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Review of Dredged Volumes in the 2016-2017 Dredging Season

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Glossary

DEM	Digital Elevation Model
MLLW	Mean Lower Low Water Datum
M&N	Moffat & Nichol
SCPD	Santa Cruz Port District
USACE	US Army Corps of Engineers

ES. Executive Summary

The Santa Cruz Port District (SCPD) has retained Moffatt & Nichol (M&N) to investigate inconsistencies found between the total dredged volume for the 2016-2017 season, based on data from a slurry density meter installed on their new dredge *Twin Lakes,* and historical dredged volumes, that prior to the 2016-2017 season were estimated using pump curve assumptions.

For this study, M&N analyzed selected bathymetric surveys of the Santa Cruz Harbor entrance during the 2016-2017 dredging season, as well as bathymetric surveys from control dredging operations, in order to relate survey volumes to records from the slurry density meter. Additionally, a high-level review of the coastal processes for the same period was conducted to rule out potential anomalies to which low dredging production could be attributed.

The main findings from this study are summarized below:

- Analysis of offshore wave climate does not give an indication that the incident wave energy during the 2016-2017 dredging season was so low as to have resulted in abnormally low sedimentation at the harbor entrance.
- The dredged volume analysis for the 2016-2017 season was inconclusive, as large inconsistencies were found between surveyed and density meter volumes. These inconsistencies were primarily attributed to insufficient bathymetric data coverage over the dredged areas, uncertainties related to changes in bed elevation due to ongoing sedimentation, and operation of the density meter sensor.
- Survey volume estimates for the *control* dredging survey operations conducted in April 2018, were found to be consistently larger (at least twice) than the density meter volumes.
- Despite the minimized uncertainties in the *control* data, a poor correlation (R^2=44%)was found between the density meter volumes and the survey volumes.
- Underestimation of dredging production by the density meter appears to be related to inadequate operation of the equipment sensor. M&N recommends conducting an inspection to ensure that the density meter sensor is properly installed and calibrated.
- An average dredge production rate of 250 cubic yards per hour was estimated based on the surveyed dredged volumes for the *control* operations. This yields an estimated seasonal volume of 134,243 cubic yards, which is twice the total volume recorded by the density meter for the 2016-2017 season.

1. Introduction

The Santa Cruz Port District (SCPD) has retained Moffatt & Nichol (M&N) to investigate inconsistencies found between the total dredged volume for the 2016-2017 season, based on data from a slurry density meter installed on their new dredge *Twin Lakes,* and historical dredged volumes, that prior to the 2016-2017 season were estimated using pump curve assumptions.

The scope of this study included the following:

- Analysis of pre-dredging and post-dredging bathymetric surveys.

  Selected bathymetric surveys conducted by the SCPD during the 2016-2017 dredging season, as well as bathymetric surveys from control dredging operations, were analyzed to estimate daily dredged volumes at the harbor entrance.

- Review of coastal processes during the 2016-2017 dredging season.

  Publicly available wave data from the region was analyzed to rule out potential anomalies that could lead to abnormal shoaling rates at the harbor entrance channel.

1.1. Background

1.1.1. General

Dredging to maintain navigation in the Santa Cruz Harbor has been conducted since 1965, only one year after construction activities for the harbor were completed. Maintenance dredging operations were accomplished by the US Army Corps of Engineers (USACE) through contracts with private dredging operations until 1986, when operational dredging responsibilities for the harbor where assumed by the SCPD.

The floating hydraulic dredge *Seabright* was acquired by the SCPD and first put into service in 1986. This dredge served annual maintenance dredging operations at the harbor entrance, generally conducted from November to April, for 30 years. *Seabright* conducted its last dredging operations during the 2015-2016 dredging season.

Starting from the 2016-2017 season, dredging at the harbor entrance is being conducted with the new dredge *Twin lakes* (Figure 1), acquired by the SCPD in 2016 and custom-designed for the Santa Cruz Harbor. The operation mechanism in *Twin lakes* is similar to that in *Seabright*: A suction nozzle (taken from *Seabright*) is lowered to the seabed and agitates sediment into a slurry assisted by water jets. The slurry is then suctioned by means of an 803 horsepower tier III Caterpilar engine and discharged to a desired location through a plastic pipe. However, new features have been introduced in *Twin lakes*, such as a slurry density meter that records dredging production rates.

Figure 1 *Twin Lakes* Dredge

1.1.2. Historical Dredged Volumes

Total dredged volumes at the Santa Cruz Harbor entrance for seasons 1986-1987 to 2015-2016 (estimated based on pump curve assumptions) are plotted in Figure 2. During *Seabright's* operational life, total dredged volumes averaged 240,00 cubic yards per season. Seasons with abnormally large dredged volumes (i.e. equal or above 400,00 cubic yards) include 1997-1998, 2009-2010, and 2015-2016. These peaks coincide with periods of increased storm occurrence during El Niño events (particularly strong for the 1997-1998 and 2015-2016 winters), and required the dredging season to be extended beyond the regular November -April period. Meanwhile the smallest volumes i.e. 102,000 cubic yards and 112,000 cubic yards, where dredged during the 1995-1996 and 2013-2014 seasons, respectively.

The total dredged volume at the harbor entrance for the 2016-2017 season, as recorded by the new slurry density meter was about 65,000 cubic yards. This volume represents about 27% of the historic seasonal average mentioned above. Figure 3 plots daily dredged volumes at the harbor entrance for the season.

Disregarding downtimes due to maintenance and/or repairs, a total of 100 dredging events were conducted. Larger dredging was consistently recorded during November and December 2016, with daily dredged volumes in the range of 300 cubic yards up to around 3,000 cubic yards. Several days of unusual low dredging (i.e. below 50 cubic yards per day) were recorded during the first three months of 2017, while about half of the dredging days in April and March recorded volumes of 100 cubic yards and lower.

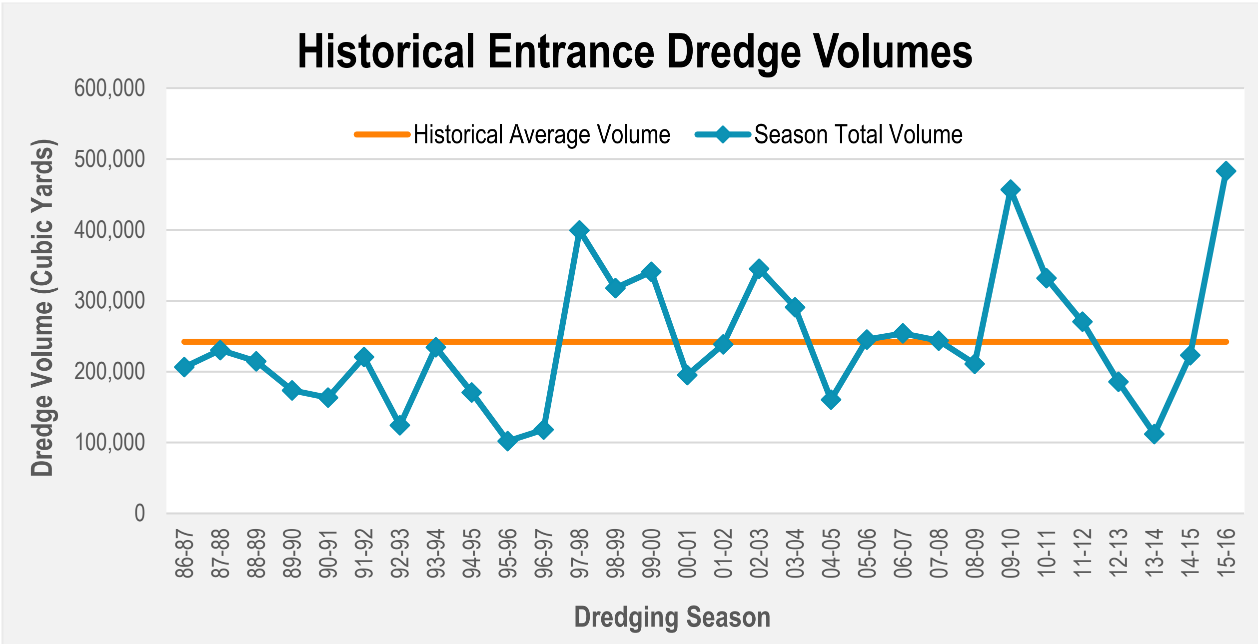


Figure 2 Historical Dredged Volumes at the Harbor Entrance

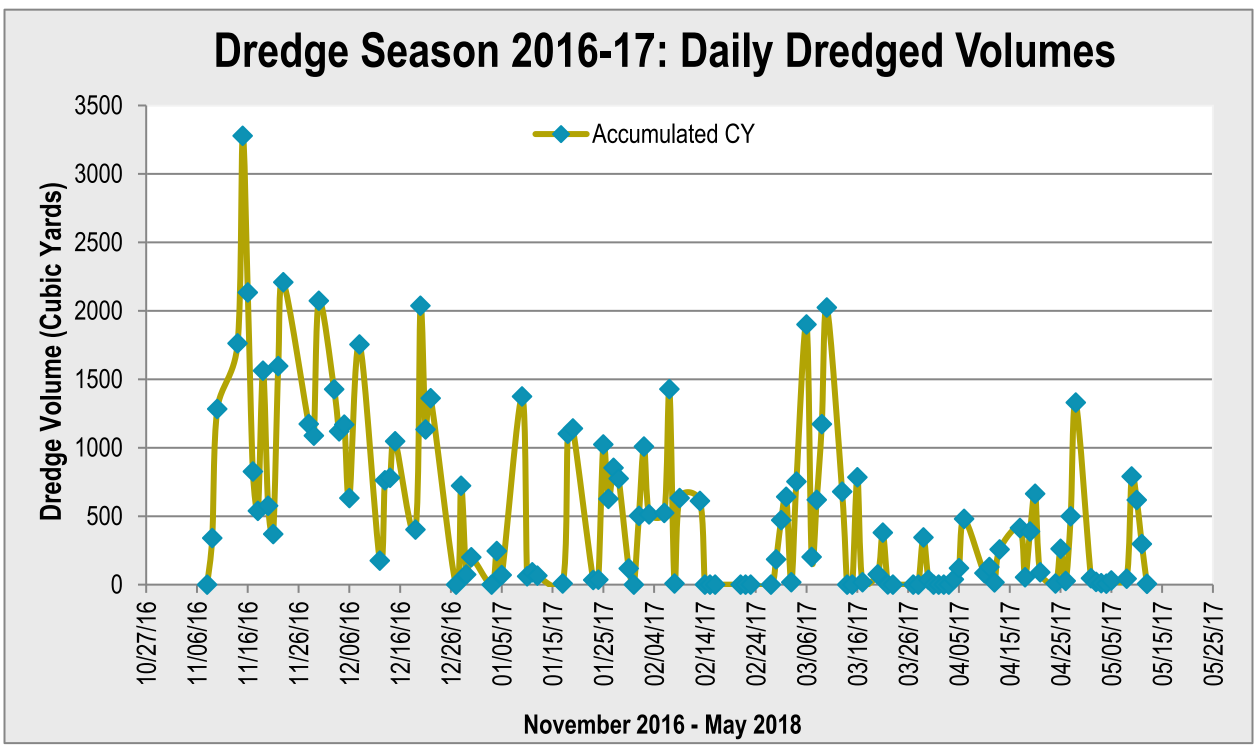


Figure 3 Daily Dredged Volumes for the 2016-2017 Season

2. Review of Coastal Processes May-November 2016

Sediment transport around the Santa Cruz Harbor, and shoaling at its entrance is predominantly driven by wave-induced in the nearshore area. For a better understanding of wave processes in the region, a wave rose summarizing annual statistics of wave height and direction offshore of Monterey Bay, is provided in Figure 4. The offshore wave climate is strongly dominated by seas and swells approaching from the west-northwest and northwest directions approximately 75% of the time during the year, with typical wave heights ranging from 6 to 12 feet (depicted with green colors in Figure 4.

Seasonal variations in the wave climate is observed with the highest and longest swells, approaching during the winter months, and lower and shorter locally generated seas occurring around the summer months. With the exception of a southerly swell component observed rarely during the summer, wave incidence from the west to northwest sectors prevails throughout the year.

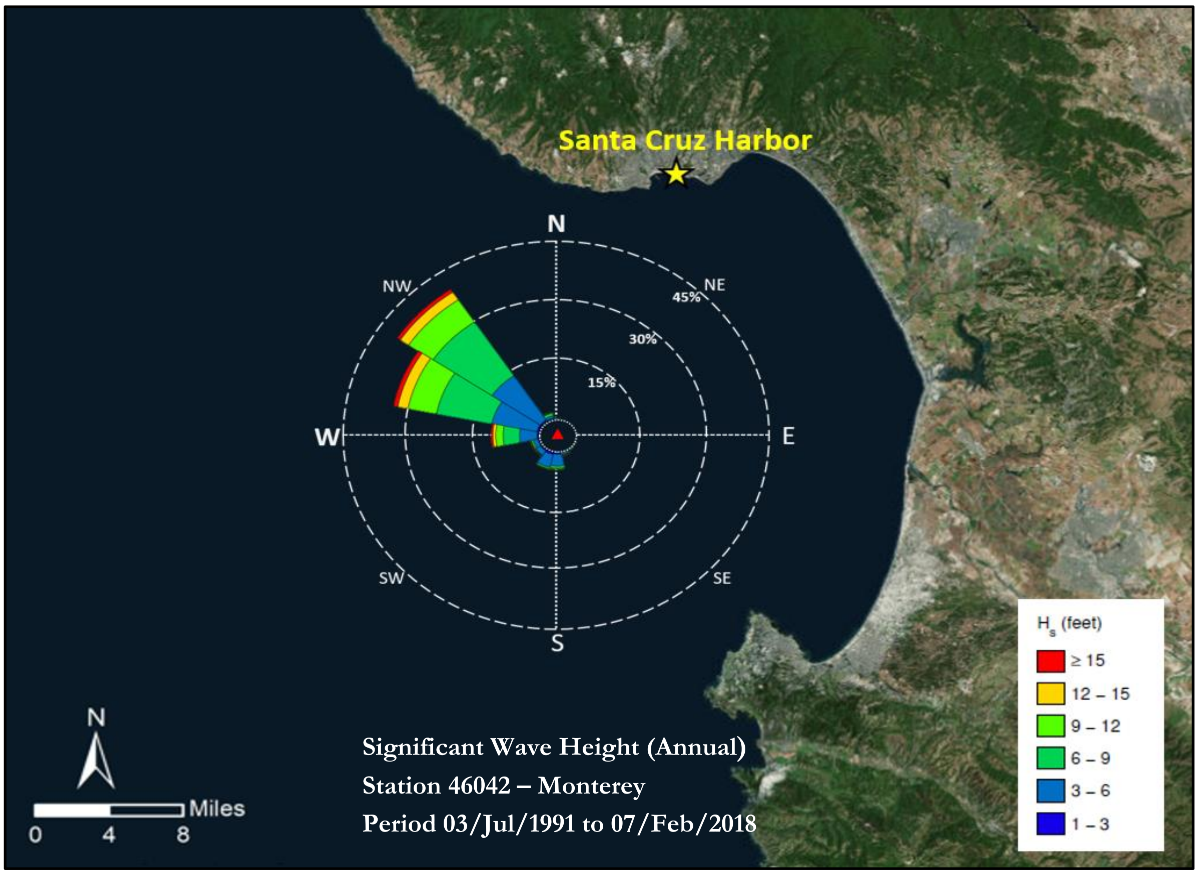


Figure 4 Annual Wave Rose for Offshore Monterey Bay (NOAA, 2016. Wave Buoy 46042)

Closer to shore, waves break and generate currents capable of mobilizing sediment along the coast. Predominance of northwesterly wave incidence throughout the year results in large occurrence of currents that flow from northwest to southeast along the northern coast of Monterey Bay, consequently leading to a net transport of sediment in the same direction (Figure 5). Due to the orientation of the shoreline at the location of the Santa Cruz Harbor, the net sediment transport direction is from west to east.

Net longshore sediment transport at the location of the harbor has been estimated to average between 200,000 to 250,000 cubic yards per year (Griggs, 1991). This transport is the primary mechanism for shoaling at the harbor entrance, as sand by-passes the west jetty (Figure 5) and deposits in the navigation channel.

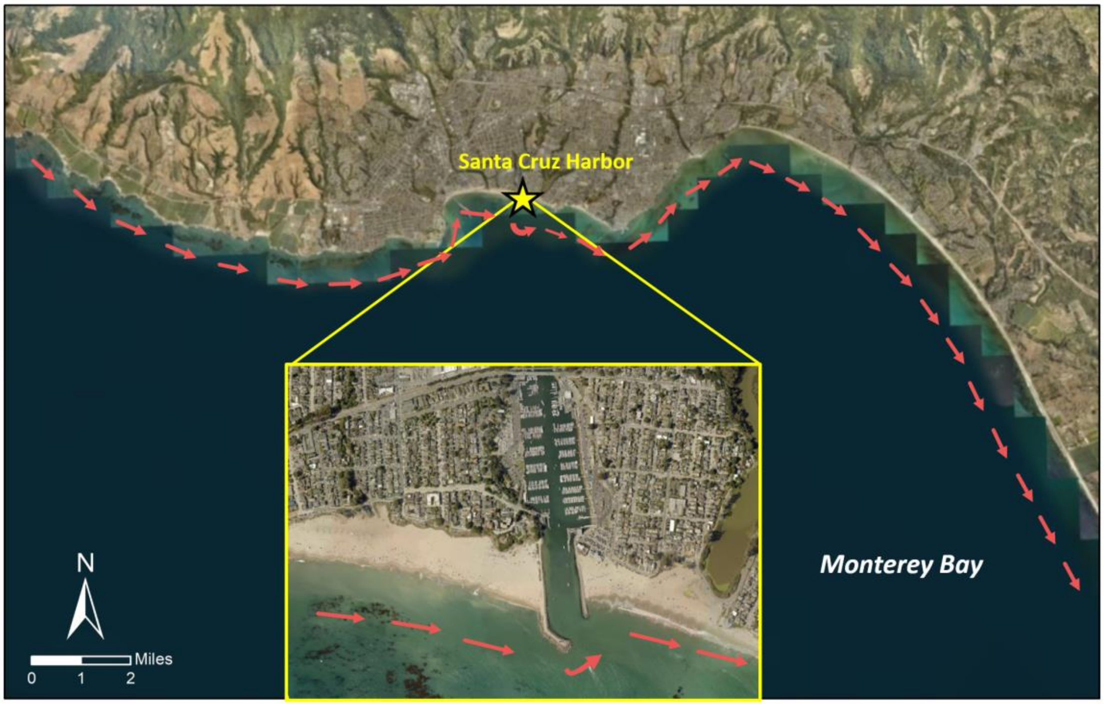


Figure 5 Net Sediment Transport Direction in Northern Monterey Bay

Most of the shoaling at the Santa Cruz Harbor entrance occurs during the winter and early spring (about 80%, per USACE, 1992), when high energy storms are most frequent. Historical survey records indicate that rapid shoaling can occur in very short periods during these months. As an example, the entrance channel shoaled 5 to 10 feet in a 12-day period in the winter of 2010 (M&N, 2011). This requires dredging operations to be prolonged through the winter, as opposed to a one-time dredge episode for the entire entrance channel.

For this study, the wave climate during the 2016-2017 winter was assessed with respect to that during representative winters, in order to identify potential anomalies leading to low siltation rates at the harbor entrance, that could help explain the low recorded production during this season.

Since the intensity of the longshore current, and hence the magnitude of the longshore sediment transport is related to the height of waves at the moment of breaking (i.e. the higher the waves, the higher the current velocity and the sediment transport capacity), the analysis consisted of a comparison of wave height and storm frequency during each winter.

Offshore wave height data (assumed to remain proportional to the nearshore breaker height) was analyzed from the 30-year wave record from NOAA-NDBC station 46042 (Monterey), located approximately 19 miles southwest of the Santa Cruz Harbor (location depicted with a red triangle in Figure 4). A storm wave height threshold (i.e. 18 feet) was defined as the wave height exceeded by only 0.5% of the incident waves.

Figure 6 compares the recorded offshore significant wave height (H_s, depicted with black curves) during the 2016-2017 dredging season, to that during the 1995-1996 and 2013-2014 seasons, i.e. the seasons with the lowest historical dredged volume (see Figure 2). Lower wave heights are especially apparent for the 2013-2014 records (center plot Figure 6). During this winter the offshore H_s remained below 10 feet approximately 85% of the time. Somewhat higher waves were observed for the 1995-1996 (top plot) and 2016-2017 (bottom plot) winters, with wave heights below 10 feet around 75% of the time and 70% of the time, respectively. A more remarkable difference between the 1995-1996 and 2013-2014 H_s records, with respect to the 2016-2017 winter is found in the occurrence of extreme storm events, often responsible for high shoaling rates at the Santa Cruz

Harbor entrance. Eight storm events were recorded during the 2016-2017 dredging season, while only 3 occurred during both the 1995-1996 and 2013-2014 seasons.

As an additional comparison, the offshore H_s recorded during dredging seasons with the highest historical dredged volumes is depicted in Figure 7. A total of ten and thirteen storms were recorded during the 2009-2010 and 2015-2016 dredging seasons (center and bottom plots), respectively. While the offshore wave buoy experienced downtime during the 1997-1998 winter (recording only two storm events in early October 1997, as shown in the top plot), a similar analysis performed on the data set for an offshore buoy located off the coast of San Francisco (NOAA NDBC Station 46026) indicated occurrence of 15 storm events during this winter.

Although the amount of shoaling at the harbor entrance is not exclusively related to the incident wave climate, and furthermore, even though a more detailed analysis would be required to determine the actual wave conditions occurring around the harbor, this analysis does not give an indication that the incident wave energy during the 2016-2017 dredging season was sufficiently low to explain the abnormally small recorded dredged volumes during that season.

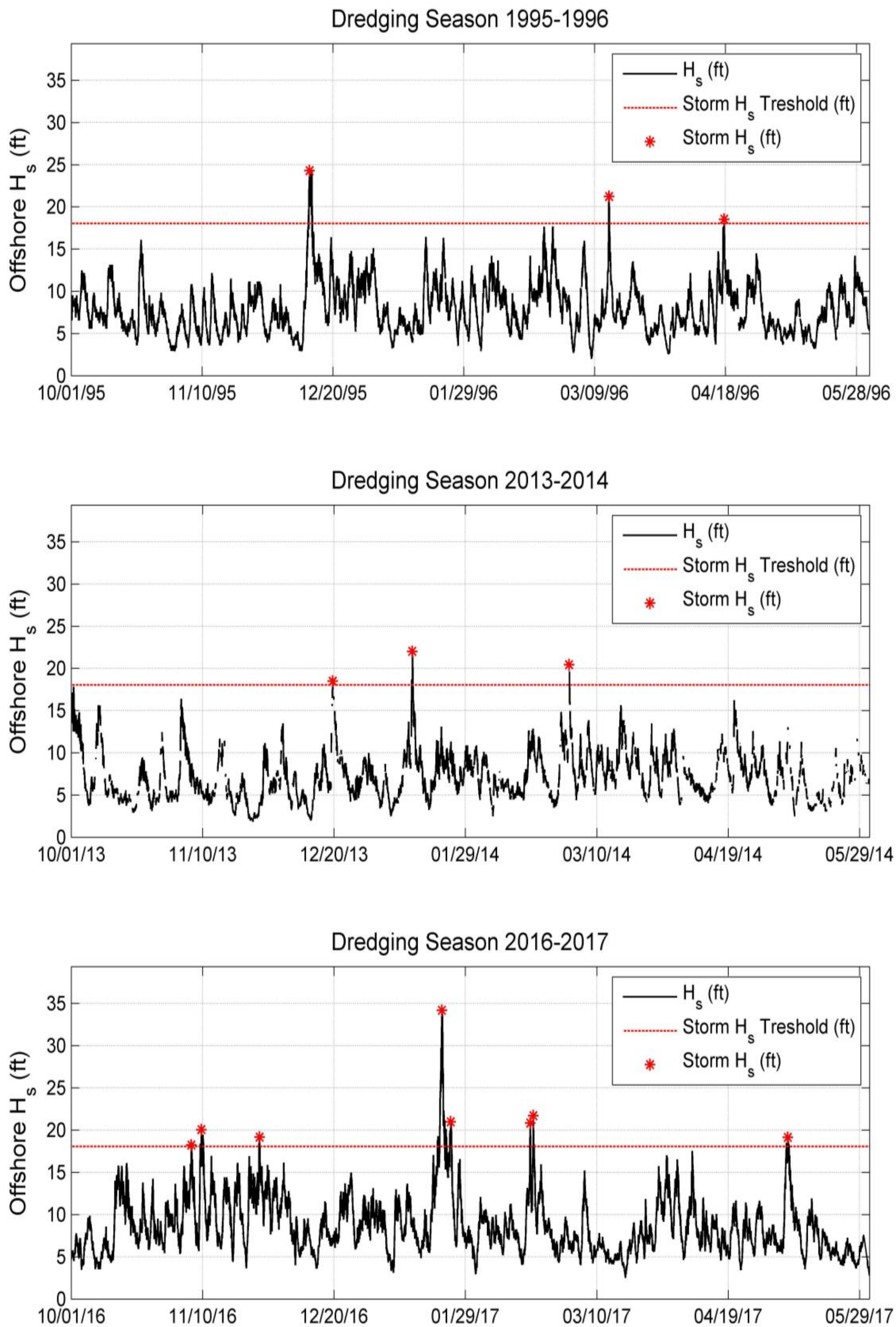


Figure 6 Offshore Significat Wave height (Hs) during the 1995-1996, 2013-2014 and2016-2017 Dredging Seasons

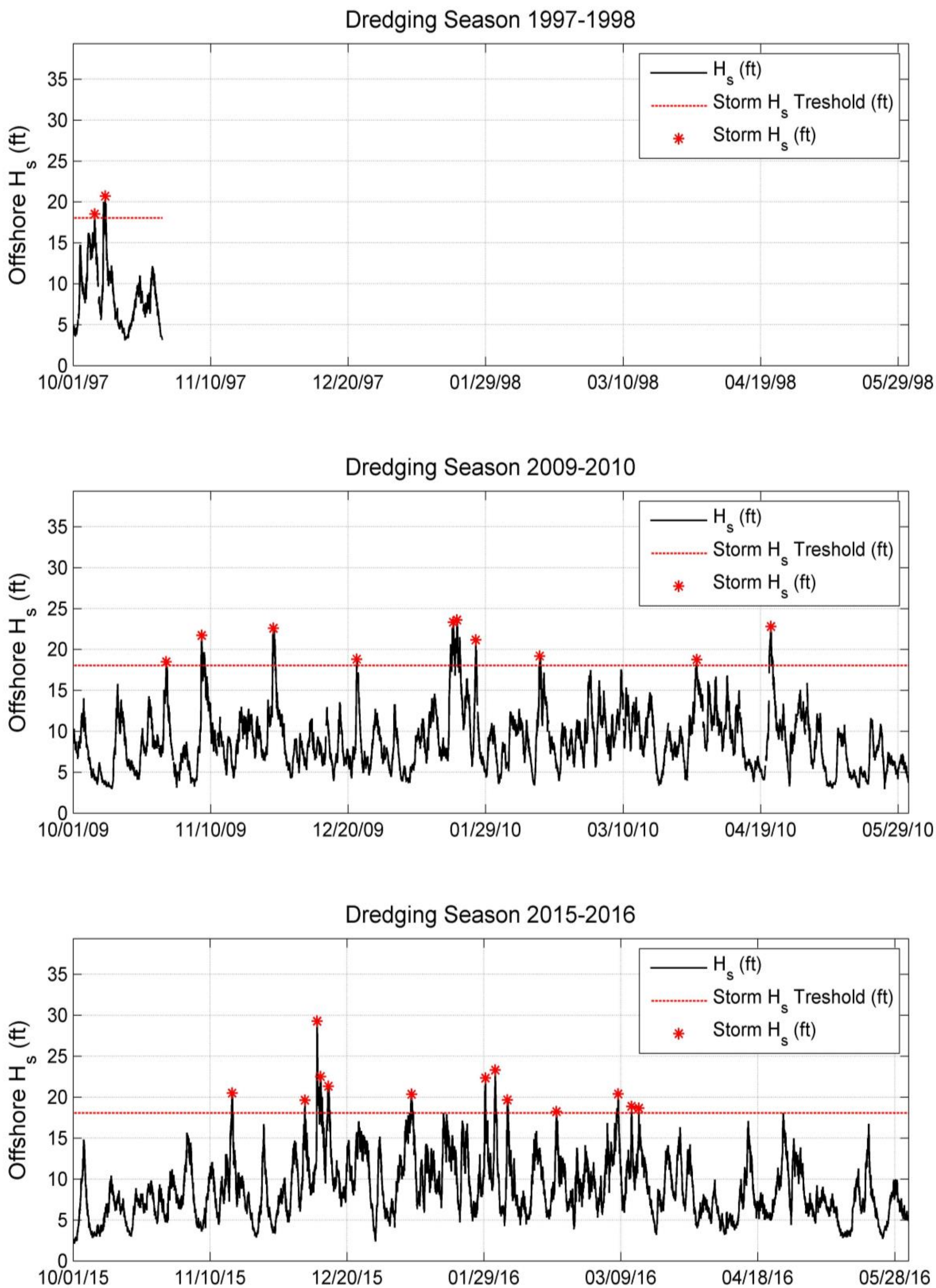


Figure 7 Offshore Significat Wave height (Hs) during the 1997-1998, 2009-2010 and 2015-2016 Dredging Seasons

3. 2016-2017 Dredged Volume Estimate

3.1. Dredging Quadrants

For operational purposes, the Santa Cruz Harbor entrance has been divided into stations and quadrants. Figure 8 shows the quadrant arrangement (per the SCPD dredging operations manual) at the harbor entrance, which comprises 16 stations (starting from station 09+00, at the north) and 47 quadrants.

The federal navigation channel is authorized at 20 feet below Mean Lower Low Water (MLLW) from station 24+00 at the southern reach, to station 14+00 within the channel (central quadrants in stations 11+00 to 20+00, and quadrants7,4, and 1 southwards.). High shoaling rates during the winter storm season usually do not allow a steady-state condition at the authorized depths, however dredging operations strive to maintain a minimum depth of 14 feet (MLLW) in the channel.

The operational approach to conduct maintenance dredging at the harbor entrance is determined weekly and daily by the SCPD staff in a manner compliant with the different dredging permits issued by state and federal agencies. During the 2016-2017 season, dredging was focused on the southern reach of the entrance, especially on the west and central quadrants in stations 15+00 to 20+00, where most of the shoaling occurs. Dredging was typically conducted in two quadrants per dredging day, with the exception of a few days, where dredging was required over a broader area.

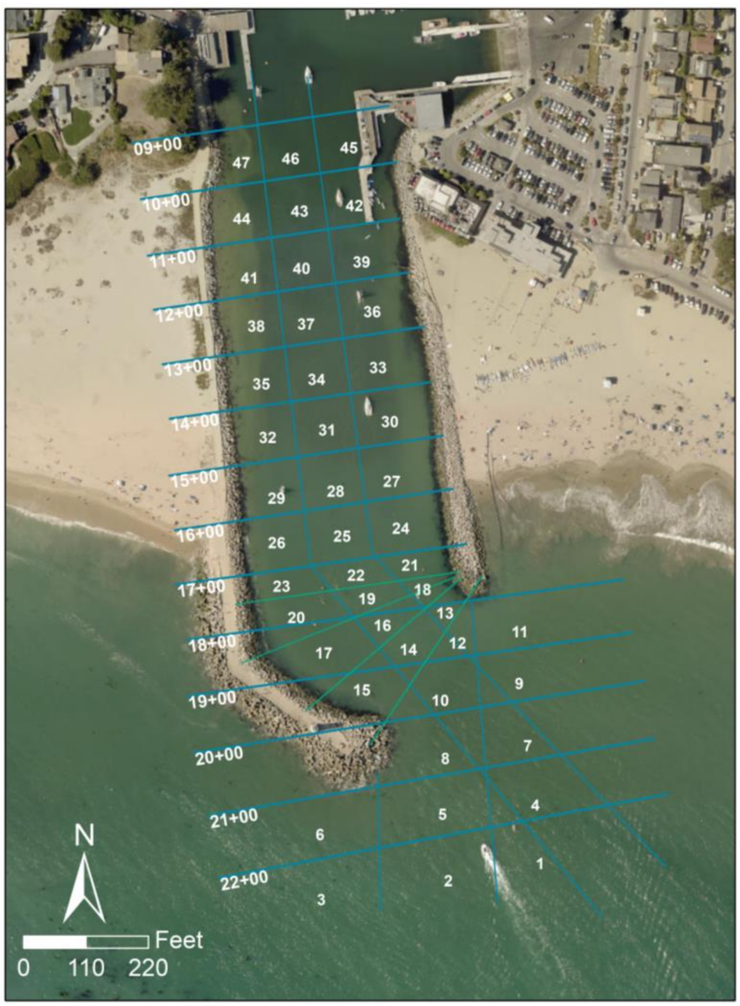


Figure 8 Dredging Quadrants for Harbor Entrance (recreated from Santa Cruz Harbor District, 2014)

3.2. Volume Estimate Methodology

The SCPD conducts bathymetric surveys of the harbor entrance channel on a regular basis. Selected surveys conducted during the 2016-2017 dredging season, representing pre-dredging and post-dredging conditions were analyzed with the purpose of estimating daily dredged volumes.

Prior to computation of volumes, bathymetric survey data was used to develop Digital Elevation Models (DEM) of the Santa Cruz Harbor entrance. Subsequently, a *cut and fill* volume analysis was conducted in AutoCAD Civil 3D. This analysis consisted in computing the volume between a *base* Digital Elevation Model (DEM) and a subsequent *comparison* DEM, representing pre-dredge and post-dredged conditions, respectively.

Although *cut and fill* volumes were estimated throughout the extent of the compared DEMs, daily dredged volume estimates were exclusively related to the *cut* volumes computed at and around the areas where dredging was conducted. Table 1 provides a list of the bathymetric surveys used in the analysis, and the quadrants dredged during each of the dredging events.

Table 1 Bathymetric Surveys Analyzed to Estimate Daily Dredged Volumes.

No.	Dredging Event	Dredged Quadrants	Pre-Dredge Survey Completion	Post-Dredge Survey Completion
1	November 21, 2016	14,15,16,17	11/21/2016 7:00	11/22/2016 07:00
2	November 28, 2016	14,29	11/28/2016 7:00	11/29/2016 08:30
3	December 5, 2016	32,29	12/5/2016 12:00	12/6/2016 07:20
4	December 6, 2016	12,13,14,16,18,19,22,25	12/6/2016 7:20	12/7/2016 12:30
5	December 12, 2016	32,29	12/12/2016 7:00	12/13/2016 8:30
6	January 3, 2017	22,17	1/3/2017 12:00	1/4/2014 15:00
7	February 27, 2017	29,17	2/27/2017 11:00	2/28/2017 8:30
8	April 10, 2017	31,27	4/10/2017 07:00	4/11/2017 12:00
9	May 2, 2017	31	5/1/2017 16:00	5/2/2017 18:00

3.1. Results

Results of the survey analysis are summarized in Table 2 and Figure 9, where the survey volume estimates are compared to density meter volumes. Out of the analyzed cases, only four yielded a survey volume higher than the density meter volume (see blue points above the orange curve in Figure 9). Additionally, good correlation was not found between the two data sets (correlation for best fit curve was only 27%).

Table 2 Dredged Volume Comparison: Density Meter vs Survey Volumes, 2016-2017

No.	Dredging Event	Density Meter Daily Production (CY)	Survey Volumes (CY)
1	November 21, 2016	1,597	1,347
2	November 28, 2016	1,087	606
3	December 5, 2016	632	134
4	December 6, 2016	1,754	4,264
5	December 12, 2016	762	401
6	January 3, 2017	245	931
7	February 27, 2017	184	106
8	April 10, 2017	129	471
9	May 2, 2017	10	729

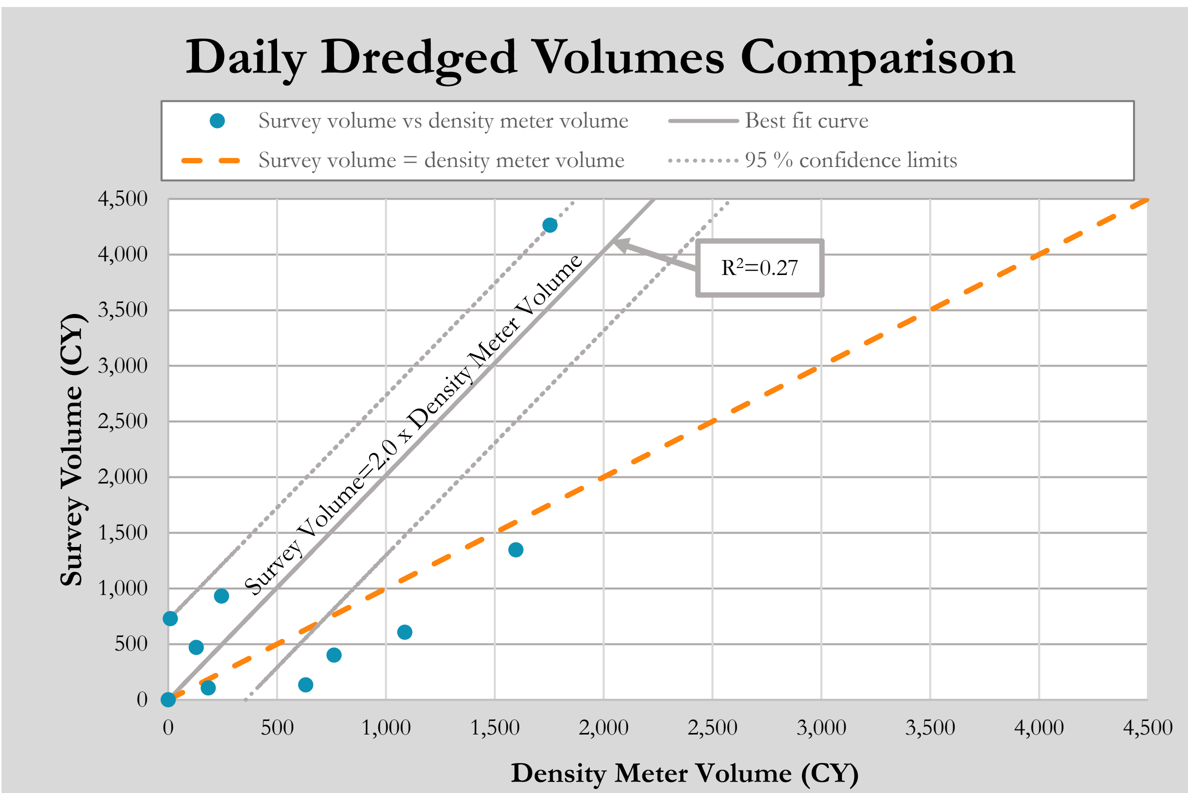


Figure 9 Dredged Volume Comparison: Density Meter vs Survey Volumes, 2016-2017

The main limitations and sources of uncertainties for this analysis are discussed below:

1) <u>Time span between pre-dredge and post-dredge survey.</u>
   Sediment transport around the Santa Cruz Harbor is well known to occur at high rates. Especially during the winter storm season, considerable shoaling of the harbor entrance has been observed over periods of only a few days. With such dynamic bed conditions at the harbor entrance, the time span between the pre-dredge and post-dredge surveys and the dredge event itself, introduces a considerable uncertainty as these might not be reflective of the immediate pre-dredge and post-dredge conditions.

To minimize this uncertainty in the analysis, survey volumes were only estimated for dredging events in which the pre-dredge and post-dredge conditions surveys were available with a time span of no more than one day (see Table 1). Typically, post-dredge conditions surveys were available from the morning following each dredging event. Comparison of the pre-dredge and post-dredge condition DEMs suggested that this might already be too long, as considerable changes in bed elevations are typically captured not only around the dredged areas, but also throughout the extent of the DEMs.
As an example, Figure 10 depicts changes in bed elevation between May 01 and May 02, 2017. Darker blue shades representing deepening of 6 to 9 feet, are observed around the dredged area (quadrant 31, enclosed by a yellow square) but also to the north and south, around stations 12+00 and 16+00, respectively. Furthermore, shoaling of around the same magnitude (depicted by the darker red shades) around station 13+00, suggests that the survey volumes estimates are not exclusively related to dredging activities.

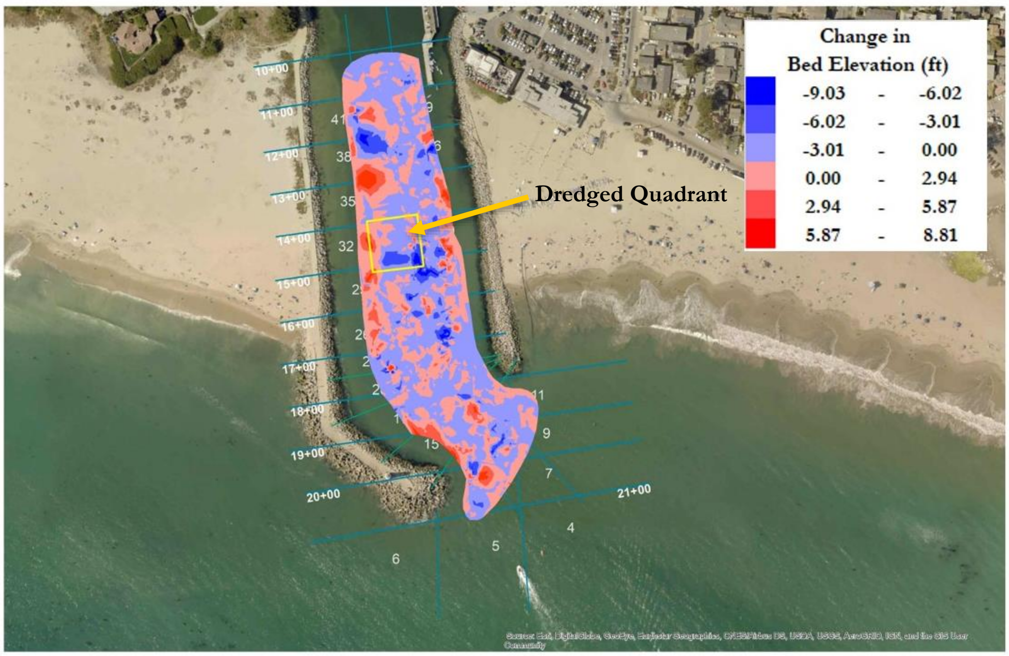


Figure 10 Change in bed elevation between May 01 and May 02, 2017

2) Coverage of data over area of interest.
   A survey volume analysis can only be conducted for overlapping surfaces. Consequently, an adequate data coverage extending beyond the area of interest (i.e. the dredged areas and its surroundings), is required for both the pre-dredge and post-dredge conditions survey. For most of the analyzed cases, data coverage was insufficient, leading to partial estimates of the survey volumes between pre-dredge and post-dredge conditions. This is illustrated in Figure 11, which shows the survey points from soundings conducted on December 05 and December 06, 2016. Better estimates of the dredged volumes could be obtained with a larger spatial data coverage, as pothole dredging triggers changes in bed elevations not only over the dredged area, but also on its surroundings.

3) Uncertainties in interpolation method of a DEM.
   In addition to the discussion provided in *2),* data coverage extending beyond the dredged areas is required for a more accurate estimate of dredged volumes. Edge effects, including distortion and inaccurate interpolation of elevations are common at the boundaries of a DEM. To avoid propagation of these errors into the volume estimates, all DEMs were refined prior to the volume analysis. For many cases, this resulted in a smaller overlap between the compared DEMs. This is depicted in Figure 12, where the survey volume for dredging conducted February 27, 2017 is about 350 cubic yards before refinement of the DEMs (left) and 106 cubic yards after their refinement (right).

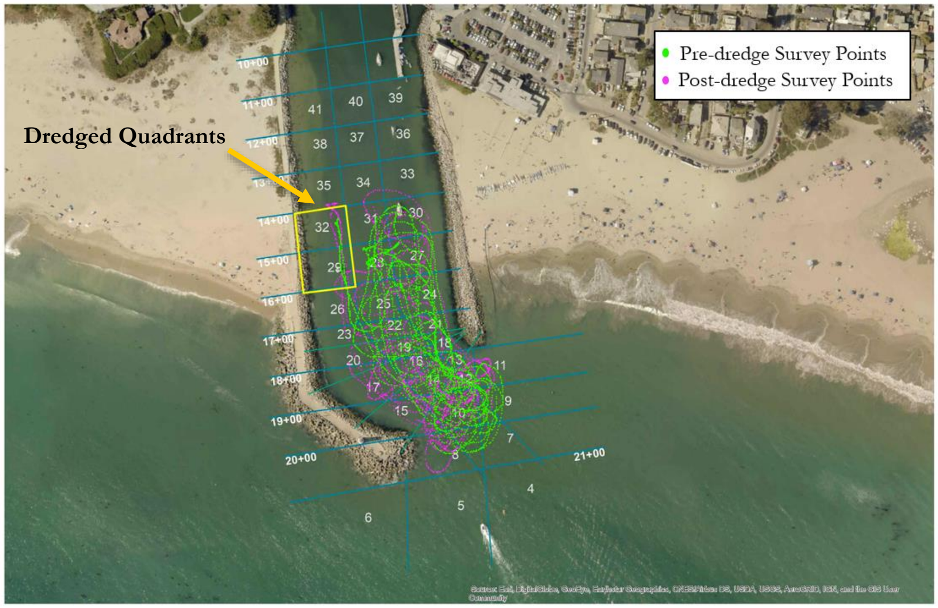


Figure 11 Survey Points for Soundings conducted December 05 and 06, 2016

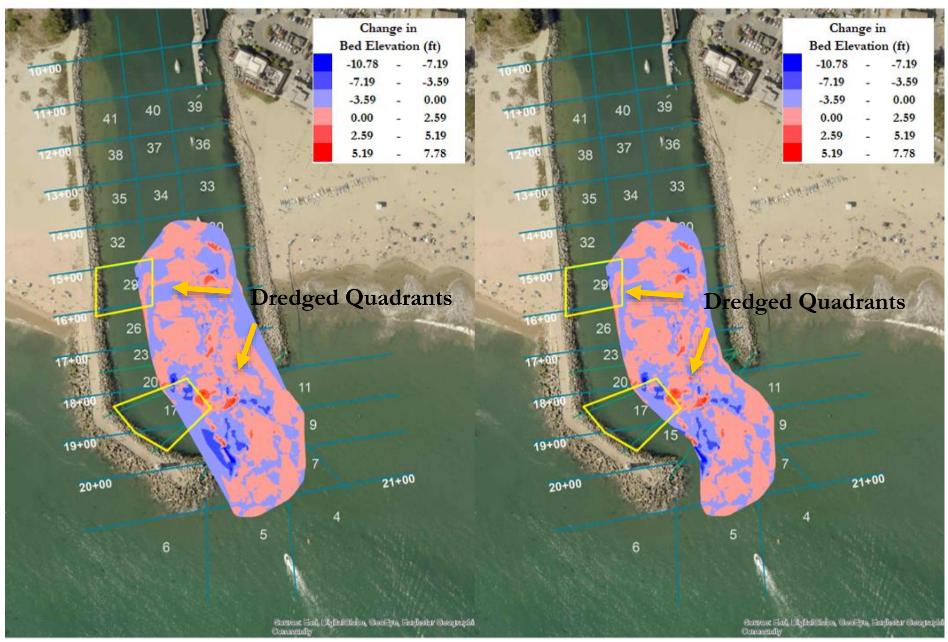
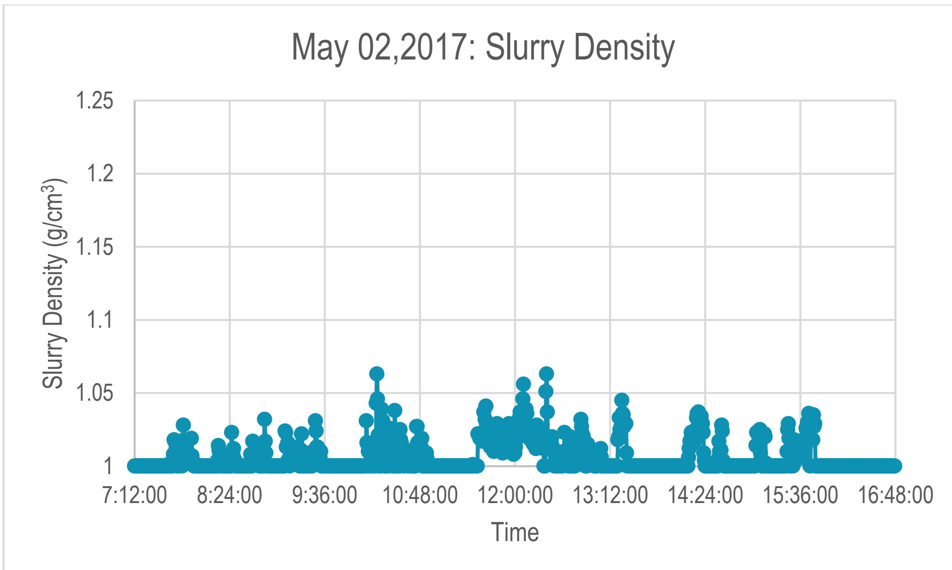


Figure 12 Change in bed elevation between February 27 and 28, 2017: before (left) and after (right) refinement of DEMs

Detailed results of the survey analysis are provided in Appendix A. Although no correlation was found between the density meter volumes and survey volume estimates, owed primarily to the reasons discussed above, there is an indication of survey volumes being more than twice the density meter volumes for those cases in which there was adequate data coverage in at least one of the dredged quadrant areas (December 06 2016; January 03 2017, April 10 2017, and May 02 2017). This suggests an underestimation of the dredge production by the slurry density meter.

Examination of the slurry density meter data confirms that the underestimation in the production rates are consistently related to low density readings, as velocity and flow rate readings appear to be within the expected range. The plots in Figure 13 show slurry density and velocity as recorded by the density meter. Throughout the 6.5 hours in which dredging operations took place, densities of no more than 1.06 g/cm^3 were recorded. Implying an almost exclusively intake of water (seawater density 1.025 g/cm^3) during the entire dredging operation for that day.

A common reason for underestimation of densities by slurry density meters is an inadequate positioning of the equipment sensor (Rhosonics, 2018),but depending on the type pf meter could be due to other operational issues.



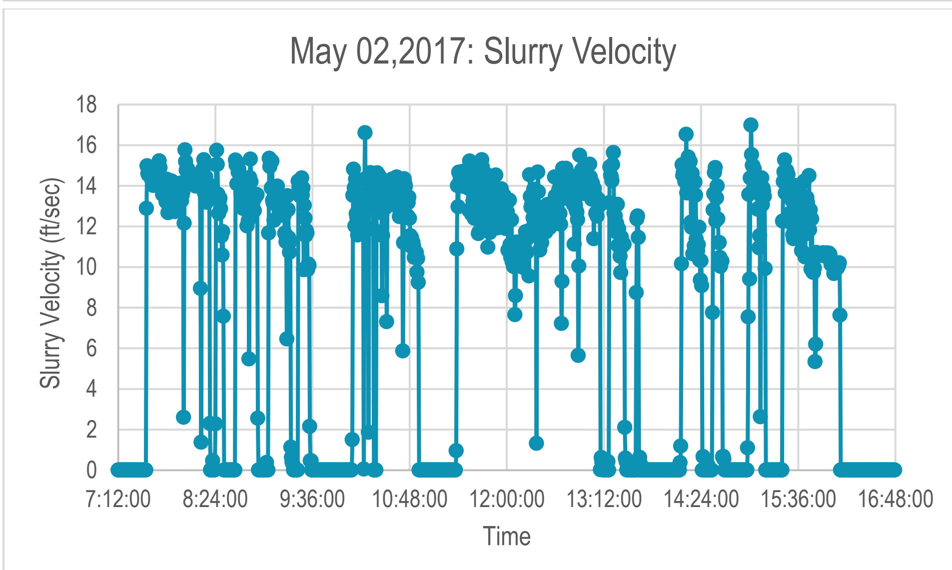


Figure 13 Slurry Density Meter Data for May 02,2017: Slurry Density (Top) and Velocity (Bottom)

4. Dredged Volume Estimates on Control Operations

Based on the findings and conclusions drawn from the estimation of dredged volumes over the 2016-2017 season, M&N recommended that the SCPD performed a number of *control* dredge and survey operations to minimize the uncertainties in the collected data, and estimate more reliable dredged volumes.

The *control* operations consisted in dredging of quadrants that are less susceptible to wave and/or tidal induced currents which have a potential to redistribute sediment, leading to changes in bed elevations that are unrelated to dredging operations. The quadrants selected for this purpose where thus located far from the harbor entrance, between station 09+00 and station 12+00 (see Figure 8).

Additionally, Pre-dredging condition bathymetric surveys were conducted every morning, right before initiation of dredging activities. Similarly, post-dredging conditions surveys were conducted immediately after termination of the daily dredge operations. Bathymetric data was collected not only for the dredged quadrants, but also for the surrounding areas to ensure that errors related to interpolation of the DEMs were minimized.

Survey volumes were estimated for 4 *control* dredge and survey operations, conducted in April 18th, April 19th, April 23rd and April 24th, 2018. This time, dredged areas were easily identified graphically, as areas with pronounced decrease in bed elevation, indicating that the dredged volumes are well captured in the *control* data. This is illustrated in Figure 14, which depicts the changes in bed elevation after dredging was conducted on April 18, 2018. Detailed results of the survey analysis for the *control* operations are provided in Appendix B.

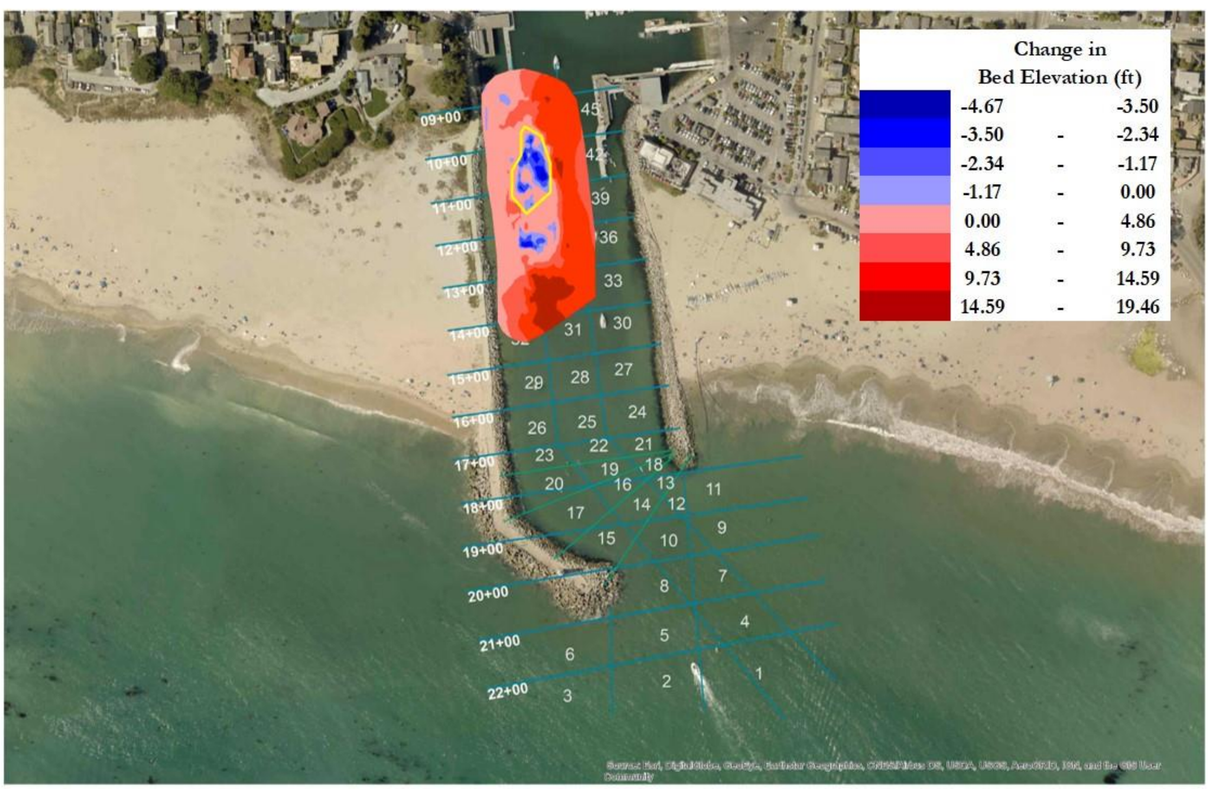


Figure 14 Change in Bed Elevations After Dredging Operation Conducted April 18,2018

Table 3 compares the survey volume estimates from the survey analysis, and the daily dredged volumes recorded by the slurry density meter. A graphic comparison of the data is provided in Figure 15.

Table 3 Dredged Volume Comparison: Density Meter vs Survey Volumes, April 2018

Date	Dredged Quadrants	Density Meter Daily Production (CY)	Survey Volumes (CY)
April 18th, 2018	44,40	16	379
April 19th, 2018	40,39	405	688
April 23rd , 2018	47	168	2,361
April 24th, 2018	47	1,428	2,778

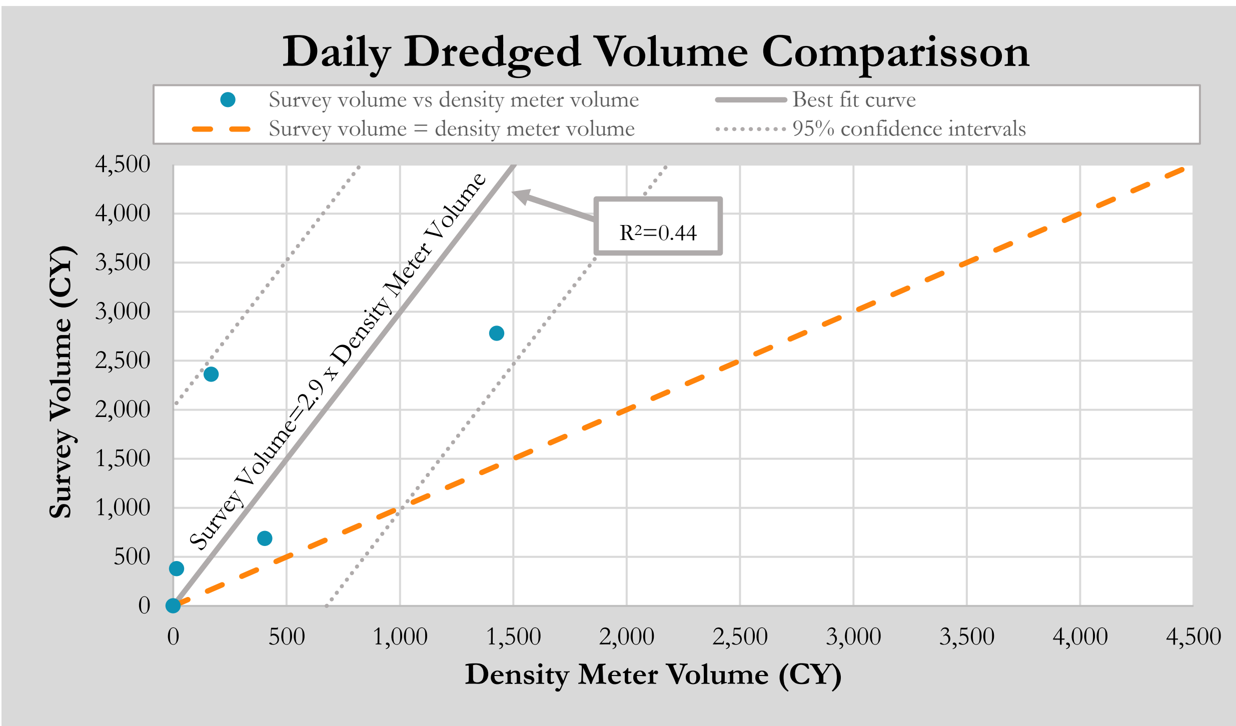


Figure 15 Dredged Volume Comparison: Density Meter vs Survey Volumes, April 2018

Although all volume estimates from the survey analysis are larger than the volumes recorded by the density meter (all blue points are above orange curve in Figure 15), good correlation could not be found between the two (correlation for best fit of 44 %). Underprediction of dredged volumes by the slurry density meter varies from around 50% (April 24th, 2018) up to 4% (April 18th, 2018). M&N therefore recommends conducting an inspection to ensure that the slurry density meter sensor is properly installed and calibrated.

An average production rate of about 250 cubic yards per hour was estimated based on the survey volumes from the 4 *control* operations (see Appendix B). Assuming this as the average production rate of *Twin Lakes*, and accounting for a total of 540 hours during which dredging was conducted, the total dredged volume at the

Santa Cruz Harbor entrance for season 2016-2017 is 134,243 cubic yards, which is twice the total volume recorded by the slurry density meter for the season This number is about 55% of the historic seasonal average, but is well within the range of total volumes reported in previous seasons (483,000 cubic yards – 102,000 cubic yards).

5. Conclusions and Recommendations

The following conclusions can be drawn regarding the investigation of dredged volumes on the Santa Cruz Harbor entrance:

- Analysis of offshore wave climate does not give an indication that the incident wave energy during the 2016-2017 dredging season was so low as to have resulted in abnormally low sedimentation at the harbor entrance.
- The dredged volume analysis for the 2016-2017 season was inconclusive, as large inconsistencies were found between surveyed and density meter volumes. These inconsistencies were primarily attributed to insufficient bathymetric data coverage over the dredged areas, uncertainties related to changes in bed elevation due to ongoing sedimentation, and operation of the density meter sensor.
- Survey volume estimates for the *control* dredging survey operations conducted in April 2018, were found to be consistently larger (at least twice) than the density meter volumes.
- Despite the minimized uncertainties in the *control* data, a poor correlation (R^2=44%)was found between the density meter volumes and the survey volumes.
- Underestimation of dredging production by the density meter appears to be related to inadequate operation of the equipment sensor. M&N recommends conducting an inspection to ensure that the density meter sensor is properly installed and calibrated.
- An average dredge production rate of 250 cubic yards per hour was estimated based on the surveyed dredged volumes for the *control* operations. This yields an estimated seasonal volume of 134,243 cubic yards, which is twice the total volume recorded by the density meter for the 2016-2017 season.

6. References

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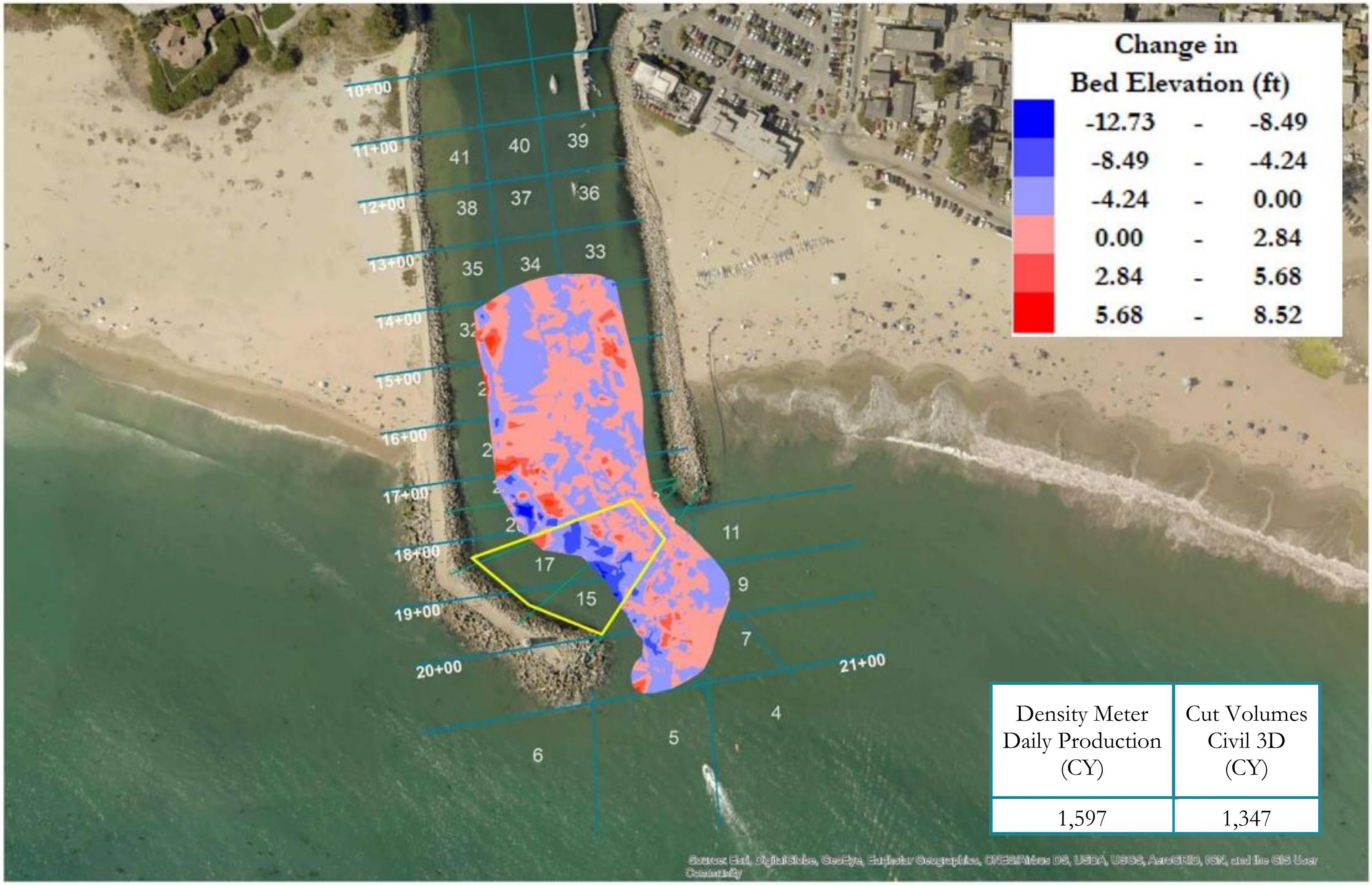
Appendix A
Cut and Fill Volume Analysis Results

Table A 1 Cut and Fill Volumes over Entire Pre-Dredge and Post-Dredge Surveys

No.	Dredging Event	Cut Volume Civil 3D (CY)	Fill Volume Civil 3D (CY)	Net Volume Civil 3D (CY)
1	November 21, 2016	-4,037.80	3,621.52	416.29
2	November 28, 2016	-3,880.37	2,220.74	1,659.63
3	December 5, 2016	-2,473.25	2,731.12	257.86
4	December 6, 2016	-9,818.92	1,359.69	-8,459.25
5	December 12, 2016	-4,601.98	3,785.56	-816.42
6	January 3, 2017	-7,336.15	5,799.41	-1,536.74
7	February 27, 2017	-2,698.81	2,424.82	-274.00
8	April 10, 2017	-3,393.08	2,158.68	-1,234.42
9	May 2, 2017	-6,286.61	5,341.85	-944.76

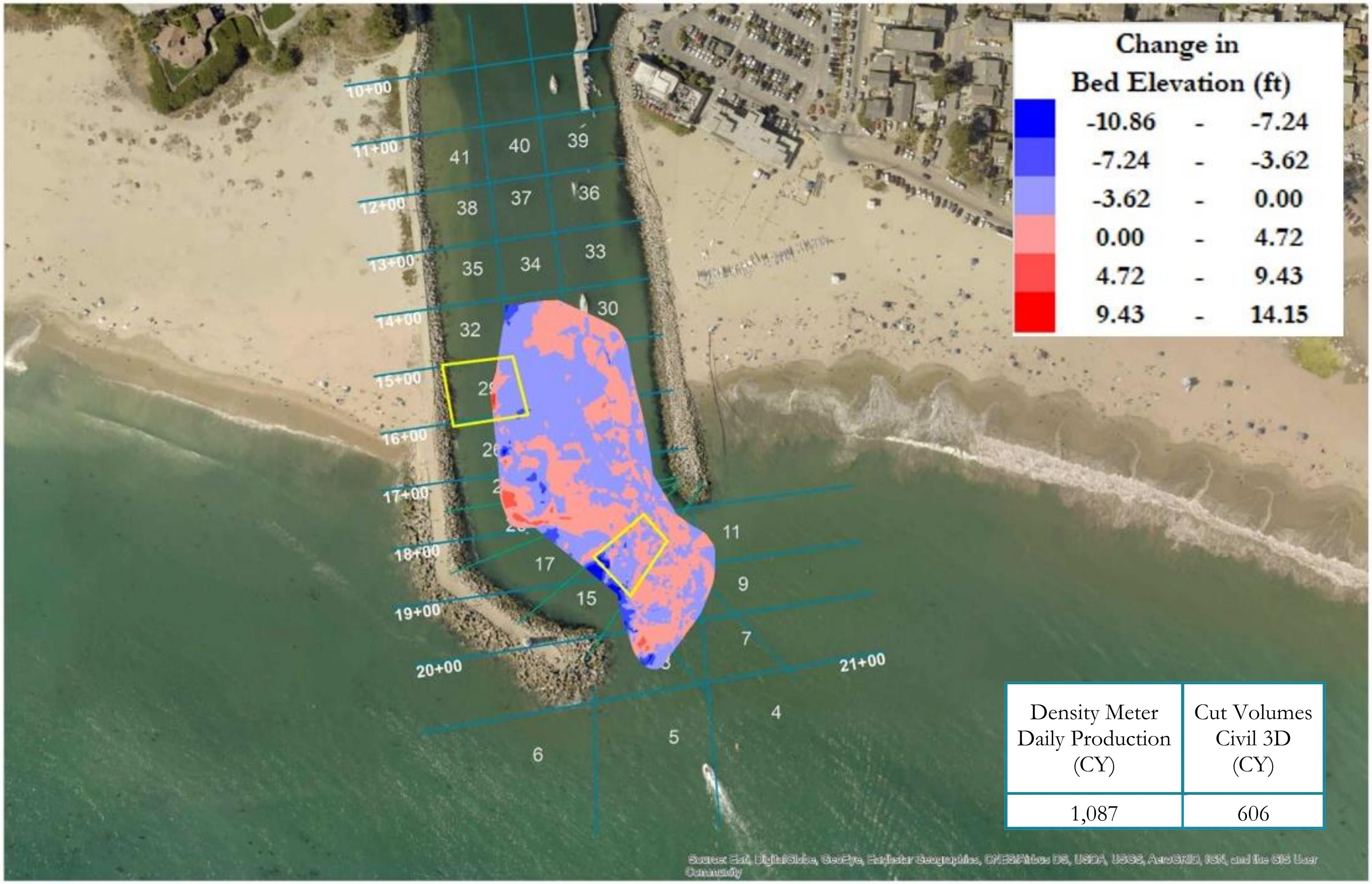
Table A 2 Cut and Fill Volumes over Dredged Areas Only

No.	Dredging Event	Cut Volume Civil 3D (CY)	Fill Volume Civil 3D (CY)	Net Volume Civil 3D (CY)
1	November 21, 2016	-1,347	273	1,073.72
2	November 28, 2016	-606	192	-414.19
3	December 5, 2016	-134	170	36.28
4	December 6, 2016	-4,264	145	-4,119.72
5	December 12, 2016	-401	175	226.16
6	January 3, 2017	-931	430	-501.17
7	February 27, 2017	-106	73	-33.18
8	April 10, 2017	-471	71	-399.15
9	May 2, 2017	-729	251	477.87



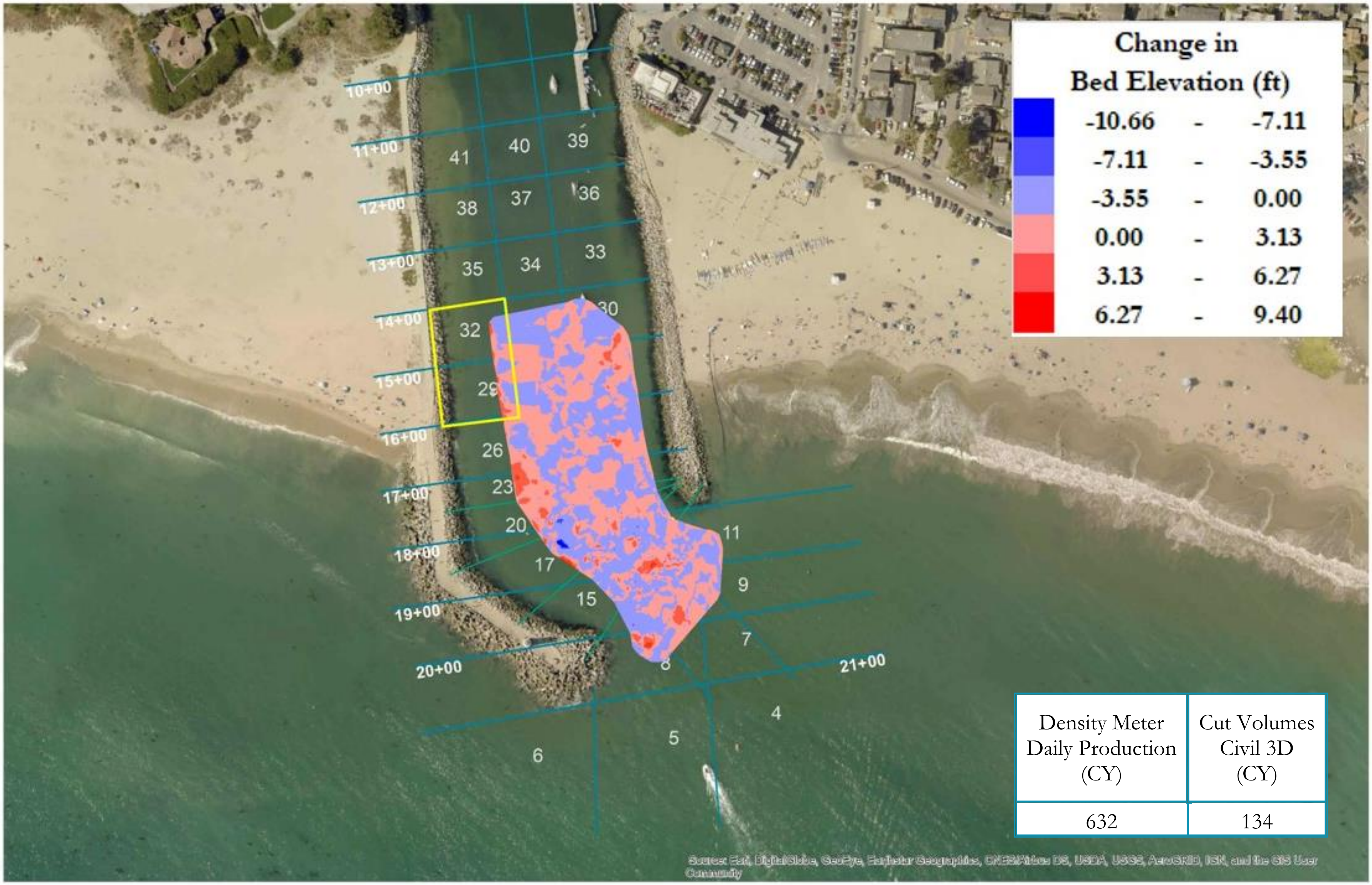
Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
1,597	1,347

Figure A 1 Change in Bed Elevations Between November 21 and November 22, 2016



Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
1,087	606

Figure A 2 Change in Bed Elevations Between November 28 and November 29, 2016



Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
632	134

Figure A 3 Change in Bed Elevations Between December 05 and December 06, 2016

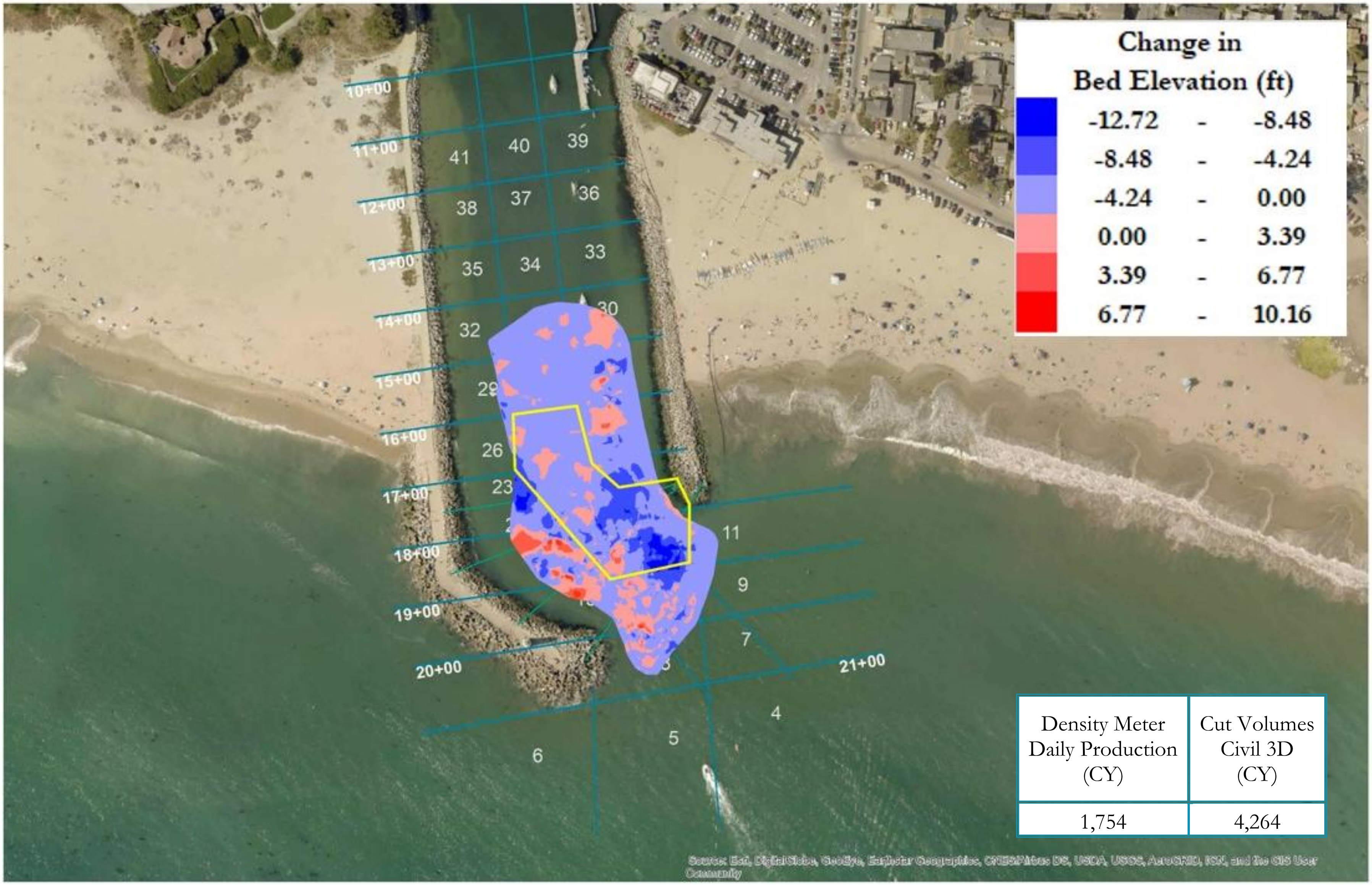


Figure A 4 Change in Bed Elevations Between December 06 and December 07, 2016

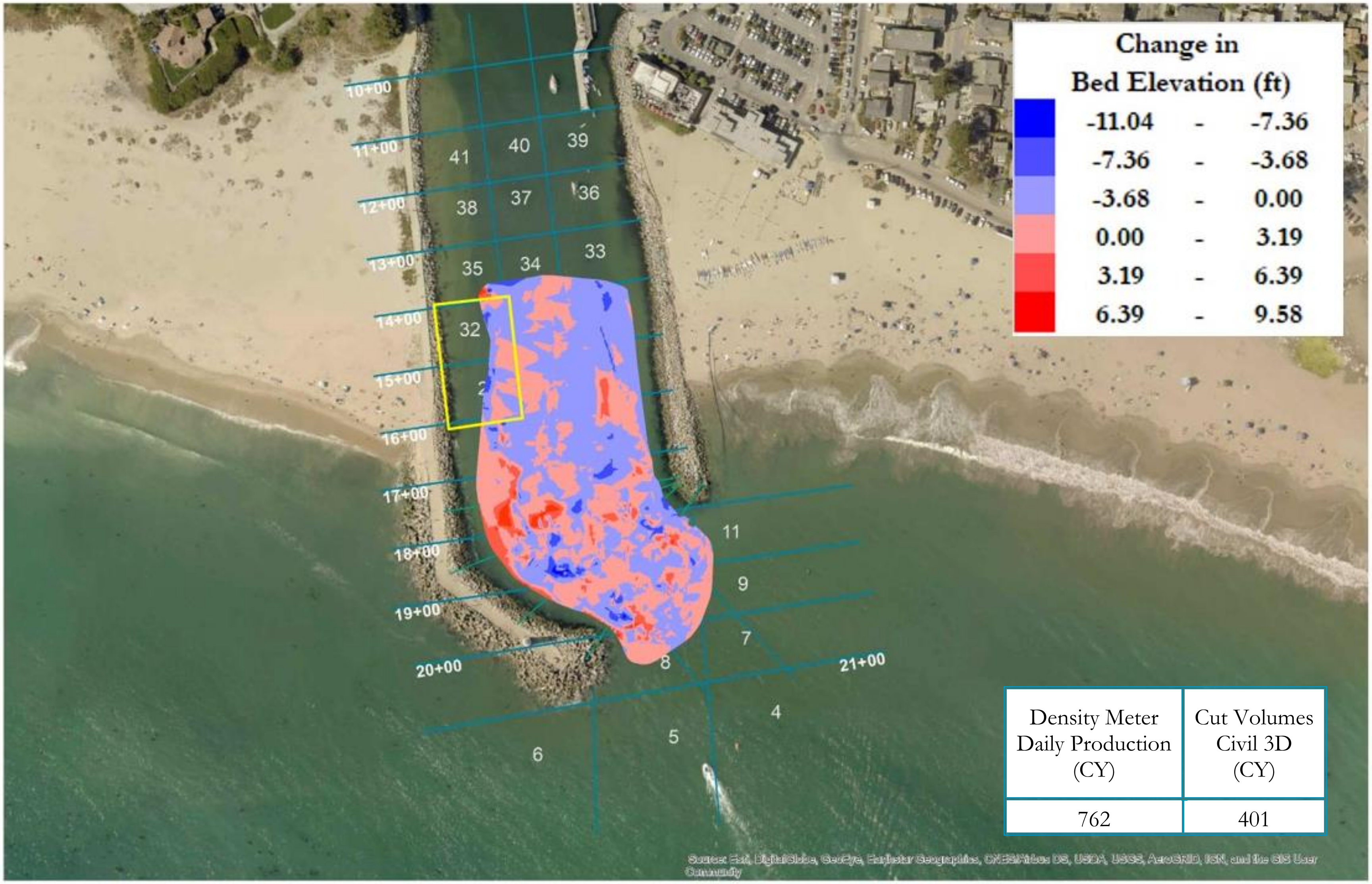
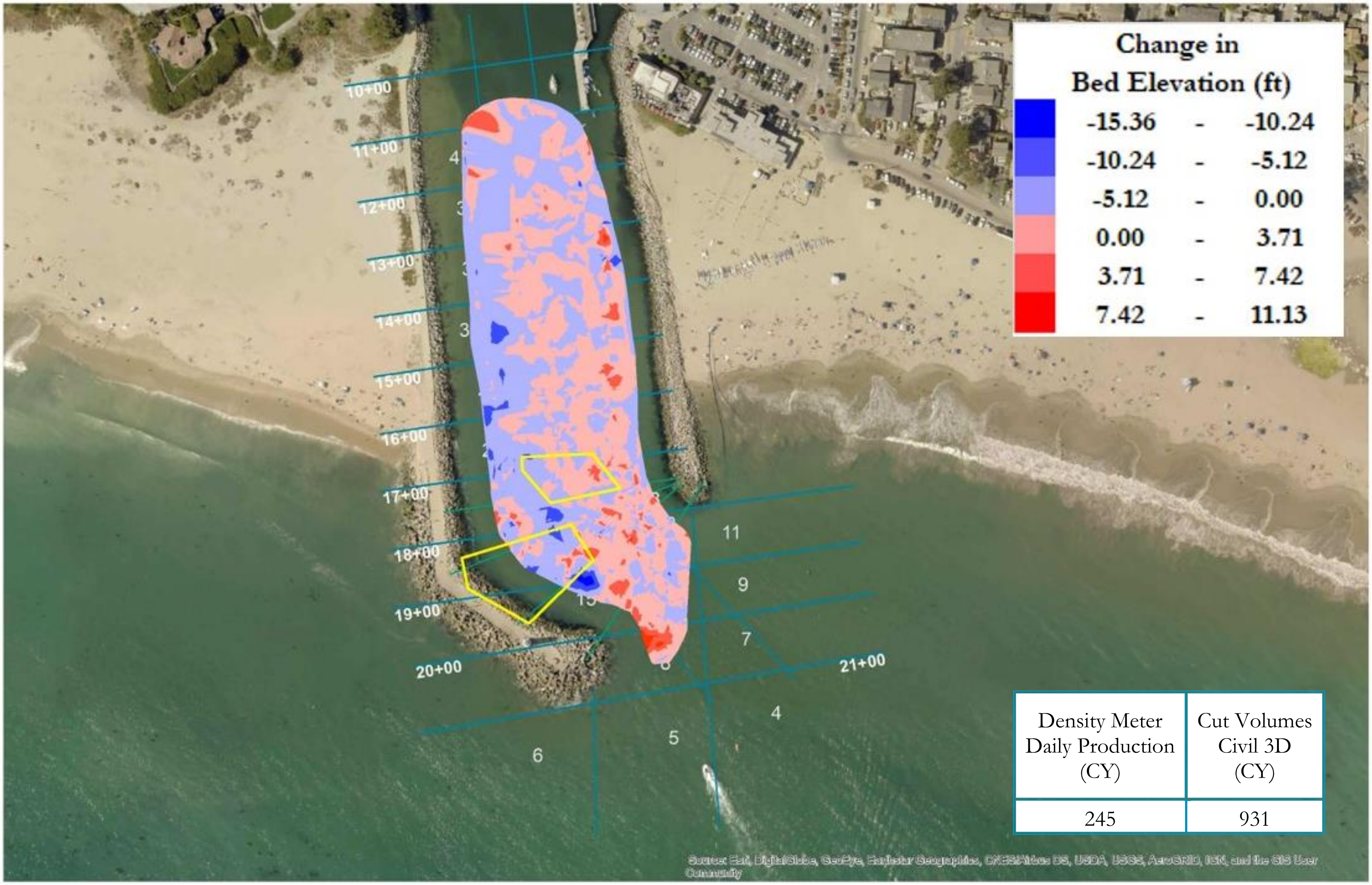


Figure A 5 Change in Bed Elevations Between December 12 and December 13, 2016



Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
245	931

Figure A 6 Change in Bed Elevations Between January 03 and January 04, 2017

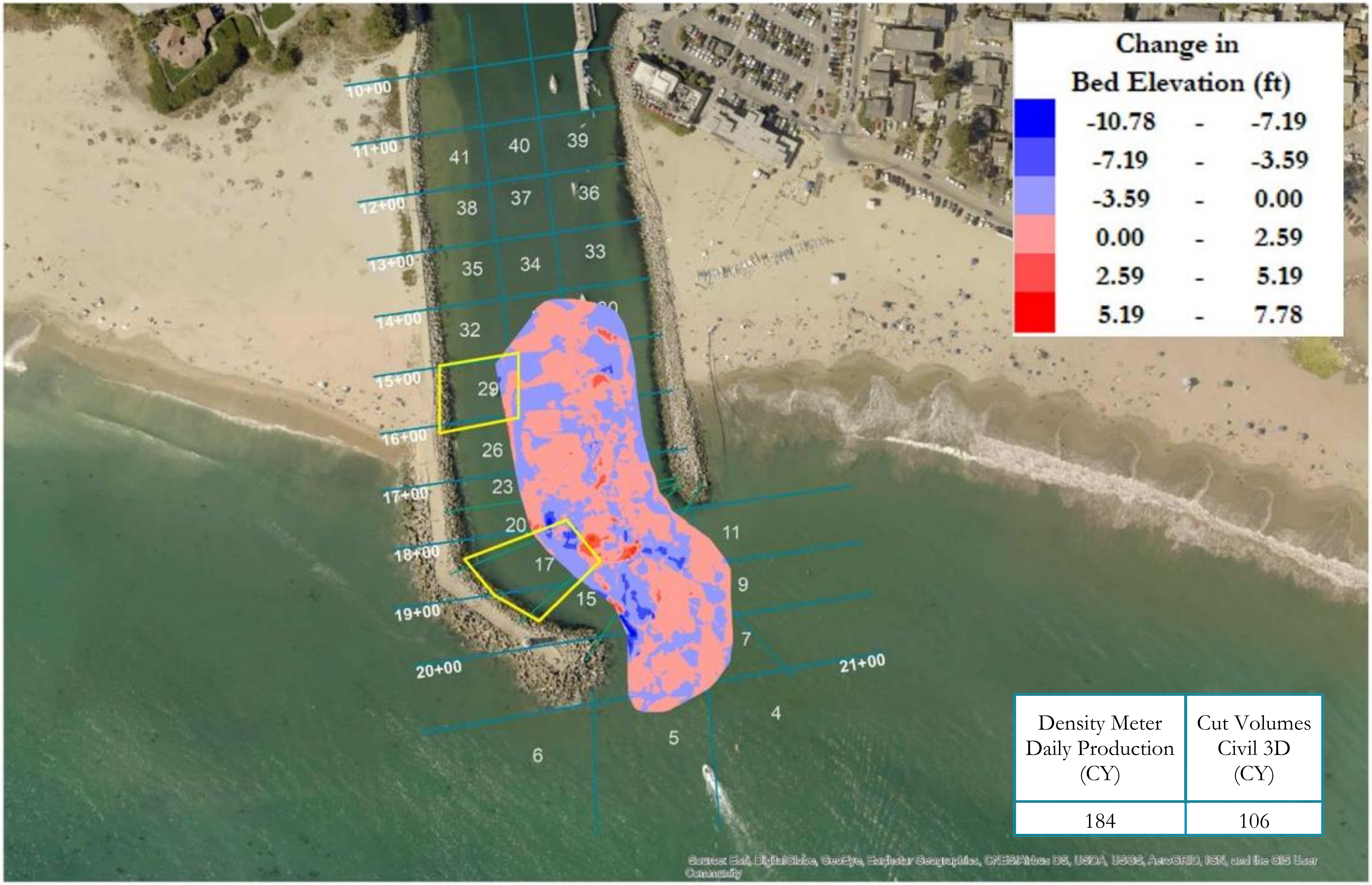


Figure A 7 Change in Bed Elevations Between February 27 and February 28, 2017

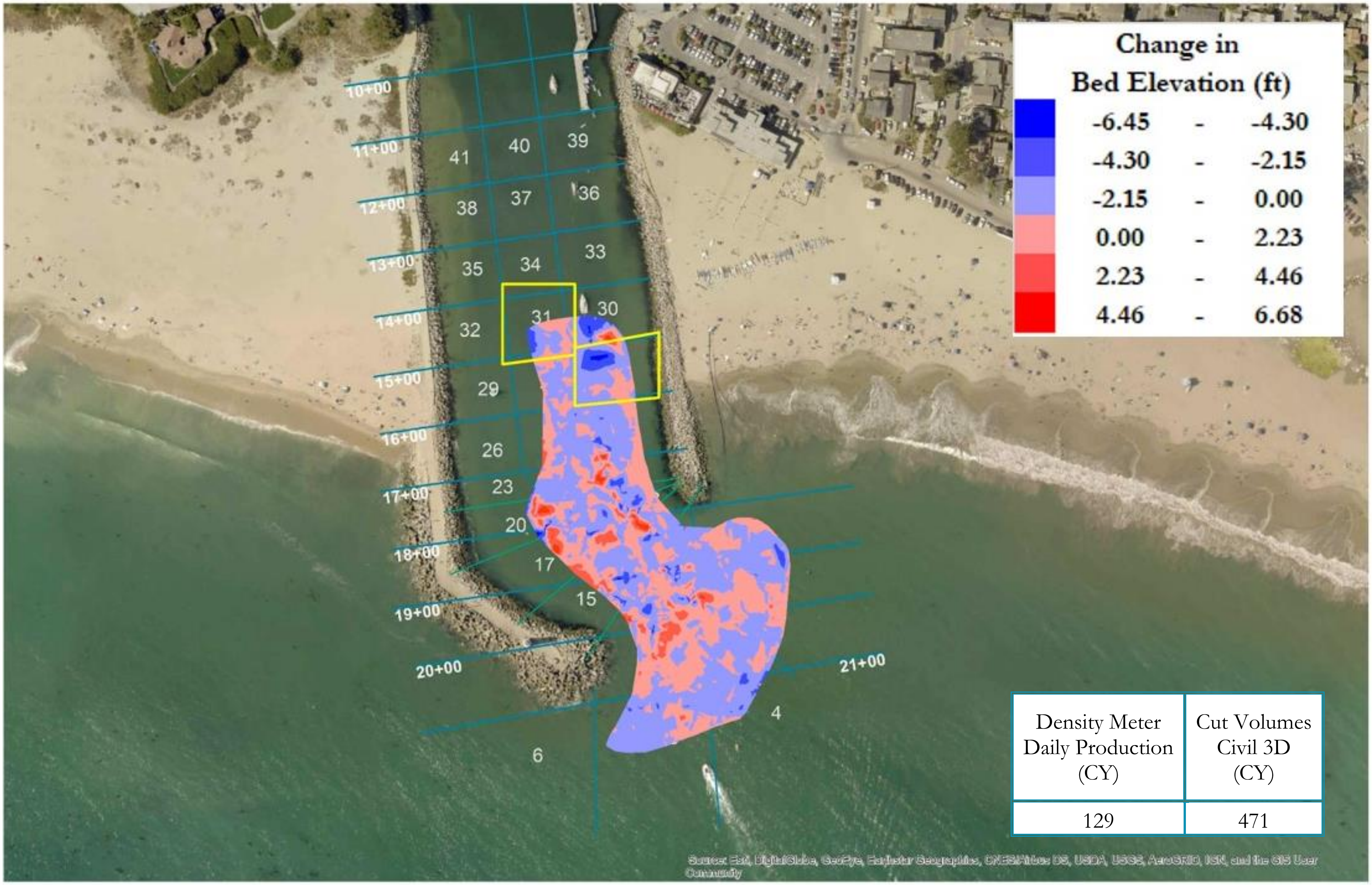
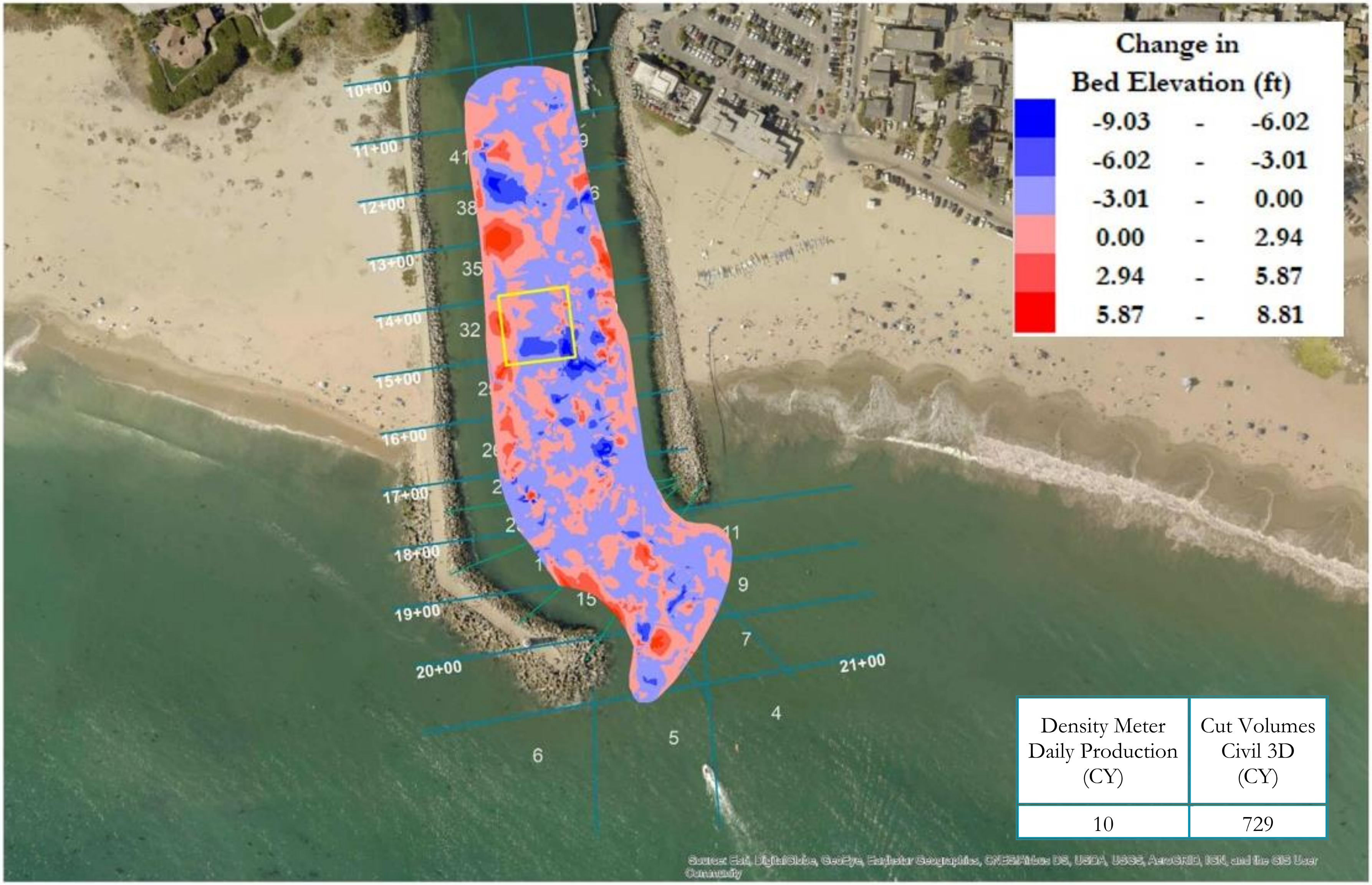


Figure A 8 Change in Bed Elevations Between April 10 and April 11, 2017



Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
10	729

Figure A 9 Change in Bed Elevations Between May 01 and May 02, 2017

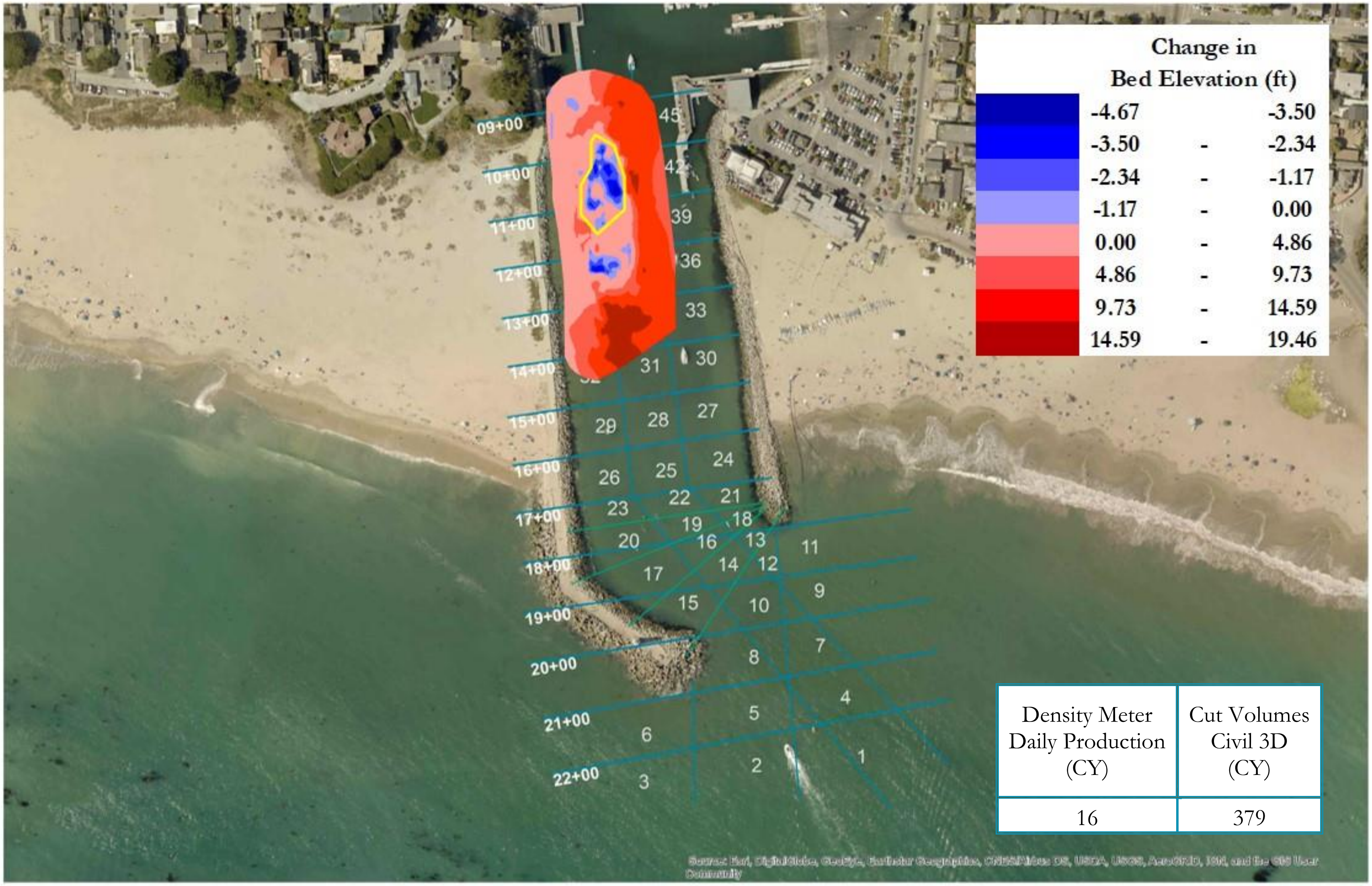
Appendix B
Control Dredging and Survey Operations
Cut and Fill Volume Analysis Results

Table B 1 Cut and Fill Volumes over Dredged Areas

Date	Dredged Quadrants	Density Meter Daily Production (CY)	Cut Volume Civil 3D (CY)	Fill Volume Civil 3D (CY)	Net Volume Civil 3D (CY)
April 18th, 2018	44,40	16	-379	182	-197
April 19th, 2018	40,39	405	-688	46	-642
April 23rd, 2018	47	168	-2,361	230	-2,131
April 24th, 2018	47	1,428	-2,778	20	-2,758

Table B 2 Dredge Production Rates

Date	Dredged Quadrants	Dredged hours	Cut Volume Civil 3D (CY)	Average Production (CY/hr.)
April 18th, 2018	44,40	6.4	379	59
April 19th, 2018	40,39	6.5	688	106
April 23rd, 2018	47	4.8	2,361	489
April 24th, 2018	47	7.2	2,778	387
Total		24.9	6,207	249



Density Meter Daily Production (CY)	Cut Volumes Civil 3D (CY)
16	379

Figure B 1 Change in Bed Elevations After Dredging Operation Conducted April 18,2018

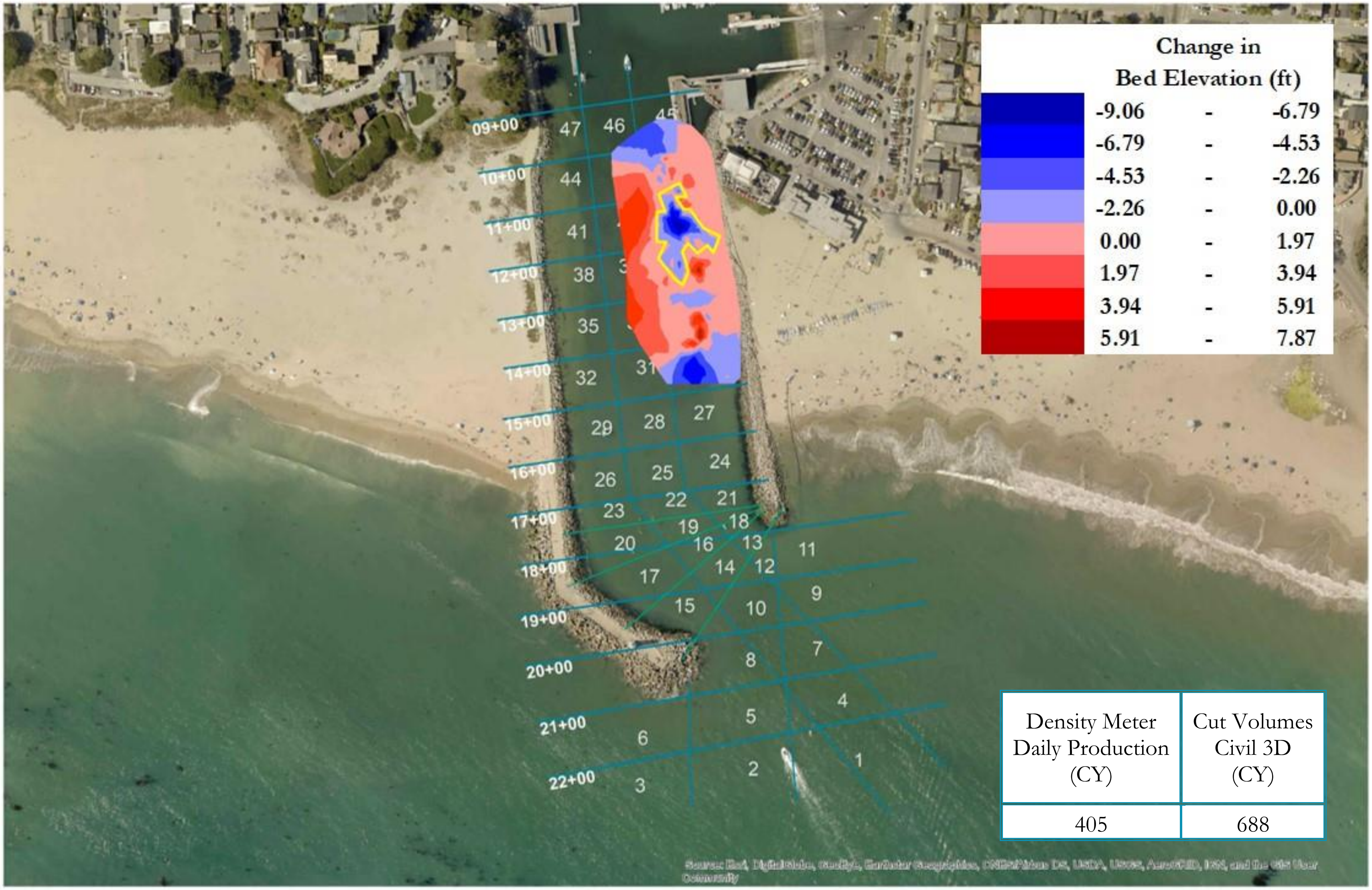


Figure B 2 Change in Bed Elevations After Dredging Operation Conducted April 19,2018

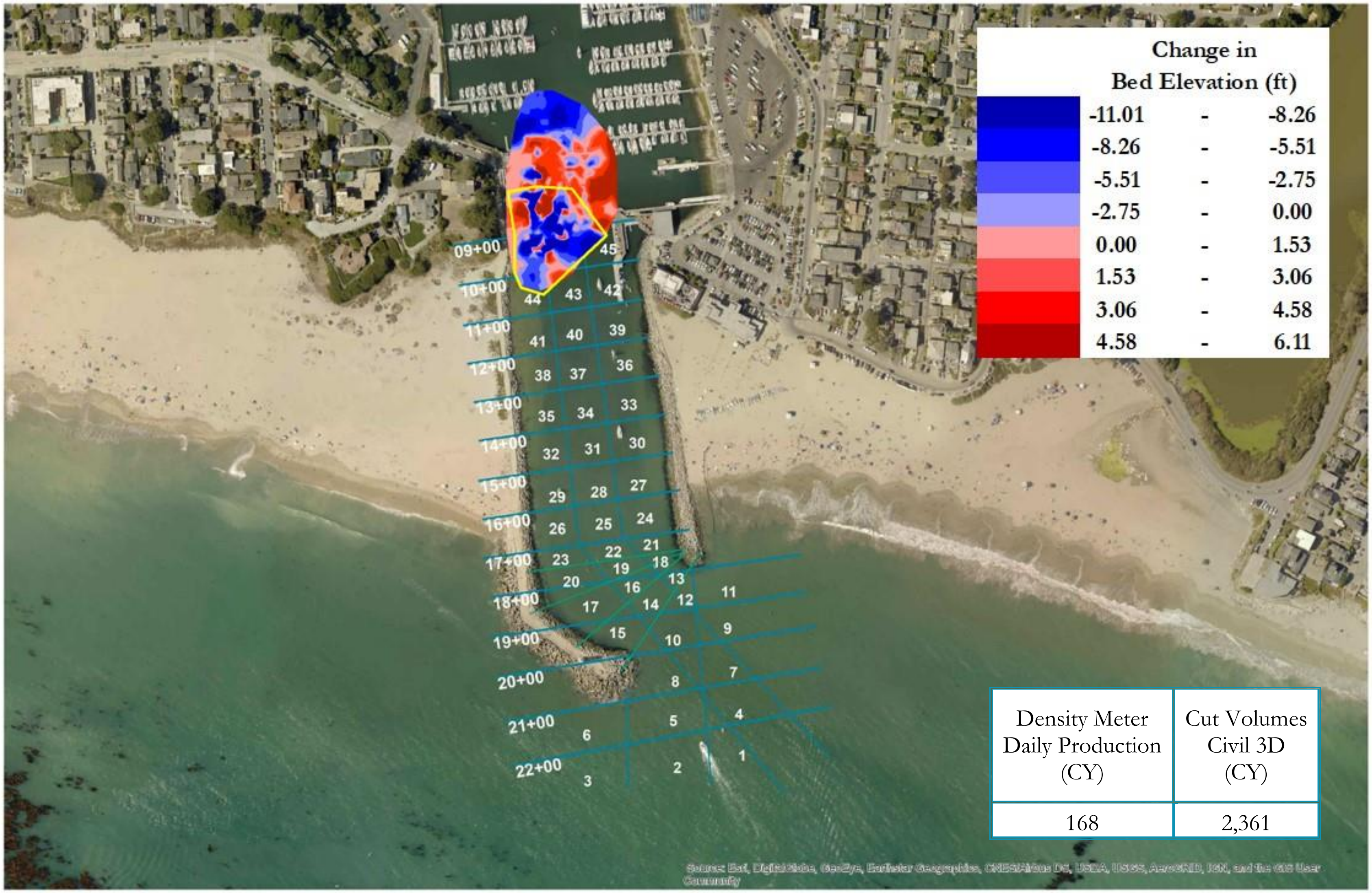


Figure B 3 Change in Bed Elevations After Dredging Operation Conducted April 23,2018

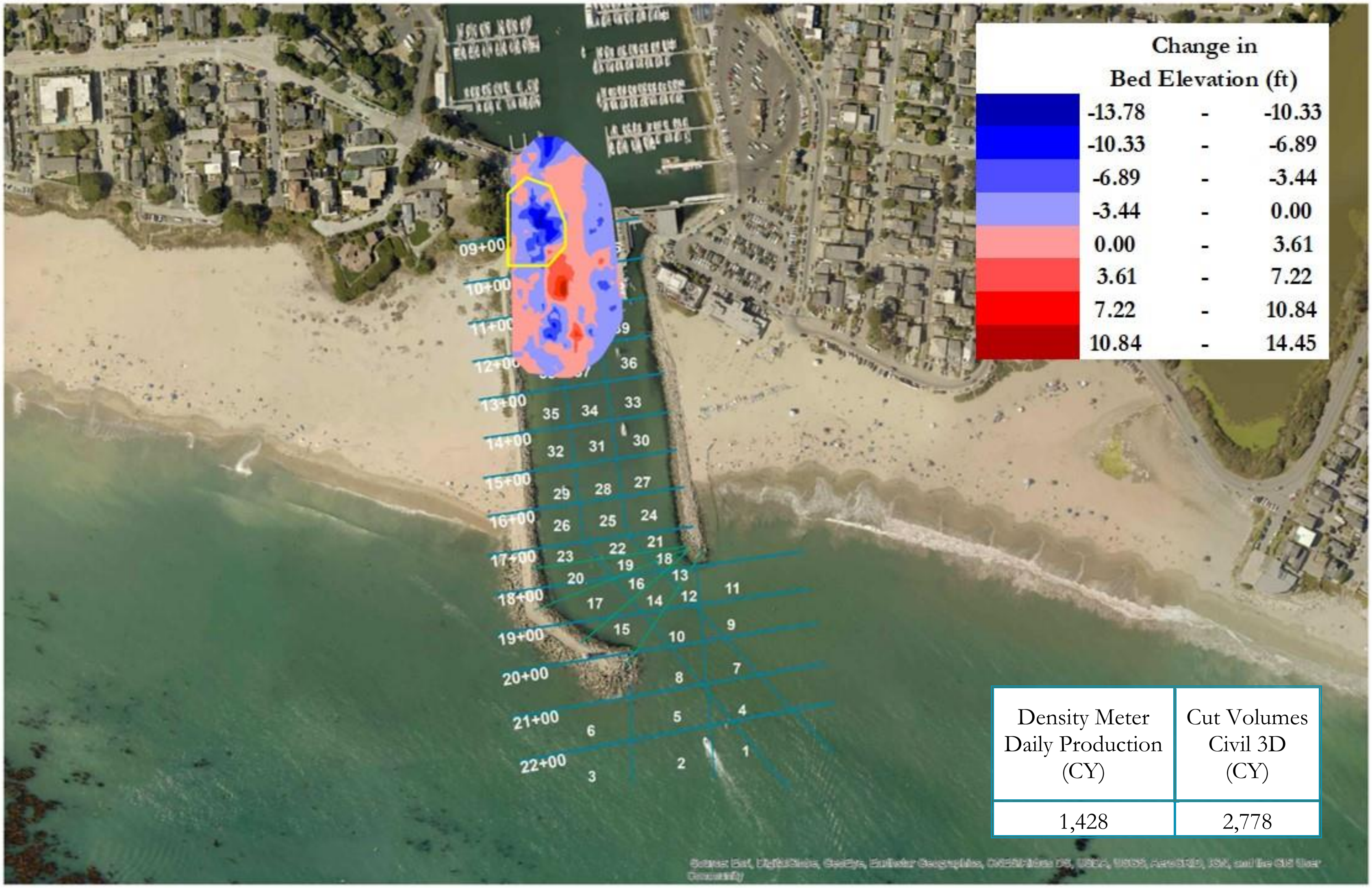


Figure B 4 Change in Bed Elevations After Dredging Operation Conducted April 24, 2018 moffatt & nichol

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