total cover	% cover
Festuca myuros	30	1%
Frankenia salina	130	5%
Non-native grasses & Foeniculum vulgaris (Festuca perennis, Bromus diandrus, ..)	1090	44%
Salicornia pacifica	565	23%
Spartina foliosa	50	2%
Spergularia sp. (CF S. rubra)	310	12%
Bare	315	13%
Water	10	0%
	2500	100%

Transect 3E

Species	Total cover	% cover
Elymus triticoides	370	15%
Non-native grasses & Raphanus sativa (Festuca perennis, Bromus diandrus, ..)	150	6%
Raphanus sativa	50	2%
Salicornia pacifca	550	22%
Spartina foliosa	40	2%
Spergularia sp. (CF S. rubra)	960	38%
Bare	340	14%
water	40	2%
	2500	100%

Transect 1W

Species	Total cover	% cover
Brasica nigra	450	33%
Non-native grasses & Brassica sp. (Avena sp, Festuca spp. .)	870	64%
Salicornia pacifica	30	2%
	1350	100%

Transect 2W

Species	Total cover	% cover
Atriplex prostrata	10	1%
Carduus pycnocephalus	20	2%
Festuca myuros	430	39%
Foeniculum vulgaris	66.25	6%
Raphanus sativa & nonnative annual grasses	360	33%
Spergularia sp. (CF S. rubra)	20	2%
Bare	188.75	17%
	1095	100%

Transect 3W

Species	Total cover	% cover
Carduus pycnocephala	10	1%
Raphanus sativa	1860	93%
Salicornia pacifica	80	4%
bare	50	3%
	2000	100%

Total Percent Cover by Native and Non-Native Vegetation, East Side of West Levee

Transect	Total cover	Native	Non-native
East Side Transects on West Levee			
Transect 1E	87%	42%	44%
Transect 2E	87%	30%	57%
Transect 3E	85%	38%	46%
Average for bench vegetation	**86%**	**37%**	**49%**
West Side Transects on West Levee			
Transect 1W	100%	2%	98%
Transect 2W	83%	0%	83%
Transect 3W	98%	4%	94%
Average for bench vegetation	**93%**	**2%**	**91%**

C-6: Species Percent Cover Below HTL, by Transect

Date: 9/21/2016
Surveyor: Diana Benner & Claire Brown
Transect Area: Western Levee
Transect Length: Variable (based on width of levee and adjacent habitats)

A. Species Composition Below High Tide Line, by Transect

Transect position	Species	Distance along transect (cm)
1E	Bolboschoenes maritimus	100
	Salicornia pacifica	537
	Atriplex prostrata	3
	Total Length of Transect	**640**
2E	Spartina foliosa	50
	Water	10
	Salicornia pacifica	565
	Total Length of Transect	**625**
3E	Spartina foliosa	40
	water	40
	Salicornia pacifca	550
	Total Length of Transect	**630**
1W	Non-native grasses & Brassica	250
	Brasica nigra	450
	Non-native grasses (Festuca pe	620
	Salicornia pacifica	30
	Total Length of Transect	**1350**
2W	Foeniculum vulgaris	66.25
	Bare	188.75
	Atriplex prostrata	10
	Raphanus sativa & nonnative a	360
	Carduus pycnocephalus	20
	Festuca myuros	430
	Spergularia sp. (CF S. rubra)	20
	Total Length of Transect	**1095**
3W	Raphanus sativa	1860
	Carduus pycnocephala	10
	Salicornia pacifica	80
	bare	50
	Total Length of Transect	**2000**

B. Average Native Vegetation Cover Between Cordgrass and High Tide Line

Transect	Total cover	Native	Non-native
Transect 1E	100%	100%	0%
Transect 2E	98%	98%	0%
Transect 3E	94%	94%	0%
Average Cover	97%	97%	0%

C-7: Floristics Summary, Western Levee

Date: September 21, 2016
Surveyor: Claire Brown & Diana Benner

Species	Location	Notes
Atriplex semibaccata	levee	non-native perennial, moderate Cal-IPC ranking
Baccharis glutinosa	levee toe	native-planted
Baccharis pilularis	levee	native-planted
Centaurea solstitialis	far northern end of levee	non-native, annual, moderate Cal-IPC ranking
Cotula coronopifolia	middle section of bench	non-native perennial
Cuscuta salina	bench	native
Dittrichia graveolens	far northern end of levee	non-native, annual, moderate Cal-IPC ranking
Euthamia occidentalis	levee toe	native-planted
Frankenia salina	bench	native
Polygonum arenastrum	middle section of bench	non-native annual
Rumex sp.	levee	non-native, species not identified

APPENDIX D. FIXED-PERSPECTIVE PHOTOGRAPHY: 2007 - 2016

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PBM 1 - E

North Breach, looking East

April 6, 2007 12:00 Tide Height: 2.8’ MLLW

April 8, 2008 10:45 Tide Height : -0.9’ MLLW

July 23, 2009 10:00 Tide Height : -1.0’ MLLW

August 4, 2011 10:30 Tide Height *: 1.1’ MLLW

September 21, 2016 15:00 Tide Height *: 4’ MLLW

PBM 1 - N

North Breach, looking North

April 6, 2007 12:00 Tide Height : 2.8’ MLLW

April 8, 2008 10:45 Tide Height : -0.9’ MLLW

July 23, 2009 10:00 Tide Height -1.0’ MLLW

August 4, 2011 10:30 Tide Height *: 1.1’ MLLW

September 21, 2016 15:00 Tide Height *: 4’ MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

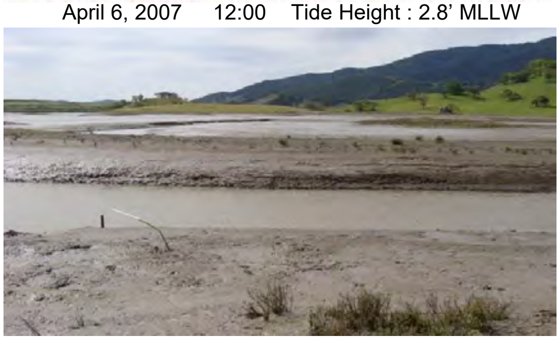
Photo Benchmarks PBM 1-E,N: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

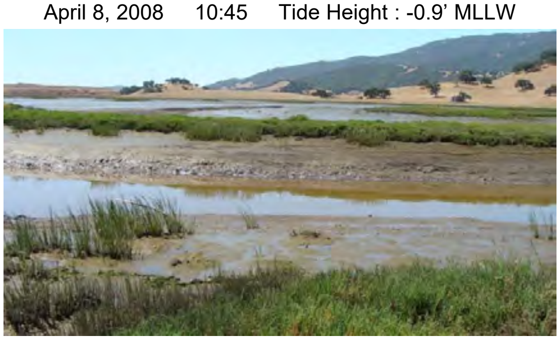
PBM 1 - S

North Breach, looking South

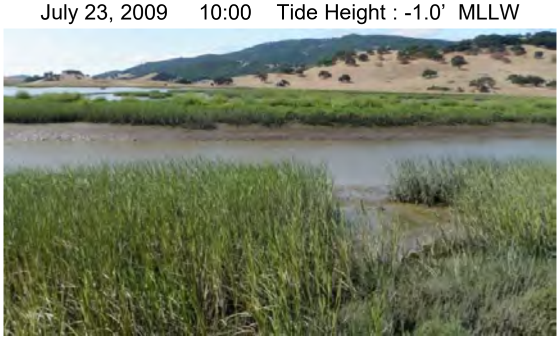
April 6, 2007 12:00 Tide Height : 2.8' MLLW



April 8, 2008 10:45 Tide Height : -0.9' MLLW



July 23, 2009 10:00 Tide Height : -1.0' MLLW



August 4, 2011 10:30 Tide Height *: 1.1' MLLW

September 21, 2016 15:00 Tide Height *: 4' MLLW

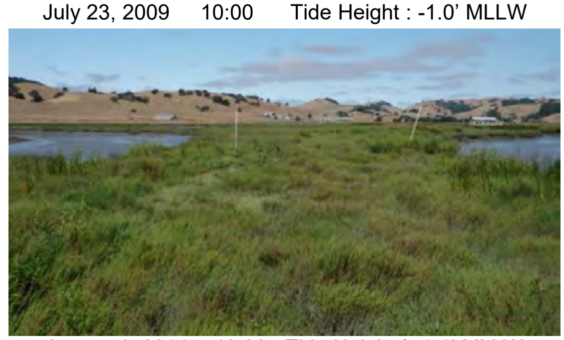
PBM 1 - W

North Breach, looking West

April 6, 2007 12:00 Tide Height : 2.8' MLLW

April 8, 2008 10:45 Tide Height : -0.9' MLLW

July 23, 2009 10:00 Tide Height : -1.0' MLLW



August 4, 2011 10:30 Tide Height *: 1.1' MLLW

September 21, 2016 15:00 Tide Height *: 4' MLLW

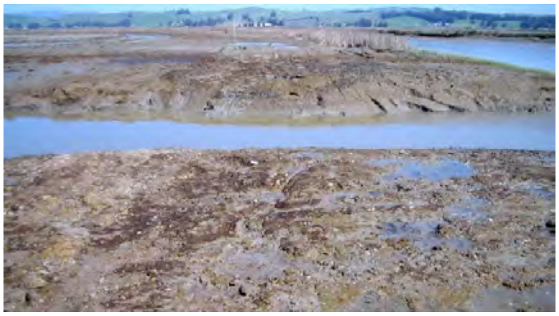
Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

Photo Benchmarks PBM 1-S,W: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

PBM 2 - NE

South Breach, looking Northeast

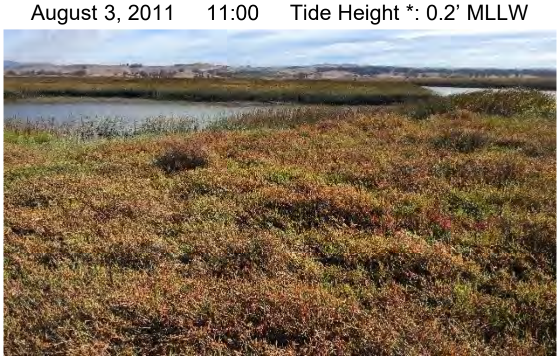


April 6, 2007 12:30 Tide Height : 3.1' MLLW

April 8, 2008 9:30 Tide Height : -0.5' MLLW

July 23, 2009 11:15 Tide Height : -0.8' MLLW

August 3, 2011 11:00 Tide Height *: 0.2' MLLW



September 21, 2016 10:00 Tide Height *: 2' MLLW

PBM 2 - NW

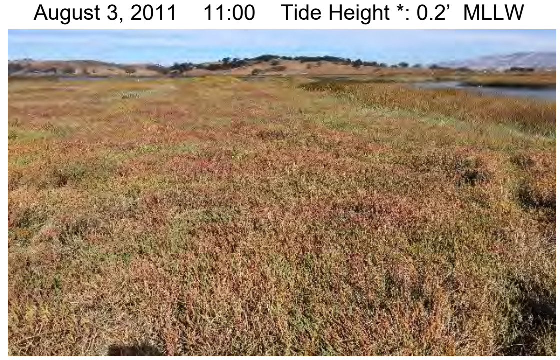
South Breach, looking Northwest

April 6, 2007 12:30 Tide Height : 3.1' MLLW

April 8, 2008 9:30 Tide Height : -0.5' MLLW

July 23, 2009 11:15 Tide Height : -0.8' MLLW

August 3, 2011 11:00 Tide Height *: 0.2' MLLW



September 21, 2016 10:00 Tide Height *: 2' MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

Photo Benchmarks PBM 2-NE,NW: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

PBM 2 - SE

South Breach, looking Southeast

April 6, 2007 12:30 Tide Height : 3.1’ MLLW

April 8, 2008 9:30 Tide Height : -0.5’ MLLW

July 23, 2009 11:15 Tide Height : -0.8’ MLLW

August 4, 2011 11:00 Tide Height *: 0.2’ MLLW

September 21, 2016 10:00 Tide Height *: 2’ MLLW

PBM 2 - SW

South Breach, looking Southwest

April 6, 2007 12:30 Tide Height : 3.1’ MLLW

April 8, 2008 9:30 Tide Height : -0.5’ MLLW

July 23, 2009 11:15 Tide Height : -0.8’ MLLW

August 4, 2011 11:00 Tide Height *: 0.2’ MLLW

September 21, 2016 10:00 Tide Height *: 2’ MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

Photo Benchmarks PBM 2-SE,SW: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

PBM 3 - NW

Southern West Levee, looking Northwest

April 6, 2007 16:00 Tide Height : 5.9’ MLLW

April 8, 2008 10:00 Tide Height : -0.8’ MLLW

July 23, 2009 9:15 Tide Height : -0.9’ MLLW

August 4, 2011 13:45 Tide Height *: 1.9’ MLLW

September 21, 2016 12:00 Tide Height *: 1.5’ MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

Photo Benchmarks PBM 3-NW: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

PBM 4 - NW

Northern West Levee, looking Northwest

April 6, 2007 12:00 Tide Height : 2.8' MLLW

April 8, 2008 10:45 Tide Height : -0.9' MLLW

July 23, 2009 10:00 Tide Height : -1.0' MLLW

August 4, 2011 13:30 Tide Height *: 1.6' MLLW

September 21, 2016 12:00 Tide Height *: 1.5' MLLW

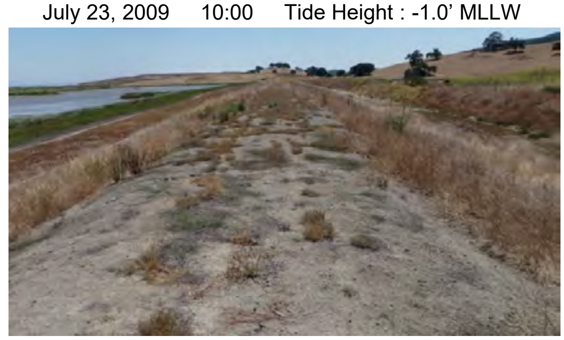
PBM 4 - SE

Northern West Levee, looking Southeast

April 6, 2007 12:00 Tide Height : 2.8' MLLW

April 8, 2008 10:45 Tide Height : -0.9' MLLW

July 23, 2009 10:00 Tide Height : -1.0' MLLW



August 4, 2011 13:30 Tide Height *: 1.6' MLLW

September 21, 2016 12:00 Tide Height *: 1.5' MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

Photo Benchmarks PBM 4-SE,SW: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

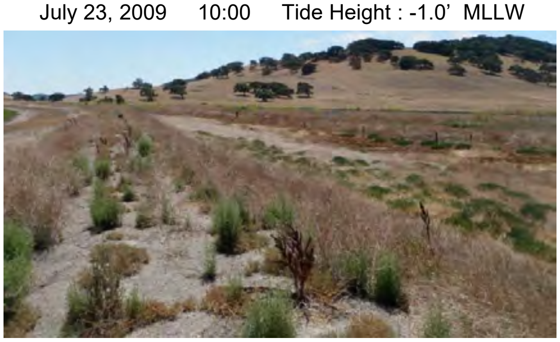
PBM 5 - S

Northern West Levee, looking South

April 6, 2007 12:00 Tide Height : 2.8' MLLW

April 8, 2008 10:45 Tide Height : -0.9' MLLW

July 23, 2009 10:00 Tide Height : -1.0' MLLW



August 4, 2011 13:30 Tide Height *: 1.6' MLLW

September 21, 2016 14:00 Tide Height *: 3' MLLW

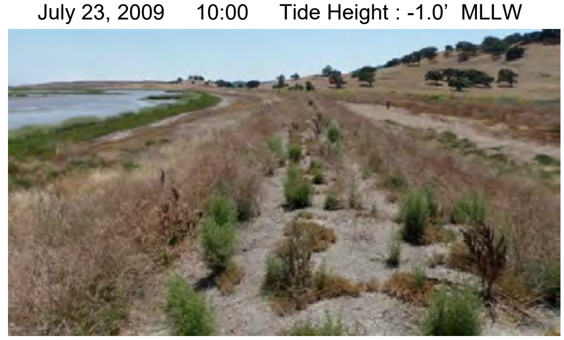
PBM 5 - SE

Northern West Levee, looking Southeast

April 6, 2007 12:00 Tide Height : 2.8' MLLW

April 8, 2008 10:45 Tide Height : -0.9' MLLW

July 23, 2009 10:00 Tide Height : -1.0' MLLW



August 4, 2011 13:30 Tide Height *: 1.6' MLLW

September 21, 2016 14:00 Tide Height *: 3' MLLW

Tide stage from NOS Hog Island, San Antonia Creek Station (9415344)

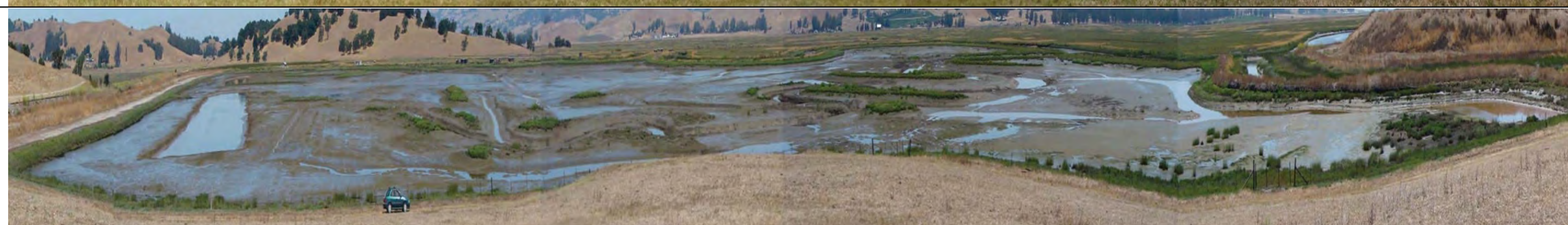
Photo Benchmarks PBM 5-S,SE: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

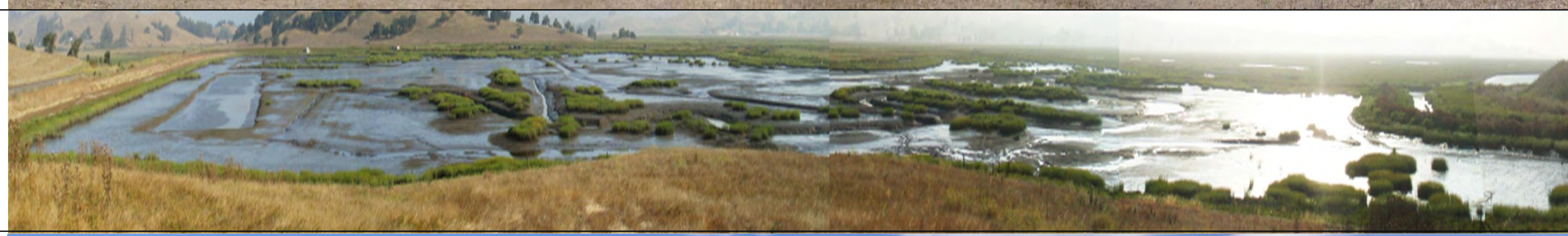
PBM 6
January 25, 2007

PBM 6
April 8, 2008

PBM 6
July 24, 2009



PBM 6
August 18, 2011



PBM 6
September 21, 2016

Note: vertical exaggeration: 150%

Photo Benchmark PBM 6: 2007-2016

Photo sources: PWA (2007, 2008, 2009), WWR (2011); SE (2016)

APPENDIX E. JUNE 2017 LEVEE CONDITION PHOTOGRAPHS

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Western levee and constructed bench. Looking North

Levee crown, looking south

Example of minor surface cracking observed on levee crown

Wetland depression along eastern levee toe at the north end

APPENDIX F. JANUARY 2010 PHOTOGRAPHS OF CONSTRUCTED WESTERN LEVEE

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Northern section of levee bench facing south. Photo Credit: Diana Benner (1/28/10)

Southern section of levee bench facing north. Photo Credit: Diana Benner (1/28/10)